DELIVERABLE 1.2

DAIAD Requirements and Architecture

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Abstract

This report presents the User Requirements of the DAIAD system, as extracted by analyzing stakeholder surveys, discussion panels and one-to-one interviews. Further, we present the System Architecture of DAIAD, across all its software and hardware components. Finally, we provide information regarding the roadmap and first version of the Synthetic Data Generator (SDG), a software for generating synthetic big water consumption data.

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Executive Summary

This document presents the user requirements and system architecture of DAIAD, a system which will support the entire life-cycle of collection, management and analysis of highly-granular water consumption data, and the provision of services to several end user communities: single consumers, consumer groups, utilities and policy makers. The user requirements and system architecture will serve the needs of the project in terms of guiding the software development, and ensuring its accurate and timely technical targeting. However, DAIAD does not reside on a *vacuum*; external technical advances, new policy frameworks, and stakeholder insights on water use can *evolve* during its duration. For this purpose, we intend to update this document when relevant to reflect such changes and ensure it contains a complete and current overview of the DAIAD system.

The layout of the document is the following.

In Chapter 1, we introduce the requirements elicitation process that included online surveys, panels, and one-to-one interviews. Requirements elicitation targeted several stakeholder groups, such as consumers, scientists, utility stakeholders and policy regulators. Further, we present our methodology and tools for a continuous requirements elicitation from end-users. Throughout the duration of the project we will be able to update the system's user requirements and validate its operation.

In Chapter 2, we elaborate on the process for collecting user requirements and present the major insights we obtained. First, we provide information on the design and distribution of our online surveys. We then present an analysis of the responses and highlight important insights. Second, we provide the methodology and insights derived from our discussion panels and one-to-one interviews. These have been implemented to augment the online surveys by fostering an active discussion beyond the confines of predefined questions. In order to ensure an open discussion and solicit critical feedback, participation in the discussion panels and interviews was *confidential*. As such, the minutes provided in Appendix I have been anonymized.

In Chapter 3, we present the major use cases of DAIAD organized per the major deployment and exploitation scenarios. A high-level scenario description is provided for every group of use cases in order to identify: the environment and assumptions under which DAIAD will operate; the involved stakeholders and their relationships; significant key performance indicators and/or goal-setting that must be achieved. This chapter essentially serves the purpose of conveying a *homogenized vision* of the DAIAD system across all involved in the software development process.

In Chapter 4, we present the formal user requirements of DAIAD system, as extracted from analyzing the user requirements and use case scenarios. The user requirements are categorized in the five fundamental components of the DAIAD system: DAIAD@feel (sensing water consumption), DAIAD@know (conveying knowledge and stimuli), DAIAD@home (data management and analysis for consumers), DAIAD@commons (data management and analysis for consumer groups), and DAIAD@utility (data management and analysis for utilities).

In Chapter 5, we discuss the architecture of DAIAD across its software and hardware components. First, we present an overview of the DAIAD logical architecture, identify the main DAIAD hardware and software modules, and establish the dependencies and data flow paths between them. Next, we show a more detailed view of each module and investigate different architectural solutions, enumerating the advantages and drawbacks of each one. In the following, we describe the integration practices which are going to be used for streamlining all the stages of design, implementation and testing of all software and hardware modules of DAIAD. Finally, we provide information regarding the roadmap and first version of the Synthetic Data Generator (SDG), a software for generating synthetic big water consumption data.

In Chapter 6 we present the libraries, frameworks and tools we are going to evaluate for implementing the software components of the DAIAD system, as well as, the software systems and applications that we will deploy, extend and incorporate in the DAIAD architecture. First, we present data management systems and processing frameworks for managing and analyzing big water consumption data. Next, we briefly enumerate mobile application development approaches and evaluate two distinctive frameworks to be applied. Finally, we discuss web application development and present web development libraries and frameworks organized in two sections, targeting client-side and server-side development respectively.

In Appendix I, we provide anonymized minutes of the discussion panels and one-to-one interviews. The minutes have been anonymized by the Consortium partner involved in the organization of each specific panel and interview. Consequently, the minutes have been treated *confidentially* even within the Consortium. Finally, in Appendix II we provide responses to the optional demographics questions of the consumer surveys.

