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The influence of measuring residential water usage on water consumption

Wpływ mierzenia zużycia wody na jej zużycie w gospodarstwie domowym

(Collection of thematically cohesive articles and studies)

Doctoral dissertation

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1. Introduction

1.1 Brief justification of the choice of the research subject and the research problem

Water scarcity is an escalating global issue that impacts millions of people worldwide. Based on UNESCO (2023) global water consumption has been on a consistent upward trajectory, increasing at a rate of approximately 1% per year over the past four decades. This trend is projected to continue through 2050 and is primarily fueled by factors like population growth, socio-economic development, and shifting consumption habits. The consequence of this escalating demand for water is the emergence of widespread water scarcity. This scarcity arises from the local impacts of physical water stress, exacerbated by the expansion of freshwater pollution. On a global scale, approximately 10% of the world's population resides in countries facing high or critical levels of water stress. Notably, countries across the spectrum of income levels, including low, middle, and high-income nations, exhibit vulnerabilities related to water quality.. World Meteorological Organization (2021) predicts that more than 5 billion people in the world will suffer from water scarcity by 2050. In the 21st century, the global water crisis has emerged as a significant and multifaceted threat, capable of triggering a range of adverse consequences. This crisis encompasses the potential for diminishing food security, hindering economic progress, degrading the environment, and even leading to the extinction of species (Si et al., 2022) .

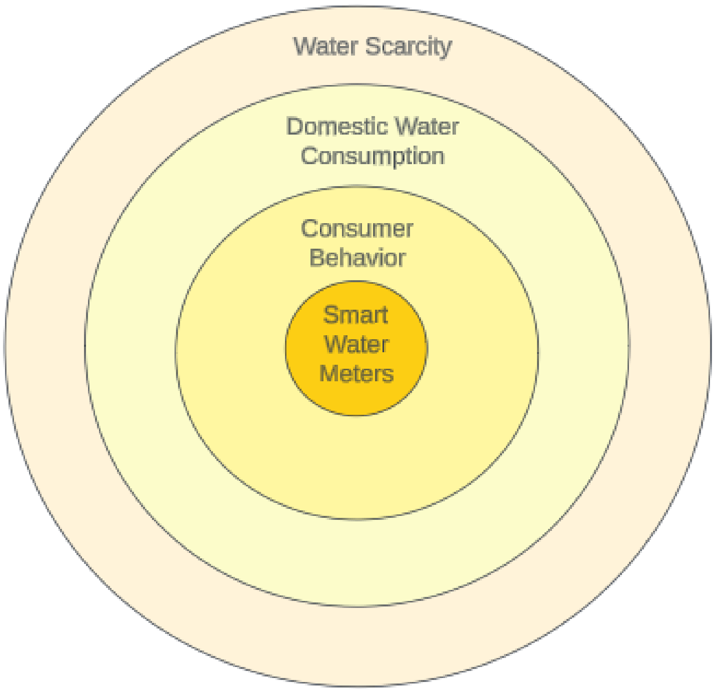
To address current water demand and mitigate a potential water crisis, a more effective supply-and-demand management system must be implemented, alongside conservation efforts at the agricultural, industrial and household level (Koop et al., 2019). Agricultural irrigation stands out as the largest consumer, utilizing around 70% of the total water supply (Al Hamedi et al., 2023). Industrial water usage accounts for approximately 19% of the total (UNESCO, 2023), and domestic water usage accounts for the 11% of the total water consumption (Flörke et al., 2013), globally, thus by reducing it there is a high chance of decreasing the issue of water scarcity. Household water consumption pertains to the distinct activities, both indoors and outdoors. These activities encompass a spectrum of tasks such as showering, laundering clothes, house cleaning, and vehicle washing. To delve further, the specific endpoints where water is employed, like kitchen taps, showerheads, or bath faucets, are considered as end-uses. In essence, household water consumption encapsulates the various routines and practices within a residence that necessitate the use of water resources (Crouch et al., 2021).

While prior research has primarily focused on infrastructure, industrial and agricultural upgrades, this dissertation concentrates household water consumption due the rapid increase in domestic water demand attributed to consumers (Grafton et al., 2011). A comprehensive understanding of household water consumption is vital to gain valuable insights into consumer behavior and develop strategies to reduce domestic water usage. Empirical evidence suggests that consumers, even those considered conservation-minded, lack awareness of their water wastage, hindering their ability to translate intentions into water conservation actions (Islam et al., 2021). The existing body of literature on water demand management predominantly gravitates towards social and economic factors that influence domestic water consumption, such as water pricing, income levels, gender and other environmental attitudes (Bithas, 2008; Hoffmann et al., 2006; Horsburgh et al., 2017; Koutiva & Makropoulos, 2016a; Madias & Szymkowiak, 2022; Satur & Lindsay, 2020; Tijs et al., 2017) . While these factors are undeniably crucial, the literature has not examined broadly the behavioral determinants that can substantially impact water conservation behavior. Some of the behavioral aspects that have been research in regards with their impact on household's water consumption, are the environmental attitudes of the consumer, their attitudes towards water conservation, and their awareness of their water conservation (Fielding et al., 2012; Gregory & Leo, 2003; Syme et al., 2004). However, more research is needed to understand how additional people's behavioral determinants, can be effectively altered concerning their daily domestic water consumption.

In addressing the identified research gap, this dissertation delves into the critical issue of household water consumption, the behavioral factors influencing consumers to decrease their water usage, the effect of knowledge on water consumption, and the conservation methods that could avert a significant escalation in water scarcity. In this case, the conservation method examined in this dissertation are smart water meters or else Internet of Things (IoT) water meters and the effect that the actual knowledge that they provide to the consumers has on their water conservation.

To be more precise, the research subject of this dissertation endeavors to resolve are centered around four key pillars (Figure 1). The primary objective and focus of this dissertation are to contribute to the global mitigation of water scarcity (First Circle). To achieve this, the dissertation concentrates on domestic water consumption, recognized as a substantial contributor to the overall global water usage (Second Circle). The primary approach to curbing domestic water consumption involves targeting consumers responsible for household water usage. The emphasis is on comprehending the factors influencing their water usage behaviors and strategizing ways to influence them to reduce water consumption effectively (Third Circle). The fourth circle involves smart water meters, which are the conservation method in this research. This includes an exploration of how behavioral determinants may influence consumers to install these meters in their households by overcoming barriers such as innovation diffusion. Furthermore, it assesses the application of smart water meters as a conservation method in real life, exploring how it may impact consumers water consumption.

Figure 1. Dissertation Subject



(Source: Own Elaboration)

1.2 Reference to the research papers included to this dissertation

In pursuit of understanding consumer behavior and promoting sustainable practices to reduce water consumption, this research dissertation comprises five interrelated articles. Each article serves as an integral component, contributing to a comprehensive exploration of the topic.

The foundation of this research endeavor is the article titled "Residential Sustainable Water Usage and Water Management: Systematic Review and Future Research Madias Konstantinos, Szymkowiak Andrzej, Water, 2022, vol. 14, no. 7, pp.1-18, Article number:1027. DOI:10.3390/w14071027". This systematic review aimed to identify research gaps and chart future directions in residential water usage and water management, particularly focusing on water scarcity. Notably, the candidate is the lead and corresponding author, contributing 60% to the concept/research plan, 70% to the literature review, 55% to the development of assumptions and methods, 65% to data collection, 50% to result analysis, 60% to the interpretation of results and conclusions, and 80% to manuscript editing.

Following the identification of gaps related to consumer behavior, technology, and knowledge about water consumption, the second paper, titled "The role of knowledge about water consumption in the context of intentions to use IoT water metrics Madias Konstantinos, Borusiak Barbara, Szymkowiak Andrzej, Frontiers in Environmental Science, 2022, vol. 10, pp.1-12, Article number:934965. DOI:10.3389/fenvs.2022.934965", delves into how both knowledge influence consumers' decisions to install smart water meters. The candidate is the leading and corresponding author, contributing 55% to the concept/research plan, 70% to the literature review, 60% to the development of assumptions and methods, 65% to data collection, 50% to result analysis, 65% to the interpretation of results and conclusions, and 80% to manuscript editing.

Building on insights from the second paper, the third and fourth articles are:

1) Innovative technology for sustainable behavior – investigating predictors of consumer intention to use smart water meters Madias Konstantinos, Borusiak

Barbara, Szymkowiak Andrzej, Zeszyty Naukowe Politechniki Śląskiej. Organizacja i Zarządzanie, 2023, no. 173, pp.469-485. DOI:10.29119/1641-3466.2023.173.31

2) What builds consumer intention to use smart water meters –Extended TAM-based explanation Madias Konstantinos, Szymkowiak Andrzej, Borusiak Barbara, Water Resources and Economics, 2023, vol. 44, pp.1-13. DOI:10.1016/j.wre.2023.100233

These articles leverage the Technology Acceptance Model (TAM) to investigate factors influencing smart water meter adoption. The fourth article extends TAM by incorporating variables like frugality, personal innovativeness, and environmental concerns. The candidate is the leading and corresponding author, contributing 50% to the concept/research plan, 60% to the literature review, 60% to the development of assumptions and methods, 65% to data collection, 50% to result analysis, 70% to the interpretation of results and conclusions, and 80% to manuscript editing.

The final segment of this dissertation is an experimental study titled "The effect of water usage knowledge on water consumption provided by IoT water meters. Madias Konstantinos, Borusiak Barbara, Szymkowiak Andrzej, Working Paper”. This experiment involved installing smart water meters in participants' showers and was structured into four phases over six weeks. The candidate is the leading author, contributing 80% to the concept/research plan, 90% to the literature review, 90% to the development of assumptions and methods, 100% to data collection, 60% to result analysis, 90% to the interpretation of results and conclusions, and 90% to manuscript editing.

2. Description of the research subject and problem

2.1 Description of the subject and of the research problem

To begin with in this dissertation there are two main research questions:

1) What affect consumers' intentions to apply smart water meters in their households?

2) How knowledge (actual – provided by smart water meters, and environmental– -provided by marketing materials) can affect water consumption?

Past research focusing on examining domestic household water consumption and metering, have been investigating various reasons that may affect water consumption. Renwick and Green (2000) developed an econometric framework for analyzing household water demand, constructing a model to examine the impact of climate variabilities on the typical seasonal patterns. Another research, has been focusing on how geographical, seasonal, and population variables may affect households water consumption (Makki et al., 2015). Previous research have also focused on factors that may directly impact household water consumption, such as economic and sociodemographic variables (Abu-Bakar et al., 2021). For example, factors such property ownership, the income level of households, the characteristics of households have demonstrated to affect water consumption, the gender and the education have been examined and proven that they affect water consumption (Arbues & Villanua, 2006; Hoffmann et al., 2006; Horsburgh et al., 2017; Vieira et al., 2017).

Even though there is a broad literature about household water consumption, little is known about what motivates individuals to install smart water meters in their household in order to reduce their water consumption. Past research that focused on examining the behavioral characteristics of consumers that may impact the water consumption behavior mainly focused on habits – past behavioral patterns (Fielding et al., 2012) and environmental attitudes/appeals (Tijs et al., 2017) which are found to be crucial when it comes to household water consumption. However, understanding what drives individuals to install smart water meters with the intention to save water will shed light on human behavior in the context of water usage, contributing to both scientific knowledge and efforts to reduce household water consumption, thus, the main research problem that this dissertation is focusing on is to minimize this research gap and gain a deeper understanding on what may affect consumers to adopt smart water meters in their households and how knowledge can impact them to reduce water consumption and tackle the issue of water scarcity.

As far as the choice of smart water meters as the conservation method that was investigated is due to the fact that the implementation of smart water meters has been shown to raise consumer awareness about water usage, potentially leading to a reduction in water consumption and fostering sustainable consumption practices. According to Joo et al. (2015), the application of smart water meters may result in a 5.3% decrease in water consumption, with changes in awareness and consumption behavior being contributing factors. While past research has explored the effectiveness of smart water meters in reducing household water consumption, a research gap still remains concerning strategies to influence consumer willingness to adopt these meters in their households. The primary focus of this dissertation is to scrutinize consumer behavioral characteristics that influence the adoption of smart water meters in households, with the overarching goal of reducing household water consumption. Additionally, to bridge the theory-behavior gap, this dissertation incorporates an experiment. In this experiment, smart water meters were installed in consumers' households, not only to assess the changes in their water consumption patterns but also to examine how knowledge is affecting the consumer behavior.

This dissertation embarks on a nuanced exploration that seeks to unravel the complex dynamics between consumer adoption of smart water meters and their consequential impact on sustainable water consumption. As societies grapple with the critical need for innovative solutions to ensure the responsible use of water resources, this research endeavors to provide a substantial contribution by delving into the motivations, behaviors, and outcomes associated with the integration of Internet of Things (IoT) water meters in households, and then to examine if/how the knowledge provided by IoT water meters and from informative materials has an actual impact on household water consumption.

The intellectual underpinning of this dissertation rests on a comprehensive and meticulous review of existing literature, beginning with a theoretical exploration of studies related to residential water consumption and management, with a keen emphasis on sustainability (Research One). Building upon this theoretical groundwork, subsequent studies navigate through specific dimensions of smart water meter adoption. The dissertation synthesizes the literature regarding perceived knowledge and Value-Belief- Norms of household water usage and its intricate relationship with the intention to adopt smart water meters (Research Two). The Technology Acceptance Model (TAM) plays an important role on understanding consumer behavior and their intentions to adopt smart water meters (Research Three). Drawing inspiration from the works of Davis (1989), this theoretical framework becomes the lens through which the research seeks to unravel the motivations propelling consumers to install smart water meters in their households. Expanding the theoretical landscape further, the dissertation investigates additional determinants influencing consumers' decisions to adopt smart water meters, introducing variables such as environmental concerns, frugality, and personal innovativeness (Research Four). In its final theoretical stride, the dissertation integrates an experimentation to validate theoretical frameworks of knowledge in a real-world setting (Research Five).

In synthesis, this dissertation weaves together theoretical frameworks and empirical investigations in a tapestry that aims to provide not just a theoretical understanding but a holistic exploration of the factors influencing consumers' behavior. Beyond theory, it aspires to shed light on the practical implications for sustainable domestic water management. By unraveling the intricate threads of the literature, this research endeavors to contribute nuanced and valuable insights to the ongoing discourse on water scarcity and sustainable water usage.

2.2 Key terms and concepts of the dissertation

Key terms and concepts: domestic water usage/consumption, smart water meters – IoT water meters, perceived, actual, and environmental knowledge, VBN, TAM.

Domestic water usage/consumption:

Household water consumption or else domestic water consumption refers to the specific activities, both inside and outside the home, that entail the use of water by the household. Common domestic water usage activities include bathing, using washing machines, flushing toilets, and engaging in outdoor activities like watering a garden, maintaining swimming pools, etc. In the context of water sustainability, it aligns with the definition from the Brundtland report, which emphasizes ensuring that development meets current needs without compromising the ability of future generations to meet their own needs (Nations, 1987). Sustainable water usage involves finding ways to use and manage water resources that guarantee ongoing development while preventing critical water scarcity issues for future generations.

Smart water meters:

Smart water meters are an IoT technology based devices that offer benefits to both consumers and water authorities by enabling the monitoring and control of water consumption. For consumers, the advantages of using smart water meters extend beyond mere recording of water consumption. They include remote reading of water usage, the ability to actively control water consumption, and subsequently, manage water costs efficiently. Furthermore, the practicality and feasibility of smart water meters are underscored by their ease of installation in the majority of households. This feature enhances the likelihood of consumer adoption, making them a viable option for water conservation efforts. A smart water meter is an electronic device designed to record water consumption for both the utility company and the user (Sønderlund et al., 2016). However, the smart meters utilized in this dissertation are implemented at showers, providing real-time data exclusively to the user. In contrast to traditional water meters, which manually read the water consumption at monthly or yearly intervals, smart meters record consumption in real-time or near real-time and communicating the consumption data both to the utility and the consumer (Adams & Jokonya, 2022). The smart water meter utilized in our research, and introduced to consumers in both the quantitative study and the experiment, is manufactured by the company Amphiro (Figure 2,3). Specifically designed for shower usage, this meter can be seamlessly installed in consumers' showers. Its primary function is to record the water consumption associated with shower usage, transmitting this real-time data directly to the consumer's mobile phone through the mobile application that is developed by Amphiro.

Figure 2. Amphiro Smart Water Meter

(Source: Amphiro Webpage)

Figure 3. Amphiro Smart Water Meter application

(Source: Amphiro Application/ Webpage)

Perceived knowledge, Actual knowledge, and Environmental knowledge:

Perceived knowledge involves an individual's subjective interpretation of their understanding of the environment. When it comes to water usage this encompasses not only their awareness of absolute water consumption but also their personal assessment of how their water usage compares to that of the average person, reflecting a nuanced perspective shaped by individual experiences and perceptions (Beal & Flynn, 2015).

Actual knowledge, in contrast, is rooted in objective and verifiable information. It pertains to concrete facts and data, providing a reliable foundation for understanding various subjects, including water usage (Martono et al., 2019).

Environmental knowledge, as defined by Mostafa (2007), extends beyond the individual realm to encompass a broader comprehension of environmental issues. This includes an individual's consciousness of the environmental impact of their actions, a genuine appreciation for the natural world, and a sense of shared responsibility for the well-being of the planet. In essence, environmental knowledge involves a more holistic and interconnected understanding of our relationship with the environment and the importance of sustainable practices.

Value Belief Norm Model:

The Value Belief Norm model by Stern et al. (1999) offers a causal framework for understanding individual environmental awareness. According to this model, an individual's values are pivotal in initiating environmental consciousness. The activation of both personal and social norms then reinforces the intention to partake in pro-environmental behaviors, which involve concrete actions aimed at mitigating the negative impacts of one's activities on the environment. This theoretical framework focuses on analyzing pro-environmental behavior by considering factors such as awareness of consequences, ascription of responsibility, personal norms, and the intention to engage in environmentally responsible actions. When applied to environmental studies, it underscores the interconnectedness of personal values, social norms, and intentional actions in fostering environmentally responsible behaviors.

Technology Acceptance Model:

The Technology Acceptance Model (TAM) has emerged as a prominent theoretical framework in the study of technology adoption processes, widely employed in various research contexts. TAM's popularity is primarily attributed to its simplicity, comprehensibility, and robustness (Gao & Bai, 2014). Introduced by Davis (1989), TAM was initially developed for modeling user acceptance of information systems. It draws its roots from the Theory of Reasoned Action, a well-established theory that elucidates behavioral intentions and how they translate into actual behaviors, influenced by two key factors: one's attitude toward a particular behavior and the subjective norm associated with that behavior (Davis, 1989).

TAM posits that the intention to adopt an innovative technology is primarily predicted by one's attitude towards using that technology, which, in turn, is influenced by behavioral beliefs. Within TAM, these beliefs are encapsulated by two critical variables: perceived ease of use and perceived usefulness, which directly or indirectly elucidate the outcomes of technology adoption. Perceived ease of use denotes the extent to which consumers believe that using a specific technology will be effortless. On the other hand, perceived usefulness pertains to a potential user's conviction that using the given technology will enhance their task performance. Both perceived ease of use and perceived usefulness exert positive effects on consumers' attitudes toward the technology under examination and subsequently foster their intentions to use and adopt that technology.

2.3 Leading discipline/subdisciplines in which the considerations are embedded, a demonstration of the relationship between the chosen discipline, the research subject, and the research problem.

The articles contained in this dissertation have a central focus on consumers, delving into various aspects of their characteristics, attitudes, intentions, and behaviors. This research territory finds its grounding in the academic discipline of economics and finance, particularly aligning with the domain of behavioral economics. This approach examines how consumer behavior is shaped by cognitive and emotional factors, thereby offering insights into the decision-making processes related to household water consumption and the adoption of water-saving technologies such as IoT water meters.

Given the broader context of sustainability and the pressing global issue of water scarcity, the subject of this research also extends its connections to ecological economics. The intertwined relationship between consumer behavior, technological adoption, and sustainable water usage is multifaceted. It not only impacts individual households but also has far-reaching implications for environmental resource management, water conservation, and the overarching sustainability goals. Consequently, this research addresses the intersection of environmental economics and behavioral economics, shedding light on how consumers' choices can contribute to mitigating water scarcity, preserving water resources, and fostering sustainability.

3. Justification of the addressed research problem

In numerous water-scarce regions globally, the availability of water is still often perceived as abundant. However, as mentioned above, the World Meteorological Organization (2021) predicts that more than 5 billion people in the world will suffer from water scarcity by 2050. This already complex situation is further exacerbated by the challenges posed by rapid urbanization, climate change, and increased affluence, as discussed by Koop et al. (2019). The ever-pressing issue of climate change is expected to lead to more frequent heatwaves and drought events, causing sudden spikes in water demand. These abrupt changes in water pressure can result in problems such as tap water discoloration, necessitating costly infrastructure enhancements and incurring high energy costs for the treatment, pumping, and maintenance of water supply networks, as detailed in Beal and Flynn (2015).

The primary source of pressure on the world's diminishing freshwater resources is attributed to agriculture, industrial and domestic water consumption (Koop et al., 2019) .Nonetheless, it is crucial to recognize that households can significantly contribute to reducing overall water demands. On a global scale, the majority of household water consumption is allocated to essential hygiene activities, including bathing, showering, toilet use, and operating washing machines as highlighted by Carragher et al. (2012) and Gato-Trinidad et al. (2011).

Existing studies that delve into water demand management primarily revolve around critical social and economic factors influencing domestic water consumption (Garcia et al., 2013). Notably, a volumetric charge for water and higher average water prices have shown efficacy in encouraging water conservation (Grafton et al., 2011; Hoffmann et al., 2006; Syme et al., 2004; Worthington & Hoffman, 2008). In addition to income and pricing, education is regarded as another explanatory factor for water conservation customers' behavior by various scholars (Syme et al., 2000). Nevertheless, the correlation is not always straightforward. For instance, a survey of 26,689 Spanish households conducted by Mondéjar-Jiménez et al. (2011) found that while individuals with higher education levels tend to have more knowledge about environmental issues, their higher income and more comfortable lifestyles often lead to increased water consumption. In fact, there is an overarching paradoxical pattern where, compared to individuals with less formal education, well-educated individuals tend to be more committed to water conservation but actually consume more (Aprile & Fiorillo, 2016; Fan et al., 2013; Gilg & Barr, 2006)

While this body of literature focusing on various social and economic factors is highly relevant for explaining consumption patterns, it often overlooks the fundamental behavioral factors that influence water conservation behavior. Consequently, there has been limited empirical knowledge about how people's behavior can be altered concerning their daily domestic water.

This scarcity of research is primarily attributed to the intricate nature of the drivers behind water-saving behavior. Jorgensen et al. (2009) have categorized these drivers into two main groups: direct drivers, including factors like climate variability, financial incentives and disincentives, regulations, property and household characteristics, and indirect drivers, which encompass socio-economic factors, interpersonal factors, and institutional trust. Both groups play a crucial role in shaping water-saving behavior. However, when it comes to these drivers, there should be also a conservation method to be examined as a way to reduce household water consumption, such as green technologies.

Green technology, aimed at achieving international sustainable development goals and minimizing the environmental impact of economic growth (Ikram et al., 2022), offers a promising avenue for this purpose. Smart water meters, considered a part of green technology, have been found to significantly reduce household water consumption, as they provide real-time consumption data and detect potential water leaks, as indicated by Russell and Knoeri (2020). By raising consumer awareness about their water usage, smart water meters have the potential to contribute to a reduction in water consumption and the promotion of higher levels of sustainable water use. Sønderlund et al. (2014) observed an average 19.6% reduction in water consumption among households with smart water meters. While Cominola et al. (2021) not replicate this magnitude of effect, they still reported an 8% reduction in water consumption among households with smart meters. However, past research has primarily focused on the financial motives behind adopting smart water meters, neglecting consumers' intentions to adopt such technology in their households.

The central aim of this dissertation is to provide a comprehensive exploration of some behavioral patterns that underpin consumers' motivations to reduce household water consumption through the adoption of IoT (Internet of Things) water meters, within their homes. The novelty of this research lies in its dedication to uncovering previously uncharted territory concerning the multifaceted factors that drive consumers to embrace these devices. Furthermore, this study goes beyond theoretical exploration by conducting a field experiment to examine and validate these factors empirically. The research aims to scrutinize how knowledge may actually affect water consumption when smart water meters are installed in real-life settings.

In summary, this dissertation distinguishes itself by its focused examination of the multifaceted aspects of consumer behavior and the adoption of IoT water meters, and it goes a step further by conducting a real-world experiment to validate its findings. By delving into this underexplored domain and empirically demonstrating the impacts of various factors on consumer behavior, this research aspires to illuminate the intricate interplay that motivates consumers to embrace water-saving technologies. Through this pioneering effort, which combines theory and field experimentation, this research endeavors to contribute to the global efforts to address the critical issue of water scarcity and promote a sustainable approach to domestic water consumption.

4.Research goals

In this chapter, I will present the overarching goals of the dissertation. To facilitate this, I will categorize these goals into two distinct categories. The first category pertains to the main objectives of this research, while the second category encompasses the specific goals associated with each individual study that forms a part of this dissertation.

The central and overarching goal of this dissertation is to address the pressing global issue of water scarcity by investigating the behavioral determinates that impact consumers' decision to install smart water meters in their households. Additionally, this research endeavors to shed light on how the adoption of smart water meters can lead to a reduction in domestic water consumption.

As far as the specific goals of this dissertation I will present them separately based on each research.

Research one:

The main objective of the research was to explore and understand the existing body of literature related to residential water usage and water management, with a specific focus on sustainability. The primary theoretical goal was to comprehensively examine the existing studies in residential water usage and water management, particularly those related to sustainability. This involves conducting a thorough bibliometric analysis to identify the extent and depth of research in this domain. The cognitive objective was to evaluate the influence and impact of research in residential water usage and management. This included identifying influential authors and journals within the domain, shedding light on the key contributors to the field's development. Additionally, it aimed to determine the most popular research topics and trends in this area, providing insights into the cognitive aspects of water conservation research. The methodological objective was to employ a rigorous research methodology, including bibliometric and content analysis (ADO analysis), to synthesize and systematize existing knowledge. This research integrated theoretical, cognitive, and methodological research goals to comprehensively assess the state of knowledge in residential water usage and management, with a specific emphasis on sustainability.

Research two:

The primary theoretical goal was to investigate the relationship between consumers' perceived knowledge of household water usage and their intention to adopt smart (IoT-based) water meters. This aims to contribute to the theoretical understanding of the behavioral factors that influence the adoption of smart water meters, thereby filling a significant gap in the existing research. The research aimed to enhance our cognitive comprehension of how awareness and understanding of water usage impact individuals' choices and behaviors related to water conservation. Methodologically, the study employed a rigorous research approach to collect and analyze data. This involves the application of a well-established theoretical framework (perceived knowledge and VBN variables), survey instruments, and statistical analysis to draw valid and reliable conclusions. The research methodology was structured to provide insights into the relationships between perceived knowledge and the intention to adopt smart water meters. From a practical standpoint, the research offers valuable insights for policymakers, water utilities, and environmental advocates.

Research three:

The theoretical goal of this research was centered around advancing our understanding of the factors influencing consumers' intentions to adopt smart water meters and promote sustainable water consumption. This involves delving into the application of the Technology of Acceptance Model (TAM) within the context of smart water meters, thus contributing to the theoretical body of knowledge concerning technology adoption in the domain of water conservation. From a cognitive perspective, the research aimed to shed light on the motivations that drive consumers to install smart water meters in their households. Methodically, the research in order to examine the empirical evidence regarding the factors influencing the willingness of consumers to embrace smart water meter it employed TAM. Furthermore, this research has practical implications by exploring effective ways to encourage consumers to adopt sustainable water consumption practices through the application of smart water meters.

Research four:

The theoretical goal of this study was to expand our understanding of the determinants that influence consumers' decisions to install smart water meters in their households. This involves extending the existing Technology Acceptance Model (TAM) – that was used and confirmed on the previous research - by exploring additional variables, such as environmental concerns, frugality, and personal innovativeness, as moderators between perceived ease of use, perceived usefulness, and attitudes toward smart water meters. By delving into these theoretical aspects, the research aimed to provide a deeper understanding of the drivers behind the adoption of innovative technologies for water management. On the cognitive front, this research enhanced our comprehension of how consumer behaviors and characteristics are linked to the acceptance of smart water meters. By analyzing the cognitive dimensions associated with perceived ease of use, perceived usefulness, and attitudes toward technology, the study managed to uncover the intricate interplay of factors that motivate consumers to embrace water-saving technologies. Methodically, this research employed a quantitative empirical approach to examine the impact of various factors on consumers' decisions to install smart water meters in their households. The research methodology involved collecting and analyzing data to test the proposed model, incorporating TAM determinants and additional moderating variables. Through this methodical approach, the study aimed to provide empirical evidence that validates the theoretical framework, and shaded light on the practical implications of smart water meter adoption. The insights gained from this study have the potential to inform policymakers, governments, and water companies, ultimately leading to increased adoption of IoT water meters and reduced household water consumption to combat the global issue of water scarcity.

Research five:

This research seeks to understand how environmental and actual water consumption affects participants' water consumption. Specifically, the goal is to determine whether providing information about their water consumption and general facts about water scarcity can influence participants to reduce their water usage. Methodically, the study is designed to develop and implement a rigorous experimental methodology for studying the impact of knowledge on water consumption behaviors. On the implementational front, the research strives to offer practical insights that can be applied in real-world scenarios to promote sustainable water management practices. It assesses the feasibility and effectiveness of using smart water meters and knowledge-based interventions to reduce water consumption in households, thereby contributing to the implementation of water-saving strategies in residential settings. These research goals collectively aim to provide empirical evidence and practical guidance regarding the impact of knowledge on water consumption.

5. Theoretical and conceptual foundations of the study and research hypotheses/questions.

Research 1:

There are three sectors account for the majority of water consumption: agricultural (70%), industrial (19%), and domestic (11%) (Flörke et al., 2013). While the domestic sector represents a smaller portion of total water consumption based on the data from the WRI's Aqueduct platform there is nearly 600% increase from 1960 to 2014, attributed to population growth, climate change, urban development, and consumer actions such as showering (Otto & Schleifer, 2020). Previous research in the domestic sector has focused on determinants of consumer water demand, home water consumption, causes of domestic water consumption, and urban sustainability policies (March et al., 2017; Ojeda de la Cruz et al., 2017; Shan et al., 2015; Velasco-Muñoz et al., 2019). However, there is a significant research gap in addressing water management and sustainability in the residential sector, even in consumer-oriented studies (Ehret et al., 2021; Gómez-Román et al., 2020). To bridge this gap, this study aims to conduct bibliometric and ADO framework analyses on the theoretical and conceptual foundations of residential water use, focusing on urban, household, and consumer perspectives.

In light of the aforementioned context, our study endeavors to address several research questions:

RQ1: What is the current landscape of research on residential water usage and management?

RQ2: To what extent do existing studies on water usage and management in residential settings specifically emphasize sustainability?

RQ3: Who are the primary authors exerting influence in this domain?

RQ4: Which journal(s) holds the most significance in publishing research on residential water usage and management?

RQ5: What are the prevailing research themes and topics within the field of residential water consumption?

RQ6: Do existing studies propose solutions or foresee future implications for sustainable water consumption in residential areas?

RQ7: What are the factors preceding, influencing decisions, and resulting outcomes presented in the selected articles?

Through this systematic examination of existing knowledge pertaining to water consumption in the context of sustainability, our aim was to unveil discernible trends and provide insights that can guide future research endeavors.

Research 2:

The hypotheses for this study are grounded in the theoretical framework of the Value-Belief-Norm (VBN) model, initially introduced by Stern et al. (1999), and extended to incorporate the moderating factor of perceived knowledge. The VBN model primarily addresses pro-environmental behaviors by investigating individuals' values, beliefs, and norms (Ghazali et al., 2019). The central components of this model, including ascription of responsibility, awareness of consequences, and personal norms, are typically employed to scrutinize consumers' pro-environmental intentions. This study extends the VBN model by introducing perceived knowledge as a moderator in the relationship between these key variables.

The primary focus of this research is on consumers' perceived knowledge and its direct and indirect influence on their intention to adopt smart water meters. Perceived knowledge about water usage encompasses individuals' perceptions of their absolute water consumption and their consumption relative to the average person. Prior research has established that consumers' knowledge and perceived knowledge play pivotal roles in their decision-making processes, particularly in environmentally related contexts (Lee et al., 2006; Martono et al., 2019; Suryanda et al., 2021b). Thus, the assumption here is that consumers who are more confident in their perceived knowledge, regardless of its accuracy, are more inclined to desire precise data regarding their water usage, thereby increasing their willingness to adopt smart water meters. Past research has demonstrated that perceived knowledge can motivate consumers to make environmentally friendly choices (Kim et al., 2018).

Building on this, it is posited that consumers with higher perceived knowledge about water usage will exhibit stronger intentions to save water by being more eager to apply smart water meters in their household knowing that it will contribute to their water consumption reduction. Based on that, the first two hypotheses were formed:

H1: Perceived knowledge about personal water usage is positively related to the intention to adopt smart water meters.

H2: Perceived knowledge about personal water usage is positively related to the intention to save water.

Moreover, prior studies examining water meters have shown that the implementation of smart water meters can lead to substantial reductions in household water consumption (Sønderlund et al., 2014). Hence, it is assumed that consumers with a strong intention to reduce their water consumption are more likely to be inclined to adopt smart water meters:

H3: The intention to save water is positively related to the intention to adopt smart water meters.

Pro-environmental behaviors and intentions have often been explained by the concept of personal norms (de Groot & Steg, 2009; Jansson et al., 2017) which represent internalized standards for behavior (Bamberg & Möser, 2007). According to Schwartz (1977) Norm Activation Theory (NAT), pro-environmental actions are often driven by a personal belief that environmental conditions pose a threat to others and can be alleviated by one's actions. The Value-Belief-Norm (VBN) theory, an extension of NAT by (Stern et al., 1999), establishes causal connections between values, beliefs, awareness of consequences, ascription of responsibility, personal norms, willingness to sacrifice, and consumer behavior. Given that both the intention to save water and the act of saving water are considered highly pro-environmental behaviors, it is postulated that personal norms concerning water conservation influence the intention to reduce household water consumption:

H4: The personal norm about saving water is positively related to the intention to save water.