Abbreviations and Acronyms

API	Application Programming Interface
BT	Bluetooth
CORS	Cross-Origin Resource Sharing
DRBD	Distributed Replicated Block Device
GPL	GNU General Public License
HDFS	Hadoop Distributed File System
ICT	Information and Communication Technology
IoT	Internet of Things
JSON	JavaScript Object Notation
M2C	Meter-to-cash
MVC	Model–view–controller
MVVM	Model View ViewModel
NDA	Non-Disclosure Agreement
NGO	Non-Governmental Organization
RADOS	Reliable Autonomic Distributed Object Store
RF	Radio Frequency
SaaS	Software-as-a-Service
SDG	Synthetic Data Generator
SPA	Single Page Application
SPSS	Statistical Package for the Social Sciences
UI	User Interface
WDM	Water Demand Management
YAML	YAML Ain't Markup Language
YCSB	Yahoo! Cloud System Benchmark

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1. Requirements Elicitation

1.1. Requirement elicitation methods

For the purpose of gathering and categorizing user requirements for the DAIAD system, we adopted three common practices: *online surveys*, *discussion panels* and *one-to-one interviews*. The first method enables reaching a wider population across the Internet, but with the drawback of limiting user responses across a predefined set of questions. The last two methods enable the extraction of broader, more precise, and intuitive findings based on open discussions and interactive communication.

1.1.1. Online survey

Online surveys consist of questions targeting diverse sets of users, allowing the collection and modeling of different behaviors and points of view, but, compromising, on the other hand, the granularity of the available answers. Terms, concepts, and boundaries of the domain must be well established and understood by the participants and questionnaire designer. Further, questions must be focused to avoid gathering large amounts of redundant and irrelevant information.

1.1.2. Discussion panels

The purpose of discussion panels is to have an open discussion regarding the functionality and services of DAIAD. The organizer has complete freedom to direct the panel based on its composition and area of expertise. At the beginning, a short overview of DAIAD is provided and then the discussion is steered to cover at least some of the points mentioned in the online surveys. Minutes are kept during the discussion (*number of participants, focus of the panel, major points/insights*), which are then utilized to extract formal user requirements.

1.1.3. One-to-one interviews

Similarly to discussion panels, their purpose is to have an open discussion regarding the functionality and services of DAIAD. However, in this case, the discussion is performed with only one expert. The general structure of the interview follows the one of a discussion panel. Minutes are kept during the discussion (*short profile, focus, major points/insights*), which are then utilized to extract formal user requirements.

1.2. User groups

In order to gather a complete and representative set of requirements, we addressed to a diverse set of users, either individuals or organizations. Specifically, we identified the following target audiences:

- Consumers. Ordinary citizens who consume water in their everyday lives are the central figures in WDM, since (a) they constitute the vast majority of end users, and (b) they are the actual body on which WDM models and pricing policies are applied.
- Active citizens. Apart from being water consumers and end users themselves, they have the additional incentive of preserving water and participating in awareness initiatives and campaigns. Thus, apart from obtaining useful feedback from this group, the project can also benefit from the dissemination of the project's initiatives and results, as well as from their potential interest in participating in studies and trials.
- NGOs. NGOs and citizen associations aim at educating the general population, promoting sustainable changes in consumer behavior, and driving market and innovation towards new sustainable products and services. Members of these communities, through their collective action, will embrace the project's initiatives, provide valuable feedback and form a critical mass that can lead to larger-scale adoption of ICT solutions for sustainable water consumption.
- Public sector. This target audience comprises governments, Local Authorities, International Bodies, the EC, and in general entities responsible for designing and/or enforcing water demand management strategies and pricing schemes. These will apply the novel capabilities DAIAD can provide in understanding, estimating, and influencing water demand, and will be able to provide feedback from the viewpoint of WDM stakeholders.
- Water Utilities. Similarly, water utilities must understand the emerging challenges and potential benefits of integrating real-time water monitoring technologies, big data management and analysis, as well as water management and pricing. With these insights utilities will provide useful feedback from the aspect of WDM experts. This feedback will define the requirements of the system regarding the facilities for building new and effective WDM models.
- Private Sector. These include existing companies in the water domain, and knowledge management companies in the forefront of the data economy. They can extend and contribute to the project's technologies, delivering novel value added products, applications and services for real-time water monitoring. These stakeholders make up the heart of the data economy and given adequate opportunities (e.g. reusable services, open software, open access to data) they can rapidly produce and market added value products. Thus, they can contribute valuable feedback that will allow us to prescribe proper requirements covering their specific application needs.