Furthermore, the influence of perceived knowledge on pro-environmental behaviors has been demonstrated in previous studies (Bamberg, 2012; Hamzah & Tanwir, 2021; Onel &

Mukherjee, 2016). From these findings, it is hypothesized that perceived knowledge regarding environmental issues is related to the intention to save water:

H5: Perceived knowledge about water usage is positively related to the personal norm about saving water.

According to VBN, personal norms are predicted by awareness of environmental consequences and the ascription of responsibility (Dalvi Esfahani et al., 2015). The ascription of responsibility is defined as the sense of responsibility for the negative consequences of failing to act pro-socially (de Groot & Steg, 2009). The awareness of consequences, on the other hand, relates to the belief that taking or not taking a specific action will harm others (de Groot & Steg, 2009). These factors are strongly interrelated.

H6: Perceived knowledge about water usage is positively related to the ascription of responsibility for excessive water usage.

H7: The ascription of responsibility for excessive water usage is positively related to the personal norm about saving water.

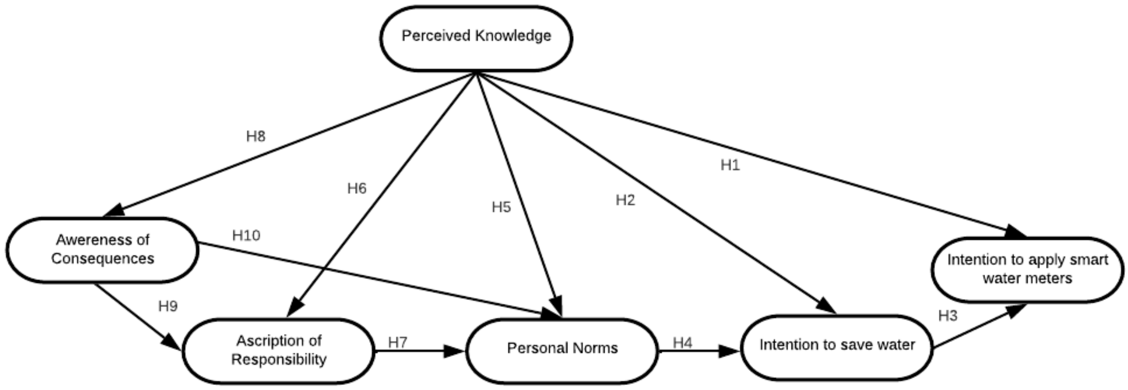
H8: Perceived knowledge about water usage is positively related to the awareness of consequences regarding excessive water usage.

H9: The awareness of consequences regarding excessive water usage is positively related to the ascription of responsibility for using too much water.

H10: The awareness of consequences regarding excessive water usage is positively related to the personal norm about saving water.

These hypotheses are represented in the research model outlined in Figure 4, serving as the basis for our study's investigation into the relationship between perceived knowledge, personal norms, and water-saving intentions.

Figure 4. Research Model



(Source: Own elaboration)

Research 3:

The Technology Acceptance Model (TAM) has emerged as one of the most widely used theories for studying technology adoption processes. This widespread use is attributed to its simplicity, comprehensibility, and robustness. TAM was originally introduced by Davis (1989) and was designed for modeling user acceptance of information systems. It is based on the Theory of Reasoned Action, which explains behavioral intentions and actual behavior based on intention, itself determined by attitude toward a given behavior and subjective norms. In the context of TAM, the intention to adopt an innovative technology is primarily predicted by attitude toward using that technology. This attitude, in turn, is influenced by behavioral beliefs, represented by two core variables: perceived ease of use and perceived usefulness. Perceived ease of use reflects consumers' beliefs about the ease of using a particular technology, while perceived usefulness relates to the user's perception that the technology will enhance their task performance. Both perceived ease of use and perceived usefulness have positive effects on consumers' attitudes toward the technology, subsequently influencing their intentions to use and apply it (Figure 5).

TAM has previously been applied to understand technology acceptance, especially in the domains of computers and the Internet, such as personal computers, email, voice mail, and online shopping, among others (Andaregie & Astatkie, 2021; Bruque & Moyano, 2007; Nguyen & Borusiak, 2021). It has also been employed in technology contexts related to smart solutions. For example, studies by Gao and Bai (2014) and Park et al. (2014) examined consumer acceptance of the Internet of Things (IoT) technology and smart grid technology, respectively, both confirming the relationship between perceived ease of use, perceived usefulness, and the intention to adopt smart solutions. In the present study, TAM was employed to explain the intention to apply smart (IoT) water meters. The key variables used in the hypothesis formulation included the intention to apply a smart (IoT) water meter in a consumer's household, attitude toward smart (IoT) water meter use, perceived ease of use, and perceived usefulness of smart (IoT) water meters. Drawing on findings from prior TAM-based studies, the following hypotheses were constructed to articulate the relationships between these variables:

H1: Perceived ease of IoT water meter use (PEOU) is positively related to attitude toward smart (IoT) water meter use (ATW).

H2: Perceived usefulness of IoT water meter (PU) is positively related to attitude toward smart (IoT) water meter use (ATW).

H3: Perceived ease of IoT water meter use (PEOU) is positively related to perceived usefulness of smart (IoT) water meters (PU).

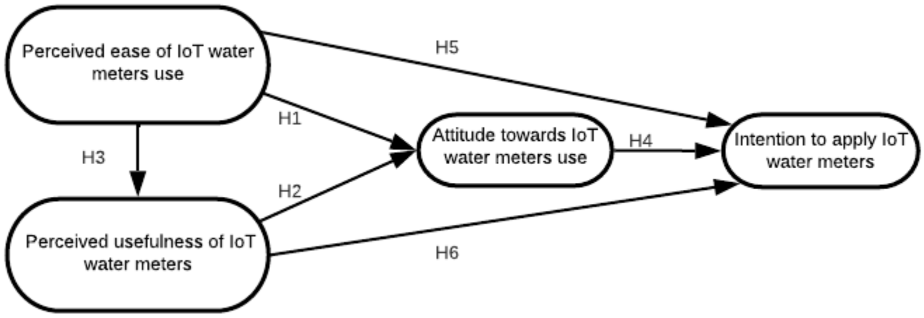
H4: Attitude toward IoT water meters use (ATW) is positively related to intention to apply smart (IoT) water meters (IAW).

H5: Perceived ease of IoT water meter use (PEOU) is positively related to intention to apply smart (IoT) water meters (IAW).

H6: Perceived usefulness of IoT water meter (PU) is positively related to intention to apply smart (IoT) water meters (IAW).

These hypotheses form the basis for the research model, as depicted in Figure 3.

Figure 5. Research Model



(Source: Own elaboration)

Research 4:

To construct the research model from which the hypotheses of this study are derived, the Technology Acceptance Model (TAM) by Davis (1989) was extended by incorporating three moderators: environmental concern, frugality, and personal innovativeness. The Technology Acceptance Model (TAM) proposed by Davis has been widely utilized to elucidate how consumers embrace innovative technologies. TAM postulates that the belief-attitude-intention relationship predicts technology acceptance and suggests that perceived usefulness and ease of use represent key beliefs. In this model, attitude pertains to a user's evaluation of the desirability of technology, while behavioral intention represents the likelihood that an individual will employ the technology. In the context of TAM, intention is a central indicator of technology acceptance, and attitude toward using technology is a primary determinant of intention. Thus, the below hypothesis was constructed:

H1. Attitude toward applying IoT water meters (ATW) determines the intention of applying them (IAW).

TAM posits that attitude is influenced by perceived ease of use and perceived usefulness. Perceived usefulness has been extensively examined in technology acceptance research. Prior studies that are presented by a literature review by Jeyaraj et al. (2006) indicate that perceived usefulness significantly influences the intention to adopt IT technologies. Perceived ease of use, another central construct in TAM, is a customer's perception of the effort required to interact with a technology. Research has shown that perceived ease of use is a significant predictor of attitudes toward various technologies, including online airline ticketing, e-learning services, and mobile financial services (Lee et al., 2011; Lee et al., 2012; Siringoringo, 2013). Perceived ease of use has also been found to affect intentions and attitudes toward specific technologies, both directly and indirectly, through its influence on perceived usefulness (Revels et al., 2010; Venkatesh & Davis, 2000). Thus, based on TAM the hypotheses 2, 3, and 4 were constructed:

H2. Perceived usefulness of IoT water meters (PU) is positively related to attitudes toward IoT water meter use (ATW).

H3. Perceived ease of IoT water meter use (PEW) is positively related to attitudes toward IoT water meter use (ATW).

H4. Perceived ease of IoT water meter use (PEW) is positively related to perceived usefulness of IoT water meters (PU).

To expand upon the TAM model, three moderators were included in the study: frugality, personal innovativeness, and environmental concern. Frugality is characterized by the proactive decision to purchase value products at low prices, limit consumption, use products for an extended period, and engage in repairing, reusing, and recycling (Lastovicka et al., 1999). Given the assumption that frugality is associated with saving and the potential overlap with environmental conservation values, frugality is examined as a moderator.

Personal innovativeness, as a construct, addresses the influence of individual traits on the acceptance of new technology. Consumers with higher personal innovativeness tend to be more curious, bold, and risk-takers, which can lead to more positive beliefs about new technology and a greater willingness to try it (Agarwal & Prasad, 1998).

Environmental concern, which relates to individuals' worry about ecological issues and their willingness to take action to address them (Dunlap & Jones, 2002), has been shown to influence consumer attitudes and behavior toward environmentally friendly actions (Li et al., 2022).

Based on the above, it is hypothesized that frugality, personal innovativeness and environmental concern moderate the relationships between perceived ease of IoT water meter use, perceived usefulness, and attitudes toward IoT water meters:

H5. Frugality moderates the relationship between perceived ease of IoT water meter use (PEW) and attitudes toward IoT water meter use (ATW).

H6. Frugality moderates the relationship between perceived usefulness of IoT water meter use (PU) and attitudes toward IoT water meter use (ATW).

H7. Personal innovativeness moderates the relationship between perceived ease of IoT water meter use (PEW) and attitudes toward IoT water meter use (ATW).

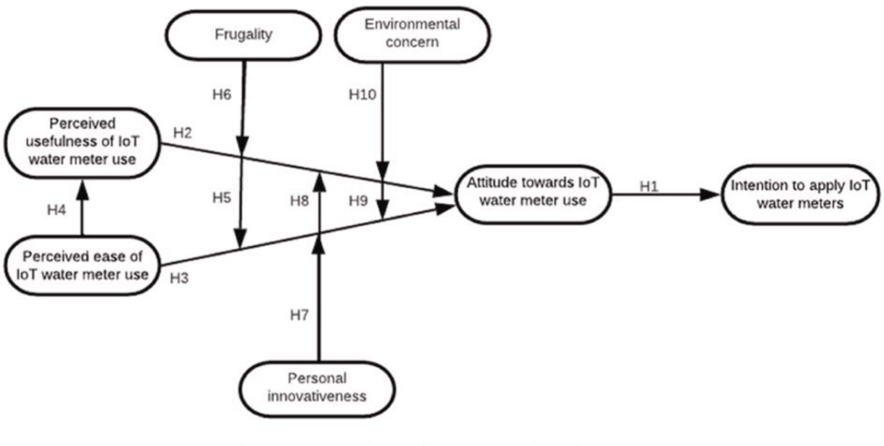
H8. Personal innovativeness moderates the relationship between perceived usefulness of IoT water meter use (PU) and attitudes toward IoT water meter use (ATW).

H9. The relations between perceived ease of IoT water meter use (PEW) and attitudes toward IoT water meter use (ATW) are affected by environmental concern.

H10. Environmental concern moderates the relationship between perceived usefulness of IoT water meter use (PU) and attitudes toward IoT water meter use (ATW).

This comprehensive research model integrates the Technology Acceptance Model with these moderating variables, shedding light on the factors that influence consumer intentions to apply IoT water meters (Figure 6).

Figure 6. Research Model



(Source: own elaboration)

Research 5:

This experimental study comprises two distinct components. Initially, it delves into previous research related to smart water meters, aiming to assess their influence on consumer behavior by imparting factual knowledge. Subsequently, it delves into examining environmental knowledge, in shaping participants' water consumption behavior.

This study seeks to explore the underlying factors that could amplify the impact of smart water meters on consumer water consumption, with a specific focus on environmental knowledge. Environmental knowledge in this study is defined as the understanding of environmental issues, encompassing an individual's awareness of environmental impact, appreciation for the environment, and a sense of collective responsibility (Mostafa, 2007) .Past studies have consistently highlighted the influence of environmental knowledge on pro-environmental behavior. Given the recognized role of general knowledge in shaping behavioral intentions (Martono et al., 2019), environmental knowledge has been associated with pro-environmental actions in studies such as Suryanda et al. (2021b). Based on the above, this study formulates a first hypothesis:

H1: Environmental knowledge delivered to participants through emails will lead to reduced water consumption

Previous research indicates that possessing actual knowledge of water consumption can lead to a reduction in water usage. For instance, in a study in South-East Queensland, Australia, households receiving tailored information through smart meters showed a collective 7.9% reduction in water usage compared to a control group (Fielding et al., 2012). Another research studied the effectiveness of the Dubuque Water Portal (DWP), a real-time water consumption feedback system Erickson et al. (2012) for 303 households. The portal displayed smart meter data, hourly graphs comparing household usage to peers, and included a team-based weekly game on water conservation. The intervention group exhibited a 6.6% reduction in normalized water consumption during the initial nine weeks, suggesting that more frequent feedback could reduce consumption in the short term. These findings contribute to the formulation of the second hypothesis:

H2. The installation of smart water meters in households will lead to a consistent reduction in the water consumption of consumers throughout the course of the study.

6. Research methodology and data sources

Research one:

The first article was a systematic review. We selected the Web of Science database for our literature search, primarily due to its reputation for providing a comprehensive collection of high-quality scientific papers and publications across various disciplines dating back to 1945 (Durán-Sánchez et al., 2018). Our search strategy did not specify a particular time frame, aiming to encompass all relevant research available up to January 23, 2021. We concentrated our search on three main domains: water management, residential water usage, and sustainability (Figure 8).

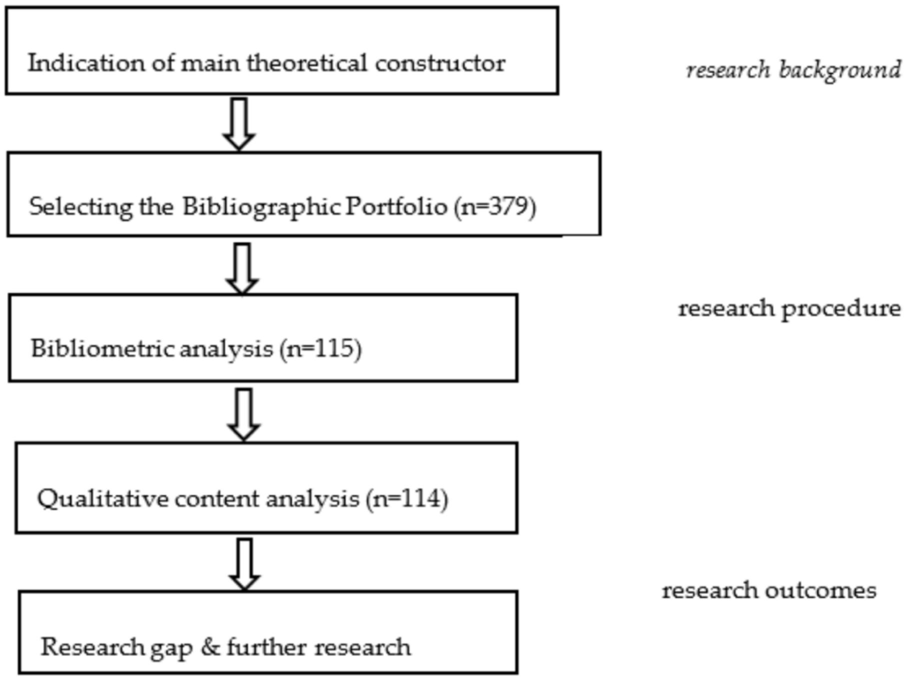
- For water management, our query included terms such as "water management," "water consumption," and "water-use."
- For residential areas, we employed terms like "resident," "household," "house," and "home."
- For sustainability, we included terms like "sustainable" and "sustainability."

We used the "OR" operator to indicate that at least one of the mentioned terms must be present in the articles. Additionally, the "*" symbol captured words starting with the preceding prefix. We limited the search to articles published in English, resulting in 379 initial articles. Our article selection process involved reviewing the abstracts, titles, and keywords of the identified articles to identify synonymous terms and exclude articles that did not align with our research focus. Each author independently reviewed the articles, and in cases of discrepancies, full-text reading and discussions were used to reach a consensus. This process reduced the list to 114 articles for further review.

To gain insights into the selected articles that could inform future research, we conducted a bibliometric analysis. This analysis involved statistical approaches, analysis of article trends, source impact, analysis of the most influential publications, keyword analysis, so-word and network analysis. We extracted the necessary data from the Web of Science and analyzed it using R software to conduct the analysis but also to visualize them in order to make them more understandable to the reader.

In the subsequent phase, we conducted a detailed analysis of the full texts of the 114 selected articles. These articles were categorized into three main groups: those related to consumers and their behavior toward water, households and their water consumption, and urban water consumption. We employed the Antecedents-Decisions-Outcomes (ADO) framework to synthesize the studies (Paul & Benito, 2018), focusing on the motives behind analyzing water consumption (antecedents), the specific aspects each article addressed (decisions), and the results in relation to water consumption and sustainability (outcomes). It's important to note that the ADO framework analysis was applied to this research area for the first time, and it complemented the bibliometric analysis to generate novel insights and suggest future research directions. This approach allowed us to gain a comprehensive understanding of the current state of research in the field of sustainable residential water management and usage.

Figure 8. Research Methodology



(Source: Own elaboration)

Research two:

The second study was a quantitative study. We conducted a three-part empirical study to validate model which was developed by the Value Belief Norm model (Stern et al., 1999).

Data were collected with a self-administered questionnaire and in the first part, they were provided with basic information about smart water meters. This information included technical details about the meter's mechanical operation without emphasizing or referencing potential benefits. It also included visual representations of current devices on the market designed for individual customers, along with web and mobile application interfaces for accessing consumption data. This information was crucial for establishing the research's credibility and enabling participants to acquire the same knowledge about smart water meter solutions, which are considered both product and process innovations not widely known to all consumers.

In the second part, respondents used a seven-point scale (ranging from 1, "I strongly disagree," to 7, "I strongly agree") to express their opinions on various statements. These statements were derived from previously validated scales that are based on the VBN model (Stern et al., 1999) (Table 1).

Table 1. Variables and Research Statements

Variable	Questions	Sources
Intention to apply IoT water meters	IAW1. I plan to apply IoT-based water meters in my household IAW2. I am willing apply IoT water meters in my household IAW3. I will make an effort to apply IoT water meters in my household	Chen and Tung (2014)
Ascription of responsibility for using too much water	AOR1. I believe all consumers need to take responsibility for water resource usage AOR2. I think that every consumer is partly responsible for water resource deterioration caused by human kind	Shin et al. (2018)
Awareness of consequences of using too much water	AOC1. I believe that using too much water can help increase the tempo of exhaustion of natural resources AOC2. Using too much water can possibly have a negative impact on the environment AOC3. I think that using too much water supports environmental degradations	Shin et al. (2018)
Personal norm concerning saving water	PN1. I believe I have a moral obligation to save water PN2.Saving water is consistent with my moral principles PN3. My personal values encourage me to save water	Shin et al. (2018)

Perceived knowledge on personal water usage	EK1. I have more knowledge on my water usage than an average person EK2. I know how much water I use every week on average EK3. I have the knowledge about my personal usage of water dedicated for the sustainability symbols used on product packages EK4. I am very knowledgeable about my water usage	Joshi and Rahman (2016)
Intention to reduce water usage	IP1. I plan to reduce water usage	Chen and Tung (2014)

(Source: Own elaboration)

In the final part, respondents provided their demographic information. We conducted the survey on Amazon Mechanical Turk, focusing on English-speaking residents of the United States with a high rate of completed tasks (over 90%). Participants who completed the initial part of the survey in less than 15 seconds or answered the main questions significantly faster than the average pre-test time were excluded. We also implemented attention check questions to ensure careful reading and removed respondents who failed them. The final sample consisted of 532 responses, with participants varying in terms of age, gender, household size, income, education, employment status, and type of residence.

Research three:

To collect data for this study, a self-administered questionnaire was used, employing the computer-Assisted Web Interview (CAWI) method. Participants were asked to respond to a series of statements using a 7-point scale, where 1 indicated "I strongly disagree," and 7 indicated "I strongly agree." Validated scales were used to measure latent variables based on the Technology of Acceptance model TAM (Davis, 1989) (Table 2)

Table 2. Variable and Survey Statements

Variables	Questions	Sources
Perceived usefulness of IoT water meters	PU1. Using an IoT water meter in my household would allow me to measure water usage more precisely. PU2. Using an	Davis (1989)

	IoT water meter in my household would improve knowledge on my water usage. PU3. Using an IoT water meter in my household would enhance my effectiveness in water usage management	Tsourela and Nerantzaki (2020)
Perceived ease of IoT water meter use	PEOU1.Learning to operate IoT-based water meters would be easy for me. PEOU2. I would find it easy to get IoT-based water meters to do what I want them to do. PEOU3. My interaction with IoT-based water meters would be clear and understandable. PEOU4. I would find IoT-based water meters to be flexible in interaction. PEOU5. It would be easy for me to become skillful at using IoT-based water meters. PEOU6. I would find IoT-based water meters easy to use.	Davis (1989)
Attitude towards IoT water meter use	ATW1. Using IoT water meters is a good idea. ATW2. Using IoT water meters is wise. ATW3. Using IoT water meters is beneficial. ATW4. Using IoT water meters is interesting	Schierz et al. (2010)
Intention to apply IoT water meters	IAW1. I plan to apply IoT-based water meters in my household. IAW2. I am willing to apply IoT water meters in my household. IAW3. I will make an effort to apply IoT water meters in my household.	Chen and Tung (2014)

(Source: Own elaboration)

The study was conducted on the Amazon Mechanical Turk platform. To ensure the credibility of the responses, an answer selection process was employed, which included attention-checking questions. Responses from individuals who passed this test were considered for analysis. Additionally, answers from participants who provided unreliable information, such as extreme values for age (e.g., 2222), were excluded. The time taken to complete the survey was also considered, and responses from participants who completed the survey significantly faster than the mean time (less than 3 times the standard deviation) were not included, as this might indicate insufficient time to thoroughly read the statements.

The final dataset comprised 366 participants, exceeding the recommended sample size of 300 for structural models. The number of participants was 22 times greater than the number of statements, indicating a sufficient sample size.

Research four:

A self-administered questionnaire was developed to investigate the predictors of the intention to apply smart water meters. The survey comprised two parts. The first part aimed to introduce participants to the concept of smart water meters, providing textual explanations and illustrative images. The explanation was carefully crafted to be comprehensive and neutral, avoiding any bias towards the potential benefits of the device. It included examples from various companies manufacturing smart water meters. This detailed description was essential for ensuring the credibility of the research and enabling participants to gain knowledge about smart water meters.

In the second part of the survey, participants were asked to respond to statements using a 7-point scale, ranging from "strongly disagree" (1) to "strongly agree" (7). Validated scales were employed to measure latent variables that derived from TAM (Table 3).

Table 3. Variables and Research Statements

Variables	Questions	Sources
Frugality	FR1. I believe in being careful about how I spend my money. FR2. I discipline myself to get the most from my money. FR3. I am willing to wait on a purchase I want so that I can save money. FR4. There are things I can resist buying today so I can save for tomorrow.	Lastovicka et al. (1999)
Personal innovativeness	PI1. When finding out about new technology, I look forward to trying it. PI2. Among my friends or family, I am usually the first to try new technologies. PI3. I prefer to explore and try new technologies.	Lu et al. (2005)
Environmental concern	EC1. I am concerned about the environment. EC2. The condition of the environment affects the quality of my life. EC3. I am willing to make sacrifices to protect the environment. EC4. I am emotionally involved in environmental protection issues.	Chuah et al. (2020)
Perceived usefulness of IoT water meters	PU1. Using the IoT water meter in my household would allow me to measure water usage more precisely. PU2. Using the IoT water meter in my household would improve knowledge on my water usage. Teo and Lee [63]; Tsourela and Nerantzaki [18]; PU3. Using the IoT water meter in my household would enhance my efficiency/ effectiveness in water usage management.	Davis (1989)

Perceived ease of IoT water meters use	PEW1. Learning to operate IoT based water meters would be easy for me. PEW2. I would find it easy to get IoT based water meters to do what I want it to do. PEW3. My interaction with IoT based water meters would be clear and understandable. PEW4. I would find IoT based water meters to be flexible for interaction. PEW5. It would be easy for me to become skillful at using IoT based water meters. PEW6. I would find IoT based water meters easy to use.	Davis (1989)
Attitude towards IoT water meter use	ATW1. Using IoT water meters is a good idea. ATW2. Using IoT water – energy meters is wise. ATW3. Using IoT water – energy meters is beneficial. ATW4. Using IoT water – energy meters is interesting	Schierz et al. (2010)
Intention to apply IoT water meters	IAW1. I plan to apply IoT based water meters in my household. Han et al. (2010); IAW2. I am willing apply IoT water meters in my household. IAW3. I will make an effort to apply IoT water meters in my household.	Chen and Tung (2014)

(Source: Own elaboration)

The research was distributed via the Amazon Mechanical Turk platform. Rigorous measures were taken to ensure data validity and reliability. These measures included the use of attention-checking questions for verification and the exclusion of respondents who completed the survey too rapidly. On average, participants took 8 minutes to complete the survey.

To ensure the validity and reliability of responses, a multi-stage verification step was incorporated, utilizing attention-checking questions. Any unreliable answers were excluded from the analysis. The final number of respondents was 657. To mitigate the potential impact of Common Method Bias (CMB), both procedural and statistical measures were integrated into the research methodology. These measures included techniques during the questionnaire design phase to disrupt potential patterns leading to CMB, maintaining respondent anonymity, ensuring question clarity, and conducting Harman's single-factor test after data collection. The results of the single-factor test suggested that CMB was not a significant issue in the data, enhancing the validity and reliability of the study findings.

Research 5:

The fifth article involved the practical application of IoT meters in households (Figure 9). Participants were selected based on specific criteria outlined in a survey using the snowball method. The criteria included: households not planning to relocate during the experiment, those with fewer than four guests per week, and households with two or fewer members to facilitate data analysis. Additionally, household characteristics such as age, gender, income level, education level, willingness to participate in research conducted in their private space, and readiness to accept a metering device in their household were also assessed.

After recruiting the participants, a date was arranged to visit the participants' households. During the initial visit to the participants' households, where the smart water meter was installed, participants were requested to sign a contract. This contract detailed data protection measures, data usage, and consequences related to equipment loss or delayed return. Participants were also required to sign instructions to ensure their comprehension of the experiment's procedures. In this phase, each household had one IoT smart water meter installed in their shower. The IoT water meters were purchased from Amphiro. These meters could monitor water consumption during showers, display the data on the showerhead, and transmit the information to a free mobile application for our and the participants to access.

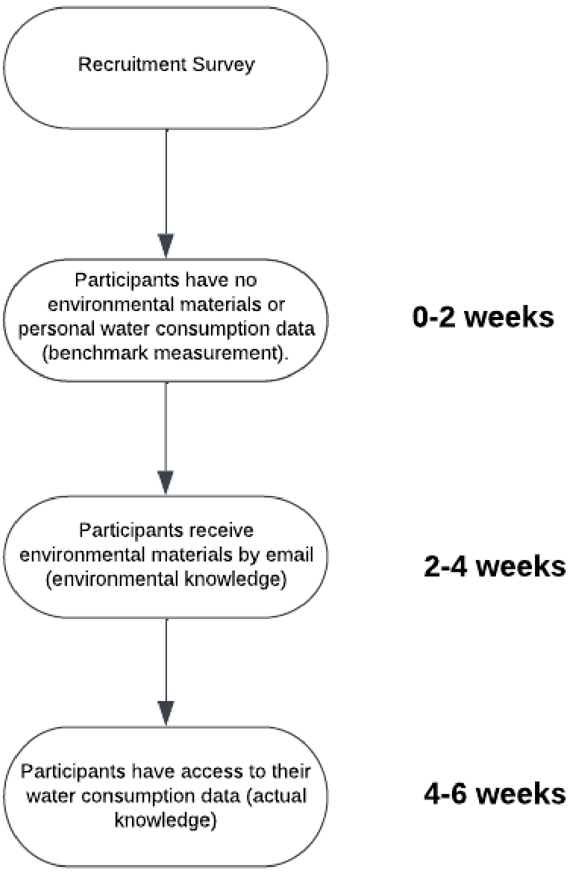
After the installation of smart water meters, we conducted three water consumption comparisons. The first comparison occurred during the initial two weeks when participants had no access to their water consumption data. These two weeks served as a benchmark to estimate average consumption and facilitate comparisons with subsequent stages.

The following two weeks involved participants were still having no access to their water consumption but receiving informative emails about water scarcity and water-saving tips. Four different designs and topics were employed, with two sent to our participants each week. The first topic provided information about water scarcity in Europe and its impact on individuals. The second topic focused on water scarcity in Poland. The third topic shared water-saving tips specifically for the shower, and the last topic offered more general water-saving tips. These materials were designed to address various aspects of water scarcity information, aiming to provide a comprehensive understanding of how water scarcity can affect us all and how to reduce household water consumption. We monitored email engagement by sending the email through a platform called "sendinblue". During weeks 2 to 4, the candidate revisted the participants' households to check their water consumption and compared it with the benchmark weeks.

The last two weeks participants were granted full access to their water consumption data via the mobile application that the IoT meter is connected and sending real-time data. This mobile application was installed at the participants' mobile phone so as to have direct access to their water consumption whenever they wanted. In the end of the 6th week, we visited their homes again to check the latest consumption data and compared it with the previous four weeks to determine the most effective approach for reducing water consumption.

After collecting all the data an analysis was conducted in order to examine if the smart water meters and/or the marketing materials were actually effective to reduce the water consumption of the consumers, and if so, which characteristics of the consumers were mediating this relationship the most.

Figure 9. Experiment Methodology



(Source: Own elaboration)

7. Research results and discussion

Research one:

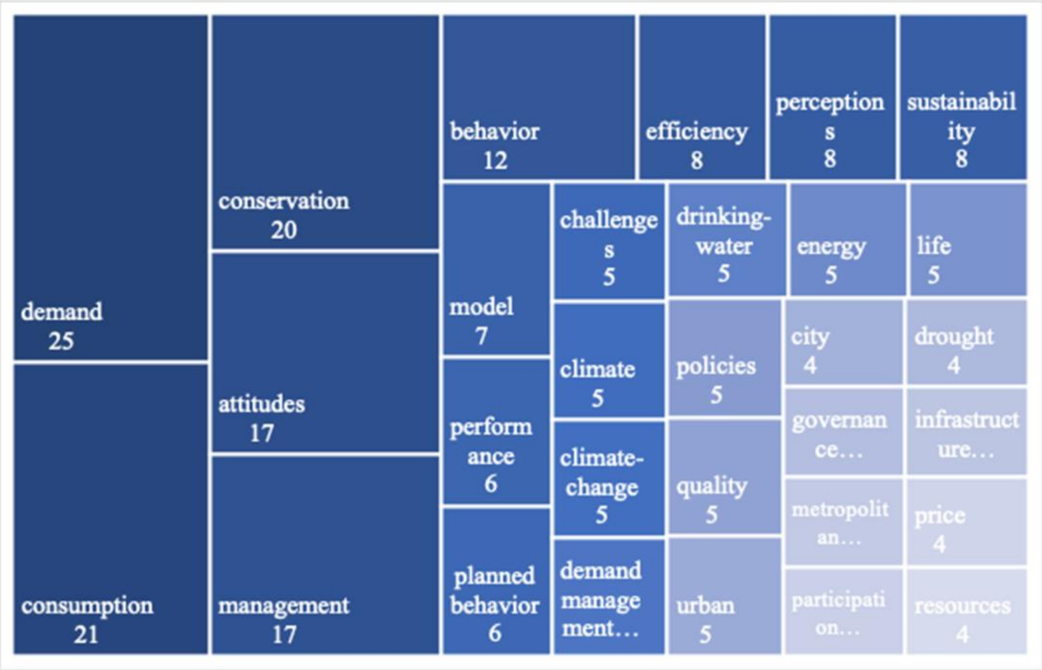
The research delved into an extensive analysis of the literature surrounding residential water use. Employing a comprehensive approach, the study combined bibliometric analysis with the innovative Antecedents, Decisions, and Outcomes (ADO) framework, spanning the years 2004 to 2021 and encompassing a scrutiny of 115 articles. The aim was to unearth trends, discern influential journals, identify notable publications, and extract key insights pertaining to residential water consumption.

When it comes to the bibliometric analysis which was focused on presenting the number of articles that were published in that specific research area throughout these years, the journals where these articles were mainly published, the journal's source's local impact, the most cited articles, keyword analysis, co-word analysis and clustering.

Discernible trend in the revealed an upward trajectory number of publications within the field, exhibiting an annual growth rate of approximately 22.11%. The zenith was reached in 2020, characterized by the highest volume of published articles. Among journals, the Journal of Cleaner Production emerged as the standout leader with the highest h-index, signifying its pronounced impact in the domain

A keyword analysis elucidated the core concepts and recurrent themes within the amassed articles, offering a snapshot of the field's predominant areas of focus (Figure 10).

Figure 10. Keyword Analysis



(Source: Own elaboration)

Additionally, the study employed a strategic diagram (Figure 11) created through co-word network analysis and clustering to detect, quantify, and visualize the evolution of the research field in residential water use. This diagram utilized two axes, namely development and relevance, while taking into account various factors such as the number of publications, local and global citations, and the strength of relationships with other clusters. The analysis revealed distinct quadrants within the diagram.

In the upper-left quadrant, niche topics with limited external relevance were identified. One such topic was "income," which, although well-researched, demonstrated limited influence on the broader research area. For instance, it examined the impact of consumers' economic status on their behavior, including water demand.

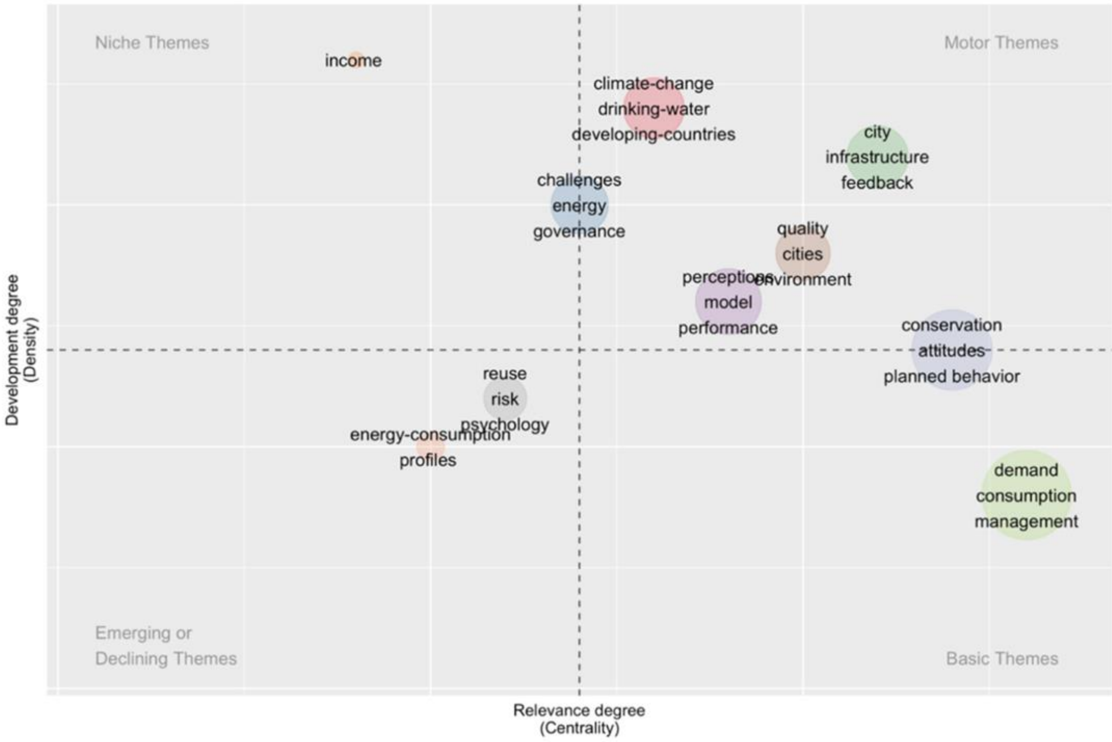
The lower-left quadrant encompassed themes that were underdeveloped and had marginal importance in the field. This quadrant featured clusters related to "reuse, risk, and psychology" and "energy consumption and profiles." These clusters explored topics like the adoption of water reuse using the Social Amplification of Risk framework and the examination of societal and personal practices related to showering.

The lower-right quadrant addressed fundamental themes that were important but not yet fully developed. In this quadrant, articles often overlapped with other research fields. Notably, a cluster centered around "demand, consumption, and management" discussed issues related to smart meters' impact on water demand, consumption, and management.

The upper-right corner was designated for "motor themes," which were well-developed and held high centrality and density in the research field. These themes covered various aspects, such as "city, infrastructure, and feedback," focusing on smart meters' influence on a city's water consumption. Additionally, themes like "climate change, drinking water, and developing countries" examined water resource adaptations in response to climate change. Another cluster centered on keywords like "quality, cities, and environment," highlighting how different water quality targets for water purification could save energy and benefit urban environments. Other motor themes encompassed topics like "perception, model, and performance" using empirical agent-based models to analyze risk perception related to water reuse, as well as "challenges and energy governance," which delved into user perceptions of decentralized water.

Importantly, the cluster relating to "conservation, attitudes, and planned behavior" stood out as highly significant but less developed than other motor themes. This thematic map not only provided insights into the current state of research but also indicated research gaps and future directions, particularly in the realm of consumers' water attitudes and conservation behavior in connection with planned behavior theory.

Figure 11. Strategic Diagram



(Source: Own elaboration)

After the bibliometric analysis, we used the ADO framework was invoked to scrutinize the antecedents, decisions, and outcomes of articles pertaining to residential water use. This entailed a dissection of the core themes within the field: urban, household, and consumer dimensions.

In the urban context, antecedents spanned diverse categories, encompassing sustainable water use, water scarcity and droughts, water supply systems, and the overarching objective of augmenting water accessibility in urban settings.

Antecedents in the household dimension featured the pursuit of making household appliances more ecologically efficient, embracing sustainable housing practices, and a multifaceted exploration of water utilization, management, conservation, and sustainability within households.

This dimension homed in on stimulating sustainable water consumption patterns among consumers. It grappled with themes such as resource usage, water consumption reduction, conservation, and the advocacy of eco-friendly behaviors among consumers.

The decisions and outcomes in these thematic dimensions provided invaluable insights. In the analysis, the concept of "decision" encompassed the specific choices made within each research theme. These decisions were critical in shaping the outcomes of the studies, and they provided valuable insights into how certain actions or strategies can lead to specific results. Let's delve into the results regarding decisions and their subsequent outcomes:

Within the household theme, the research was primarily focused on decisions related to home appliances and factors influencing household water consumption. Studies demonstrated that optimizing home appliances such as dishwashers and washing machines could effectively reduce household water consumption. However, it was also evident that promoting consumer education and technological advancements to improve appliance efficiency were key decisions to achieve sustainable water use. Furthermore, decisions such as recognizing the role of individual responsibility for climate change and the impact of external factors like COVID-19 influenced household water consumption patterns. These decisions led to outcomes highlighting the importance of education and technology in conserving water and the complex interplay between individual and external factors.

Decisions within the urban theme were primarily concerned with understanding the dynamics of local communities and their interaction with water supply, satisfaction with recycled water, and economic forces. This research emphasized the influence of pricing policies, social inequalities, and different forms of capital. Decisions in this category illuminated the multifaceted nature of urban water conservation. The outcomes highlighted that public knowledge, trust, and positive attitudes play essential roles in shaping responsible behaviors toward water resources. Additionally, the awareness of one's environmental impact was shown to correlate with knowledge of personal consumption. This reinforces the importance of fostering a sense of community responsibility for water conservation and addressing social and economic disparities in this context.

In the consumer theme, researchers explored decisions related to providing information, feedback, and marketing to encourage consumers to reduce water consumption. These studies emphasized that information, feedback mechanisms, and marketing campaigns could significantly influence consumer behavior. Decisions in this category underscored the importance of effective communication and education. The outcomes demonstrated that providing information, feedback, and marketing materials could lead to consumers changing their behavior and using less water. This suggests that empowering consumers with knowledge and engaging them through effective communication strategies can be highly impactful in achieving water conservation goals.

The analysis conducted in this study has unveiled critical research gaps that highlight promising avenues for future exploration in the field of residential water consumption. A substantial research gap brought to the forefront in this study pertains to the influence of technology and access to efficient household appliances on water consumption. This area warrants in-depth exploration to better understand the impact of technology and its role in shaping water consumption. Furthermore, delving into the intricate behavioral patterns and preferences related to water usage within households and communities offers a rich potential for research. Understanding how these factors interact and influence water utilization is crucial to improving water management strategies. Another notable research gaps emphasized in this study revolves around the role of consumer characteristics in shaping water usage habits and attitudes. This remains a fertile ground for inquiry, as understanding how individual characteristics and demographics influence water consumption is pivotal to tailoring effective conservation strategies. Finally, exploring the effectiveness of different strategies, whether through rhetorical methods, marketing campaigns, educational initiatives, or technology interventions, in promoting sustainable water consumption behavior would be invaluable. This research gap underscores the need for a comprehensive evaluation of the diverse strategies available for encouraging more responsible water usage practices.

Research two:

The study's outcomes are a compelling reflection of the extensive research conducted to explore the relationships between various factors and their impact on environmentally friendly behaviors and intentions, particularly in the context of personal water usage. The robust methodology, including structural equation modeling, validity assessments, and path analysis, provided a comprehensive understanding of these intricate relationships, allowing for insightful comparisons with the stated research hypotheses and questions.

First and foremost, the research ensured the reliability and validity of the measurement model, which played a pivotal role in the subsequent analyses. The measurement model demonstrated excellent reliability, supported by Cronbach's α values ranging from 0.89 to 0.93, well above the recommended thresholds. Standardized factor loadings, Composite

Reliability (CR), and Average Variance Extracted (AVE) all exceeded the recommended criteria, affirming convergent and discriminant validity. Furthermore, discriminant validity was effectively established using the HTMT ratio of correlations, with all ratios comfortably below the threshold of 0.9 (Table 4). The subsequent path analysis, conducted to examine relationships among latent variables, provided a wealth of insights into the complex interplay between these variables. The structural model exhibited a high degree of explanatory power, with R-squared values of 0.636 for the intention to use smart water metrics (IP), 0.810 for personal norms (PN), and 0.44 for the intention to adopt smart water meters (IAW). Following Schumacker and Lomax (1996), we applied three types of fit indices to evaluate the model: absolute fit, parsimonious fit, and incremental fit. All the obtained fit indices met the suggested ranges: CMIN/df = 2.47, RMSEA = 0.0538, GFI = 0.978, AGFI = 0.911, CFI = 0.964, and NFI = 0.911 (Hair et al., 2014).

Table 4. SEM analysis

Endogenous variable	Exogenous variable	Beta	B	Se	*p*-value	CI lower	CI upper
AOC	PK	0.17	0.18	0.05	***	0.08	0.28
AOR	PK	0.20	0.31	0.07	***	0.19	0.45
AOR	AOC	0.71	1.10	0.14	***	0.84	1.41
PN	AOR	0.57	0.83	0.16	***	0.58	1.21
PN	AOC	0.32	0.73	0.17	***	0.40	1.08
PN	PK	0.17	0.39	0.06	***	0.26	0.51
IP	PN	0.73	0.53	0.08	***	0.39	0.69
IP	PK	0.14	0.23	0.06	***	0.12	0.36
IAW	IP	0.36	0.29	0.05	***	0.20	0.39
IAW	PK	0.42	0.57	0.07	***	0.44	0.71

(Source: Own elaboration)

This study found that consumers' perceived knowledge about personal water usage significantly impacts their intentions to adopt smart water meters, both directly and indirectly. The direct effect of perceived knowledge on adoption intention was strong suggesting that individuals aware of their water consumption are more inclined to use smart meters for precise data.

Perceived knowledge also indirectly influences the intention to save water, supporting previous research that links knowledge with pro-environmental behaviors (D. S. Levine & M. J. Strube, 2012). Consumers motivated to save water are more likely to implement smart meters to achieve this goal Sønderlund et al. (2014). The indirect effect was calculated by combining the direct effects of intentions to save water and perceived knowledge. Indirect impacts were observed through personal norms, which connect perceived knowledge of water use with the intention to reduce consumption and adopt smart meters, aligning with studies on pro-environmental behaviors such as the study conducted by de Groot and Steg (2009). Perceived knowledge also influences ascription of responsibility and awareness of consequences, consistent with the Value-Belief-Norm (VBN) theory. Our findings suggest that ascription of responsibility significantly impacts personal norms, which in turn affect intentions to reduce water consumption and apply smart meters. The study highlights that perceived knowledge, rather than objective knowledge, is a stronger predictor of environmental behaviors which aligns with previous findings Kim et al. (2018).

Research three:

The study's findings are rooted in rigorous statistical analyses, including confirmatory factor analysis and structural equation modeling, aimed at assessing the relationships between the variables under investigation. The results indicate that the research model is robust and well-constructed.

First, confirmatory factor analysis was conducted to evaluate the measurement method for the variables. The loading values for all variables significantly exceeded the recommended threshold of 0.6, ranging from 0.72 to 0.94, affirming the suitability of the chosen measurement approach. Furthermore, internal consistency was assessed through Cronbach's α and Composite Reliability (CR), which both exceeded the recommended 0.7 for all variables and ranged from 0.79 to 0.93. This underscores the reliability of the variables in the measurement model. Additionally, the Average Variance Extracted (AVE) analysis demonstrated the recommended internal consistency among the variables, with values ranging from 0.58 to 0.76 (Table 5).

Concerns about common method bias were addressed through a correlation analysis, which revealed that none of the variables correlated above the recommended threshold of

0.85, with the maximum correlation observed at 0.71. This finding supports the absence of common method bias in the data. The model's robustness was further confirmed using bootstrapping with 2000 repetitions.

The goodness-of-fit indices for the model also suggest that it is well-constructed. The RMSEA value was 0.065, chi2/DF did not exceed 3 and was 2.54. Other parameters were also below the cutoff level: CFI = 0.968, GFI = - 0.929, TLI = 0.958, and NFI = -

0.948. This indicates that the theoretical model is correctly constructed, and individual relations have been analyzed.

The subsequent analysis of direct effects revealed that the majority of relationships were significant at a high level of significance ($p < 0.001$) (Table 5). Specifically, the study confirmed hypotheses related to the Technology Acceptance Model (TAM). Perceived Ease of Use (PEOU) significantly influenced both Perceived Usefulness (PU) and Attitude Towards Use (ATW), aligning with hypotheses H1 and H3. PU had a significant impact on ATW, consistent with H2. However, the effect of PU on Intention to Adopt Wearable Technology (IAW) was found to be statistically insignificant, leading to the rejection of hypothesis H6.

Table 5. SEM analysis

Endogenous variable	**Exogenous variable**	**Beta**	**B**	**SE**	***p*-value**	**CI lower**	**CI upper**
ATW	PEOU	0.24	0.37	0.10	***	0.17	0.55
ATW	PU	0.62	0.83	0.18	***	0.55	1.26
PU	PEOU	0.51	0.60	0.07	***	0.46	0.76
IAW	ATW	0.63	0.60	0.14	***	0.37	0.93
IAW	PEOU	0.42	0.61	0.13	***	0.37	0.91
IAW	PU	0.30	0.38	0.20	*Ns*	-0.88	-0.10

(Source: Own elaboration)

The objective of this study was to extend our understanding of the predictors of consumer intention to apply IoT water meters in households, which may contribute to reducing household water consumption. Using the Technology Acceptance Model (TAM), this study posits that the intention to adopt a new technology is predicted by the attitude towards using that technology, which is further influenced by perceived ease of use and perceived usefulness. The findings of this study align with previous TAM-based research, confirming the majority of hypotheses (H1-H5).

Consistent with TAM, our results verify that the behavioral intention to use smart water meters is determined by attitudes towards the technology. This relationship has been supported by previous studies, such as Robles-Gómez et al. (2021) and Kranz et al. (2010), who found that attitudes towards technology platforms and energy smart meters significantly affect the intention to use these technologies.

In addition to the impact of attitudes on intention, our study examined the determinants of attitudes towards using IoT water meters. As found in previous TAM-based research, perceived ease of use and perceived usefulness positively impact attitudes towards the technology. Chen et al. (2017) similarly reported that these factors predict consumer attitudes towards renewable energy and e-learning services, respectively.

Our research also supports the notion that perceived ease of use influences both attitudes and consumer intention to apply smart water meters. This is consistent with findings by Kuo and Yen (2009), who noted that perceived ease of use affects consumer intention to use technology facilities and mobile services.

Interestingly, our study did not find a significant direct relationship between perceived usefulness and intention to apply smart water meters, a deviation from typical TAM findings, However, the meta-analysis by Yousafzai et al. (2007) also noted instances where this relationship was not significant, highlighting the variability in these findings.

Positive relationships were found between perceived usefulness and attitudes towards using smart water meters, and between attitudes and the intention to apply these meters. This indicates that attitude mediates the relationship between perceived usefulness and the intention to adopt smart water meters. At the attitude formation stage, the perceived benefits of using smart water meters provide a strong rationale, while at the behavioral intention stage, perceived ease of use becomes a more critical predictor. Our results also confirm that perceived ease of use can explain the perceived usefulness of IoT water meters. This aligns with previous research by Gao and Bai (2014) who found that ease of use is closely connected with perceived usefulness. Consumers are more likely to find IoT water meters useful if they can use them without difficulties, reinforcing the importance of user-friendly designs.

Research four:

The primary aim of this study was to explore the factors influencing consumers' intentions to adopt IoT water meters and how these factors relate to each other. To achieve this, the study employed the Partial Least Squares Structural Equation Modeling (PLS-SEM) approach. The research began by rigorously assessing the convergent and discriminant validity of the individual variables and composite reliability of the items used. Confirmatory factor analysis established that all factor loadings exceeded the recommended threshold of 0.6, attesting to the validity of the measurement model. Scale reliability was assessed through Cronbach's α, indicating excellent consistency, ranging from 0.84 to 0.93. Furthermore, the study verified convergent and discriminant validity using standardized factor loadings, Composite Reliability (CR), and Average Variance Extracted (AVE), all of which met the recommended criteria (Table

Discriminant validity was confirmed using the HTMT ratio of correlations, with all ratios well below the threshold of 0.9. The model fit indices were assessed and found to be satisfactory, with values below the accepted cutoffs: RMSEA of 0.06, CFI of 0.97, GFI of 0.94, TLI of 0.96, and NFI of 0.96, indicating the proper construction of the theoretical model.

Subsequently, the study conducted an analysis of the direct effects of the variables, revealing that all relationships were statistically significant at the $p < 0.001$ level (Table 6).

Table 6. SEM analysis

Endogenous Variable	Exogenous Variable	Beta	B	SE	p-value	CI lower	CI upper
PU	PEW	0.50	0.57	0.07	***	0.44	0.71
ATW	PEW	0.23	0.41	0.08	***	0.25	0.56
ATW	PU	0.68	1.03	0.14	***	0.80	1.35
IAW	ATW	0.66	0.51	0.06	***	0.40	0.62

(Source: Own elaboration)

Notably, the direct effect of attitudes towards IoT water meters on intentions to apply them was significant, confirming hypothesis H1. Similarly, the effect of perceived usefulness on attitudes was statistically significant, supporting hypothesis H2. Perceived ease of use exhibited a direct influence on perceived usefulness and attitudes towards IoT water meters, confirming hypotheses H3 and H4.

Consistent with Davis (1989), perceived usefulness and perceived ease of use affect the intention to use information technology via attitudes. In addition, Lule et al. (2012) found that both perceived ease of use and perceived usefulness significantly impacted attitudes towards M-banking.

Our results further underscore the importance of improving consumers' perceptions of ease of use and usefulness. Providing comprehensive information and education about smart water meters can enhance these perceptions, thereby increasing the likelihood of adoption

The study also explored the interaction between perceived ease of use and perceived usefulness, confirming that these variables are interrelated. Ma et al. (2017) found similar relationships in their studies on sustainability labels and internet banking, respectively. Consumers who perceive smart water meters as easy to use are more likely to find them useful, enhancing their overall attitudes towards these devices.

In addition to the primary frugality moderated the relationship between perceived usefulness and attitudes, indicating that frugal consumers see the financial benefits of smart water meters. However, it did not moderate the relationship between perceived ease of use and attitudes. Personal innovativeness moderated the relationship between perceived ease of use and attitudes, with innovative consumers finding the meters easier to use. Environmental concern negatively moderated both relationships, suggesting that highly environmentally concerned consumers may already be aware of their consumption patterns and thus see less additional benefit from the meters.

Research five:

The study was conducted over a six-week period (for each household), divided into three distinct phases of two, four, and six weeks to observe the progressive impact of the interventions on water consumption. During the first two weeks, baseline water consumption data was collected to capture the natural usage patterns of the participants without any interventions. In the second phase, lasting four weeks, participants received educational materials designed to increase their environmental knowledge, including information on water conservation, tips to reduce usage, and the environmental impact of excessive consumption. In the final six-week phase, smart water meters were installed in the participants' households to provide real-time feedback on water usage, allowing participants to see their consumption patterns immediately. The study monitored and recorded water usage throughout these phases to evaluate the effectiveness of the interventions.

A repeated measures ANOVA was conducted to assess the impact of the intervention phases on water consumption over time. The analysis revealed a statistically significant effect of the intervention phases on water consumption, $F(2,56)=3.310, p=0.044$, $\eta 2=0.106$. This suggests that the interventions had a notable impact on the water consumption patterns of the participants.

Table 7. Descriptive Statistics

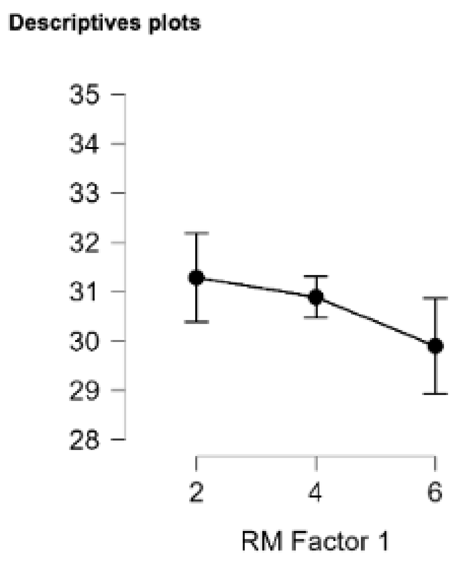
Descriptives

RM Factor 1	N	Mean	SD	SE	Coefficient of variation
2	29	31.286	8.780	1.630	0.281
4	29	30.890	7.787	1.446	0.252
6	29	29.900	6.552	1.217	0.219

(Source: Own elaboration)

Post hoc comparisons using the Holm method were performed to further investigate the differences in mean water consumption between the time points (see Table 7). The comparisons indicated that there was no significant difference in water consumption between 2 weeks (M = 31.286, SD = 8.780) and 4 weeks (M = 30.89, SD = 7.78), with a mean difference of 0.397, $t(56)=0.715$, Cohen's $d=0.051$, $p=0.478$. Similarly, no significant difference was observed between 4 weeks and 6 weeks (M = 29.900, SD = 6.552), with a mean difference of 0.990, $t(56)=1.783$, Cohen's $d=0.128$, $p=0.160$. However, a significant reduction in water consumption was observed between 2 weeks and 6 weeks, with a mean difference of 1.386, $t(56)=2.498$t, Cohen's $d=0.179$, $p=0.046$, indicating that the introduction of the smart water meters had a significant impact on reducing water consumption by the end of the study period (Figure 7).

Figure 7. Descriptive Plots



(Source: Own elaboration)

This study aimed to investigate the impact of environmental knowledge and real-time consumption feedback on household water consumption through the use of smart water meters. The results indicated that while there was no significant reduction in water consumption between weeks 2 and 4, the reduction between weeks 2 and 6 was significant. This suggests that providing actual knowledge on water usage can significantly influence consumer behavior, supporting hypothesis H2. However, the environmental knowledge provided through informative materials alone did not lead to a significant reduction in water consumption, as seen in the non-significant difference between weeks 2 and 4, thus not supporting hypothesis H1.

One of the ways to explain the results is based on the varying levels of pre-existing environmental knowledge among participants could have influenced the effectiveness of the educational materials. Previous research supports these findings. For instance, Abrahamse et al. (2005) found that frequent feedback was effective in reducing household energy consumption, while Bager and Mundaca (2017) highlighted the impact of loss-framed, salient information on reducing electricity demand. Meanwhile, Erickson et al. (2012) demonstrated the effectiveness of smart water meters in reducing household water usage through real-time feedback.

Providing consumers with actual knowledge on their water usage can enhance the effectiveness of conservation efforts. Combining this practical knowledge with targeted environmental education campaigns could further reinforce sustainable water consumption behaviors.

The significant reduction in water consumption observed between weeks 2 and 6 indicates that actual consumption knowledge is a crucial component in influencing consumer behavior. While environmental knowledge is important, it may not be sufficient on its own to drive significant behavioral changes. The synergy of practical and environmental knowledge appears to be more effective in promoting sustainable water usage.

8. Conclusions

The collective findings of these five studies provide a comprehensive understanding of residential water use, consumer behavior, and the impact of knowledge through technological interventions on water conservation. These studies address the two main questions of this dissertation and help to minimize the research gap concerning how to influence consumers to install smart water meters to reduce water scarcity.

This dissertation enhances our understanding of consumer behavior and demonstrates how we can encourage consumers to install smart water meters which based on our experiment may lead to household water reduction which is crucial in addressing the broader issue of water scarcity. This conclusion synthesizes the theoretical and practical insights derived from the research, highlighting the added value to the field and identifying critical areas for future exploration.

The extensive bibliometric analysis conducted in Research One revealed a significant upward trend in publications related to residential water use, underscoring the growing academic interest in this domain. By employing the Antecedents, Decisions, and Outcomes (ADO) framework, the study provided a nuanced understanding of the core themes within the urban, household, and consumer dimensions of water use. The finding adds a unique perspective to the existing body of knowledge on residential water consumption. Building on the systematic review results Research Two adds a valuable theoretical contribution by highlighting the significance of perceived knowledge as a pivotal variable capable of directly and indirectly influencing consumers' intentions to adopt smart water meters in their households. The research demonstrates that perceived knowledge, coupled with values-beliefs-norms theory, can positively influence sustainable behavior, such as adopting smart water meters, which can help reduce household water consumption. These findings are valuable not only for researchers but also for policymakers aiming to design effective campaigns for reducing household water consumption, a critical factor in addressing global water scarcity issues.

Research Three makes a substantial theoretical contribution by examining the scope of the Technology Acceptance Model (TAM) within the context of smart water meter adoption. The study identifies attitude towards IoT water meters as a key determinant of intention, acting as both a mediator for the impact of perceived usefulness and perceived ease of use on intention to apply smart water meters. This unique perspective challenges conventional expectations and suggests that perceived usefulness plays a more significant role than perceived ease of use in shaping attitudes towards IoT water meters. Moreover, adding to that, Research Four extends our understanding of factors influencing consumer intention to adopt smart water meters by incorporating three key moderators into the TAM framework: frugality, personal innovativeness, and environmental concern. The findings reveal that frugality and personal innovativeness positively moderate the relationships between perceived usefulness, perceived ease of use, and attitudes towards smart water meters. Conversely, environmental concern negatively moderates these relationships, emphasizing that consumers focused on environmental conservation prioritize water reduction goals over the ease of use or usefulness of these devices.

Research Five underscores the value of integrating smart water meters into broader water conservation strategies. The results show that providing environmental knowledge alone did not significantly reduce water consumption, whereas actual consumption knowledge from smart water meters led to significant reductions. This indicates that practical insights into consumption patterns effectively motivate sustainable water-saving behavior. This study provides practical evidence supporting the theoretical constructs identified in the earlier studies.

Despite the significant contributions, these studies have several limitations. For instance, the limited generalizability due to the participant pool's demographic characteristics, lack of experience with smart meters, the small sample size and the influence of external factors when it comes to the research five.

In summary, these studies collectively advance our understanding of residential water use and provide effective strategies for promoting sustainable behaviors. They also address several identified research problems: the lack of understanding of the influence of knowledge on water consumption from smart water meters, the scarcity of research on ways to influence consumer behavior to adopt smart water meters in households, and the broader issue of water scarcity caused by household water consumption.

The integration of theoretical insights, such as the confirmation and extension of the Technology Acceptance Model (TAM), and the examination of perceived knowledge using the Value-Belief-Norm (VBN) framework, offers a robust approach for studying consumer behavior and technology adoption in the context of environmental conservation. The confirmation of the TAM model establishes attitudes towards smart water meters as a critical determinant of adoption intention, with perceived usefulness and ease of use shaping these attitudes. Extending TAM by incorporating moderators such as frugality, personal innovativeness, and environmental concern reveals how these factors influence the adoption process, providing a more nuanced understanding of consumer behavior.

Moreover, the studies demonstrate that perceived knowledge and values-beliefs-norms can significantly influence sustainable behaviors, such as adopting smart water meters. This offers practical insights for designing effective educational campaigns. The practical findings underscore the importance of actual knowledge from smart water meters in reducing water consumption. The findings address critical gaps in the literature, such as the lack of studies focusing on the socio-economic and demographic factors influencing water use, and provide actionable recommendations for policymakers, practitioners, and researchers. These include enhancing consumer education, improving the design and usability of smart water meters, and tailoring marketing strategies to different consumer segments based on their environmental concerns and innovativeness.

Ultimately, this research contributes to the development of more effective and impactful water conservation initiatives. The scientific contribution of this research is significant, both theoretically and practically. It minimizes the research gap in consumer studies, it extends and verifies models such as TAM and VBN, and it examines how knowledge can influence consumer behavior. Practically, it enhances our understanding of consumer behavior and sustainable water consumption, demonstrating how smart water meters and actual knowledge can influence water usage. This provides valuable insights into reducing household water consumption, which may help address the global issue of water scarcity.

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10. A list of articles and studies that constitute a thematically cohesive dissertation

Residential Sustainable Water Usage and Water Management: Systematic Review and Future Research Madias Konstantinos, Szymkowiak Andrzej, Water, 2022, vol. 14, no. 7, pp.1-18, Article number:1027. DOI:10.3390/w14071027

The role of knowledge about water consumption in the context of intentions to use IoT water metrics Madias Konstantinos, Borusiak Barbara, Szymkowiak Andrzej, Frontiers in Environmental Science, 2022, vol. 10, pp.1-12, Article number:934965. DOI:10.3389/fenvs.2022.934965

Innovative technology for sustainable behavior – investigating predictors of consumer intention to use smart water meters Madias Konstantinos, Borusiak Barbara, Szymkowiak Andrzej, Zeszyty Naukowe Politechniki Śląskiej. Organizacja i Zarządzanie, 2023, no. 173, pp.469-485. DOI:10.29119/1641-3466.2023.173.31

What builds consumer intention to use smart water meters –Extended TAM-based explanation Madias Konstantinos, Szymkowiak Andrzej, Borusiak Barbara, Water Resources and Economics, 2023, vol. 44, pp.1-13. DOI:10.1016/j.wre.2023.100233

The effect of water usage knowledge on water consumption provided by IoT water meters. Madias Konstantinos, Borusiak Barbara, Szymkowiak Andrzej, Working Paper

Part II.
Articles and studies that constitute a doctoral dissertation

water

MDPI

Review

Residential Sustainable Water Usage and Water Management: Systematic Review and Future Research

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Abstract: Sustainable water management has vital ramifications for people's societal, economic and environmental future. To advance research in this domain, this article synthesizes the current state of knowledge regarding water resource management in the residential context. The aim of this paper is to identify research gaps and future research directions for residential water management in order to recommend solutions against water scarcity. To that end, this article applies bibliometric analysis and the Antecedents, Decisions and Outcomes (ADO) framework to the literature on residential sustainable water management. We reviewed the most impactful journals, most frequently cited articles, keyword trends and density-centrality maps. The in-depth analysis on 114 articles underscored three orientations for residential water usage and management: urban, household and consumer. Based on this analysis, we were able to identify the significant topics that structure this research field, as well as research gaps and future directions.

Keywords: water usage; water consumption; water management; sustainability; residential; systematic review

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1. Introduction

The availability and management of freshwater is foundational to human civilization. However, water is a largely irreversible resource: At present, humans have no way of expanding their water allowance, but excess activity can diminish our supply [1]. While societies have invented valuable technologies for manipulating and distributing freshwater to sustain their populations [2]—dams, irrigation systems, hydropower, and so on—the demand created by human activity is outpacing our available water. People's broadening awareness of this fact is reshaping their water consumption habits.

Against this backdrop, the three most notable sectors for water consumption are agri- cultural, industrial and domestic. Agricultural irrigation uses approximately 70% of total water consumption [3] due to its foundational role in food production and economies [3]. Industrial water use, accounting for approximately 19% of the total, is the result of accel- erated economic growth, which merits finding ways to balance economic development with sustainable water resources [4]. Domestic water consumption accounts for approxi- mately 11% of total water consumption [5]. Based on WRI's Aqueduct [6], domestic water demand increased by 600% from 1960 to 2014. Some of the main domestic water usage activities are showering, washing-machine usage, toilet flashing and outdoor activities such as swimming pools [7]. The primary drivers of domestic water consumption seem to be urbanization, brisk population growth and higher living standards, which result in excessive domestic water consumption, but there are other relevant factors such as price, monetary incentives [8], socioeconomic factors, the size of housing and outdoor space, as well as house typology, which are some of the most commonly found determinants of water consumption in literature on the subject [9]. Despite this breadth of knowledge, there are relatively fewer articles regarding sustainable water usage and management in the domestic sector. Sustainability in water usage can be explained based on the Brundtland report, which defines sustainability as 'the way to ensure that development meets the needs of the present without compromising the ability of future generations to meet their own needs' [10]. Thus, sustainability on water usage is finding ways to use and manage water in a way that development will be assured while future generations will not have to face critical issues of water scarcity. In addition, as this paper will also focus on water management, it is crucial to mention that sustainable water management concerns the proper allocation of water resources, management optimization of resources, analysis of the climate change and its effect on water and management of natural disasters and their effects on water resources in order to assure that present and future generations will have water supplies [11].

In order to synthesize existing knowledge on this topic and narrow the research gap regarding finding solutions to excessive residential water usage, we followed the suggestion of many authors and performed a bibliometric review [1]. This technique uses quantitative analysis and statistical methods to construe patterns and trends among research articles on a specific topic. Here, we conducted an in-depth bibliometric analysis of articles in the Web of Science database that concern water management. Additionally, we conducted a content analysis based on the ADO framework [12], which examines the antecedents (A), decisions (D) and outcomes (O) of the collected articles. The 'antecedents' of a study are defined as the motives behind the research, 'decisions' are defined as the characteristics of a study and 'outcomes' are the results. The main aim of this content analysis is to examine the anatomy of our research area and identify any kind of research patterns [13]. Combined, our analytical methods may serve to illuminate the breadth and depth of research on residential water usage, as well as existing research gaps and future research directions. The need for this kind of research lies in the fact that research regarding residential water usage should be broader and cover similar research topics that have not been analysed up till now. However, in order to do so, we need a clear picture of what has already been researched and what has not; this can be achieved by a systematic analysis of the specific research area. By doing so, we hope this research will inspire new solutions for sustainable water management. In addition, past reviews regarding water were mostly focussed on the agricultural industry, water resources and sustainable water usage [14–16], but none of them has focussed on residential water usage and water management. The uniqueness of our study also relies on the combination of two different systematic review methods, bibliometric and content analysis; in previous reviews it is more common that only one method was used.