1.3. Continuous requirements elicitation

Collection of user requirements and their analysis for the project will be an ongoing process. This will enable us to carefully align the system's functionality based on timely stakeholder feedback, respond to potential technology advances and new policy initiatives, and most importantly, integrate insights and observations from actual users of the DAIAD system. As such, the requirements will be revised when necessary, along with the development of the core components of DAIAD and the interaction (meetings, telcos) between the partners. Further, dissemination of our progress and the respective user feedback (*through the trials, demonstrations, exhibitions, open events, social networks*) will also contribute in the refinement and extension of the initial set of requirements. In the following, we briefly provide the channels for collecting additional user requirements throughout the duration of the project.

1.3.1. Online survey

The online surveys will remain open, even after the preparation of this deliverable, *in order to attract as much user feedback as possible*. It is expected that, as the project proceeds and disseminates its visions and results, more and more people will seek to provide their *opinions/feedback*, through the online surveys. Further, since the surveys include questions relevant for other research projects and policy initiatives (EC, national, local), we will provide the responses (anonymized) to any interested stakeholder.

1.3.2. Feedback forms

All end-user applications of the DAIAD system will include functionality for collecting feedback and insights from the end-users. We believe this source of information to be valuable for identifying and evaluating potential technical and design problems. Further, we will include a feedback form in our website, available for any interested stakeholder. The form will be available throughout all website pages/sections and will invite ideas, insights and discussion regarding DAIAD as a whole. Again, we anticipate this source of information to deliver important information for the development of DAIAD.

1.3.3. Tickets

DAIAD's source code will be available in our github repository (github.com/DAIAD). We expect third-party developers to experiment throughout the duration of the project, by installing, testing, and ultimately contributing to the development of DAIAD's software. As such, the ticketing mechanism of github.com (i.e. Issues) will be a valuable source for identifying software issues that can escalate as update and/or new user requirements.

1.3.4. Social interactions

The project's progress will by constantly disseminated through several social network channels (Facebook, Twitter, LinkedIn). Further, these channels will give us the opportunity to collect further feedback from all stakeholders, regardless of their involvement in the trials.

1.3.5. Trials

Two extensive trials will be performed during the third year of the project. DAIAD sensors, software (DAIAD@feel, DAIAD@home, DAIAD@know), and smart water meters will be installed in households and at corporate consumers. Upon the end of the trials (but also through their duration), we will be able to gather massive consumption data, as well as information on the engagement of users to use the DAIAD sensors and the respective software. Thus, we will be able to identify frequently used features (resp. requirements) of the DAIAD framework and enhance/extend them or improve/remove features (resp. requirements) that are of no use/interest to the end users. The same will apply for WDM expert users by measuring their utilization of the several features of DAIAD@utility components.

2. Implementation of requirements collection

2.1. Online surveys

We have prepared **three (3) web surveys** for soliciting user feedback. Each survey is focused on a specific stakeholder group, in terms of content, targeting, and complexity. The surveys have been prepared using Google Forms and the responses are collected in the associated Google Spreadsheets. The three surveys are:

- **Consumers**. The survey is targeted to all domestic water consumers, and as such to all citizens. Consequently, we assume no technical expertise on the part of the participants, and provide questions that enable us to simultaneously imprint social perceptions regarding water, and technology preferences.
- **Utilities**. The survey is targeted to professionals working in water or energy utilities. The need to include the energy sector has been identified early in the project's duration, since DAIAD is also highly relevant for the energy sector due to the potential benefits from reducing hot water consumption. We assume a certain level of familiarity with resource management, pricing, and data analysis of consumption data.
- **Policy Makers**. The survey is targeted to professionals involved in evaluating, implementing, or planning Water Demand Management policies for the Public Sector (local, national, international levels) or a Citizen Association/NGO. As such, we assume a certain level of familiarity with water demand management terminology/processes.