Given the above, our study seeks to answer the following questions: What are the existing studies in residential water usage and water management? How much research on water usage and management specifically addresses sustainability? Who are the most influential authors in this domain? Which is the most influential journal? What are the most popular research topics in this field? Do existing studies present any solutions and/or future implications for sustainable water consumption? What are the antecedents, decisions and outcomes of the selected articles? By systematizing the available knowledge regarding water consumption in the context of sustainability, we aim to reveal trends and directions that can be utilized by future research.

The present article is divided into five main sections. Following this introduction, the second section details the conceptual framework that underpins our analyses. The third section describes our research methodology, search criteria and data collection. The fourth section details the results, while the fifth section presents the conclusions of the findings from our analysis to establish the theoretical framework of our study.

2. Conceptual Framework

With many nations facing water scarcity issues for the foreseeable future, proper water usage and management are crucial topics for academics, policymakers, water system managers and administrators [17]. While water management is integral to sustaining a good quality of economic, environmental and societal life, the term itself is broad and complex, taking on different meanings in various contexts. In agriculture, for instance, water management concerns the usage and conservation of water for crops, but in the context of irrigation systems, the term is related more to addressing industrial, domestic and recreational needs [18]. Given this dynamic, research has generally defined water management as the control of water resources for the sake of increasing efficiency. This encompasses activities such as fresh water supply, water treatment systems, waste water management, irrigation and drainage [19]. Here, we take water management and water usage as correlated terms because they both reflect how water is controlled.

As mentioned in the introduction, there are three sectors that consume the major- ity of water: agricultural (70%), industrial (19%) and domestic (11%) [5]. Obviously, water is essential to agriculture; it is necessary for increasing crop production, and by extension, maximizing food productivity, lowering food insecurity and strengthening the economy [20]. Without proper water usage and management, the agriculture sector cannot sustain itself [21]. Because of the sector's high total water use, scholars have already per- formed extensive studies on sustainable water management in agriculture. Case in point: previous bibliometric research identified and examined 436 articles related to agricultural water use, management and sustainability issues [15]. For example, previous research has examined how to improve sustainability in irrigation systems [15,22] and has presented the agricultural poverty index in order to showcase vital issues regarding sustainable agri- culture management [23]. In addition, a recent study by [24] summarized the water-saving techniques utilized by farmers.

The second-largest water consumer is the industrial sector, which encompasses manu- facturing firms, mines and other energy generating facilities. The advance of industrializa- tion has led to constant increases in water usage, and there is little reason to think this trend will abate in the near future [25]. This sector uses water primarily for goods production and cooling purposes, but also for activities such as plant cleaning and sanitation [5]. In this domain, authors have explored the factors that influence industrial water use [24], investigated policies that can lead to better utilization [26] and examined tools for better water management [27], particularly in relation to sustainability [28].

The third sector, domestic, represents a smaller amount of total water consumption, but is nonetheless a critical domain due to the rapid increase in domestic water use. Data from WRI's Aqueduct platform [6] indicate that domestic water use increased by nearly 600% from 1960 to 2014. Population growth, climate change and urban development may explain the bulk of this trend, but certain consumer actions—such as showering—are also notable. In the Netherlands, 40% of domestic water was used in the shower, 28% in the toilet and 12% from washing machines [29]. Previous research in this domain has adopted a similar focal point: the determinants of consumer water demand in terms of water end behaviours, socio-demographics and psychological constructs [30]; the determinants of home water consumption [31]; the causes of domestic water consumption in terms of hous- ing infrastructure [32] and urban sustainability policies [33]. However, it is clear that few articles have examined sustainable solutions to water consumption in the residential sector. Sustainability addresses the relationships between economic and ecological systems—in other words, how humans can develop while simultaneously protecting and developing ecological life. Water is a foundational consideration in this regard. Previous systematic reviews have focused on sustainable irrigation systems [33], water use [16,33] and agri- cultural efficiency [16]. Other systematic reviews have examined water management and sustainability in terms of managing storm water [34] and roof-harvested water [35], as well as addressing water allocation problems [36]. There have also been some efforts to map humanity's water footprint [37] and manage sustainable resources [1]. We synthe- sized these reviews in the table below, which makes it apparent that few articles have concentrated on water management and sustainability in the residential sector. Notably, even the consumer-oriented articles—such as the study on household water conservation behaviours [38] and the systematic review of public perceptions surrounding decentralized wastewater systems—do not adopt a specific framework for their analyses [39]. Thus, Table 1 illuminates a considerable research gap regarding water use in the residential sector. To fill this gap, we will perform bibliometric and ADO framework analyses on the three pillars of residential water use: urban, household, and consumers.

Table 1. Overview of systematic reviews on water usage.

	Main Area(s) of Interest	Limitation(s)	Articles Reviewed	Method(s)
Ricart et al. (2021) [40]	Reclaimed and desalinated water returned and rainwater	Focused on south-eastern Spain	81	Bibliometric and literature review
Nkosi et al. (2021) [14]	Land Management on Water Resources	Focused on the South African context	39	Literature review with thematic analysis
Gebre et al. (2021) [36]	Water Allocation Problems		49	Systematic literature review
Gómez-Román et al. (2020) [39]	Public perceptions of the acceptance of decentralised wastewater treatment systems		46	Systematic literature review
Ochoa-Noriega et al. (2020) [15]	Water in Agriculture	Focused on Mexico	436	Bibliometric
McCarroll & Hamann (2020) [41]	Water literacy		55	Thematic Literature review
Ehret et al. (2019) [38]	Interventions based on content and water conservation effectiveness		66	Systematic literature review
Velasco-Muñoz et al. (2019) [33]	Sustainable Irrigation in Agriculture		713	Bibliometric
Wu et al. (2019) [34]	Stormwater Management		3080	Bibliometric
Aleixandre-Tudó et al. (2019) [42]	Global water-use efficiency focusing on Agricultural Science		2077	Bibliometric
Harmanny & Malek (2019) [43]	Irrigated agriculture	Focused on the Mediterranean area	85	Systematic literature review of case studies
Jeuland et al. (2019) [44]	Water information systems		764	Systematic literature review
Boeuf & Fritsch (2016) [45]	Water Framework Directive in Europe		89	Meta- and bibliometric analysis
Amos et al. (2018) [35]	Roof Harvested Rainwater Usage in Urban Agriculture	Focused on Australia and Kenya	160	Scopus review
Aznar-Sánchez et al. (2018) [46]	Sustainable water use	Scopus Subject areas of: "Economics, Econometrics and Finance", and "Business, Management and Accounting"	1022	Bibliometric
Durán-Sánchez et al. (2018) [1]	Sustainable Water Resources Management	Query string limited to article title	370	Bibliometric
Velasco-Muñoz et al. (2018) [16]	Sustainable Water Use in Agriculture		2084	Bibliometric
Zhang et al. (2017) [37]	Water footprint research		636	Bibliometric

3. Methods

We conducted a structured review of the literature in order to accomplish our objec- tives. Figure 1 depicts the research scheme we followed.

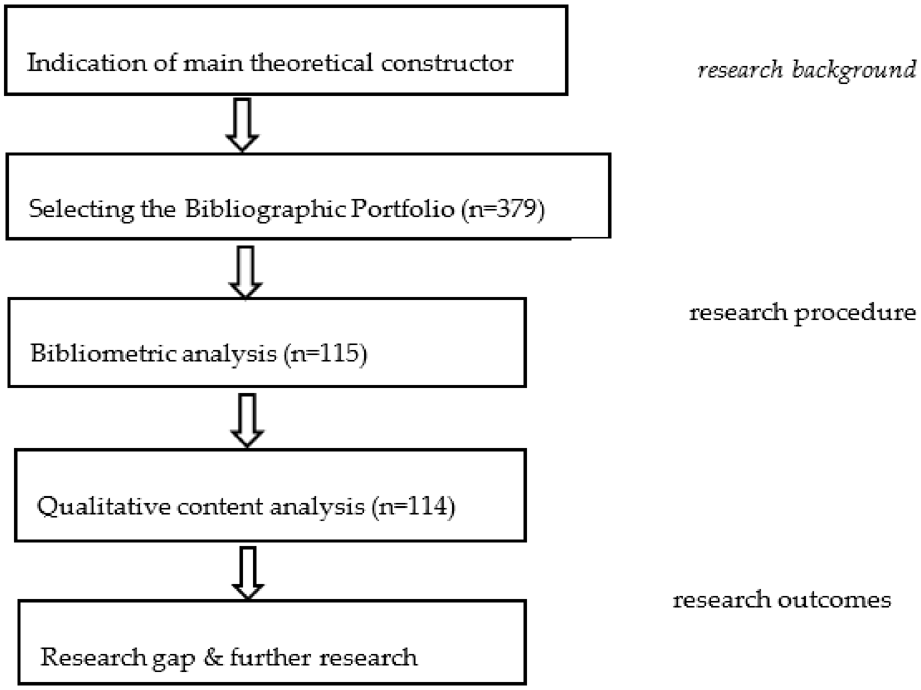

Figure 1. Structured review procedure.

We specifically focused on scientific articles published in journals that are listed in the Web of Science database. Web of Science was chosen based on previous research as it provides high standard literature with many available and updated scientific papers and publications from many disciplines since 1945 that can be used for our review [1,40].

We refrained from specifying a time frame in order to capture all research to date; thus, the study considered all articles indexed in the analysed database as of 23 January 2021. We limited the search to three domains: water management, residential usage and sustainability. We also reviewed the articles' abstracts and keywords in order to derive a list of synonymous terms. The final version of the query in the search engine was:

(1) water management—"water management" OR "water consumption" OR "water-use" OR "use of water" OR "water use" OR "water usage";
(2) resident—resident* OR household* OR house OR home;
(3) sustainability—sustainable OR sustainability.

Where the OR separator indicates the need for at least one of the indicated terms, and the symbol "*" captures all words that start with the preceding prefix. The search was limited to research articles published in English. Given these parameters, we arrived at 379 items before manual selection. This database resulted from the limitation of articles related to water management (7689 articles), the residential area (1409 articles, which con- stituted 18.23% of all articles) and, additionally, the field of sustainable water management. Next, all authors reviewed the abstracts, titles and keywords in order to exclude articles whose research subject was non-compliant with our focal issues. Specifically, each author reviewed each paper in order to identify whether it related to sustainable residential water management or usage and elected to exclude it otherwise. After individually reviewing the articles, we compared our results. In the case of discrepancies, we read the full texts and reached a consensus through discussion. There were 42 cases that merited this extra step. Of these 42 cases, we reached a total agreement rate of 94%. This process left us with 114 articles for the full review.

First, we conducted a bibliometric analysis in order to discern patterns in the articles that could be used to inform future research avenues. This type of analysis is statistical in nature and is often accompanied by author analysis, conceptual maps, citation analysis and other tools. We downloaded the data from WOS and uploaded them into R software, which is a powerful analytical tool that can visualize the results. We also incorporated keywords and their frequency, alongside the articles' time stamps, in order to detect trends. In the second part of the analysis, we examined the full texts. There was one case where we could not obtain the full text, and thus we focused our analysis on the remaining 114 articles. The analysis used the Antecedents-Decisions-Outcomes (ADO) framework to synthesize all studies and uncover new research directions. Prior to analysis, we separated the collected articles into three main categories: the first concerning articles related to consumers and their behaviour toward water; the second concerning articles about households and their water consumption, and the third concerning articles about urban water consumption. Following this step, we examined the antecedents for each category (i.e., the motives behind analysing water consumption), the decisions (which includes what the articles decides to focus on) and the outcomes (i.e., the results as they relate to water consumption and sustainability). It is crucial to mention that ADO dimensions are inter-related: For instance, droughts (A) may influence the characteristics of decisions such as location (D), which will further have an impact on the outcomes (O). The ADO framework analysis has not been applied to this research area yet, and thus can work in tandem with the bibliometric analysis to generate novel insights and future research directions.

4. Results

4.1. Bibliometric Analysis

The first step in the bibliometric analysis was to determine the total number of articles, the places of publication, and any relevant trends. The articles covered the time period 2004–2021. The number of publications increased by an average of 22.11% per year, with the largest volume [20] being published in 2020. All 115 of the analysed articles were published across 68 journals. Figure 2 presents the cumulative change in the number of articles over the years. Additionally, in this graph, the number of articles in the 5 journals that most often published results in this area is shown.

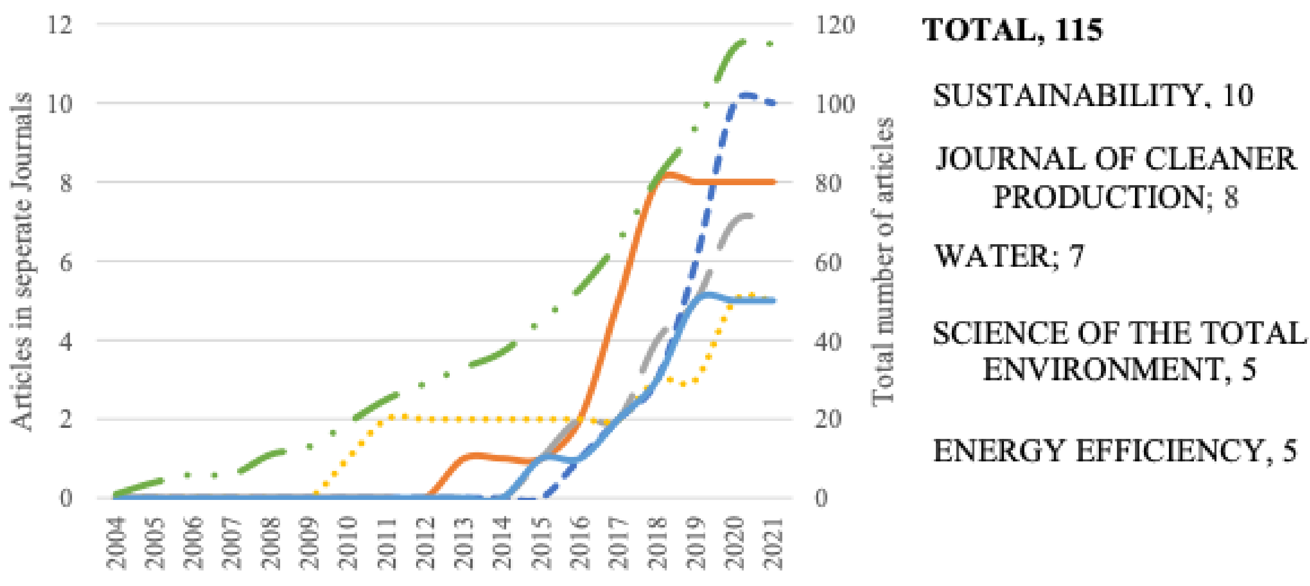

Figure 2. Article trends.

Figure 2. Article trends.

In the second step of the analysis, we considered the source's local impact. The h-index value—encompassing the number of citations, the number of articles and the publication time range—was the highest (h-index = 6) for the Journal of Cleaner Production. Table 2 presents a list of the 10 journals with the highest h-index, taking both the productivity and impact of the published articles into account. When examining the m-index, which is a variant of the h-index (considering the year of the first publication), we found that Science of the Total Environment achieved the highest ratio.

Table 2. Source's local impact.

Source	h-Index	M-Index	Total Citations	Articles	First Article
Journal of Cleaner Production	6	0.67	183	8	2013
Science of the Total Environment	5	0.71	58	5	2015
Resources Conservation and Recycling	4	0.31	44	4	2009
Sustainability	3	0.50	28	10	2016
Water	3	0.43	25	7	2015
International Journal of Consumer Studies	3	0.27	56	4	2011
Energy Efficiency	2	0.17	113	5	2010
Journal of Environmental Management	2	0.14	77	3	2008
Ecological Economics	2	0.14	58	2	2008
Journal of Industrial Ecology	2	0.17	36	2	2010

At the next stage, we analysed individual articles. The most cited article in global terms was by Gill [47], which was referenced 196 times in total or 16.3 times per year. Table 3 presents the 20 papers with the highest number of citations. In total, all 115 articles were cited 2007 times. The articles represented 371 authors in total, with each document having an average of 3.23 authors. Nine cases were single-author works. The author with the most publications was Stamminger R., who published five articles.

Table 3. The most influential publications.

Paper	Total Citations	TC per Year
GILL ZM, 2010 [47]	196	16.3
GUHATHAKURTA S, 2007 [48]	135	9.0
SYME GJ, 2004 [49]	126	7.0
HARLAN SL, 2009 [50]	99	7.6
BEAL CD, 2013 [51]	89	9.9
PAKULA C, 2010 [52]	88	7.3
HOUSE-PETERS L, 2010 [53]	88	7.3
DOMENE E, 2005 [54]	72	4.2
KURZ T, 2005 [55]	70	4.1
HURLIMANN A, 2008 [56]	61	4.4
HEAD L, 2007 [57]	60	4.0
MALLER C, 2012 [58]	57	5.7
MILLER E, 2008 [59]	53	3.8
BITHAS K, 2008 [60]	45	3.2
BROWNE AL, 2014 [61]	32	4.0
LOWE B, 2015 [62]	29	4.1
DEAN AJ, 2016 [63]	26	4.3
DEUTSCH M, 2010 [64]	26	2.2
STAMMINGER R, 2011 [65]	25	2.3
LIU A, 2015 [66]	23	3.3

In order to obtain the main keywords that were used to the collected articles, we used Keywords Plus, which is the proprietary algorithm of Clarivat, a database of WOS articles for assigning keywords. Based on Keyword Plus, 344 keywords were obtained. Differently from the authors' keywords, the Keywords Plus field is normalized. Figure 3 presents a list of the 30 most common keywords.

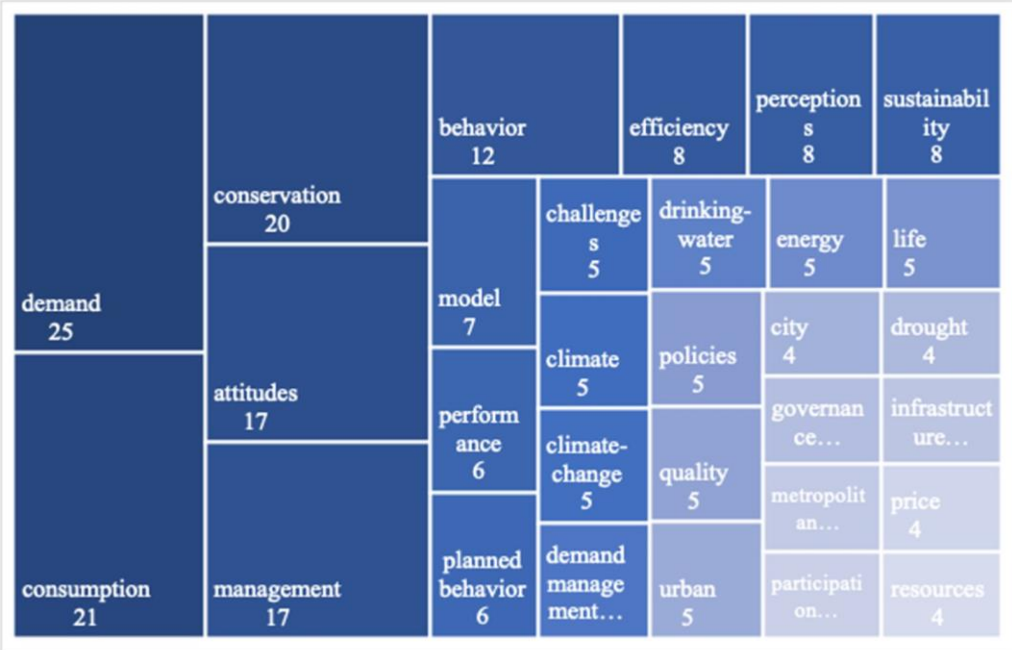

Figure 3. Most common keywords.

In order to detect, quantify and visualize the evolution of a research field, we created a strategic diagram using co-word network analysis and clustering [67]. All clusters are visualized on two axes, development and relevance, while accounting for the number of publications, their citations in local and global terms and the strength of the relationship with other clusters into account (Figure 4).

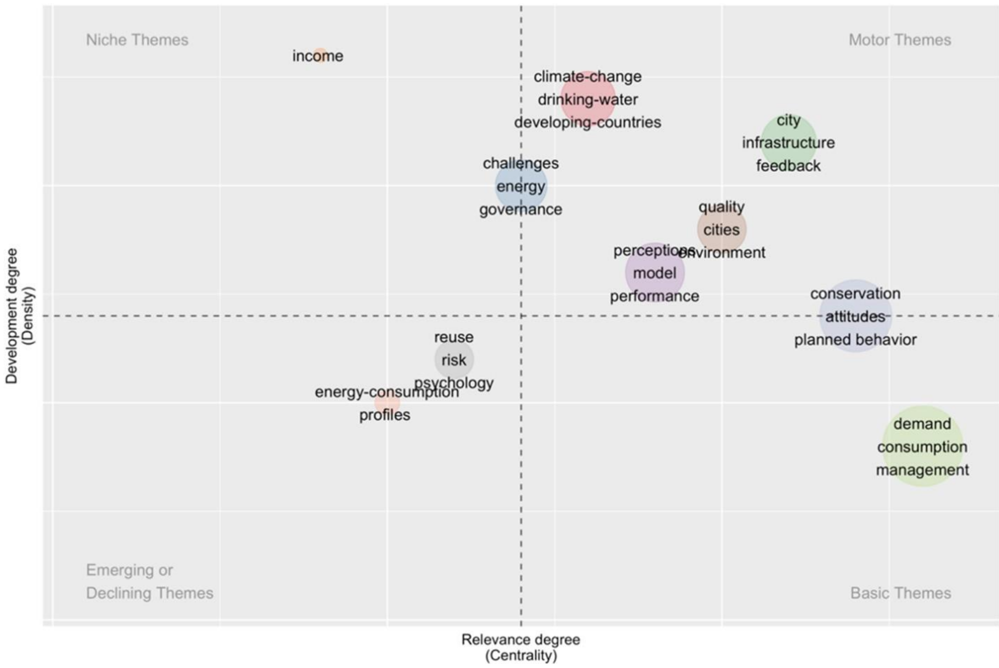

Figure 4. Strategic diagram.

The axes naturally gave rise to quadrants in the graph above. Centrality is the degree and the strength of interaction between clusters and research themes; the more links a research theme has with others, the more central that theme becomes. Density is the strength of the internal ties that comprise a theme. In our case, the research themes were represented by the keywords used in the articles and their links. Topics that appear in the upper-left quadrant are considered niche topics with marginal importance in the research area. The one niche topic is the area of "income", which is well-researched but has little external relevance. One example is a study which mainly examined the influence of consumers' economic status on their behaviour, including water demand [68]. Themes placed in the lower-left quadrant are not well developed and have marginal importance to the topic. This quadrant features two clusters: the first using the keywords "reuse, risk and psychology" and the second using "energy consumption and profiles". Examples of these clusters include the studies that investigated the adoption of water reuse by applying the Social Amplification of risk framework [69] and studies that examined the societal and personal practices of showering [70]. The lower-right quadrant covers basic themes that are important for the field, but not yet developed. In that quadrant, there are usually articles that also appear in other research fields. Our analysis revealed one cluster in this quadrant built around the terms "demand, consumption and management". As an example, there was one study that investigated smart meters in the context of water demand, consumption and management [71]. Finally, the upper-right corner presents "motor themes". These articles have high density and centrality and are thus considered well-developed and important for the research field. One cluster in this quadrant contains the terms "city, infrastructure and feedback", which exemplified research on the influence of smart meters on a city's water consumption [72]. Another theme from this quadrant is "climate change, drinking water and developing countries", which is reflected in a paper dealing with water resource adaptions in the face of climate change [73]. A third cluster includes keywords such as "quality, cities and environment". As an example, a paper described how different water quality targets for the water purification process can actually save energy and help the environment in cities [74]. A fourth cluster, featuring the keywords "perception, model and performance", is embodied by studies that use an empirical agent-based model to analyse the risk perception of water reuse [69]. A fifth cluster, built on the keywords "challenges and energy governance", is exemplified by a study which analysed the challenges of user perceptions toward decentralized water [75]. Notably, the cluster referring to "conservation, attitudes and planned behaviour" is highly significant, but less developed than the rest of the motor themes. Thus, this thematic map illustrates a research gap and provides directions for future research, specifically in relation to consumers' water attitudes and conservation behaviour in connection with planned behaviour theory

4.2. ADO Framework Analysis

After conducting the bibliometric analysis, we proceeded to analyse the antecedents, decisions and outcomes (ADO) of articles related to residential water use. In order to more finely analyse the antecedents, we separated the articles into three themes: urban, household and consumer. For the urban theme, we separated articles' antecedents into four main categories. The first category, sustainable water use, covers articles focused on sustainable water use in cities [60] and buildings [76], as well as outdoors [77]. In all these cases, the specific motive for analysis is unsustainable urban water consump- tion. The second category is water scarcity and droughts, specifically in countries such as Australia [78,79] and Jordan [80]. The third category, water supply systems [74], is motivated by a desire to improve these systems. For instance, previous research focused on how to improve such systems in urban settings [81], while other studies analysed a local community's supply systems [82] or semiarid regional supply systems [83]. The fourth category of urban antecedents is underpinned by the motive to generally improve and provide water to everyone. These studies grapple with the prices of drinking water [84], water and sanitation services [85,86], securing long-term water availability [87] and water access [75,88] in the context of urban environments.

The second theme for which we identified antecedents is household water consump- tion. The first category of antecedents is related to ways of making household appliances more environmentally efficient [52,89,90] in order to counteract relatively high household water and energy consumption. The second category of antecedents involves ways to make housing more sustainable [90] and perform green renovations [58]. The third category of antecedents is connected to water use [91], management [49,71], conservation [92] and sustainable practices [93] in households.

The third theme, consumers, concentrates on their regular and sustainable water consumption [66,72,94,95], sustainable water management [72,96], the use of resources, water consumption reduction [68,73], consumption conservation [62,97] and eco-friendly behaviours [98]. The majority of these studies highlight the importance of finding ways to reduce excessive water consumption and thereby mitigate water scarcity. In relation to this, much of the consumer-oriented research emphasizes the importance of sustainability; a number of studies regard water shortage [99,100], short-term supply constraints [101] and drought [102] as problems that should be examined and addressed from the con- sumer perspective. In almost all the categories of antecedents, authors highlighted climate change [73,103] and environmental problems [104], and protection of water resources [105] were also discussed in order to find adequate solutions.

After uncovering the antecedents for these themes, we proceeded to analyse the de- cisions within each article. Studies focused on households were largely concerned with analysing home appliances. Past researches examined how dishwashers can be energy- efficient and waste less water [89,90,106], while others did the same with washing ma- chines [52]. Similarly, Brunzell [107] investigated technological household improvements that can reduce water consumption, while Retamal and Schandl [93] investigated the most efficient methods for doing laundry. Other studies in this realm considered factors that affect household water consumption. For example, March [71] examined how metering systems could be effective in water conservation, while Beal [51] analysed how smart metering can be used to find the socio-demographic factors that affect water consumption. Other researchers analysed how demographics, lifestyle, social desirability, conservation attitudes, garden interest and garden recreation could play an important part in household water consumption [91]. Notably, the decisions in this category did not refer to the location or size of the study, but rather to other dimensions such as the factors and tools used.

Regarding the urban theme, a major dimensional focus was on local communities. Moshtagh and Mohsenpour [83] examined the community's view on water issues, while other researchers analysed the community's perception of water supply [88] or its satisfac- tion with recycled water [56]. Another dimension of this category is the influence of social and economic forces on water conservation [81,84], as well as social inequality [59]. Many researchers in this category used economic dimensions to examine water consumption; for instance, "water management pricing" [60], "low income population" [68], "pricing policies" [80] and "forms of capital on consumption" [82]. In summary, this category focuses on society and how it is interrelated with not only the aforementioned antecedents, but also the outcomes that will be highlighted below.

Regarding the consumer theme, these articles largely focus on how providing informa- tion can help to reduce consumers' water consumption. For instance, many scientists have analysed how providing feedback can contribute to water conservation, while others have focused on the marketing dimension (e.g., advertisements, social and water marketing campaigns, eco-visuals, leaflets and labels), but also more personal and direct information for the consumer, such as information provided by water metering systems. Additional research in this category was focused on the factors that influence water use [59,96] and water habits [108].

The third part of the ADO analysis, the outcomes, reflects the results of the collected studies. It is important to emphasize here that outcomes are interrelated to both antecedents and the decision. Thus, because the urban theme was largely related to the community, the outcomes naturally concerned the impact of the community's water behaviour. For instance, the study by Moshtagh and Mohsenpour [83] found that public knowledge and clarification would help enhance social trust and positive attitudes, as well as encourage the adoption of more responsible behaviours toward water resources. Moreover, Brown and Pena [85] came to the conclusion that people's awareness of their environmental impact is predicated on their knowledge regarding their own consumption. As seen in the antecedents and decisions of urban category, societal outcomes were also examined. For example, the study by Satur and Lindsay [76] focused on low income and how it influences water consumption. The outcome of the study was that low-income societies consume water just to meet their needs, without consuming excessively.

For the household theme, the outcomes mainly referred to home equipment. For ex- ample, studies examining the effectiveness of household appliances reached the conclusion that dishwashers [89,90,106] and washing machines [52,93] can actually reduce household water consumption. However, other studies suggested that consumers should be educated and technology should be improved [109] in order to make household appliances more efficient. Moreover, some researchers in this domain examined the factors that may produce more sustainable water consumption behaviours in households. For instance, one paper found out that one's feeling of responsibility toward climate change can affect household water consumption [109], while Cvetkovic´ [110] found that households increased their water consumption in response to COVID-19 and the increased amount of time spent indoors. Lastly, Pearce [92] noted that location, household size and annual household income affect households' water consumption.

As with the above themes, the outcomes of research focused on consumer water use were connected to their antecedents and decisions. Specifically, these studies focused on methods for encouraging consumers to behave in a sustainable way (e.g., through mar- keting materials, educational materials, consumption feedback, etc.), and the outcomes were related to the most successful techniques. For example, studies focused on providing information to consumers [66,94,111,112] concluded that information can indeed impact water consumption. Likewise, studies found that feedback [66,104] and marketing cam- paigns [55,62,95,99,100] can influence consumer behaviour. Ultimately, these studies signal that having more knowledge [63]—whether in the form of feedback or marketing—can incline consumers to change their behaviour and consume less water [113].

5. Discussion

Although scholars have made progress in the domain of water management, there are still important questions that need to be answered. Thus, this section outlines the research gaps and some future research directions.

The first gap, arising from the literature review (see Table 1), is the lack of systematic analyses in the field of residential water use. While our use of bibliometric and framework analysis may help narrow this gap, there is still a gap regarding systematic analysis in the field of residential water consumption, while focusing on a different scope, for instance, con- centrating specifically on urban, household or consumer aspects. In addition, our keyword analysis suggests an opening to more deeply explore the keywords "price" and "resources",

which only appeared in the studies by de Lira Azevêdo [114] and Okello et al. [115], re- spectively. The reason for the above research gap could be that researchers may not have access to reliable pricing information in order to examine this strand of literature. Future studies could, for instance, adopt a more economic orientation in order to more equitably address the three pillars of sustainability (economic, social, environmental). Another gap revealed by the keyword analysis is the exclusion of consumer characteristics. While "atti- tude", "perception" and "behaviour" were present in some studies [102,116], there were no keywords relating to consumers' environmental behaviours, demographics or subjective norms. We could justify this research gap based on the fact that is impossible to define a behaviour in a way that is comparable in many different contexts. The field would benefit from more research regarding how consumer characteristics influence water demand, as well as people's attitudes, perceptions or conservation efforts.

Our ADO framework analysis, a novelty in this field, revealed other meaningful re- search gaps and future research directions in relation to our three themes: urban, household and consumer. Most of the analysed articles on household water consumption concentrated on home appliances or green renovations as part of efforts to increase sustainabil- ity. For instance, studies examining how dishwashers and laundry techniques can affect water resource consumption, and these studies also uncovered more sustainable alterna- tives [93,106]. However, the excessive focus on this aspect of household consumption has created some research gaps. For instance, it would be beneficial to examine how household consumption is shaped by countries' differing levels of technology. Do countries without access to efficient household appliances consume more or less water? Another research gap concerns residential behaviour; for instance, why do residents use home appliances the way they do? This topic represents an exciting opportunity for the field to make progress in understanding and improving water management.

With regard to the urban aspect of residential water consumption, the analysis un- covered a heavy emphasis on societal issues, for instance, scholars focusing on topics such as community satisfaction, community perception, cities' water usage and water accessibility [56,83]. However, these articles tended to focus on communities embedded in countries or cities that are facing water scarcity, such as Australia or Jordan. While finding a solution for such communities is undoubtedly important, water scarcity is quickly becoming a global issue. Thus, future research might focus on finding proactive urban solutions for communities that are not currently facing water scarcity, but may in the future. In relation to this, researchers could look for ways to not only address water scarcity, but also prevent it. Moreover, as the ADO analysis uncovered, there is a need for more research examining communities' characteristics, for instance, their political situation, technological development, economic background, environmental sensitivity, and how these factors jointly affect a community's water consumption. As with the household theme, the urban theme needs more investigations into the characteristics that drive behaviour.

Lastly, with regard to the consumer theme, the ADO framework analysis revealed that previous research has mostly focused on how to prompt consumers to adopt more sustainable behaviours. For instance, studies focusing on educating consumers—whether via information or feedback regarding water usage, or through marketing materials [50,66]. In this vein, future research could explore other ways of encouraging consumers to be- have more sustainably, for instance, with advertisements, water meters, social groups, visuals, information, educational materials, authorities, etc. On this point, there is a lack of research on the consumer characteristics that may shape their willingness to behave more sustainably. For example, "Is water consumption feedback internalized differently by older or younger consumers?", "Are environmentally-friendly consumers keener on reading educational materials?", "Does a consumer's geographical location affect their perception of green advertisements?", "Are consumers facing water scarcity more sensi- tive toward water conservation information?" Understanding these characteristics will be crucial to determining the effectiveness of any given rhetorical method and promoting more sustainability.

6. Conclusions

Research on sustainable water use is becoming increasingly popular—a point evi- denced by our bibliometric analysis. By collecting and analysing a significant number of studies regarding sustainable residential water consumption, we make a twofold contribu- tion to the literature. First, we used thematic mapping to illustrate the topic's evolution, and second, we identified research gaps and future research directions.

With the bibliometric analysis, we depicted an annual increase in the number of publications that reflects the significance of the discussed topic. There were 68 journals with relevant publications, with the Journal of Cleaner Production being the most influential based on the local impact analysis. Moreover, we found that journals are publishing more and more articles on this specific field, and these articles are being broadly cited. Thus, our subject of interest—residential water consumption—could be considered as important but developing.

Based on the keyword analysis, we gleaned that demand, consumption and conser- vation are the most prominent themes for this research field. Meanwhile, the keywords “resources” and “prices” are related to more specific studies: For instance, “prices” would be more applicable in a study with a socio-economic interest. Moreover, the centrality and density map indicated that the research direction of this research field is expected to be about “conservation, attitudes and planned behaviour”.

The ADO framework analysis was useful for uncovering key patterns in the research field. Most of the articles adhere to a similar motive (antecedent): namely, sustainable water uses in cities and households and personal use in order to stop existing environ- mental issues or prevent new ones. Considering the decisions, it can be is observed that previous research was dedicated to specific scopes without trying to extend their aims. In terms of analysed outcomes, research largely found that home appliances, feedback on individual water consumption, information campaigns and societal factors have an impact on residential water consumption. That said, we want to reiterate that antecedents, decisions and outcomes are interrelated. For instance, the antecedent of household water consumption was sustainable water use, its decision was the use of home appliances and its outcome was that home appliances can affect water consumption; thus, changing one part of the ADO may change the others. Interestingly, all three aspects—urban, household and consumer—had the same antecedent of sustainable water use. Consequently, we can say that the majority of studies in the field are being conducted for sustainable and environmental reasons such as reducing the water consumption in households in order to prevent water scarcity issues and not for economic or societal ones, such as to analyse the ways the household water consumption is affecting or is being affected by economic factors nor by the society.

The main achievement of this research is the fact that we managed to collect and analyse a broad number of articles in this research field, which gave us the opportunity to find the research gaps and the future directions regarding domestic water usage and management. Based on this analysis and by knowing the research gaps, we are able to continue with future researches in order to narrow them down. The main research gaps we identified are related to extending the research field of residential water consumption and its relation with pricing, resources, attitude, perception, behaviour, technology and water appliances, community behaviour and consumer characteristics and its influence on water consumption based on knowledge. Thus, future research in this area could focus on the relation between water consumption and the above keywords in order to minimize the research gaps and extend our knowledge on residential water consumption.

Lastly, we recognize that this study is limited by the specific nature of bibliometric analysis. Future research may also include network or world maps in order to present the collaborations between institutions and researchers, as well as to show the importance of the subject based on geographical locations.

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The role of knowledge about water consumption in the context of intentions to use IoT water metrics

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Technological progress can contribute to a more conscious and sustainable consumption of water. This is especially important in the context of dwindling resources and climate change. The objective of the study is to investigate how consumers' perceived knowledge on water usage influences their intention to adopt smart (IoT-based) water meters, which deliver very precise data on the amount of water used in a household. We hypothesized that perceived knowledge on personal water usage exerts a direct and indirect influence on the intention to adopt a smart water meter. For the mediators, we used the intention to save water and variables derived from Value-Belief-Norm theory: awareness of consequences, ascription of responsibility and personal norm. We verified the hypotheses by applying structural equation modelling to a sample of 532 respondents. We found that perceived knowledge on water usage directly influences the intention to adopt a smart water meter, and that all considered variables worked to mediate the relationship between perceived knowledge and intention. Thus, based on our results perceived knowledge plays an important role on the relationship between values-beliefs-norms and intentions to apply smart water meters, which can be used for future research in order to reduce household water consumption by increasing the probability of installing smart water meters.

KEYWORDS
IoT, smart meter, water consumption, knowledge, sustainability

Introduction

Water is a fundamental resource to human life, integral to our personal survival and to everything that societies produce (Cosgrove and Loucks, 2015). Water is a finite resource that has no substitutes—and yet, there is growing proof that human activities are contributing to water scarcity across the globe (Fielding et al., 2012). Such activities include the expansion of businesses, urbanization, population growth, water pollution, increasing water demands, the overallocation of rivers flows, and climate change (Cosgrove and Loucks, 2015). The consequences of water scarcity are far-reaching, encompassing food insecurity, the destruction of eco-systems, the extinction of species and social stress (Addo et al., 2019). Past research has found that about one fifth of the world population lives in areas that lack sufficient water to meet all demands, while one third of the population does not have access to clean drinking water (Cosgrove and Loucks, 2015). As population growth spurs greater water usage, more and more parts of the world will face water stress.

One of the leading causes of water scarcity is increasing domestic water use—the demand for which is primarily driven by high consumption in urban centers, households and industrial sectors. In fact, domestic demand is said to comprise about 15% of the global water demand (Addo et al., 2019). Thus, governments, policymakers, and citizens are challenged to find ways to reduce household water consumption while satisfying the water demands of society at large (Lowe et al., 2015). In households, about half of water usage is dedicated to indoor activities, including toilets, showers, washing machines and other daily activities (Shan et al., 2015) and the other half of water consumption is dedicated to outdoor activities (Lee et al., 2011). According to past research, the factors that influence household water consumption are number of people in a household, education level, infrastructure, income, devices, usage patterns, lifestyle and consumer attitudes toward water consumption (Willis et al., 2011; Rondinel-Oviedo and Sarmiento-Pastor, 2020). Regardless of the reason, societies need to implement conservation practices in order to achieve sustainable water usage. Lee et al. (2011) advanced that applying water conservation as the residential level is important since households account for the majority of water demand in cities.

Despite the need to reduce household water consumption, there is a lack of research on the best ways to do so. This is primarily due to the complexity behind the drivers of water-saving behavior. According to Jorgensen et al. (2009), there are two groups of behavioral drivers: direct (climate variability, financial incentives and disincentives, regulations, property and household characteristics) and indirect (socio-economic factors, inter-personal factors and institutional trust). Both play an important role in water-saving behavior. We want to highlight that personal characteristics occupy both spaces: the intention to and knowledge of how to conserve water was found to be a direct driver, whereas environmental values and conservation attitudes are recognized as an indirect one.

Based on past literature review, the research area about household water conservation has been focused on consumers' demographics and characteristics, pricing, the efficient use of household appliances, and consumer-focused messaging (Madias and Szymkowiak 2022). Fielding et al. (2012) discovered that demographic variables are among the strongest predicts of conservation behaviors. Cary (2008) analyzed the ways to influence consumers' behavior and attitudes in order to reduce their water consumption. Similarly, Corral-Verdugo et al. (2003) found that consumers who are more concerned about the environment are more likely to adjust their water habits, such as limiting their time taking showers, washing dishes, watering plants, etc. Scholars have also established that water pricing plays an important role in consumers' conservation practices (Dupont and Renzetti, 2013). Likewise, residents will sometimes modify their water consumption in response to conservation messages (Addo et al., 2019).

Moving beyond consumers, research has examined methods of making household appliances more environmentally efficient (Belke et al., 2019; Boyano and Moons, 2020; Pakula and Stamminger, 2010) in order to counteract households' relatively high water usage. One of the way to achieve that is through Green Technology, which refers to technology that helps to achieve the international sustainable development goals and to minimize the environmental impact cause by economic growth (Ikram et al., 2022). Smart water meters are also considered as green technology as it is proven that they play an important role on reducing the household water consumption (Russell and Knoeri, 2020) as they can track people's real-time water consumption and detect any water possible leakage (Fuentes and Mauricio 2020). In fact, Sønderlund et al. (2014) found that households reduced their water consumption by an average of 19.6% when they received information from a smart water meter. Cominola et al. (2021) did not replicate the size of this effect, they still found an 8% reduction in water consumption among households with smart meters installed.

However, past research has not examined consumers' intentions to adopt smart water meters in their households which could help with understanding better the water consumption behavior but they mostly focus on the financial motives behind applying smart water meters (Montginoul and Vestier 2018). Thus, this paper focuses on how consumers' perceived knowledge about water usage shapes their intention to install smart (IoT-based) water meters. In this way, we address the scientific gap, as well as provide valuable insights for future research on smart water meters. We hypothesized that perceived knowledge (PK) on water usage in a household determines the intention to adopt smart water meters (IAW), both directly and indirectly. In this study, we followed other studies that treated water-saving as a pro-environmental behavior (Carmela and Damiano, 2016), which is aligned with some theory on perceived knowledge, so we assumed that perceived knowledge is also related to intention to save water and to VBN variables (Esfahani et al., 2015) which are usually adopted for explaining pro-environmental behavior. We also examined how consumers' perceived knowledge about household water usage is related to their personal norm about saving water, and whether that norm results from their awareness of the consequences and ascription of responsibility in relation to excess water usage.

This paper is structured as follows: The first section reviews the relevant literature in order to synthesize existing knowledge and construct our hypotheses. The second section details our methodology. The third section presents our results, while the fourth discusses and interprets them. The final section summarizes our main contributions and outlines future research directions.

Hypotheses development

In order to construct our hypotheses we adopted the Value-Belief-Norm model by Stern et al. (1999) and extended it by adding the moderator of perceived knowledge. VBN model is primary used for examining green behaviors by researching individuals' values, beliefs and norms (Ghazali et al., 2019). The variables that the model is using in order to investigate the pro-environmental intentions of consumers are: ascription of responsibility, awareness of consequences and personal norms. However, in this study we extend the VBN model by adding the moderator or perceived knowledge. Thus, the hypotheses are constructed based on an extended version of VBN model.

Our primary focus is on consumers' perceived knowledge and its influence (both direct and indirect) on their intention to adopt smart water meters. Past research has established that consumers' knowledge and perceived knowledge are key factors in their decision-making, especially in relation to the environment (Lee et al., 2006). Indeed, knowledge in general determines behavioral intentions (Martono et al., 2019), while environmental knowledge in particular is related to pro-environmental behavior (Levine and Strube, 2012; Suryanda et al., 2021). According to Min-Seong Kim et al. (2018), environmental knowledge can be categorized into two parts: real knowledge and perceived knowledge (i.e., someone's feeling of knowing something). Here, we focus on the latter category in relation to water consumption.

Perceived knowledge on water usage reflects people's opinions on two issues: their perception of absolute water consumption and how much they use relative to the average person. Previous studies have highlighted a discrepancy between perceived and actual water consumption (Beal et al., 2013). However, we assume that consumers who are more confident in their perceived knowledge (regardless of its accuracy) will be more interested in possessing precise data about their water usage—and thus will be more willing to adopt smart water meters. To that end, we formulated our first hypothesis:

H1. Perceived knowledge on personal water usage is positively related to the intention to adopt smart water meters.

We know from past research that perceived knowledge can compel consumers to make environmentally friendly decisions (House et al., 2004; Kim et al., 2018). From this, we postulate that consumers with higher perceived knowledge on water usage will have higher intentions to save water:

H2. Perceived knowledge on personal water usage is positively related to the intention to save water.

Past research focusing on water meters have proved that smart-water meters may reduce the household water consumption on an average rate of 19.6% (Sønderlund et al., 2014) while Davies et al. (2014) found out a reduction of 1.05 kl per month in water consumption when smart water meters were applied. Thus, we assume that consumers who have higher intentions to reduce their water consumption are more likely to have high intentions of adopting smart water meters. Formally:

H3. The intention to save water is positively related to the intention to adopt smart water meters.

In numerous previous studies, pro-environmental behaviors and behavioral intentions have been explained by personal norm (Schwartz, 1977; De Groot and Steg, 2009; Jansson et al., 2017): an internalized behavioral standard (Bamberg, 2012) that is contrasted with subjective norms. Personal norm is a key construct in two theories used to explain pro-environmental behavior. Schwartz's (1977) Norm Activation Theory (NAT) focuses on moral (personal) norm as a main motivator of altruistic behaviors, including pro-environmental ones. The theory posits that individuals undertake pro-environmental actions due to a personal belief that environmental conditions pose a threat to other people and all other species (awareness of consequences) and those harmful consequences can be prevented by their actions (ascription of responsibility). According to NAT, these types of actions are often rewarded by a sense of pride, security, fulfilling one's duty and experiencing joy as a result, as well as enhanced self-esteem. Meanwhile, Stern et al. (1999) Value-Belief-Norm (VBN) theory extends NAM to a broader context by establishing causal links between the following variables: values (especially altruistic ones); beliefs about the environment and the effects of human activity on it; an awareness of consequences; the ascription of responsibility; personal norms concerning pro-environmental behavior, the willingness to sacrifice, and consumer behavior. Both the intention to and action of saving water should be considered highly pro-environmental and pro-social behavior (Sulaeman et al., 2018). Thus, we assume that pro-environmental personal norms about saving water influence the intention to reduce household water consumption. This leads to our fourth hypothesis:

H4. The personal norm about saving water is positively related to the intention to save water.

Regarding the influence of perceived knowledge on pro-environmental behaviors, Bamberg (2012) concluded that perceived knowledge about environmental problems is highly predictive of people's norms development personal Similarly, Onel and Mukherjee (2016) found that the former is a better predictor for the latter than actual scientific and environmental knowledge. Hamzah and Tanwir (2021) established that environmental knowledge (which can be defined as perceived knowledge based on how they measured the variable) is a moderator of perceived green value, green purchase attitude, perceived behavioral control, subjective norms and their impact on green purchase intention. From this, we hypothesize that perceived knowledge on environmental issues is related to the intention to save water:

H5. Perceived knowledge on water usage is positively related to the personal norm about saving water.

According to both NAT (Schwartz, 1977) and VBN (Stern et al., 1999), personal norm is predicted by both an awareness of environmental consequences and the ascription of responsibility (Esfahani et al., 2015). The ascription of responsibility is defined as the feeling of responsibility for the negative consequences of failing to act pro-socially (De Groot and Steg, 2009). It also reflects an opinion about who should be responsible for something (Stern, 2000). According to VBN, this factor mainly arises from the awareness of consequences, but it can also be driven by other factors like one's internal locus of control (Pavalache-Ilie and Unianu, 2012). Given previous findings that knowledge and problem awareness influence pro-environmental attitudes and behaviours (Bamberg and Möser, 2007), we formulated the following hypothesis:

H6. Perceived knowledge on water usage is positively related to the ascription of responsibility for excessive water usage.

Based on both NAT and VBN (Schwartz, 1977; Stern et al., 1999), we expect to find a positive relation between the ascription of responsibility for excessive water usage and the personal norm about saving water. This leads us to the next hypothesis:

H7. Ascription of responsibility for excessive water usage is positively related to the personal norm about saving water.

The awareness of consequences is the belief that taking (or failing to take) a given action will be harmful for others (De Groot and Steg, 2009; Kiatkawsin and Han, 2017). In this study, we assume that consumers' perceived knowledge about water usage will influence their awareness of consequences. Formally:

H8. Perceived knowledge on water usage is positively related to the awareness of consequences about excessive water usage.

Previous studies (Vining and Ebreo, 2002; Shin et al., 2018) have argued that the awareness of consequences is an antecedent to ascription of responsibility, as individuals tend to feel responsible for negative consequences when they are aware of inflicted harm. In our study, we assume that individuals who are aware of the consequences of excessive water usage will take personal responsibility for said consequences. Formally:

H9. The awareness of consequences about excessive water usage is positively related to the ascription of responsibility for using too much water.

Lastly, prior research has uncovered that consumers' awareness of consequences for taking (or not taking) a certain activity determines their personal norm about a given behavior (Liu et al., 2017). Thus, we hypothesized the following:

H10. The awareness of consequences of excessive water usage is positively related to the personal norm about saving water.

We built the following research model (Figure 1) to visualize our hypotheses.

Methods

We designed a three-part study to empirically verify the above model. In the first part, participants received basic information about smart water meters. The description only contained technical information about the meter's mechanical operation, without any emphasis on or reference to possible benefits. The description also showed example pictures of current devices on the market, which are targeted at individual customers, as well as a visualization of web and mobile applications, through which device users can access consumption information. This description was especially important for estate the credibility of the research, as it allowed users to obtain knowledge in the field of smart water metrics solutions. Moreover, it is related to the fact that such solutions are treated as a product and process innovation, so they are not widely known to all consumers.

In the second part, respondents used one to seven scales (where 1 = I strongly disagree and 7 = I strongly agree) to give their opinion on various statements. We derived the statements from previously validated scales: The study by Shin et al. (2018) was used to evaluate Ascription of responsibility for using too much water (AOR), which was measured on three items, as well as the Awareness of the consequences of using too much water (AOC) (e.g., I think that using too much water supports environmental degradations). In addition, personal norm concerning saving water (PN) was examined on three items derived by Shin et al. (2018) (e.g., "I believe I have a moral obligation to save water"). We measured Perceived Knowledge (PK) on personal water usage using a modified four-item scale proposed by Joshi and Rahman (2017) (e.g., "I am very knowledgeable about my water usage"). To evaluate the Intention to reduce water usage (IP) and the Intention to adopt IoT water meters (IAW), we adopted questions from Han et al. (2010) and Chen and Tung (2014) (e.g., "I will make an effort to reduce water usage", "I plan to apply IoT based water meters in my household") (Appendix A1). In the final part, respondents answered questions about their demographics.

We conducted the survey over Amazon Mechanical Turk (hereafter, Mturk). Although MTurk data has proven to be of good quality, we still undertook a multistage verification

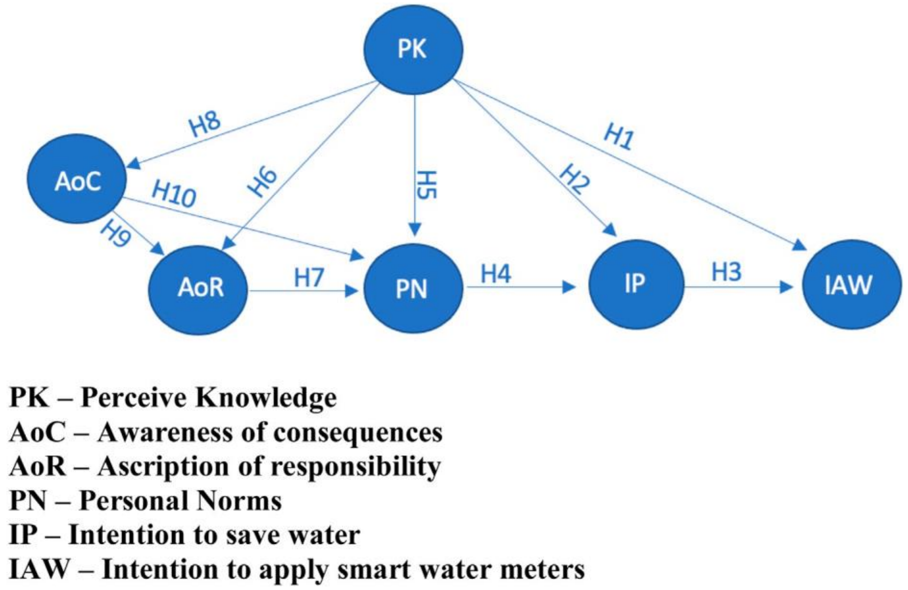

FIGURE 1
Research model.

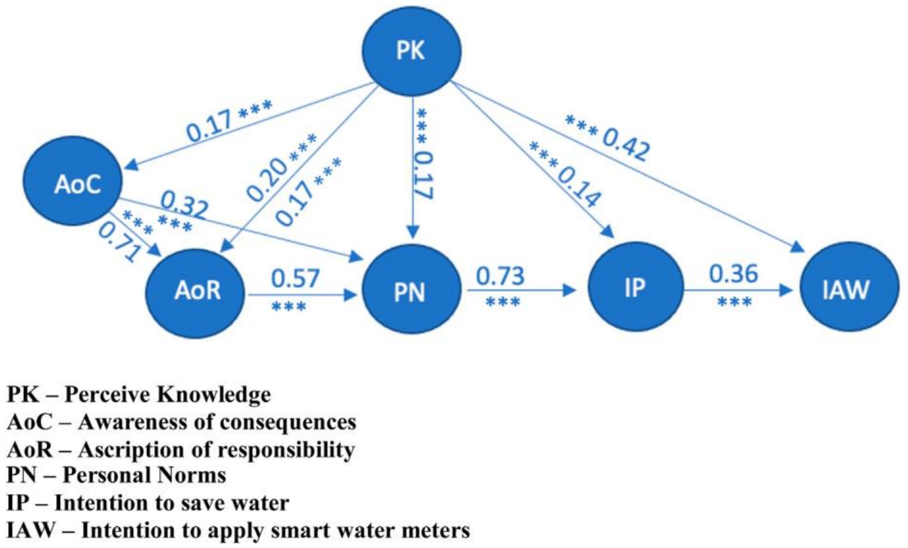

FIGURE 2
SEM results.

procedure. We limited the participant pool to English-speaking United States residents, as well as those users with a high rate of completed tasks (over 90%). In addition, we eliminated anyone who completed the first part (reading the information about smart water metrics) in less than 15 s, as well as so-called "speed runners" who answered the main questions faster than 80% of the average pre-test time. Moreover, we implemented two attention check questions to verify careful reading and removed any respondents who failed them. In the last step, we excluded any participants who gave unlikely answers to open-ended

TABLE 1 Respondent characteristics.

Characteristic	Category	Frequency	Percent
Education	Bachelor's degree	283	53.195
	Doctorate	12	2.256
	High school degree or equivalent	117	21.992
	Master's degree	108	20.301
	Other	12	2.256
Income	$20.000 - $29.999	55	10.338
	$30.000 - $39.999	64	12.030
	$40.000 - $49.999	59	11.090
	$50.000 - $59.999	65	12.218
	$60.000 - $69.999	99	18.609
	$80.000 - $89.999	48	9.023
	$90.000 ≥	101	18.985
	≤ $19.999	41	7.707
Status	Employed full-time	331	62.218
	Employed part-time	63	11.842
	Retired	34	6.391
	Self-employed	34	6.391
	Student	14	2.632
	Unable to work	13	2.444
	Unemployed	43	8.083
Residence	Apartments	147	27.632
	Multi-family homes	13	2.444
	Single-family home	372	69.925
	Total	532	100.000

questions (e.g., listing 1,111 years as their given age). Through this process, we achieved 532 responses for the core analysis. This final sample differed in terms of age (m = 40.1, SD-13.46, min. = 18, max. = 76), gender (male-44.55%, female-55,45%), household size (M = 3.0, SD = 1.39, min. = 1, max. = 9) income, education, status and type of residence. Table 1 presents the detailed respondent data.

Results

We analyzed the data in two stages using structural equation modeling. Following recommendations by Bagozzi and Yi (2012), we first evaluated the convergent and discriminant validity of individual items, as well as the composite reliability of the variables. A confirmatory factor analysis indicated that all factor loadings for the individual items achieved values above 0.821, in excess of the recommended 0.6 threshold (Chin et al., 1997). Next, we measured scale reliability by applying Cronbach's α: The values ranged from 0.89 to 0.93, representing good to very good consistency according to Hair et al. (2014). To measure convergent and discriminant validity, we used standardized factor loading along with two parameters: Composite Reliability (CR) and Average Variance Extracted (AVE). The AVE values were between 0.73 and 0.83 (Table 2), which is above the acceptable limit of 0.5 as recommended by Hair et al. (2014). The CR values also exceeded the acceptable limit of 0.6 (ranging from 0.89 to 0.93), which indicates the internal consistency of multiple indicators (Bagozzi and Yi 2012). We used the HTMT ratio of correlations to assess the discriminant validity: As shown in Table 3, the ratios of each construct were below 0.9, and thus established discriminant validity (Henseler et al., 2014).

Following Schumacker and Lomax (1996), we applied three types of fit indices to evaluate the model: absolute fit, parsimonious fit, and incremental fit. All the obtained fit indices met the suggested ranges like CMIN/df = 2.47, RMSEA = 0.538, GFI = 0.978, AGFI = 0.911, CFI = 0.964 and NFI = 0.911 (Hair et al., 2014).

After confirming the reliability and validity of the measurement model, we performed path analysis to evaluate the relationships among the latent variables. We used the R programming environment and Lavaan, Psych package for this purpose, incorporating bootstrapping (2,000 re-samples) to improve the reliability of the results.

TABLE 2 Confirmatory factor analysis.

Construct	Item	Loading	*p* Value	Cronbach's α	CR	AVE
AOR	AOR1	0.83	***	0.89	0.89	0.74
	AOR2	0.84	***			
	AOR3	0.89	***			
IAW	IAW1	0.93	***	0.93	0.93	0.82
	IAW2	0.82	***			
	IAW3	0.93	***			
AOC	AOC1	0.87	***	0.89	0.89	0.73
	AOC2	0.82	***			
	AOC3	0.86	***			
PN	PN1	0.92	***	0.93	0.93	0.83
	PN2	0.90	***			
	PN3	0.89	***			
PK	PK1	0.80	***	0.93	0.94	0.79
	PK2	0.91	***			
	PK3	0.87	***			
	PK4	0.93	***			
IP	IP1	0.88	***	0.93	0.93	0.81
	IP2	0.89	***			
	IP3	0.92	***			

TABLE 3 SEM analysis.

Endogenous variable	Exogenous variable	Beta	B	Se	*p*-value	CI lower	CI upper
AOC	PK	0.17	0.18	0.05	***	0.08	0.28
AOR	PK	0.20	0.31	0.07	***	0.19	0.45
AOR	AOC	0.71	1.10	0.14	***	0.84	1.41
PN	AOR	0.57	0.83	0.16	***	0.58	1.21
PN	AOC	0.32	0.73	0.17	***	0.40	1.08
PN	PK	0.17	0.39	0.06	***	0.26	0.51
IP	PN	0.73	0.53	0.08	***	0.39	0.69
IP	PK	0.14	0.23	0.06	***	0.12	0.36
IAW	IP	0.36	0.29	0.05	***	0.20	0.39
IAW	PK	0.42	0.57	0.07	***	0.44	0.71

The applied structural model explains the high variability of the IP ($R^2 = 0.636$), PN ($R^2 = 0.810$) and IAW ($R^2 = 0.44$) (Table 4). In line with hypotheses H1 and H2 (Figure 2), we confirmed that the PK of water consumption influenced both the intention to use smart water metrics (b = 0.42, $p < 0.001$) and the intention to reduce water (b = 0.14, $p < 0.001$). Additionally, the study confirmed hypothesis H3: The Intention to save water was positively related to the intention to adopt smart water meters (b = 0.36 $p < 0.001$). Further, we established the direct influence of all theoretical variables on Personal Norms, i.e., AOR (b = 0.57 $p < 0.001$), AOC (b = 0.32 $p < 0.001$), and PK (b = 0.17 $p < 0.001$). In line with hypothesis H4, the Personal Norm on saving water was positively related to the intention to save water (b = 0.73, $p < 0.001$). We also found that PK influenced AOR (b = 0.17 $p < 0.001$) and AOC (b = 0.20, $p < 0.001$), in respective alignment with H5 and H6. As we assumed, AOC had a strong direct effect on AOR (b = 0.71, $p < 0.001$) and on PN (b = 0.32, $p < 0.001$), in accordance with H8 and H9, respectively. Lastly, AOR seemed to influence PN, in support of H10 (b = 0.57, $p < 0.001$).

Discussion

This study found that consumers' perceived knowledge about personal water usage has both a direct and indirect impact on

TABLE 4 Discriminant validity (HTMT).

	AOR	IAW	AOC	PN	PK	IP
AOR	1.00					
IAW	0.49	1.00				
AOC	0.75	0.30	1.00			
PN	0.85	0.52	0.77	1.00		
PK	0.34	0.58	0.18	0.43	1.00	
IP	0.72	0.55	0.60	0.78	0.46	1.00

their intentions to adopt smart water meters. The direct impact of perceived knowledge on intentions to apply smart water meters was indicated by an effect of strength 0.42. From this result, we assume that people who are more aware of their water consumption (which proxies their general interest and involvement in this issue) are also more willing to adopt smart meters that will provide more precise data.

We also uncovered that perceived knowledge indirectly influences the intention to save water. This corroborates prior research arguing that knowledge influences pro- environmental behaviors (Levine and Strube, 2012; Suryanda et al., 2021). It follows that consumers who are willing to save water are also more eager to implement smart meters that can help them achieve that goal (Sønderlund et al., 2014). In order to calculate the strength of the indirect effect, we multiplied the direct effects of intentions to save water towards intentions to apply smart water meters with the indirect effect of perceived knowledge to intentions to save water.

Notably, perceived knowledge exerted an indirect impact in several ways. The first was through personal norms. Personal norms are significantly connected with people's perceived knowledge of personal water use and also impact the intention to reduce water (and by extension, adopt smart meters). Thus, our results affirm prior studies positing that personal norms can explain pro-environmental behaviors (Schwartz, 1977; De Groot and Steg, 2009; Jansson et al., 2017).

In addition, perceived knowledge impacts the ascription of responsibility and the awareness of consequences, in support of the VBN theory. However, VBN argues that personal norms arise from both the awareness of consequences and ascription of responsibility. By contrast, we found that ascription of responsibility is individually, indirectly and significantly impacting personal norms. Thus, ascription of responsibility is impacting personal norms which influence the intention to reduce water consumption which impacts the intentions to apply smart water meters.

Furthermore, perceived knowledge of personal water use is also indirectly impacting the intentions to implement smart water meters through ascription of responsibility and awareness of consequences of excessive water use, we calculated the strength of this effect by multiplying the indirect and direct impacts. These variables are based on the Norm Activation model. Based on our founding knowledge is impacting both of these variables. Awareness of consequences requires some knowledge on the effects of water consumption in order to be determined, meanwhile ascription of responsibility is requiring awareness of consequences of excessive water consumption in order to be determined. Moreover, based on our results and the original model ascription of responsibility and awareness of consequences are impacting personal norms, which are influencing the intentions to reduce water which leads to higher intentions to implement smart water meters in order to reduce water consumption. Our results also serve to extend the VBN model. According to this theory, personal norms stem from the awareness of consequences and the ascription of responsibility. However, our research suggests that personal norms do not necessarily require this connection, and can instead be impacted by other variables, such as perceived knowledge.

Lastly, we want to highlight that the majority of past research has focused on people's real environmental knowledge without considering their perceived knowledge (Bang et al., 2000; Mostafa, 2006; William et al., 2009). For instance, Levine and Strube (2012) sought to determine whether environmental knowledge encourages environmentally friendly behavior; however, they adopted a questionnaire from NEETF that used questions such as "what is biodiversity" to measure real environmental knowledge. However, previous research suggests that green behaviors are associated more with perceived knowledge than objective knowledge (House et al., 2004). Kim et al. (2018) confirmed that perceived knowledge is a strong predictor of environmental friendly behavior. Our results contribute to this latter stream by affirming that perceived knowledge can directly and indirectly influence the intention to engage in environmental behaviors, such as adopting smart water meters.

Conclusion

The main aim of this research paper was to broaden our understanding and extend the scientific knowledge about consumer behavior when it comes to pro-environmental decisions such as applying smart water meters in order to reduce their water consumption. Based on our results, we can say that perceived knowledge is an important variable that can directly and indirectly influence consumers' intentions to adopt smart water meters in their households. In addition, we demonstrated that different variables impact consumers' decision to implement smart water meters. Thus, our findings may hold value for future studies on implementing smart water meters at the household level. Contrary to traditional water meters, the use of IoT gives residents the insight to constantly and precisely measure the place, time and context of water use, including the possibility of determining the possibility of determining an individual residents' water consumption. This knowledge can increase individual responsibility and possibly translate into a more efficient use of resources. Moreover, this research managed to verify that perceived knowledge of consumers in addition to their values-beliefs-norms can influence consumers to behave in a more sustainable manner.

In addition, based on our results, not only we managed to extend the scientific knowledge about consumers' behavior towards water consumption but also to find ways in order to influence them to behave more sustainably by applying smart water meters and reducing their water consumption. The results could be used not only from researchers in order to extend the research area, but also from policy makers in order to create successful campaigns aiming on reducing household water consumption which plays an important role on the global water scarcity matter. IoT water meter manufactures could also use the results to not only make their product more appealing but also to contribute in water scarcity. The results present that there are ways to influence consumers to behave more sustainably and that could help with the global issue of water scarcity.

That said, our study features several limitations that may spur further research. First, we did not determine if any participants were living in water-stressed areas and how that might have influenced their answers. Second, most of our participants were well educated people, whereas as it was found out that socio-economic characteristics of consumers influenced their perceived water usage (Beal et al., 2013), so as more of our responders are well educated that may impact our findings. We also did not examine the source of respondents' perceived knowledge: We assumed that it was connected with people's general interest in the quantity of water used, but it could also stem from a general belief in one's knowledge superiority.

Regarding future research directions, scholars could explore other predictors of the intention to adopt smart water meters: for instance, by using theories of technology acceptance as the main theoretical framework, like the Technology Acceptance Model, the Unified Theory of Acceptance and Use of Technology (UTAUT2), or the Theory of Planned Behavior. Additionally, future research could investigate the influence of some moderating variables (e.g., environmental concern, frugality, or personal innovativeness) on the relationship between the perceived usefulness and ease of IoT water meters and the intention to adopt them. Lastly, while our research underscores the role of one's willingness to save water in the decision to adopt smart water meters, future research could assess how various motives (e.g., financial, environmental) shape this relationship.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by The Committee of Ethical Science Research of Poznan University of Economics provided us with approval for the research. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

KM and BB contributed to the conception and design of the study. AS organized the database. AS performed the statistical analysis. KM wrote the first draft of the manuscript. KM, BB, and AS wrote sections of the manuscript. BB and KM reviewed the manuscript. BB found funding for the research. All authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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APPENDIX TABLE A1 Survey questions.