2.1.1. Design

Overall, the three aforementioned surveys aim to capture *use cases, behaviors, opinions and, eventually, requirements* from DAIAD end users. They include diverse sets of questions, focusing on the specific end-user needs, intentions, and expertise. At the end of each survey, we invite the participant to *optionally* provide us with her email for future communication.

2.1.1.1. Consumers

Consumers are asked a total of 38 questions, categorized into the following groups: *General questions, Technology preferences, Interventions, Pricing* and *Demographics*. The set of questions belonging to each group is presented in the following tables. The "*" symbol after a question denoted that an answer to the question was mandatory in the survey.

General questions		
No	Question	Type
Q1	I consider my household to be a:*	Nominal, Single Choice
Q2	According to your estimate, how much water do you consume every day? (in liters) *	Numerical, Single Choice
Q3	According to your estimate, how much water do you consume per shower? (in liters) *	Numerical, Single Choice
Q4	According to your estimate, how much energy do you use for water heating per shower? (in kWh) *	Numerical, Single Choice
Q5	According to your estimate, what is the total cost for your showers in one month? (in Euros) *	Numerical, Single Choice
Q6	How often are you informed about the water consumption of your household? *	Nominal, Single Choice
Q7	I would consume less water if: *	Rate items on a 5-Scale
Q8	If you had to, would you find it easier to consume less electricity or less water? *	Nominal, 3-Scale Choice

Table 1: Consumer - General Questions

Technology preferences		
No	Question	Type
Q9	Do you carry your mobile phone with you when you are inside your residence? *	5-Scale Choice
Q10	Is your mobile phone within reach or visual range when you: *	Rate items on a 5-Scale
Q11	Would you be able to replace the shower-head in your residence without anyone helping you? *	5-Scale Choice
Q12	If you own both a mobile phone and a tablet, which one do you generally use more when inside your residence? *	5-Scale Choice
Q13	Is Bluetooth ON in your mobile phone? *	5-Scale Choice
Q14	Do you own another device that connects to your phone over Bluetooth? *	Rate items on a Yes/No scale

Table 2: Consumer - Technology preferences

Interventions		
No	Question	Type
Q15	Would like to have more information about your water consumption than your periodic water utility bill? *	5-Scale Choice
Q16	Assuming you could have information on a mobile device about how much water you consume, which of the following devices would you prefer? *	Rate items on a 5-Scale
Q17	What type of information would you prefer to be given instantly (i.e. in real time) as you consume water? *	Rate items on a 5-Scale
Q18	Would like to have access to your historical water consumption data? *	5-Scale Choice
Q19	Assuming you had access through a web site to your historical water consumption data, what kind of information would you find useful? *	Rate items on a 5-Scale
Q20	Assuming you had access through a web site to your historical water consumption data, how would you prefer this information to be presented? *	Rate items on a 5-Scale

Q21	Assuming you could compare your water consumption data with others, which of the following groups would you prefer? *	Rate items on a 5-Scale
Q22	Would you share your water consumption information with others? *	Rate items on a 5-Scale
Q23	Would you have any worries regarding sharing your water consumption data with others? *	Rate items on a 5-Scale

Table 3: Consumer - Interventions

Pricing		
No	Question	Type
Q24	How much money would you pay for a device enabling you to monitor and learn about your water consumption in real-time? *	Ordinal, Single Choice
Q25	If such a device was offered to you for free, would you use it? *	5-Scale Choice
Q26	Let's assume you were in the market for a replacement shower-head and had three choices: (a) a regular shower-head for 29€, (b) an intelligent shower-head that displays your water consumption and water temperature in real time for 79€, or (c) a luxury shower-head with great design and multiple jets for 79€. Which one would you choose? *	Nominal, Single Choice
Q27	If I purchased a shower monitor that provides real-time water consumption information, I would do that because: *	Rate items on a 5-Scale