Variables	Questions	Sources
Intention to apply IoT water meters	IAW1. I plan to apply IoT-based water meters in my household	Chen and Tung (2014)
	IAW2. I am willing apply IoT water meters in my household	
	IAW3. I will make an effort to apply IoT water meters in my household	
Ascription of responsibility for using too much water	AOR1. I believe all consumers need to take responsibility for water resource usage	Shin et al. (2018)
	AOR2. I think that every consumer is partly responsible for water resource deterioration caused by human kind	
	AOR3. Everyone must take responsibility for the amount of accessible water	
Awareness of consequences of using too much water	AOC1. I believe that using too much water can help increase the tempo of exhaustion of natural resources	Shin et al. (2018)
	AOC2. Using too much water can possibly have a negative impact on the environment	
	AOC3. I think that using too much water supports environmental degradations	
Personal norm concerning saving water	PN1. I believe I have a moral obligation to save water	Shin et al. (2018)
	PN2.Saving water is consistent with my moral principles	
	PN3. My personal values encourage me to save water	
Perceived knowledge on personal water usage	EK1. I have more knowledge on my water usage than an average person	Joshi and Rahman (2017)
	EK2. I know how much water I use every week on average	
	EK3. I have the knowledge about my personal usage of water dedicated for the sustainability symbols used on product packages	
	EK4. I am very knowledgeable about my water usage	
Intention to reduce water usage	IP1. I plan to reduce water usage	Chen and Tung (2014)

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INNOVATIVE TECHNOLOGY FOR SUSTAINABLE BEHAVIOR – INVESTIGATING PREDICTORS OF CONSUMER INTENTION TO USE SMART WATER METERS

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Purpose: Smart water meters (Internet of Things based) are technologically advanced tools delivering precise data on water consumption in a household. However, it has not been examined yet what influences consumer intention to adopt smart water meters. The study objective is to investigate predictors of consumer intention to install smart water meters. The Technology Acceptance Model was applied as the main theoretical framework.

Design/methodology/approach: Data were collected from 366 respondents through an online survey conducted in 2021. Structural equation modeling was used for hypotheses verification.

Findings: The intention to adopt smart water meters was mainly predicted by attitude towards the use of smart water meters. which, in turn, was predicted both by perceived ease of use and by perceived usefulness of these devices. The direct positive impact of perceived ease of use on the intention to adopt smart water meters was also found, whereas the direct relation between perceived usefulness of smart water meters and the intention for the adoption turned out to be statistically insignificant.

Research limitations/implications: One research limitation is the probable lack of smart water meter usage among the responders, which may have affected their perception on how these devices are useful and easy to use. Additionally, only the main variables of TAM were applied, thus, other variables were not considered that may have had impact on perceived usefulness and perceived ease of use or usage behavior.

Social implications: Considering practical implications, by analyzing what may influence consumers to adopt smart water meters, we are able to apply this knowledge in real life and increase the amount of smart water meters in households, which may lead to household water reduction.

Originality/value: In previous research. what influences consumers to apply smart water meters has not been examined. This research indicates variables (adopted by TAM) influencing consumers to apply smart water meters, potentially leading to reduction in household water consumption.

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Keywords: smart water meter, intention to adopt innovative technology, water, Technology Acceptance Model, sustainable consumption

Category of the paper: Research paper

1. Introduction

Good water quality o is vital for human society. Yet, water scarcity is a global problem; about 500 million people live in countries where water resources are not sufficient for the local population (Evans, Sadler, 2008). The increase of the global population has caused an increase in water demand, both for domestic and also industrial purposes, which together with climate change, stress the global water supply (Evans, Sadler, 2008). According to the United Nations, water usage has been constantly increasing by about 1% per year since 1980, and it is expected to keep rising (WWAP, 2019). Water scarcity and its predictors have been well-documented. Predictions suggest that the main drivers for the increase in water demand will be the domestic and industrial sector (Pimenta, Chaves, 2021). Therefore, the importance of efficient water uses and sustainable water management is crucial.

Although technological advancement is occurring, in many cases, it is not possible to precisely measure the real-time domestic water consumption in order for it to be monitored and water conservation behaviors implemented. Most countries rely on analogue and manual water-metering systems which are cost-effective, but cannot provide consumers with real-time and precise data. Applying automatic reading devices that have the ability to measure real-time water consumption can provide enormous potential both for the end users and also the environment (Pimenta, Chaves, 2021). These automatic water meters, so-called smart water meters or IoT (Internet of Things based) meters, are devices that are linked to home appliances and record the water consumption while they automatically transmit the data in a remote device (smartphone etc.) (Meyer, Nguyen, Beal, Jacobs, Buchberger, 2021). The smart water meter is connected to a remote device via WiFi for remote control (Hsia, Wang, Hsu, 2021). The main aim of smart water meters is to provide information to the consumer about her/his water usage, which can lead to water consumption reduction or to detect any possible leaks (Mudumbe, Abu-Mahfouz, 2015). Thus, as the interest in sustainable water consumption is increasing, it is noted that the interest in smart water meters is also rising (Pimenta, Chaves, 2021).

One of the ways to reduce water consumption may be achieved by individual efforts in the household (Larrabee Sonderlund, Smith, Hutton, Kapelan, 2014).In past research, the positive effects of smart water meters on reducing water consumption in households have been proven. Erickson et al. (2012) conducted research in order to evaluate the effectiveness of the Dubuque Water Portal which included a real-time consumption feedback recorded by smart-water meters that were given to households. The results indicated a 6.6% decrease in water consumption during the first 9 weeks. Petersen, Shunturov, Janda, Platt, and Weinberger (2007) also conducted research on smart water meters and water consumption: smart water meters were installed in college dormitories, the group of students who got feedback from the smart-water meters reduced their water consumption by about 3% per person. Larrabee Sonderlund et al. (2014) conducted a review on smart water meters and the influence of feedback on water consumption. These authors came to the conclusion that in studies focusing on this area, a water reduction between 3% and 53.4% what observed when information about water consumption was fed back to consumers. Cominola et al. (2021) carried out a study on long-term changes in the behavior of consumers who installed smart water meters and received feedback regarding their water consumption. They recorded a long-term decrease in volumetric water consumption by 8%. Further research was conducted by Daminato, Diaz-Farina, Filippini, and Padrón-Fumero (2021) who examined annual consumption data from approximately 51,000 households during the timeline of 10 years and concluded that due to applying smart water meters, a decrease by about 2% was noted for water consumption. Although the reductive effect of smart water meter application on water consumption was proven, in a study conducted by Montginoul and Vestier (Montginoul, Vestier, 2018), it was shown that the level of consumers' willingness to adopt this technology was low, even when they were offered smart water meters for free by water utility companies. This leads to the conclusion that attention should be focused not only on the results of smart water meter usage concerning water consumption, but also on the intention to adopt this technology by consumers as well as the predictors of this intention.

Despite the fact that there is much research regarding the effect of smart water meters on the reduction of water consumption, in not many papers has it been examined what influences the consumers to install smart water meters in their households. In a precedent study focused on the future acceptance of smart water meters by consumers based on their beliefs and expectations towards them, it was found that the majority of consumers had a positive attitude towards accepting smart grids in their households (Chang, Nam, 2021; Krishnamurti et al., 2012). In a previous study focused on consumers' perceptions of smart home devices, such as smart water meters, it was also concluded that consumers had a positive perception of smart home consumption devices (Paetz, Dütschke, Fichtner, 2011). However, past research was not focused on factors influencing consumer intention to apply smart water meters in their households. It is very important to examine these determinants in order to find effective ways of making consumers adopt sustainable lifestyles and, in particular, decrease water usage. There is still a research gap related to factors influencing these pro-environmental behaviors that lead consumers to care about the environment and that will make them act accordingly (Obery, Bangert, 2017), such as installing smart water meters in order to reduce their household water consumption. In this research, to investigate the motivation of consumer intentions to apply smart water meters, the Technology of Acceptance Model (TAM) was applied as the main theoretical framework. TAM, introduced by Davis (1989), is still one of the most frequently applied and influential models in numerous studies on the adoption of various technologies, such as: cloud e-learning applications (Wang, Lew, Lau, Leow, 2019), driverless cars (Koul, Eydgahi, 2018), smart homes (Hubert et al., 2019). TAM was proposed for information technology adoption but is currently being used in many other disciplines and fields, such as examining the intention to use a smartwatch for medical purposes (Elnagar et al., 2022).

Although TAM is a model that is nowadays used in order to examine consumer acceptance of technology, there are not many studies in which this model has been adopted to examine the acceptance of smart water meters. Park, Kim, and Kim (2014) examined the technological acceptance of smart grids, i.e., energy smart meters, and noted a positive relationship between perceived ease of use and perceived usefulness towards intentions to use energy smart grids, however, they did not examine smart water meters. Thus, it is noted that there is a research gap concerning determinants affecting the intention to apply smart water meters, specifically. By finding out the mechanism as to how TAM variables predict consumers' intentions to apply smart water, a possibility to more effectively promote the application of smart water meters in households will emerge. The aim of this paper is not only to bridge this gap but also, to practically apply its results in order to find ways to encourage consumers to use smart water meters in order to reduce their household water consumption and introduce a water conservation strategy.

The paper is structured as follows; the first part is devoted to a literature review, where hypotheses are developed on the basis of TAM and previous studies on the investigated area of research. The second part is focused on the methodology of the current study. The third part contains a presentation of the results achieved in our empirical research. The last part is focused on discussion of the results, directions of further research as well as practical applications of our results. Last but not least, a conclusion is given, in which the key findings and the limitations of our research paper are included.

2. Literature background and hypotheses development

Innovative technologies are currently developed very rapidly due to the fact that technological limitations have been successfully overcome in numerous sectors. However, in the case of various technologies, the willingness to apply them by potential users remains the most important barrier in launching them onto the market. In previous research, predictors of technology acceptance were examined both in the case of institutional entities, such as enterprises (Andaregie, Astatkie, 2021; Bruque, Moyano, 2007), and also consumers (Chan, Yee-Loong Chong, 2013; Nguyen, Borusiak, 2021). Numerous theoretical frameworks have been applied in these studies (Lai, 2017; Marangunić, Granić, 2014; Taherdoost, 2018). Two groups of them may be distinguished. The first one consists of universal models widely applied for any type of research on consumer behavior, mainly focused on behavioral intention predictors, i.e. Theory of Reasoned Action (Fishbein, Ajzen, 1975), Theory of Planned Behaviour (Ajzen, 1991), Theory of Interpersonal Behaviour (Moody, Siponen, 2013), or Social Cognitive Theory (Schunk, 2012). The other set includes theories strictly dedicated to the process of examining the adoption of new technologies, such as: Technology Acceptance Model (Davis, Bagozzi, 1989), Diffusion of Innovation theory (Dingfelder, Mandell, 2011), or Unified Theory of Acceptance and Use of Technology (Venkatesh, Morris, Davis, Davis, 2003).

Technology Acceptance Model (TAM) has become one of the most widely-used theories in the examination of technology adoption processes (King, He, 2006; Svendsen, Johnsen, Almås-Sørensen, Vittersø, 2013; Yousafzai, Foxall, Pallister, 2007a). This is mainly due to its simplicity, understandability and robustness (Gao, Bai, 2014). It was proposed by Davis in 1986 (Davis et al., 1989) for modeling user acceptance of information systems. TAM is based on the Theory of Reasoned Action - one of the most popular theories explaining people's behavioral intentions and their actual behavior predicted by the intention which, in turn, is determined by two other variables: attitude towards a given behavior and subjective norm concerning this behavior. TAM posits that intention to adopt an innovative technology is chiefly predicted by attitude towards using a technology which, in turn, is driven by behavioral beliefs. These beliefs in TAM are expressed by two key variables: perceived ease of use and perceived usefulness, which - directly or indirectly - explain outcomes (Marangunić, Granić, 2014; Scherer, Siddiq, Tondeur, 2019). Perceived ease of use is the degree to which the consumers believe that the use of a particular technology will be effortless. Perceived usefulness is defined as a potential user's probability that using a given technology will increase her/his task performance. Both perceived ease of use and perceived usefulness have positive effects on the attitude of the consumers towards the examined technology and they further positively affect consumer intentions to use and apply the particular technology.

Previous studies using TAM for explaining the predictors of technologies were mainly connected with computers and the Internet, such as: personal computers, electronic mail, voice mail, word processor, graphic software, the world wide web, smart cards, online shopping, virtual stores, digital libraries and Internet banking (Yousafzai et al., 2007a). It was also applied for technologies which are, in some ways, related to the smart water metering technology. Gao and Bai (2014) examined factors influencing consumer acceptance concerning the 'Internet of Things' technology, whereas Park et al. (2014) focused their research on smart grid technology acceptance. Both studies proved that two basic motivation variables - perceived ease of use and perceived usefulness - are related to the intention to apply smart solutions.

In the current study, TAM was implemented to explain the intention to apply smart (IoT) water meters. In order to build hypotheses, the following variables were used: intention to apply a smart (IoT) water meter in a consumer's household, attitude towards smart (IoT) water meters use, perceived ease of use and perceived usefulness of smart (IoT) water meters. The following hypotheses were constructed expressing relations proved by previous TAM-based studies:

H1: Perceived ease of IoT water meter use (PEOU) is positively related to attitude towards smart (IoT) water meter use (ATW).

H2: Perceived usefulness of IoT water meter (PU) is positively related to attitude towards smart (IoT) water meter use (ATW).

H3: Perceived ease of IoT water meter use (PEOU) is positively related to perceived usefulness of smart (IoT) water meters (PU).

H4: Attitude towards IoT water meters use (ATW) is positively related to intention to apply smart (IoT) water meters (IAW).

H5: Perceived ease of IoT water meter use (PEOU) is positively related to intention to apply smart (IoT) water meters (IAW).

H6: Perceived usefulness of IoT water meter (PU) is positively related to intention to apply smart (IoT) water meters (IAW).

All hypotheses are presented in the research model (Figure 1).

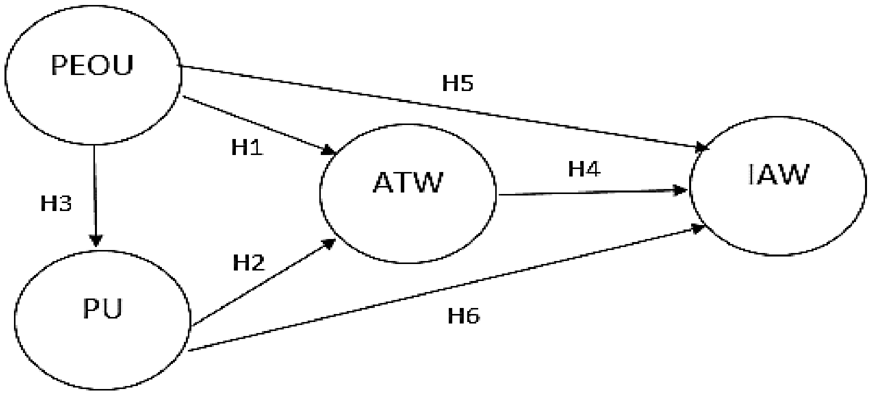

Figure 1. Research Model.

3. Methods

In order to collect data, a survey was conducted using a self-administered questionnaire – the Computer-Assisted Web Interview (CAWI) method. The participants responded to the statements on a 7-point scale (1 – 'I strongly disagree'; 7 – 'I strongly agree'). Validated scales were used to measure latent variables: Perceived usefulness of IoT water meters (PU), Perceived ease of IoT water meter use (PEOU), Attitude towards IoT water meter use (ATW) and Intention to apply IoT water meters (IAW). The full list of statements and sources is presented in Table 1.

Table 1.
Measures

Variable	Statements	Source
Perceived usefulness of IoT water meters	PU1. Using an IoT water meter in my household would allow me to measure water usage more precisely. PU2. Using an IoT water meter in my household would improve knowledge on my water usage. PU3. Using an IoT water meter in my household would enhance my effectiveness in water usage management.	Davis, F.D. (1989) Tsourela, M., Nerantzaki, D.M. (2020) Gao, L., Bai, X. (2014)
Perceived ease of IoT water meter use	PEOU1.Learning to operate IoT-based water meters would be easy for me. PEOU2. I would find it easy to get IoT-based water meters to do what I want them to do. PEOU3. My interaction with IoT-based water meters would be clear and understandable. PEOU4. I would find IoT-based water meters to be flexible in interaction. PEOU5. It would be easy for me to become skillful at using IoT-based water meters. PEOU6. I would find IoT-based water meters easy to use.	Davis, F.D. (1989)
Attitude towards IoT water meter use	ATW1. Using IoT water meters is a good idea. ATW2. Using IoT water meters is wise. ATW3. Using IoT water meters is beneficial. ATW4. Using IoT water meters is interesting.	Schierz, P.G., Schilke, O., Wirtz, B.W. (2010)
Intention to apply IoT water meters	IAW1. I plan to apply IoT-based water meters in my household. IAW2. I am willing to apply IoT water meters in my household. IAW3. I will make an effort to apply IoT water meters in my household.	Han et al. (2010) Chen, Tung (2014)

The study was conducted on the Amazon Mturk platform. In order to ensure the credibility of the provided answers, an answer selection step was performed. In the survey, attention-checking questions were used. The answers of people who passed this test were accepted for analysis. In addition, the answers of people who gave unreliable responses to the question about age, e.g., 2222, were eliminated. Moreover, the time of answering was considered and people who gave them in less than 3xSD from the mean were not taken into account because this may indicate lack of time to thoroughly read the statements. The final number of participants was 366, which exceeds the recommended 300 for structural models. The number of participants was 22 times greater than the number of statements, which allows us to assume that the sample was sufficient. In total, 56.56% of respondents were women and 43.43% comprised men. The mean age was 41 years (min. 18, max. 76, SD 14.09). The full characteristics of the sample is presented in Table 2.

Table 2.
Characteristics of the sample

Variable		**Frequency**	**Percentage**
Sex	Female	207	56.557
	Male	159	43.443
Education	Bachelor's degree	190	51.913
	Doctorate	8	2.186
	High school degree or equivalent	83	22.678
	Master's degree	76	20.765
	Other	9	2.459
Income	$20.000 - $29.999	36	9.836
	$30.000 - $39.999	45	12.295
	$40.000 - $49.999	42	11.475
	$50.000 - $59.999	45	12.295
	$60.000 - $69.999	70	19.126
	$80.000 - $89.999	32	8.743
	$90.000 ≥	65	17.760
	≤ $19.999	31	8.470
Status	Employed full-time	213	58.197
	Employed part-time	51	13.934
	Retired	31	8.470
	Self-employed	25	6.831
	Student	9	2.459
	Unable to work	13	3.552
	Unemployed	24	6.557
Residence	Apartment	108	29.508
	Multi-family home	8	2.186
	Single-family home	250	68.306
	Total	366	100.000

4. Results

First, confirmatory factor analysis was performed to test the method of measuring the variables. For all variables, the loading values exceeded the recommended 0.6, ranging from 0.72 to 0.94. Moreover, the values of Cronbach's α and CR also exceed the recommended 0.7 for all variables and ranged from 0.79 to 0.93. The AVE analysis showed recommended internal consistency among the variables ranging from 0.58 to 0.76. In the next sequence, HTML analysis demonstrated that none of the variables correlated with each other above the recommended 0.85, reaching a maximum of 0.71. On this basis, it was found that there was no common method bias and the model was assessed using bootstrapping at the level of 2000 repetitions. The RMSEA value was 0.065, chi^2/DF did not exceed 3 and was 2.54. Other parameters were also below the cut-off level: CFI 0.968, GFI- 0.29, TLI 0.958 and NFI- 0.948. This indicates that the theoretical model is correctly constructed and individual relations have been analyzed.

The analysis of direct effects showed that all except one relationship was significant at the level of $p < 0.001$. In the case of PEOU, both the influence on PU (b=0.51, $p < 0.001$) and ATW (b = 0.24, $p < 0.001$) turned out to be significant, which confirms the adopted H1 and H3 hypotheses. PU affected ATW (b = 0.62, $p < 0.001$), which is in agreement with H2, however, the effect of PU on IAW turned out to be statistically insignificant (b=-0.3, ns), indicating that there is no basis for confirming hypothesis H6. IAW was significantly influenced by PEOU (b = 0.42, $p < 0.001$) and ATW (b = 0.63, $p < 0.001$), which is a confirmation of H5 and H4, respectively. All SEM analysis values are presented in Table 3.

Table 3.
SEM Results

Endogenous variable	Exogenous variable	Beta	B	SE	*p*-value	CI lower	CI upper
ATW	PEOU	0.24	0.37	0.10	***	0.17	0.55
ATW	PU	0.62	0.83	0.18	***	0.55	1.26
PU	PEOU	0.51	0.60	0.07	***	0.46	0.76
IAW	ATW	0.63	0.60	0.14	***	0.37	0.93
IAW	PEOU	0.42	0.61	0.13	***	0.37	0.91
IAW	PU	0.30	0.38	0.20	*ns*	-0.88	-0.10

5. Discussion

The objective of this study was to extend our knowledge regarding predictors of consumer intention to apply IoT water meters in their households, which may lead to a better understanding of how to reduce household water consumption. Based on TAM, intention to adopt a new technology is predicted by attitude towards using a certain technology, which is further influenced by the belief of perceived ease of use and perceived usefulness of the technology. The findings of this study are consistent with previous TAM- based research. The majority of hypotheses (H1-H5) posed in the current study are supported.

Consistent with TAM, our results allowed to verify that the behavioral intention to use smart water meters is determined by positive or negative attitude towards using smart water meters, thus, one of the predictors of the intention to apply smart water meters is attitude towards using them. In previous studies, it was found that attitude affects behavioral intention of consumers. Robles-Gómez, Tobarra, Pastor-Vargas, Hernández, and Haut (2021) found that attitude towards IoT cloud platforms affects the intention of using this platform. The research results obtained by Kranz, Gallenkamp, and Picot (2010) are also in line with ours, as their findings suggest that attitude towards using energy smart meters mediates the intention to use smart meters. In addition, based on our results, attitude, compared to other variables, has the strongest influence on intention (b = 0.63, $p < 0.001$).

In addition to our finding that attitude towards using smart water meters influences consumer intention of using them, determinants that impact the consumers' attitude towards using IoT water meters were also examined. Consistent with previous research based on TAM, our result allowed to verify that perceived ease of use and perceived usefulness of the technology positively impact attitudes towards the technology. Chen, Xu, and Arpan (2017), while investigating what has impact on consumers towards accepting renewable energy, it was found that both perceived ease of use and perceived usefulness are predictors of consumer attitudes towards using renewable energy. Zhang, Guo, and Chen (2007) noted that the attitude of consumers towards e-learning services is affected by perceived usefulness and perceived ease of use. In the present study, perceived usefulness has stronger impact on attitude ($b = 0.62$, $p < 0.001$) than perceived ease of use ($b = 0.24$, $p < 0.001$). Thus, future research, policymakers and IoT water meter producers need to focus on perceived ease of use and perceived usefulness of smart water meters as they are positively related to attitude which can affect the intention to apply smart water meters.

Based on the current study, perceived ease of use does not only influence attitude towards using smart water meters, but it also has impact on consumer intention to apply smart water meters. Our research supports previous results achieved by Taylor and Todd (1995) who investigated different models regarding technology acceptance of the Computer Resource Center facility. They found that consumer intention can be predicted by the facility's level of perceived ease of use. In addition, Kuo and Yen (2009) also noted that perceived ease of use affects consumer intention to use 3G mobile services. Thus, it is important for future strategies that focus on water conservation by applying smart water meters to aim on explaining the ease of use of smart water meters as it can, directly and indirectly, influence consumer intention to apply them in their households. An interesting finding is that although the TAM model and previous research suggest a rather positive connection between perceived usefulness and intention (Davis, 1989; Moon, Kim, 2001; Taylor, Todd, 1995; Yousafzai, Foxall, Pallister, 2007b), in our study, no such significant, direct relationship was found between perceived usefulness and intention to apply smart water meters. It should be also noted that in the quantitative meta-analysis of TAM conducted by Yousafzai et al. (2007b), for 8 trials out of 89, no significant relationship was indicated between perceived usefulness and intention, while in 19 out of 60, there was no proven significant relationship between perceived ease of use and intention.

In the current study, positive relationships both between perceived usefulness and attitude towards using smart water meters, as well as between attitude and intention to apply smart water meters, were found. Thus, attitude towards using IoT water meter use was proved to mediate the relationship between perceived usefulness of IoT water meters and intention to adopt them. This can be explained with a different valuation of these two beliefs, depending on the stage of action: at the level of attitude foundation, usefulness expressing outcome evaluation, i.e., the benefits of using a smart water meter delivered a potential user good rationale, whereas at the stage of behavioral intention, perceived ease of IoT water meters use turned out to be a more important predictor than perceived usefulness, actually - the only significant predictor. Thus, the most important management implication is that IoT water meters should be as easy to use as possible. To achieve this, user experience studies at the stage of a particular model of IoT water meter design could be quite helpful.

Based on the TAM model, and proved by our result, perceived ease of use can explain the perceived usefulness of IoT water meters. Based on our results, consumers will find IoT more useful if they can use it without difficulties. Past research supports our results, for instance, Gao and Bai (2014), when examining the factors that influence consumer acceptance of IoT mobile terminals, found that perceived ease of use is strongly connected with perceived usefulness, as consumers will not find it useful to use IoT mobile terminals with poor and difficult to use interfaces. Liao, Tsou, and Huang (2007), while researching mobile services, concluded that perceived ease of use directly influences perceived usefulness. Lee, Park, Chung, and Blakeney (2012) conducted research focused on acceptance of mobile financial services and verified a positive relationship between perceived ease of use and perceived usefulness. Our study also supports the results of the previous research, thus, consumers will perceive IoT water meters as more useful if they are able to use them without difficulties.

6. Conclusion

The objective of the current study was to examine the intention to apply IoT water meters using Technology Acceptance Model variables: perceived ease of use, perceived usefulness, and attitude towards IoT water meters. Based on the analysis, the intention to use smart water meters is highly explained by attitude towards the use of these devices. This conclusion is in line with the majority of studies on consumer behavioral intention based on such theories as TAM, but also on others, including the relationship between attitude towards a given behavior and behavioral intention, such as TRA and TPB. In the study, it was also found that attitude towards IoT water meter use is more strongly predicted by perceived usefulness of IoT water meter than by perceived ease of smart water meter use, intention to use smart water meters is predicted directly only by perceived ease of smart water meter use. Attitude towards IoT water meters turned out to be both mediators regarding the influence of perceived usefulness on intention to use IoT water meters and of the impact concerning perceived ease of use on the same intention. Therefore, it was noted that here, attitude towards smart water meters plays a key role as a determinant of intention with regard to smart water meter application. Based on the results of the study, 5 out of 6 posed hypotheses are supported. To be more precise, perceived ease of use and perceived usefulness of IoT water meters are positively related to attitude towards smart water meter use. At the same time, perceived ease of use is positively related to perceived usefulness of IoT water meters, while attitudes towards IoT water meters are positively related with intention to apply smart water meters and perceived ease of using IoT water meters is connected with intention to apply smart water meters. On the other hand, perceived usefulness of IoT water meters is not related to intentions to apply smart water meters. The current study has several limitations. One of them is related to the potential lack of smart water meter usage experience among respondents, as this technology is at the initial stage of its market life cycle. This fact could, to some extent, cause bias regarding both perceived usefulness and perceived ease of IoT water meter use. Another limitation of the current study is connected with the fact that only basic TAM variables were applied in order to examine predictors of intention to use smart water meters. In this research, neither the variable predicting both perceived usefulness and perceived ease of use nor of usage behavior were considered.

Despite these limitations, this study has many scientific and practical contributions. First of all, the results and understanding of determinants concerning consumer intention to apply smart water meters can be used to increase IoT smart water meter application in households. This, based on previous research, will lead to a reduction in water consumption (Sønderlund, Smith, Hutton, Kapelan, 2014). As in this study the existing TAM model was used and evaluated, future research could be focused on its extension by examining moderating effects of such variables, i.e. frugality, personal innovativeness and environmental concern, to find effective ways of influencing consumer intentions to apply smart water meters. Other directions of further studies could be related to actual behaviors and examination of predictors. Thirdly, the results of our study allow to state that policymakers, smart water meter producers and researchers should focus on improving information on how to use smart water meters, as perceived ease of use both directly and indirectly influence intentions to apply smart water meters, but also they should pay attention to providing consumers with more information about the usefulness of smart water meters in their everyday life to potentially increase the possibility of consumers adopting this technology. Moreover, based on the results of the current study, ways of influencing consumers to install smart water meters in their households, which could potentially lead to household water reduction, are identified. Thus, in this study, implications were given and more information was provided, both on the theoretical and empirical grounds which can be used to promote individuals' application of smart water meters in their households.

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What builds consumer intention to use smart water meters – Extended TAM-based explanation

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A R T I C L E I N F O

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A B S T R A C T

Water scarcity is an issue that affects the life on earth. Technological advancements, such as IoT water meters, are proven to be effective when it comes to household water reduction. However, there is a lack of research on what influences consumer to apply such devices in their households. This research aims to investigate predictors of the intention to apply smart water meters by extending the Technology of Acceptance Model; hypothesizing that intention to apply IoT water meters is predicted by attitude towards them, which, is determined by perceived usefulness and ease of IoT water meter use. To extend the model frugality, personal innovativeness and envi- ronmental concerns were added as moderators of the relationship between perceived ease of use and usefulness as well as attitudes towards IoT water meters. Afterwards, a survey was con- structed, and data were collected from 657 participants. The results supported the hypotheses. Intention to adopt water meters was determined by attitude, which was predicted by perceived ease of use and perceived usefulness of IoT water meters. Regarding the moderators, environ- mental concern was found to be the only variable moderating the influence between perceived ease of use and perceived usefulness on attitudes towards IoT water meters.

1. Introduction

Water is an essential resource for life and its existence. However, due to urbanization and population growth, the demand for freshwater is also increasing [1]. The increase in water demand could have catastrophic impact on water resources, food scarcity and poverty [2]. At the same time, the awareness regarding the importance of sustainability is rising, aiming at ensuring sustainable water management in urban areas [3]. Governments and public utilities affected by water scarcity are investigating water strategies to ensure meeting the future water demand. Proper solutions should therefore be adopted, such as water-effective devices, leakage management and Internet of Things (IoT) water meters [4]. IoT water meters can contribute to accurate water metering by collecting high-frequency data from smart sensors monitoring water consumption. This is why they are also referred as smart water meters.

IoT water meters provide remote consumption reads and real-time information on water consumption [5]. In contrast, traditional meters read manually and do not transfer this information to the consumer. IoT water meters offer the benefit of leak detection, site-specific readings and provide consumers with timely information about their water consumption through a remote device such as a smartphone [6]. Smart water meters raise consumer awareness about water usage, which may reduce water consumption and allow to achieve higher levels of sustainable consumption. Based on previous research by Joo et al. [7], applying smart water meters may cause

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a decrease in water consumption by 5.3%. These results can be partially attributed to the display of water consumption that may have caused changes in awareness and water consumption behavior. Willis et al. [4] recruited 44 households in which alarming-display water monitors were installed on the shower. Installing a smart shower water metering system significantly reduced water consumption by 27%. Erickson et al. [8] evaluated the effectiveness of the Dubuque Water Portal, which involved a real-time water consumption feedback system for households. For 15 weeks, smart meters recorded water consumption data that was transferred to 303 households and water company through an online portal. During the first 9 weeks, half of the participants were given access to the portal where they could view their consumption, and during the last 6 weeks, everyone involved had access to the portal. The results revealed that the group having access to the portal during the first 9 weeks reduced their water consumption by 6.6% compared to the second group. Thus, information about water consumption was a determinant of water reduction.

Even though, many past research focused on if and how smart water meters can reduce household water consumption there is a research gap on the ways to shape consumer willingness to apply smart water meters in their households. Thus, the key objective of this research is to examine what is influencing consumers to apply smart water meters in their households. To do so, the Technology of Acceptance Model (TAM) determinants will be used. TAM is used to investigate consumer intention towards accepting innovative technologies. Based on TAM, the intention to adopt an innovative technology is driven by behavioral beliefs such as perceived ease of use and usefulness, as well as attitude towards technology. Perceived usefulness is an individual's belief that technology will enhance work, and perceived ease of use is his/her perception that using technology will be free of effort.

However, in this paper, an extension of the TAM is examined. Apart from TAM variables, we also investigate environmental concerns, frugality and innovativeness as mediating variables between perceived ease of use, perceived usefulness and attitudes towards technology. One of the most common definitions of environmental concern is by Stern and Dietz [9]. These authors consider this to be an egoistic, social-altruistic and biospheric value orientation and belief about the consequences of environmental changes. Environmental concern can be also defined as the perception and conviction that individuals are harming the natural environmental, while paradoxically, also trying to protect it [10]. Based on past research, environmental concerns are crucial variables as they affect the attitudes of consumers [11], but they also have major influence on pro-environmental behavior [12]. Frugality is defined by Michaelis et al. [13] as a consumer trait influencing a preference for conserving resources and applying economic rationality in one's purchases. Consumer innovativeness refers to the predisposition of the consumer to adopt an innovative technology earlier than most consumers [14].

This study as it is directed on examined the consumer behavior will assume that the smart water meters are not installed by the water companies, like it happens in France free of charge [15], but purchased and installed by individuals. However, finding what is affecting consumers to apply smart water meters may help policymakers, governments, and water companies that provide smart water meters to increase the adaption rate of IoT water meters in their households, and reduce their household water consumption. Thus, as household water consumption highly accounts for total water usage, its reduction may be beneficial for the global issue of water scarcity.

The remaining parts of the paper proceed as follows: in section 2, a literature review is presented as well as the theoretical underpinnings that were used to create our research model. In section 3, the methodology of our quantitative empirical research is given. In section 4, analysis of the results is provided, while in section 5, the key conclusions are summarized with a discussion on the implementation of our results, and potential future research directions are identified.

2. Literature review and hypotheses development

In order to formulate the research model from which the hypotheses of this study will be derived the Technology Acceptance Model Davis [16] was extended with the use of three moderators; environmental concern, frugality and personal innovativeness. Based on that the below research model was constructed.

The Technology Acceptance Model by Davis [16] has been previously used to explain how consumers accept innovative

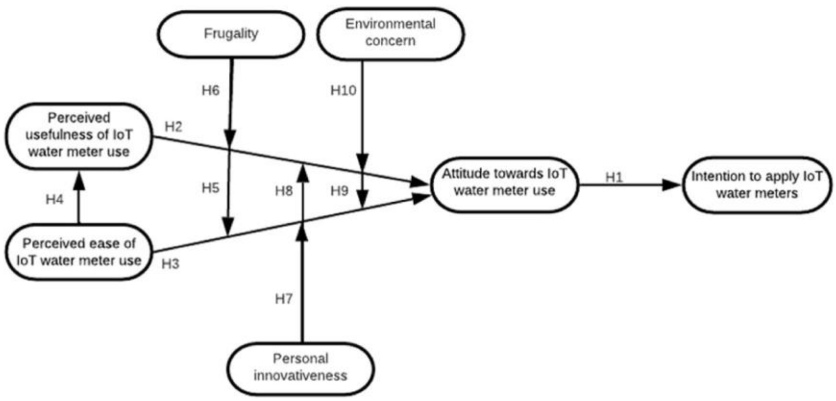

Fig. 1. Research Model (TAM and moderators).

technology. Davis conceived that the belief-attitude-intention relationship predicts technology acceptance and asserts that perceived usefulness and ease of use represent beliefs [16]. Meanwhile, attitude refers to a user's evaluation of the desirability of technology, and behavioral intention is the likelihood that a person will employ the technology [17]. In prominent technology acceptance models such as TAM, the intention is the prime indicator regarding acceptance of a technology [18]. In the realm of TAM, the main antecedent and key influence of intention is attitude towards using a technology [16]. In this study, as we have adopted TAM, we hypothesized that attitudes towards IoT water meters determine intention for their use (see Fig.1).

H1. Attitude towards applying IoT water meters (ATW) determine the intention of applying them (IAW)

TAM posits that attitude is determined by perceived ease of use and usefulness. Perceived usefulness has been widely studied in research concerning technology acceptance, while it originally refers to job-related productivity, performance and effectiveness [16]. Based on TAM, perceived usefulness affects the intention to use Information Technology over and above its influence through attitude [16]. Jeyaraj et al. [19] conducted a literature review concerning the predictors of intentions to adopt Information Technology. According to this review, perceived usefulness was found to be the strongest predictor of intention to adopt an IT technology. Perceived usefulness and its effects on intention were examined in 10 previous studies, and it was found to be significant in 9 of them [19]. In prior research, perceived usefulness has been investigated as a predictor of intention to accept technologies such as e-commerce, online games and mobile Internet activities [20–22]. In previous research, factors have been examined that influence consumer acceptance of IoT and it has been demonstrated that perceived usefulness can influence the intention of consumers to use IoT technologies, such as electronic toll collection devices [23], as well as attitudes towards IoT devices [18]. IoT water meters can help consumers track their water consumption to detect any possible leaks and significantly reduce their water bills. Accordingly, perceived usefulness of IoT water meters is likely to affect consumer intentions to install IoT water meters through attitudes. Thus, based on TAM viability and the findings of past research, we hypothesize that:

H2. Perceived usefulness of IoT water meters (PU) is positively related to attitudes towards IoT water meter use (ATW).

Similar to perceived usefulness, perceived ease of use is one of the most studied variables in technology acceptance research. Based on TAM, perceived ease of use is a customer's assessment as to what extent an interaction with technology is free of mental effort [16]. This construct is 1 of the 2 TAM beliefs influencing customer intention to use technology through attitudes. In past research, perceived ease of use has been examined as a determinant of intention through attitude towards different technologies. Renny et al. [24] conducted research on online airline tickets and found that perceived ease of use is a main predictor of attitudes towards this form of ticketing. Lee et al. [25] investigated the determinants of intentions to use e-learning services. The results allowed to prove that perceived ease of use influences attitudes towards eLearning services. Lee et al. [26] empirically tested TAM to shed some light on the technological acceptance of mobile financial services and found that perceived ease of use affects attitudes towards intention to use mobile financial services. Based on TAM and previous research, perceived ease of use is posited to influence intention to use technology through attitudes. Thus, based on the latter, we hypothesize that:

H3. Perceived ease of IoT water meter use (PEW) is positively related to attitudes towards IoT water meter use (ATW).

Perceived ease of use was found to affect intentions and attitudes towards specific technology, directly and indirectly through its effect on perceived usefulness. According to Venkatesh and Davis [27], this relationship can be explained based on the fact that if customers perceive the use of any technology as free of effort, then it is more likely that they will perceive the technology as more useful. In past research on mobile commerce [28] and IoT technological acceptance [18], it was found that perceived ease of use is a strong predictor of perceived usefulness. With these considerations and by taking TAM and past research into account when explaining technology acceptance, we hypothesize that:

H4. Perceived ease of IoT water meter use (PEW) is positively related to perceived usefulness of IoT water meters (PU).

Although in previous studies TAM has been found to be a parsimonious and robust model, TAM only examines the 2 beliefs that explain consumer acceptance of technology. This study heeds the call to broaden TAM by introducing new variables and explaining the model's existing variables in it. Thus, the aim of this research is to examine the determinants of consumer intentions to apply IoT water meters and to extend it by adding moderating variables such as frugality, personal innovativeness and environmental concern.

Frugal behavior has been defined as the voluntary and proactive decision to purchase products with value but at low prices, limiting consumption, long-term usage of products, repairing, reusing and recycling [29]. Similarly, Michaelis et al. [13] defined a frugal consumer as one who prefers conserving resources and being economically rational when purchasing goods. Frugality is a lifestyle that is closely related not only to sustainable consumption but also to environmental protection due to the anti-consumption values that it represents [30]. Based on the assumption that frugal behavior is connected with saving, it is feasible to associate it with sustainable actions such as conserving natural resources. Both consumer traits - frugality and sustainable efforts - are influenced by a similar cognitive and emotional process with a non-materialistic consumption approach [31]. However, the connection between frugality and environmental behavior is not direct. Kropfeld et al. [32] examined the influence of 3 anti-consumption lifestyles, including frugality, on environmental concern. Their results showed that out of these 3 anti-consumption lifestyles, only frugality was not associated with reducing the environmental impact or with environmental concern as frugal consumers do not necessarily buy fewer goods. Thus, in this research, frugality and the level of consumers' environmental concern is investigated separately.

As a frugal lifestyle refers to saving, we can assume that frugality could be the moderator between perceived ease of use, usefulness and attitudes towards IoT meters. More precisely, based on past research, IoT water meters play an important role in the reduction of household water consumption. Thus, we assume that as consumers following a frugal lifestyle are focused on limiting consumption to save money and resources, they will be interested in smart water meters and perceive them as useful and easy to use. Based on this consideration, we hypothesize that:

H5. Frugality moderates the relationship between perceived ease of IoT water meter use (PEW) and attitudes towards IoT water meter use (ATW).

H6. Frugality moderates the relationship between perceived usefulness of IoT water meter use (PU) and attitudes towards IoT water meter use (ATW).

The TAM model neglects one important variable, which is the influence of personal innovativeness on technological acceptance. Agarwal and Prasad [33] proposed a new construct called personal innovativeness, which is illustrated as a moderator of perceiving a new technology and its acceptance. Agarwal and Prasad [33] argued that consumers with higher personal innovativeness are expected to develop more positive beliefs about a new technology and they are expected to be more willing to try out new technologies.

Past research has been focused on examining the effects of personal innovativeness on different consumer behaviors. Lewis et al. [34] conducted research using the construct of personal innovativeness in information technology to explore influences from individual, institutional and social contexts, while interacting with IT. The results of this research allowed to note that personal innovativeness has impact on perceived ease of use and perceived usefulness.

In prior research by Lu et al. [35], it was proposed that personal innovativeness determines perceived short- and long-term ease of use and usefulness; the results verified their research assumptions. In addition, consumers with higher personal innovativeness tend to be more curious, bold and risk-takers [36]. These behavioral traits are expected cause them to develop positive intentions about using new technology and to determine higher levels of perceived usefulness as well as perceived ease of use of the technology as they are more eager to investigate the latest technology.

In this research, we assume that consumers with higher personal innovativeness are more motivated to explore the new technology leading to higher perceived usefulness and perceived ease of use. However, we want to examine if personal innovativeness will be regarded as a moderator of the relationship between perceived ease of use, perceived usefulness and attitudes towards IoT water meters. Based on this consideration and on past research, we hypothesize that:

H7. Personal innovativeness moderates the relationship between perceived ease of IoT water meter use (PEW) and attitudes towards IoT water meter use (ATW).

H8. Personal innovativeness moderates the relationship between perceived usefulness of IoT water meter use (PU) and attitudes towards IoT water meter use (ATW).

Environmental concern refers to the extent to which individuals are concerned about the environment, ecological issues and their willingness to put some effort in solving them [37]. Environmental concern is strongly related to consumers′ attitudes towards protecting the environment [38]. Prior research has investigated how environmental concern may influence consumer behavior and a positive relationship has been found between environmental concern and environmentally friendly behaviors. Hartmann and Apaolaza-Iba´n˜ez [39] researched how environmental concern may affect consumer attitude and intention towards green energy. Based on their results, environmental concern has an effect on attitudes and purchase intentions of green energy. Ham and Han [40] examined how the level of environmental concern can affect consumer intention to visit hotels that follow green practices. The results indicated that the more environmentally concerned a customer is, the higher probability of acting in an environmentally friendly way, such as visiting green hotels. The research by Jekria and Daud [41] was aimed at determining if environmental concern has impact on consumer attitudes towards recycling. Based on the results, environmental concern is related to attitudes towards recycling, which may improve recycling levels. Li et al. [42] conducted a study aiming to investigate the influence of environmental concern on water conservation behavior. The results indicated that environmental concern is related to water conservation behaviors.

Based on previous research, environmental concern is regarded as a determinant of environmental behavior. Thus, we assume that as environmentally concerned consumers are more eager to act in an environmentally friendly way, the level of consumers′ environmental concern will be a moderator between perceived ease of use, usefulness and attitudes towards IoT water meters. Based on this assumption and on past research, we hypothesize that:

H9. The relations between perceived ease of IoT water meter use (PEW) and attitudes towards IoT water meter use (ATW) is affected by environmental concern.

H10. Environmental concern moderates the relationship between perceived usefulness of IoT water meter use (PU) and attitudes towards IoT water meter use (ATW).

3. Methodology

A self-administrated questionnaire was developed to identify the predictors of intention to apply smart water meters. The survey consisted of 2 parts. The first part introduced participants to the concept of smart water meters, including textual explanations (*A smart water meter is a standard or conventional water meter, and fundamentally performs the same function. However, to make it 'smart', the meter is attached to a device that allows continuous electronic reading, storage, display, and transfer of water consumption data for example, using a mobile or web application*) and illustrative images. The explanation was meticulously crafted, being comprehensive yet neutral to avoid any bias towards the possible benefits of the device. It included examples from multiple companies manufacturing smart water meters. The description was necessary for the credibility of the research as it allowed the responders to obtain information about smart water meters.

In the second part, we asked participants to respond to statements on a 7-point scale (1 – 'strongly disagree'; 7 – 'strongly agree'). We used validated scales to measure variables (all being latent): perceived usefulness of IoT water meters (PU), perceived ease of IoT water meters use (PEW), attitude towards IoT water meters use (ATW), intention to apply IoT water meters (IAW), frugality (FR), personal innovativeness (PI) and environmental concern (EC). To evaluate frugality, 4 statements were employed from Lastovicka et al. [29], such as "I believe in being careful in how I spend my money". To assess personal innovativeness, 3 items were adopted from Lu et al. [22], an example of these statements being "When finding out about new technology, I look forward to trying it". With regard to environmental concerns, 4 statements such as "I am willing to make sacrifices to protect the environment" were adopted from Chuah et al. [13] for the deployment of environmental concern. To measure perceived ease of use, 6 statements were implemented on the basis of Davis [16], for instance questions such as "Learning to operate IoT based water meters would be easy for me". In order to measure perceived usefulness, 3 statements, such as "Using the IoT water meter in my household would allow me to measure water usage more precisely", were adopted from Davis [16], Tsourela and Nerantzaki [13] and Gao and Bai [23]. As far as the attitude towards IoT water meters is concerned, 4 statements such as "Using IoT water meters is a good idea" were taken from Schierz et al. [4]. The survey was disseminated online, with a small compensation of USD 0.9 provided to all participants who completed the questionnaire. This research was focused on American populace and was distributed via the Amazon Mturk platform, which enabled location verification. Rigorous measures were put in place to ensure data validity and reliability. These included attention-checking questions for verification and excluding respondents who completed the survey too rapidly. The average completion time for the survey was 8 min. To ensure the validity and reliability of responses, a multi-stage verification step was incorporated, utilizing attention-checking questions. Any unreliable answers were excluded from our analysis. Furthermore, the response time was also considered; respondents who completed the survey in less than three standard deviations from the mean time were excluded from the study. Moreover, answers from participants who completed the first part in less than 15 s were not included. After this filtering, the final number of respondents was 657. The mean age of the participants was 40 years (min. 18, max. 76, SD. 13.1). The gender distribution in the sample was as follows: 56.2% of the participants were women while 43.4% were men, roughly approximating the U.S. Census data of 50.5% females in the population. Given the research focus on household water consumption, the respondents were queried about their living situation. Of these, 67.1% reported living in single-family homes, while 29.4% reported residing in apartments/flats. Table 1 presents the complete demographic characteristics of the respondents, including data on their education, income, and employment status. The data suggest that our sample was relatively representative of the broader population. For instance, 58.9% of our sample was employed full-time, which is close to the U.S. Census Bureau's data indicating that 63.1% of U.S. workers are employed full time. Nevertheless, it's important to note some discrepancies between our sample and the general U.S. population. For example, the percentage of respondents with a bachelor's degree was higher in our sample (52.4%) compared to the general U.S. population (33.7%). Such discrepancies should be kept in mind when interpreting the results.

The complete characteristics of the respondents are presented in Table 1.

To assess and mitigate the potential impact of Common Method Bias (CMB), both procedural and statistical measures were integrated into the research methodology. CMB is a potential source of systematic measurement error that can introduce spurious covariance among the variables when they are collected using the same method or source. Procedurally, a combination of techniques

Table 1
Demographics.

Variable		Frequency	Percentage
Sex	Female	369	56.2%
	Male	285	43.4%
Education	Bachelor's degree	344	52.4%
	Doctorate	12	1.8%
	High school degree or equivalent	147	22.4%
	Master's degree	126	19.2%
	Other	23	3.5%
Income	$20.000 - $29.999	76	11.6%
	$30.000 - $39.999	78	11.9%
	$40.000 - $49.999	85	12.9%
	$50.000 - $59.999	88	13.4%
	$60.000 - $69.999	114	17.4%
	$80.000 - $89.999	53	8.1%
	$90.000 ≥	106	16.1%
	≤ $19.999	57	8.7%
Status	Employed full-time	387	58.9%
	Employed part-time	94	14.3%
	Retired	42	6.4%
	Self-employed	44	6.7%
	Student	20	3.0%
	Unable to work	22	3.3%
	Unemployed	48	7.3%
	Apartments	193	29.4%
	Multi-family homes	23	3.5%
	Single-family home	441	67.1%

was employed during the questionnaire design phase to disrupt potential patterns leading to CMB. These techniques included the use of different scale types for predictor and criterion variables. Anonymity of respondents was also maintained to reduce evaluation apprehension and social desirability bias. Moreover, particular emphasis was placed on ensuring the clarity of questions to prevent respondent error or confusion. Statistically, Harman's single-factor test was performed after data collection to assess the presence of CMB. This technique involves entering all the variables from the study into an exploratory factor analysis to check if a single factor emerges or accounts for most of the covariance among the variables. The result of this test showed that no single factor emerged and no single factor dominated the covariance, suggesting that CMB was not a significant issue in this data. The application of these procedural and statistical measures serves to enhance the validity and reliability of the study findings by addressing and controlling for potential issues related to Common Method Bias.

4. Results

The data from this study were analyzed using the Partial Least Squares Structural Equation Modeling (PLS-SEM) approach. The first step was to evaluate convergent and discriminant validity, both of individual variables and the composite reliability of the items [45]. Confirmatory factor analysis (Table 2) allowed to indicate that all factor loadings exceed the recommended level of 0.6 [46], ranging from 0.69 to 0.90. Next, scale reliability was measured by applying Cronbach's α and all values ranged above the recommended cutting point of 0.70 [64], from 0.84 to 0.93, representing good to very good consistency. To measure convergent and discriminant validity, standardized factor loading together with 2 parameters of Composite Reliability (CR) and Average Variance Extracted (AVE) were used. The CR value was above the recommended cut points of 0.7 while all variables ranged from 0.78 to 0.91 [45] and the AVE analysis showed the recommended internal consistency among the variables ranging from 0.56 to 0.76 (Hair, Black et al., 2014) (see Fig. 2).

The HTMT ratio was used to assess discriminant validity, and as the ratios of each item were below 0.9 (Table 3), discriminant validity was established [47]. In addition, to evaluate the fit of the model, RMSEA was applied and the value was 0.06. Other parameters were also below the cut-off level: CFI 0.97, GFI 0.94, TLI 0.96 and NFI0.96 (Hair, Black et al., 2014). Thus, the theoretical model is correctly constructed and individual relationships have been analyzed.

After this, analysis regarding the direct effects of the variables was conducted and it was shown that all relationships were significant at the level of $p<0.001$. The direct effect of attitudes towards IoT water meters on Intentions to apply IoT water meters turned out to be significant (b = 0.66, $p<0.001$), which confirms hypothesis H1. The effect of perceived usefulness on attitude towards IoT water meters was found to be statistically significant (b = 0.68, $p<0.001$), which confirms hypothesis H2. Perceived ease of use has direct influence on perceived usefulness (b = 0.50, $p<0.001$) and attitude towards IoT water meters (b = 0.23, $p<0.001$), which confirms hypotheses H3 and H4. All SEM analysis values are presented in Table 4.

As far as moderating variables of the research are concerned, moderation estimates and simple slope evaluation were conducted to determine whether the relationship between perceived ease of use and attitude towards IoT water meters as well as perceived usefulness and attitudes towards IoT water meters are intensified or weakened by different levels of frugality, personal innovativeness and environmental concern.

Frugality (FR) moderates the relationship between perceived usefulness of smart water meters (PEW) and attitudes towards IoT water meters (ATW) (estimate = 0.0733, $p = 0.004$), but not the relationship between perceived ease of use of smart water meters (PU) and attitudes towards IoT water meters ($p = 0.064$). To be more specific, when frugality levels are higher than perceived usefulness, it has a stronger effect on attitudes towards IoT water meters - and vice-versa - when the frugality levels are lower than perceived usefulness, it has a weaker effect on attitudes towards IoT water meters (Table 5). On the other hand, frugality is not a moderator of the relationship between perceived ease of use and attitudes towards smart water meters. Thus, based on these results, only hypothesis H6 is confirmed.

Personal innovativeness (PI) was also examined as a moderator. Based on the results, personal innovativeness moderates the relationship between perceived ease of use and attitudes towards IoT water meters (estimate = 0.064, $p<0.001$), however, personal innovativeness does not moderate the relationship between perceived usefulness and attitudes towards smart water meters ($p = 0.660$). Thus, when personal innovativeness of consumers is at higher levels, then, perceived ease of use affects attitudes towards IoT water meters more strongly than in case of consumers with lower personal innovativeness. As shown in Table 6, hypothesis H7 is supported, but not H8.

Based on Tables 7 and 8 environmental concerns are moderating the relationships between perceived ease of use, perceived usefulness and attitudes towards applying smart water meters. The level of environmental concern (EC), is proven to have an effect on

Table 2
Abbreviations and expansions.

Abbreviation	Expansion
PU	Perceived Usefulness
ATW	Attitude towards IoT water meters use
PEW	Perceived Ease of IoT water meter use
IAW	Intention to apply IoT water meters
FR	Frugality
PI	Personal Innovativeness
EC	Environmental Concern

Table 2
Confirmatory factor analysis.

Construct	Item	Loading	*p*-value	Cronbach's α	CR	AVE
PU	PU1	0.698	***	0.84	0.78	0.6
	PU2	0.752	***			
	PU3	0.847	***			
ATW	ATW1	0.872	***	0.9	0.9	0.69
	ATW2	0.88	***			
	ATW3	0.877	***			
	ATW4	0.705	***			
PEW	PEW1	0.799	***	0.93	0.91	0.68
	PEW2	0.852	***			
	PEW3	0.868	***			
	PEW4	0.832	***			
	PEW5	0.742	***			
	PEW6	0.86	***			
IAW	IAW1	0.842	***	0.93	0.87	0.76
	IAW2	0.908	***			
	IAW3	0.863	***			
FR	FR5	0.727	***	0.84	0.84	0.57
	FR6	0.794	***			
	FR7	0.756	***			
	FR8	0.737	***			
PI	PI1	0.797	***	0.86	0.86	0.68
	PI2	0.799	***			
	PI4	0.881	***			
EC	EC1	0.83	***	0.89	0.89	0.67
	EC2	0.809	***			
	EC3	0.896	***			
	EC4	0.762	***			

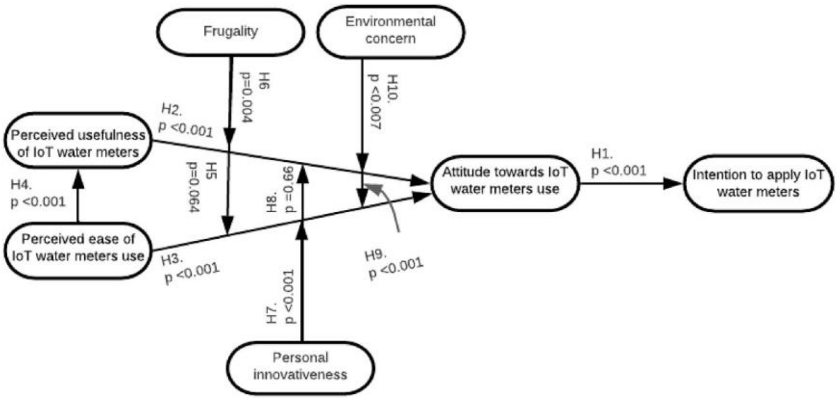

Fig. 2. Results.

Table 3
Discriminant validity (HTMT).

	PU	ATW	PEW	IAW	FR	PI	EC
PU	1						
ATW	0,763	1					
PEW	0,487	0,562	1				
IAW	0,401	0,639	0,586	1			
FR	0,364	0,409	0,326	0,17	1		
PI	0,226	0,327	0,61	0,602	0,135	1	
EC	0,445	0,582	0,375	0,514	0,357	0,37	1

the relationship between perceived ease of use and attitudes towards smart water meters (estimate = -0.102, $p < 0.001$). Additionally, environmental concern influences the relationship between perceived usefulness and attitudes towards applying smart water meters (estimate = —0.054, $p = 0.007$). The moderating estimate value of environmental concern on perceived ease of use is negative, thus, consumers with low environmental concern have higher regression values on the relationship between perceived ease of use and

Table 4
SEM analysis.

Endogenous Variable	Exogenous Variable	Beta	B	SE	p- value	CI lower	CI upper
PU	PEW	0,50	0,57	0,07	***	0,44	0,71
ATW	PEW	0,23	0,41	0,08	***	0,25	0,56
ATW	PU	0,68	1,03	0,14	***	0,80	1,35
IAW	ATW	0,66	0,51	0,06	***	0,40	0,62

Table 5
FR*PU*ATW simple slope estimates.

	Estimate	SE	95% Confidence Interval		Z	p
			Lower	Upper		
Average	0.675	0.0311	0.614	0.736	21.7	< .001
Low (-1SD)	0.604	0.0347	0.536	0.672	17.4	< .001
High (+1SD)	0.746	0.0439	0.659	0.832	17.0	< .001

Note. shows the effect of the predictor (PU) on the dependent variable (ATW) at different levels of the moderator (FR).

Table 6
PI*PEW*ATW simple slope estimates.

	Estimate	SE	95% Confidence Interval		Z	p
			Lower	Upper		
Average	0.492	0.0314	0.430	0.554	15.7	< .001
Low (-1SD)	0.402	0.0348	0.334	0.470	11.6	< .001
High (+1SD)	0.582	0.0462	0.491	0.673	12.6	< .001

Note. shows the effect of the predictor (PEW) on the dependent variable (ATW) at different levels of the moderator (PI).

Table 7
EC*PEW*ATW simple slope estimates.

Simple Slope Estimates						
	Estimate	SE	95% Confidence Interval		Z	p
			Lower	Upper		
Average	0.336	0.0274	0.282	0.390	12.25	< .001
Low (-1SD)	0.457	0.0336	0.391	0.523	13.60	< .001
High (+1SD)	0.215	0.0380	0.140	0.289	5.65	< .001

Note. shows the effect of the predictor (PEW) on the dependent variable (ATW) at different levels of the moderator (EC).

Table 8
EC*PU*ATW simple slope estimates.

Simple Slope Estimates						
	Estimate	SE	95% Confidence Interval		Z	p
			Lower	Upper		
Average	0.552	0.0310	0.492	0.613	17.8	< .001
Low (-1SD)	0.617	0.0311	0.556	0.678	19.8	< .001
High (+1SD)	0.488	0.0459	0.398	0.578	10.6	< .001

Note. shows the effect of the predictor (PU) on the dependent variable (ATW) at different levels of the moderator (EC).

attitudes towards smart water meters. Moreover, the moderating effect of environmental concern on perceived usefulness is also negative. It means that consumers with lower environmental concern have higher regression values regarding the relationship between perceived usefulness and attitudes towards IoT water meters. Based on these results, both hypotheses - H9 and H10 - are supported.

5. Discussion

Based on Davis [16], perceived usefulness and perceived ease of use affect the intention to use information technology via attitudes.

In previous studies, relationships between perceived ease of use, perceived usefulness and attitude have been confirmed. Lule et al. [48] conducted a study to examine factors influencing M-banking usage, and confirmed that perceived ease of use and perceived usefulness have an impact on attitudes towards M-banking. In this study, the TAM model was specifically adopted, and their analysis allowed to show that both perceived ease of use and perceived usefulness affect consumers' attitudes towards M-banking. Weng et al. [49] investigated how perceived ease of use and perceived usefulness will influence the intention to use multimedia in schools. The results confirmed that perceived usefulness and perceived ease of use affect attitude towards multimedia, and attitude affects the intention to use them. Gumz and Fettermann [50] examined how Hunter–Schmidt method and the UTAUT2 model can influence the acceptance of applying smart water meters, the results of this study indicated that hedonic motivation, performance expectancy and effort expectancy are the main determinants of smart meters acceptance.

Consistent with previous studies, our results show that both variables (perceived ease of use, and perceived usefulness) influence the attitude towards smart water meters. Consumers with positive perceptions regarding ease of use and usefulness of IoT water meters are more likely to develop positive attitudes towards IoT water meters, which positively influence their intentions to apply them in their households. Thus, policy makers, retailers, and water companies should provide with as much knowledge as possible to their consumers and improve their perception about the ease of use and the usefulness of smart water meters, in order to increase the chance of applying them [51]. However, it is important to mention the intention-action gap. This study is focusing on the intentions of consumers to apply smart-water meters, but the fact that having favorable intentions does not necessarily guarantee that individuals will follow through with a particular action, such as making a purchase. There are many external factors that may influence the final decision of a consumer to purchase a smart water meter such as cost considerations. While many consumers may express interest in the benefits of these devices, the upfront cost can deter them from making the final purchase. The research conducted Goulas et al. [52] found that consumers are more inclined to adopt smart meters when they are offered for free or when they are sure that there will a cost reduction in their bills. Moreover, another research by Chawla et al. [53] investigating smart meters found that the acceptance rate for having a meter is significantly higher when the meter is offered free of charge compared to when it is a paid option. Lastly, another study by Gosnell and McCoy [54] examined how by reducing the cost of the meters can actually increase the acceptance of smart meters by the consumers and found out that if the government could subsidy £10 for the smart meters then the adaptation percentage for consumers to purchase these devices would increase for about 5%. These findings highlight the existence of an intention-action gap and underscore the importance of considering variables such as costs in the consumer's final decision when adopting smart meters. Recognizing the influence of factors such as cost and offering subsidies or attractive pricing strategies can be key in bridging the intention-action gap and encouraging wider adoption of smart meters, ultimately leading to more efficient and sustainable energy and resource management.

The results of our research model indicate the presence of notable interactions between perceived ease of use and perceived usefulness. In previous research, this relationship has been examined and confirmed. Ma et al. [55] researched how consumers perceived and used sustainability labels for apparel products by adopting and developing TAM. Their research confirmed that perceived ease of use determines perceived usefulness of sustainable labels. Harryanto et al. [56] researched consumer intention to use Internet banking. Based on their results, perceived ease of use significantly affects perceived usefulness. The significant relationship between perceived ease of use and perceived usefulness can be interpreted by mentioning that consumers who perceive IoT water meters as easy to use will consider them more useful as they will be able to understand their functionalities.

The main contribution of our study is the addition of moderators to examine how they affect the relationship between perceived ease of use/perceived usefulness and attitudes towards IoT water meters. The moderators used in this study are frugality, personal innovativeness and environmental concern.

Although frugality did not significantly affect the relationship between perceived ease of use and attitude towards IoT water meters, a moderating effect of frugality was observed between perceived usefulness and attitudes towards IoT water meters. Based on past research, frugality focuses on the consumers' desire to avoid wasting resources which means consumers aim to limit their consumption [57], but is also aimed at paying less Lee [58]. Thus, in our study, consumers perceived IoT water meters as useful because they can reduce water consumption and save money. However, frugality does not moderate the relationship between perceived ease of use and attitudes towards IoT water meters. Frugal consumers may perceive IoT water meters positively, as they can benefit from them financially, but they do not influence their perception concerning ease of using IoT water meters.

In our study, personal innovativeness moderated the relationship between perceived ease of use and attitudes towards IoT water meters. Prior conceptualizations of personal innovativeness have defined it as a characteristic of individuals who are early to adopt an innovation [33], thus consumers with high levels of personal innovativeness perceive the use of IoT water meters as easier due to their openness to use them. Consistent with our results, in past research conducted by Boo and Chua [59] it was illustrated that personal innovativeness intensifies the technological benefits of perception, such as ease of use regarding facial recognition technology. In contrast, personal innovativeness does not moderate the relationship between perceived usefulness and attitudes towards IoT water meters. Consumers with high personal innovativeness levels are considered bold and risk-takers when applying new technology [36]. Another contribution of this study is the negative moderating effect of environmental concern on the relationship between perceived ease of use, perceived usefulness and attitudes towards IoT water meters. Based on previous research, environmentally concerned consumers are more willing to take action to behave more sustainably [60]. Another research focusing on smart meters, found out that customers with high familiarity and climate change risk perception are more keen on accepting technologies such as smart meters [61]. In contrast, our results indicated that in case of consumers with high environmental concern, the strength of relationship between both predictors (perceived ease of use and perceived usefulness) and attitude towards IoT water meters was weaker than in case of less concerned customers. As far as perceived ease of use is concerned, the negative moderating effect can be explained based on the fact that highly environmentally concerned consumers are not taking the ease of IoT water meter usage in to consideration, as their main focus is to find ways for reducing their water consumption [62]. When it comes to perceived usefulness of IoT water meters, the results can be interpreted by mentioning that the statements and the IoT water meter description in the survey allowed to state that the main usability of IoT water meters is the automatic measurement of water consumption in households. Thus, environmentally concerned consumers would probably find IoT water meters useful if there was a direct description that smart water meters not only measure the water usage but are also proven to contribute to water reduction. Another reason for the negative moderating effect is that environmentally concerned consumers may feel that they are fully aware of their water consumption due to their beliefs and actions, therefore, they do not see how smart water meters could benefit them.

Apart from the contributions of this study, there are also some limitations that should be mentioned. First of all, even though we provided the participants with a description on what smart water meters are, we are not able to know about their past experience with smart meters. Thus, it is not clear if the consumers know about the benefits from such devices. Based on our results, this could be important as perceived usefulness which can be connected with the benefits of these devices are impacting the consumers' attitudes towards smart water meters. Another limitation of this study is the lack of information of whether our participants live in water-stressed areas which could impact their answers.

6. Conclusion

This study allows to shed some light on what affects consumer intention to apply smart water meters in their households. The findings affirm those obtained in previous research in which TAM had been adopted. Attitude was the main predictor of intention to apply smart water meters, and perceived ease of use and perceived usefulness influenced attitude towards smart water meters. In addition, as presented via TAM, perceived ease of use defines the perceived usefulness of smart water meters.

The main contribution of this study is the extension of the TAM model by adding 3 moderators; frugality, personal innovativeness and environmental concern. Based on this study, frugality positively moderates the relationship between perceived usefulness and attitudes towards smart water meters, as frugal consumers find IoT water meters more useful due to their capabilities of measuring water and giving them a chance to reduce their water consumption while saving money. On the other hand, personal innovativeness positively moderates the relationship between perceived ease of use and attitudes towards smart water meters. This can be explained by the fact that consumers with high personal innovativeness are more open to new technologies, and they do perceive them as easier to use because of their curiosity of exploring the latest technologies, such as IoT water meters. When it comes to the third moderator in our study - environmental concern - the results illustrated a negative moderating effect of environmental concern on the relationship of perceived ease of use, perceived usefulness and attitude towards IoT water meters. Based on our analysis, high environmental concern has a lower moderating effect on the relationship between perceived ease of use and perceived usefulness, and the attitude towards IoT water meters. Consumers concerned about the environment mainly focus on reducing their water consumption and not on how easy it is to use IoT water meters, or how useful it is to automatically measure their consumption as it does not directly satisfy their water reduction goals.

The findings of this research include many scientific and practical contributions. Regarding scientific contributions, conducting this study allowed to present determinants that may influence consumer intention to apply smart water meters in their households, which may contribute to household water reduction. Secondly, to conduct our research, the TAM model was adopted, which was confirmed and extended by adding moderators. Moreover, our results allowed to indicate that all moderators are essential determinants of the relationship between perceived ease of use, perceived usefulness and attitudes towards IoT water meters.