Table 4: Consumer - Pricing

Demographics		
No	Question	Type
Q28	What is your age?	Ordinal, Single Choice
Q29	What is the highest degree or level of school you have completed? If currently enrolled, highest degree received	Nominal, Single Choice
Q30	What is your gender?	Nominal, Single Choice
Q31	What is your marital status?	Nominal, Single Choice
Q32	What is your total household income?	Ordinal, Single Choice
Q33	How many members are there in your household?	Ordinal, Single Choice
Q34	Do you own or lease your residence?	Nominal, Single Choice
Q35	In total, what is the total number of fixtures and appliances consuming water in your residence (e.g. faucet/tap, shower-head, dishwasher)?	Ordinal, Single Choice
Q36	What is your opinion of environmental issues?	Nominal, Single Choice
Q37	How well do the following statements describe your personality? I see myself as someone who:	Rate items on a 5-Scale
Q38	Please rate how well the following statements describe you.	Rate items on a 4-Scale

Table 5: Consumer – Demographics

2.1.1.2. Utilities

Utility users are asked a total of 39 questions, categorized into the following groups: *General questions*, *Water Consumption Data*, *Assessing your Data*, *Consumers and Pricing*, and *Real-time Water Consumption Data*. The set of questions belonging to each group is presented in the following tables.

General questions		
No	Question	Type
Q1	What is your position in your organization*	Nominal, Single Choice
Q2	Do you experience strong pressure to reduce the meter-to-cash costs? *	5-Scale Choice
Q3	Do you experience strong pressure to improve the quality of water demand forecasts for "next day" forecasts? *	5-Scale Choice
Q4	Do you experience strong pressure to improve the quality of demand forecasts for time scales of several years? *	5-Scale Choice
Q5	Do you feel strong pressure to reduce residential water consumption? *	5-Scale Choice
Q6	Do you feel strong pressure to reduce water consumption among commercial customers? *	5-Scale Choice
Q7	Do you feel strong pressure to reduce residential energy consumption (due to water heating)? *	5-Scale Choice
Q8	Is domestic water conservation of importance for your company? *	5-Scale Choice
Q9	Do you feel there is a need to educate and assist consumers with reducing their consumption? *	5-Scale Choice

Table 6: Utility - General Questions

Water Consumption Data		
No	Question	Type
Q10	If you do not currently apply smart water metering technologies, what are the reasons? *	Nominal, Single Choice
Q11	If you do not currently apply smart water metering technologies, what are the reasons? *	Rate items on a 5-Scale
Q12	What type of data management system do you currently have for storing water consumption data? *	Nominal, Multiple Choice
Q13	What type of analysis software do you use for extracting insights from water consumption data? *	Nominal, Multiple Choice
Q14	What is the most detailed information you have regarding the water consumption of a specific household? *	Nominal, Single Choice
Q15	What is the most detailed information you would like to have regarding the water consumption of a specific household? *	Nominal, Single Choice
Q16	What is the estimated size of your water consumption data? *	Nominal, Single Choice
Q17	What is the earliest point in time of your digital water consumption data starts from? *	Ordinal, Single Choice
Q18	Besides water consumption data, what other data do you use in order to analyze water consumption? *	Nominal, Multiple Choice
Q19	Are there departments in your organization responsible for analyzing water consumption data? *	Nominal, Single Choice

Table 7: Utility - Water Consumption Data

Assessing your Data		
No	**Question**	**Type**
Q20	How do you evaluate the quality of the water consumption data you currently have? *	5-Scale Choice
Q21	How do you evaluate the resolution of the water consumption data you currently have? *	5-Scale Choice
Q22	How do you evaluate the accuracy of the water consumption data you currently have? *	5-Scale Choice
Q23	Have you ever been limited in your work by the lack of appropriate water consumption data*	5-Scale Choice
Q24	Do you believe real-time water consumption data would be beneficial for your organization? *	5-Scale Choice
Q25	What could real-time water consumption data be good for, in your view? *	Rate items on a 5-Scale