In future research, other moderators could be added to the TAM model, which may lead to a deeper understanding of what affects consumers' intentions to apply smart water meters in their households, alike some demographic and social characteristics, as well as type of residence. In addition, other directions of future studies could be related to experimenting with the actual behavior of consumers while using IoT water meters and examining predictors. As far as the practical contributions are concerned, in this study, it was shown that policymakers, smart water meter producers and governments should provide more detailed information on the ease of use and the usefulness of IoT water meters, as both variables affect the intentions to apply smart water meters in households. Thus, this study provides valuable information that can be used to change the intention of consumers to apply smart water meters in their households, which may lead to household water reduction and contribute to the general and global issue of water scarcity.

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Author statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Apendix

Statements

Variable	Statements	Source
Frugality	FR1. I believe in being careful about how I spend my money. FR2. I discipline myself to get the most from my money. FR3. I am willing to wait on a purchase I want so that I can save money. FR4. There are things I can resist buying today so I can save for tomorrow.	Lastovicka et al. [29]
Personal innovativeness	PI1. When finding out about new technology, I look forward to trying it. PI2. Among my friends or family, I am usually the first to try new technologies. PI3. I prefer to explore and try new technologies.	Lu et al. [22]
Environmental concern	EC1. I am concerned about the environment. EC2. The condition of the environment affects the quality of my life. EC3. I am willing to make sacrifices to protect the environment. EC4. I am emotionally involved in environmental protection issues.	Chuah et al. [43]
Perceived usefulness of IoT water meters	PU1. Using the IoT water meter in my household would allow me to measure water usage more precisely. PU2. Using the IoT water meter in my household would improve knowledge on my water usage. PU3. Using the IoT water meter in my household would enhance my efficiency/ effectiveness in water usage management.	Davis [16]; Teo and Lee [63]; Tsourela and Nerantzaki [18]; Gao and Bai [23]
Perceived ease of IoT water meters use	PEW1. Learning to operate IoT based water meters would be easy for me. PEW2. I would find it easy to get IoT based water meters to do what I want it to do. PEW3. My interaction with IoT based water meters would be clear and understandable. PEW4. I would find IoT based water meters to be flexible for interaction. PEW5. It would be easy for me to become skillful at using IoT based water meters. PEW6. I would find IoT based water meters easy to use.	Davis [16]
Attitude towards IoT water meter use	ATW1. Using IoT water meters is a good idea. ATW2. Using IoT water – energy meters is wise. ATW3. Using IoT water – energy meters is beneficial. ATW4. Using IoT water – energy meters is interesting.	Schierz et al. [44]
Intention to apply IoT water meters	IAW1. I plan to apply IoT based water meters in my household. IAW2. I am willing apply IoT water meters in my household. IAW3. I will make an effort to apply IoT water meters in my household.	Han et al. (2010); Chen and Tung [25]

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Title: The effect of water usage knowledge on water consumption provided by IoT water meters.

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Abstract

This study investigates the impact of knowledge on household water consumption, provided. The growing scarcity of freshwater resources poses a significant threat to global well-being, making sustainable water consumption critical for the future. The research focuses on two types of knowledge: environmental knowledge and actual knowledge, to assess their impact on reducing water consumption. The experiment, conducted in Poznan, involved 29 households, with smart water meters monitoring water consumption patterns over 45 days. The results indicate that providing environmental knowledge through informational materials did not lead to a significant reduction in water consumption. However, providing actual consumption knowledge through smart water meters significantly reduced water usage between the second and sixth weeks of the study. The substantial decrease in consumption suggests that combining environmental knowledge actual knowledge can create a synergistic effect, enhancing pro-environmental behaviors among consumers. This research highlights the importance of integrating smart water meters with educational programs to promote water conservation. The findings can contribute to developing effective water resource management strategies that combine environmental knowledge with actual consumption data, potentially helping to mitigate the challenges posed by water scarcity.

Keywords

Freshwater resources, Smart water meters, Environmental knowledge, Actual knowledge, Behavioral change, Real-time feedback, Water Consumption

Introduction

The depletion of freshwater resources, as highlighted by Falkenmark (2013), poses a significant threat to global well-being across various regions. The challenge of maintaining water consumption at sustainable levels is expected to intensify in the near future due to factors such as population growth, evolving water consumption patterns, and the impact of climate change (Gosling & Arnell, 2016; Schewe et al., 2014). Achieving global sustainability hinges on ensuring universal access to safe water for all individuals, a key objective outlined in the UN2030 agenda for sustainable development (SDG6). However, despite this goal, the current water scarcity crisis is rapidly escalating, affecting a growing number of residential, commercial, industrial, and agricultural water consumers globally (Mishra et al., 2021; Salehi, 2022; Vollmer & Harrison, 2021). Anticipated data suggests a 55% surge in global water demand, with approximately 25% of major cities currently grappling with varying degrees of water stress (Lund Schlamovitz & Becker, 2021).

Sustainable water consumption promotion is essential for effective water resource management, requiring a comprehensive understanding of the factors influencing individual behavior. Identifying unsustainable water consumption patterns and potential changes are crucial (Gómez-Llanos et al., 2020). While current research primarily examines social and economic determinants like water pricing and income levels (Bithas, 2008; Koutiva & Makropoulos, 2016b; Madias et al., 2022; Satur & Lindsay, 2020), there's a notable gap in understanding how factors such as consumers' environmental knowledge and actual understanding impact water consumption.

To bridge this gap, this research will investigate the effects of both environmental knowledge and actual knowledge on water consumption provided by smart water meters, with a specific focus on their influence on household usage. The study will start by exploring how consumers' environmental knowledge affects their water consumption. To ensure participants have a similar level of environmental knowledge, they will be provided with informative materials on household water consumption. Previous research has indicated that environmental knowledge, in particular, is closely linked to pro-environmental behavior.

For instance, D. S. Levine and M. J. Strube (2012) examined environmental attitudes, knowledge, intentions, and behaviors among college students. They assessed students' pro-environmental behaviors, intentions, explicit and implicit attitudes about the environment, and knowledge of environmental issues. Their study found that intentions and knowledge significantly and independently predicted pro-environmental behavior. In another study conducted by Suryanda et al. (2021a), sought to understand the relationship between environmental pollution knowledge and green purchase intentions. Their findings revealed a positive relationship between environmental pollution knowledge and students' green purchase intentions.

In this study, since participants will be provided with environmental knowledge through our informative materials, it's crucial to refer to previous social marketing as it has been studied in the past regarding its impact on consumer behavior.

Previous research has explored the role of social marketing, highlighting its impact on promoting sustainable behavior. For instance, a study conducted by Lowe et al. (2015) investigated the influence of key behavioural factors on household water usage within the context of a social marketing program designed to reduce domestic water consumption. The study's findings showed that, in the absence of pricing as a rationing tool, the social marketing program significantly reduced household water consumption.

However, there remains a gap in the literature regarding the relationship between environmental knowledge and household water consumption, particularly concerning real-life actions. Most previous studies focus on the effect of environmental knowledge on behavioural intention rather than its actual impact on water consumption. This research aims to address this gap by providing participants with smart water meters allowing us to monitor their water consumption, enabling a better understanding of the actual behavioural impact of environmental knowledge on household water consumption.

Additionally, as smart water meters will be installed in the households of the participants providing them with their actual consumption knowledge, in this study will also focus on actual knowledge and how it affects household water consumption.

In our study, smart water meters will be used to provide actual consumption knowledge to consumers. Previous research examining the impact of consumption knowledge provided by smart water meters has found positive correlations between this knowledge and reduced water consumption. For instance, Joo et al. (2015) found that applying smart water meters can lead to a 5.3% decrease in water consumption. This reduction can be partially attributed to the display of water consumption data, which may have influenced awareness and behaviour. Another study by Willis et al. (2010) recruited 44 households where display water monitors were installed on their showers. Installing this smart shower water metering system significantly reduced water consumption by 27%, demonstrating how providing consumers with actual consumption knowledge can lead to reduced water usage.

However, in this experiment we want to go a step further and examine these two types of knowledge and investigate the impact of actual knowledge (provided by smart water meters) and environmental knowledge (provided by marketing materials) on household water consumption. This study holds significant practical implications for water conservation efforts and the effectiveness of smart water meter. By gaining insights into how knowledge can shape consumers' responses to smart water meters, practical strategies can be developed to optimize water conservation programs. The findings can inform the design of educational materials and campaigns to enhance the impact of smart water meters on reducing water consumption. In addressing water scarcity, the research aims to contribute actionable insights into the factors that can enhance the efficacy of smart water meters, potentially mitigating the challenges posed by water scarcity.

Literature Review

In this study smart water meters are a primary mean of quantifying any alterations in the water consumption patterns of participants. To contextualize the significance of smart water meters, it is imperative to delve into this technology. The necessity for smart water metering arises from the limitations of traditional systems, which fail to furnish real-time consumption data or offer sufficient data points to discern usage patterns. Unlike conventional water meters that merely tally the volume of water passing through without recording the timing or specific activities associated with consumption, smart water meters address these limitations. Manual recording of water consumption, typically conducted on a quarterly or semi-annual basis, results in a sparse dataset, encapsulating only two to four data points for an entire year's worth of water usage, which makes it for potential water planning in the household or to detect any real-time leakages (Britton et al., 2008). Smart water meters consist of two main components (1) metering systems that capture water usage data and (2) communication systems that can instantly transmit this information. Smart water meters serve three key functions: they automatically and electronically capture, collect, and communicate real-time water usage readings (Hauber-Davidson & Idris, 2006).

After introducing smart water meters, this literature review will be organized into two distinct yet interconnected parts, corresponding to the two different facets of the experiment. The first part explores existing studies that discuss how environmental knowledge, disseminated through marketing materials or any other type of informative materials, can shape participants water consumption behavior. The second part delves into prior research concerning smart water meters and their impact on consumer behavior by providing actual knowledge.

Environmental knowledge and its effect on water consumption measured through smart water meters.

This study aims to examine how knowledge can impact consumer behavior. Previous research has investigated various types of knowledge and their influence on consumer behavior. For instance, Okur and Saricam (2019) explored the purchase intention of consumers regarding sustainable apparel and found that knowledge in sustainability apparel significantly affects consumer behavior. Their findings indicated that when consumers have more information about sustainability in apparel, they are more inclined to purchase sustainable products. Another study by Menozzi et al. (2023) examined the effect of beliefs, as well as objective and subjective knowledge, on consumers' attitudes and intentions to purchase farmed and wild fish. The results demonstrated that both objective and subjective knowledge influence attitudes toward farmed and wild fish, ultimately shaping consumers' purchase intentions. Additionally, Meerza and Gustafson (2019) researched how prior knowledge of food fraud affects consumer behavior and discovered that it plays a crucial role in influencing consumer valuation behavior. Participants with prior knowledge of food fraud submitted significantly lower bids than those without such knowledge, accounting for the possibility of food fraud in their initial pre-information valuation. These studies collectively indicate that different forms of knowledge can impact consumer behavior. However, this research will focus specifically on environmental knowledge and actual consumption knowledge in the context of household water consumption.

Environmental knowledge is defined as the comprehension of environmental issues, encompassing an individual's awareness of environmental impact, appreciation for the environment, and a sense of collective responsibility (Mohamed, 2007). While prior research has traditionally treated environmental knowledge as a single dimension, recent perspectives advocate for a bifurcation into two constructs based on the levels of "real" (objective) and "perceived" (subjective) knowledge concerning environmental problems and solutions (Aertsens et al., 2011; Madias et al., 2022). Subjective knowledge stems from an individual's sense of understanding the environment, while objective knowledge pertains to actual knowledge. Subjective and objective environmental knowledge can manifest differently, influencing decision-making processes distinctly (Brucks, 1985). In this study, we will be focusing on objective environmental knowledge and how it is influencing participants water consumption.

Previous studies have demonstrated the influence of environmental knowledge on pro-environmental behavior. Certainly, as general knowledge is known to shape behavioral intentions, as emphasized by Martono et al. (2019), environmental knowledge has been consistently associated with pro-environmental actions, as demonstrated by previous studies.

For instance, Debra Siegel Levine and Michael J. Strube (2012) conducted a study involving 90 college students who reported their pro-environmental behaviors, intentions, explicit and implicit attitudes about the environment, and knowledge of environmental issues. The study found that both intentions and environmental knowledge significantly and independently predicted pro-environmental behavior. Additionally, a study by Zeng et al. (2023) focused on sustainable consumption, one of the "Sustainable Development Goals 2030" set by the United Nations, investigated how sustainable consumption behavior can be promoted through environmental knowledge. The results showed that environmental knowledge and risk perceptions are positively and significantly related to environmental concerns. Likewise, environmental concerns and pro-environmental behavior are positively and significantly linked to sustainable consumption behavior. Moreover, a study by Kim et al. (2018) examined the predictive validity of tourists' environmental knowledge, environmental affect, and nature affiliation on pro-environmental behavior. The findings indicated that environmental affect was significantly influenced by two dimensions of environmental knowledge (subjective and objective). Additionally, nature affiliation was positively affected by environmental affect, while pro-environmental behavior was significantly influenced by both environmental affect and nature affiliation. Expanding on this, past research have linked environmental knowledge to pro-environmental behaviors.

Drawing from the literature outlined above, this study formulates our first experiment hypothesis. Specifically, we anticipate that furnishing participants with environmental knowledge—achieved by sending them information on water consumption—will lead to a reduction in their water consumption.

H1: Environmental knowledge provided through informative materials will lead to reduced water consumption

Smart water meters, actual knowledge and their effect on water consumption.

In this study, after investigating the effect of environmental knowledge on consumers' water consumption, we will also examine the impact of actual water consumption knowledge derived from smart water meters and how it influences household water consumption behavior. The study aims to explore whether access to real-time water usage data through smart water meters can enhance environmental knowledge and ultimately encourage more sustainable water consumption practices at the household level.

Existing research in the realm of smart metering has predominantly focused on energy smart metering systems, with less emphasis on smart water meters. Specifically, the investigations have delved into the technical dimensions of energy meters, exploring topics such as the development of cost-effective smart meters for Internet of Things (IoT) applications (Ezhilarasi et al., 2023). These endeavors have entailed the incorporation of two metering algorithms or the creation of a low-cost smart meter with demand-side load management, achieved through the integration of budget-friendly components into its design (Abate et al., 2019) . Additionally, Labib et al. (2017) have conducted comparisons involving the total cost of implementing the proposed smart meter, notably priced at $40 USD, a noteworthy reduction when contrasted with commercially available smart meters in the market.

Furthermore, the exploration of energy smart meters extends beyond technical considerations, offering valuable insights applicable to research on smart water meters. Notably, Darby (2018) have identified a reduction ranging from 5 to 15% in energy consumption when employing smart electric storage heating coupled with direct feedback to households about their usage. Simultaneously, Carroll et al. (2014) highlighted that participation in a smart metering program featuring time-of-use tariffs led to a significant decrease in demand. Interestingly, although households involved in the program reported an increase in self-reported energy-reducing information, these improvements did not exhibit a clear correlation with short-term demand reductions. These findings suggest that feedback and information provided within the context of smart metering programs may primarily function as reminders and motivators, effectively reducing and shifting demand. Additionally, when it comes to the energy consumption, also consumption feedback based on energy consumption information systems that display the energy consumption of appliance has been also proven to reduce the power consumption (Ueno et al., 2006; Wood & Newborough, 2003). Thus, in the energy sector, it is proven, the direct consumption feedback – actual knowledge of the consumption – is impacting the energy consumption of the households.

However, when it comes to water metering, the literature is not as excessive as with energy metering. Arroyo et al. (2005) introduced the 'WaterBot,' a device designed to provide immediate feedback through visual and auditory reminders. Installed on household faucets, its purpose is to encourage individuals to turn off the tap when water is not in use. Although no systematic experiment has been conducted to quantify water savings resulting from the device installation, pilot studies based on observations and user reports indicated a behavioral change that has the potential to reduce water consumption. More recently, in a study in South-East Queensland, Australia, 221 households received tailored information through smart meters measuring 5-second, utility-specific data. The households were divided into a control group and three experimental groups: education-only, social comparison and education, and feedback. The intervention groups collectively reduced water usage by 7.9% compared to the control group (Fielding et al., 2013). Another research on smart water metering was by Erickson et al. (2012)who studied the effectiveness of the Dubuque Water Portal (DWP), a real-time water consumption feedback system for 303 households over 15 weeks. Smart meters recorded consumption in 15-minute intervals, and the data was displayed on an online portal updated every two or three hours. The portal included hourly graphs comparing household usage to "neighbors like me." The study also incorporated a team-based weekly game on water conservation and an anonymous chat room. During the first nine weeks, the intervention group, with access to the portal, showed a 6.6% reduction in normalized water consumption compared to the control group. The results suggested that more frequent feedback could reduce consumption, at least in the short term.

Building on the literature discussed earlier both from energy and from water smart meters, the implementation of smart metering to provide real-time water consumption knowledge to consumers appears to be an effective strategy for reducing overall water usage. Given this understanding, we hypothesize the primary expectation for this experiment:

H2. The installation of smart water meters in households will lead to a consistent reduction in the water consumption of consumers throughout the course of the study.

Methodology

This experiment comprised four distinct stages designed to accomplish its primary goal (Figure 1). Each participant was involved in the experiment for a duration of 45 days. The study involved 29 households and commenced in February 2023, concluding in May 2024. The location of the experiment was in Poznan, Poland.

The experiment utilized a specific number of smart water meters installed in participants' households to monitor and collect data on water consumption patterns. Smartphones were employed to track the consumption data from the smart meters. These meters played a crucial role in the study by providing real-time information and facilitating a comprehensive analysis of participants' behaviors in relation to water usage. The smart water meters were procured from Amphiro, a company specializing in smart metering. Throughout the experiment, four meters were acquired. Each time a participant concluded their involvement in the experiment, the equipment was passed on to the next participant. Following the procurement of the equipment, a test study involving three participants was conducted to ensure the connectivity of the smart meters and to test various scenarios to pre-emptively address any potential issues that could lead to experiment delays.

The first step of the experiment involved recruiting participants willing to take part. To identify suitable participants, a recruitment survey was distributed using the snowball method. The survey was carefully designed to screen out individuals not fitting the experiment's criteria. The participant selection criteria in household size, with a preference for limiting participants to a maximum of two people per household. This decision aimed to enhance comparability across results, as predicting specific behaviours becomes more challenging with larger households. Restricting the number of participants in each household to a consistent level facilitated more meaningful result comparisons. Another criterion was relocation, as participants were queried to ensure they would not change their permanent location during the 45 days of their participation in the experiment. Additionally, households with a certain number of guests during this period were excluded, as frequent visits could potentially alter the data, leading to an unclear representation of the participant's water consumption. Demographic details such as age, gender, and marital status were also gathered, along with a unique household code used to maintain anonymity during the experiment while still allowing for effective data collection. Additionally, the survey included a notice regarding data privacy and confidentiality. Participants were informed that by proceeding with the survey, they were indicating their agreement with the terms of the experiment and expressing their willingness to take part in it.

After receiving the answers from the surveys and the participants were selected and contacted in order to arrange a day and a time that the smart water meter would be installed at their household. After reaching an agreement, a representative from the experiment visited the participants' households. During this initial visit, participants signed a contract confirming their willingness to take part in the experiment. The contract outlined their agreement for the use of their data for research purposes and their acknowledgment that they would be held responsible in the event of any damage or loss of the equipment. Furthermore, the installation details of the meter were documented during this visit, specifying the day participants were expected to return the equipment. Additionally, participants were required to sign another document related to instructions. By signing this document, participants affirmed that they had thoroughly read and understood the experiment's instructions, and they were in alignment with the procedures outlined, demonstrating their awareness of what was expected during the course of the study.

After signing the contract and acknowledging the instructions, the smart water meter was installed and connected to a mobile phone provided by the experiment representative. This mobile phone was intentionally locked, ensuring that during this phase of the experiment, participants did not have direct access to their water consumption data. Meanwhile, the experiment team had the capability to track and collect the water consumption data transferred from the meter to the secured mobile phone left in the participants' residence.

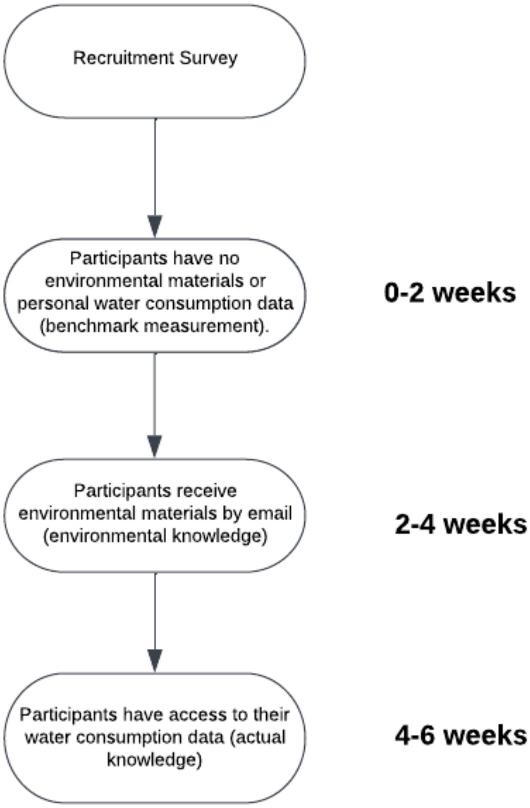
For a duration of two weeks, participants kept the provided phone locked in their residence to facilitate the tracking of their consumption data. Following this period, a representative from the experiment revisited the participants to ensure the proper functioning of the equipment and to record the initial measurement of their water consumption. This first measurement served as a benchmark, enabling the estimation of average consumption and laying the groundwork for comparisons with subsequent stages. This approach allowed us to establish a baseline for participants' average water consumption, providing a basis for evaluating any reductions over the following four weeks.

Over the course of the next two weeks, participants were notified that they would be receiving several emails addressing the topic of water scarcity. These emails featured infographics designed to convey information about water scarcity from different perspectives. The initial email focused on water scarcity in European countries, followed by one providing facts about water usage during showers. Subsequent emails covered water scarcity in Poland, and the last one offered simple tips to help participants reduce their water consumption. Before sending out these infographics, a successful manipulation test was conducted to ensure their effectiveness in our experiment. This test allowed us to confirm that the infographics could be utilized for our study. Throughout the two weeks, participants received these emails through a platform called SendInBlue.

After the initial two weeks, a representative revisited the participants for a second time to record their current water consumption and compare it with the previous data. This step aimed to examine whether there was any observable difference in water consumption due to the emails (environmental knowledge) they received. Additionally, during this visit, the representative checked the functionality of the device and ensured that the connectivity between the device and the participants' phones was still operational. Once the data was verified, and everything was in order, the representative informed the participants about the next step of the experiment.

In the subsequent phase, participants connected their mobile phones to the smart water meter, allowing them direct access to their water consumption data at any time over the next two weeks. During this period, participants were able to track their own water consumption patterns. At the end of this two-week period, the experiment's representative visited the participants once again to record the third set of data measurements and compare them with the previous collections. After this data collection, the representative retrieved the smart water meter.

Figure 8. Research Methodology



(Source: Own elaboration)

Results

The study was conducted over a six-week period (for each household), divided into three distinct phases of two, four, and six weeks to observe the progressive impact of the interventions on water consumption. During the first two weeks, baseline water consumption data was collected to capture the natural usage patterns of the participants without any interventions. In the second phase, lasting four weeks, participants received educational materials designed to increase their environmental knowledge, including information on water conservation, tips to reduce usage, and the environmental impact of excessive consumption. In the final six-week phase, smart water meters were installed in the participants' households to provide real-time feedback on water usage, allowing participants to see their consumption patterns immediately. The study monitored and recorded water usage throughout these phases to evaluate the effectiveness of the interventions.

A repeated measures ANOVA was conducted to assess the impact of the intervention phases on water consumption over time. The analysis revealed a statistically significant effect of the intervention phases on water consumption, $F(2,56)=3.310, p=0.044, \eta 2=0.106$. This suggests that the interventions had a notable impact on the water consumption patterns of the participants.

Table 1. Descriptive Statistics

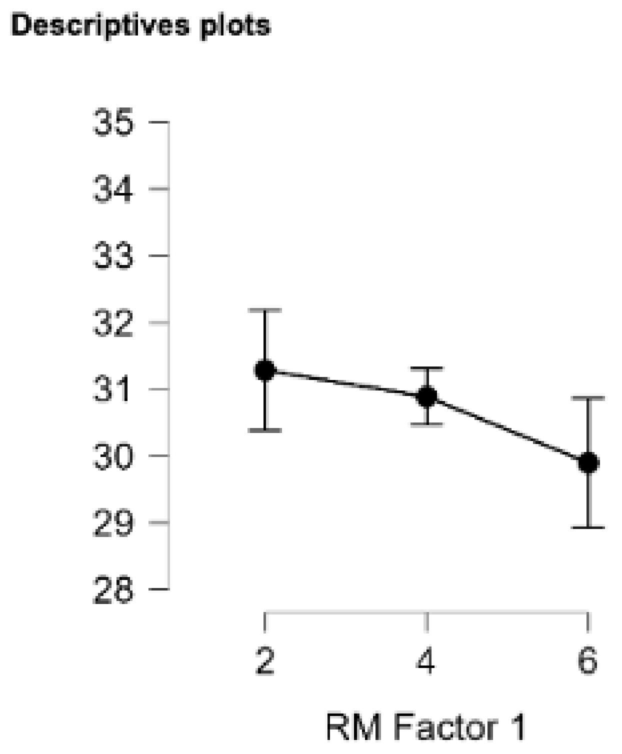
Descriptives

RM Factor 1	N	Mean	SD	SE	Coefficient of variation
2	29	31.286	8.780	1.630	0.281
4	29	30.890	7.787	1.446	0.252
6	29	29.900	6.552	1.217	0.219

(Source: Own elaboration)

Post hoc comparisons using the Holm method were performed to further investigate the differences in mean water consumption between the time points (see Table 1). The comparisons indicated that there was no significant difference in water consumption between 2 weeks (M = 31.286, SD = 8.780) and 4 weeks (M = 30.89, SD = 7.78), with a mean difference of 0.397, $t(56)=0.715$, Cohen's $d=0.051$, $p=0.478$. Similarly, no significant difference was observed between 4 weeks and 6 weeks (M = 29.900, SD = 6.552), with a mean difference of 0.990, $t(56)=1.783$, Cohen's $d=0.128$, $p=0.160$. However, a significant reduction in water consumption was observed between 2 weeks and 6 weeks, with a mean difference of 1.386, $t(56)=2.498$t, Cohen's $d=0.179$, $p=0.046$, indicating that the introduction of the smart water meters had a significant impact on reducing water consumption by the end of the study period (Figure 2).

Figure 9. Descriptive Plot



(Source: Own elaboration)

Discussion

This study aimed to investigate the impact of environmental and actual knowledge on household water consumption through smart water meters. The results revealed that there was no significant difference in water consumption between weeks 2 and 4, which meant that our H1, assuming that environmental knowledge provided through informative materials would affect the water consumption of consumers measured by smart water meters, was not supported. At the same time, our H2, which assumed that consumers would reduce their water consumption when they had practical knowledge of their actual water usage, was supported, as there was a significant decrease in consumption over time, particularly between weeks 2 and 6. It is important to discuss these results further to understand the implications of environmental and practical knowledge on sustainable water consumption practices.

The findings regarding environmental knowledge suggested that there was no significant relationship between weeks 2 and 4, meaning that consumers did not significantly decrease their water consumption after receiving the informative materials. These results can be explained by the level of pre-existing environmental knowledge. In our research, we provided identical environmental materials to all participants to ensure they had similar levels of knowledge. However, some consumers may have already possessed the intended level of environmental knowledge, so we may assume that the materials did not significantly affect their behavior.

Additionally, previous research on the psychosocial determinants of pro-environmental behavior has found that a significant portion of behavioral variance remains unexplained by knowledge alone. This supports the notion that the influence of knowledge is partially overridden by intervening factors such as normative influences, situational restrictions (Geiger et al., 2019) or established behavioral patterns (Klöckner, 2013). Therefore, actual consumer behavior is influenced by multiple factors beyond environmental knowledge.

In addition, subsequent studies have shown that while environmental knowledge is important for influencing behavior, it is insufficient to promote environmentally friendly actions on its own (Paço & Lavrador, 2017; Wiek et al., 2011). This finding underscores the roles of sentiments and beliefs (Coelho et al., 2015) suggesting that knowledge can only promote pro-environmental behaviors when it stimulates sentiment and is internalized by individuals.

Schultz (2000)argued that increased environmental knowledge typically leads to behavioral changes only among those who already care about the topic. Carmi et al. (2015) pointed out that the effect of environmental knowledge on environmentally friendly behavior is indirect, with other probable intermediaries playing a role in translating environmental knowledge into pro-environmental actions.

When it comes to our study, we can conclude that while environmental knowledge plays a role in shaping pro-environmental behaviors, it is not the sole determinant. Instead, it interacts with other factors such as sentiments, beliefs, norms, and socio-economic conditions, indicating the need for a broader and more holistic understanding of the influences on environmentally friendly behavior.

When examining the knowledge provided by smart water meters, our hypothesis (H2) is confirmed by the results, which demonstrate that consumers are altering their behavior based on actual consumption knowledge they were getting through the smart water meters.

Previous research supports these findings, not only regarding water consumption but also in the context of energy usage. For instace, Abrahamse et al. (2005) evaluated the effectiveness of interventions aimed at reducing household energy consumption, concluding that frequent feedback is particularly effective. However, they also noted that some methodological issues could cloud these conclusions. Furthermore, Bager and Mundaca (2017) examined the impact of loss aversion on consumer behavior in a non-price policy intervention following the installation of smart meter technology. Their pilot study in Copenhagen, Denmark, revealed that providing loss-framed, salient information reduced daily electricity demand by 7–11%, with standby consumption reductions between 16–25%, compared to unframed information.

Additionally, when it comes to smart water meters Erickson et al. (2012) and Fielding et al. (2013) found that smart water meters significantly reduced household water usage by providing real-time consumption feedback. Moreover, a study conducted by the municipal water company of La Laguna (Tenerife) (Daminato et al., 2021), focusing on estimating the impact of water meter replacement on smart measured water consumption found that providing access to smart metering technology, which allowed households to view daily water consumption and receive real-time feedback through an online portal, led to an average reduction in consumption by around 2%.

Based on previous research and on our findings actual consumption knowledge provided by the implementation of smart water meters has proven effective in encouraging consumers to modify their behavior and reduce water consumption. Supported by previous research on both water and energy usage, our findings underscore the value of actual knowledge in promoting conservation.

The combined impact of environmental and practical knowledge remains underexplored in previous literature. However, this study provides evidence that both types of knowledge can work synergistically to reduce water consumption. The significant decrease observed between week 2 and week 6 suggests that providing both types of knowledge may reinforce sustainable water consumption behaviors. Although the reduction between weeks

2 and 4 was not statistically significant, we can assume that some consumers managed to increase their environmental knowledge through our marketing materials. By week 6, this synergy of practical and environmental knowledge likely contributed to a significant reduction in consumption.

The study contributes to the theoretical understanding of how knowledge impacts pro-environmental behavior, specifically within the domain of water consumption. It extends previous research by highlighting the importance of combining different types of knowledge to achieve more significant behavioral changes. It also demonstrates that practical knowledge is significant in comparison with environmental knowledge. This could be attributed to the fact that consumers are now more aware of environmental issues and require data to motivate behavior change.

The findings underscore the value of integrating smart water meters into broader water conservation strategies. Policymakers and water utilities should consider combining real-time consumption feedback with targeted environmental education campaigns to enhance water-saving behaviors. By doing so, they can leverage both practical and environmental knowledge to foster more sustainable water usage. Furthermore, these results suggest that providing consumers with detailed and actionable information about their consumption patterns can significantly enhance the effectiveness of conservation initiatives.

Like in any study there are some limitations to be acknowledged. First, the sample size was relatively small, comprising only 29 households. This limited sample size may have contributed to the lack of statistical significance in the reduction of water consumption between weeks 2 and 4. Second, the study period extended over an entire year, during which external factors such as seasonal weather variations could have influenced water consumption patterns. Third, individual differences in pre-existing environmental knowledge and personal motivations for water conservation were not controlled for, which may have affected the outcomes.

Future research should address the limitations identified in this study by using larger sample. Longitudinal studies with extended data collection periods would help to better understand the long-term effects of environmental and practical knowledge on water consumption. Additionally, it would be beneficial to investigate the interaction between different types of knowledge in more depth. Specifically, research could explore how environmental knowledge and practical feedback from smart meters can be optimally combined to reinforce sustainable behaviors.

Finally, examining the role of individual differences, such as environmental attitudes, socioeconomic status, and baseline water consumption behaviors, could provide insights into how various demographic factors influence the effectiveness of knowledge-based interventions. Future studies might also explore the psychological mechanisms underlying the observed behavioral changes, such as the role of loss aversion and the framing of feedback information.

Conclusions

This study investigated the impact of environmental and actual knowledge on household water consumption using smart water meters. By providing participants with informative environmental materials and actual consumption knowledge, the research sought to understand how different types of knowledge can influence sustainable water consumption behavior.

The results showed that providing environmental knowledge through informative materials did not lead to a statistically significant reduction in water consumption between weeks 2 and 4. This could be attributed to participants' pre-existing levels of environmental knowledge, which may have diminished the impact of the materials. Some consumers may have already possessed a level of knowledge equivalent to what the materials intended to provide. As a result, their consumption behavior did not change. In addition, it is important to mention that actual consumer behavior is affected by multiple factors beyond environmental knowledge, requiring a broader consideration of influences.

Actual consumption knowledge which was provided to the participants via smart water meters, however, significantly reduced water usage between weeks 2 and 6. The practical insights into consumption patterns motivated sustainable water-saving behavior, highlighting the importance of actual knowledge.

We can also assume that combining environmental knowledge with real-time consumption feedback may have created a synergistic effect, leading to a significant reduction in water consumption between weeks 2 and 6. While environmental knowledge alone did not yield significant results, it may have enhanced the effectiveness of practical insights, emphasizing the complementary relationship between the two types of knowledge.

This study underscores the value of smart water meters that provide actual consumption knowledge to consumers and influence their water consumption patterns. Additionally, the integration of actual consumption knowledge and environmental knowledge should be further researched to refine these approaches, understand other influencing factors, and measure their actual effect.

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