Table 8: Utility - Assessing your Data

Consumers and Pricing		
No	**Question**	**Type**
Q26	Are your clients aware of water efficiency? *	5-Scale Choice
Q27	Does the geographical area you serve face any of the following challenges? *	Nominal, Multiple Choice
Q28	If you have performed awareness actions for water efficiency in the past, how would you describe their success?	5-Scale Choice
Q29	How was your water pricing policy designed? *	Nominal, Single Choice
Q30	Would personalized tariffs be feasible in the area you serve? *	Nominal, Single Choice
Q31	How long would it take to change your pricing policy to support personalized tariffs for your clients? *	Nominal, Single Choice
Q32	Which of the following actions would be required to change your pricing policy to support personalized tariffs for your clients? *	Nominal, Multiple Choice

Table 9: Utility - Consumers and Pricing

Real-time Water Consumption Data		
No	**Question**	**Type**
Q33	How do you evaluate the importance of data analysis of water consumption data and corresponding insights for the every-day operation of your organization? *	5-Scale Choice
Q34	How do you evaluate the importance of data analysis of water consumption data and corresponding insights for medium and long-term decision making of your organization? *	5-Scale Choice
Q35	Do you believe that having access to real-time water consumption data of your clients would be beneficial for your organization in terms of: *	Rate items on a 5-Scale
Q36	Do you provide your water consumption data to public sector stakeholders? *	Nominal, Single Choice
Q37	Would you object to having your organization's water consumption data publicly available? *	Nominal, Single Choice
Q38	Assuming your clients purchased a product that reduced their water consumption by 20% on average. Do you believe the purchase of this product should be subsidized by your organization? *	Nominal, Single Choice

Q39	Assuming your clients purchased a product that provided you with their real-time data water consumption, with an average error of 20%. Do you believe your organization would use this data? *	Nominal, Single Choice

Table 10: Utility - Real-time Water Consumption Data

2.1.1.3. Policy Makers

Policy makers are asked a total of 31 questions, categorized into the following groups: *General questions, Water Consumption Data, Assessing your Data*, and *Citizens*. The set of questions belonging to each group is presented in the following tables.

General questions		
No	Question	Type
Q1	What is your mandated geographical coverage for policy issues? *	Nominal, Single Choice
Q2	How many citizens do your policies influence? *	Ordinal, Single Choice
Q3	What is your position in your organization? *	Nominal, Single Choice
Q4	Do you feel strong pressure to implement water conservation measures among the residential sector? *	5-Scale Choice
Q5	Do you feel strong pressure to implement energy conservation measures among the commercial sector? *	5-Scale Choice
Q6	Do you implement measures to make the consumers understand the water-energy nexus? *	5-Scale Choice

Table 11: Policy makers - General questions

Water Demand Management		
No	Question	Type
Q7	What type of data do you use to assist with Water Demand Management (WDM)? *	Nominal, Multiple Choice
Q8	What type of data management system do you currently have for storing data relevant to WDM? *	Nominal, Multiple Choice
Q9	What type of analysis software do you use for WDM analysis and decision-making? *	Nominal, Multiple Choice
Q10	What is the estimated size of your WDM-related data? *	Nominal, Single Choice
Q11	What is the earliest point in time your WDM-related data starts from? *	Ordinal, Single Choice
Q12	What is the most detailed geographical level of information you have for water consumption? *	Nominal, Single Choice
Q13	What is the most detailed temporal level of information you have for water consumption? *	Nominal, Single Choice
Q14	What is the most detailed information you have regarding the water consumption of a specific household? *	Nominal, Single Choice
Q15	Are there departments in your organization responsible for WDM-related data analysis? *	Nominal, Single Choice
Q16	Would you object to having your organization's WDM-related data publicly available? *	Nominal, Single Choice

Table 12: Policy makers - Water Demand Management

Assessing your data		
No	Question	Type
Q17	How do you evaluate the quality of the water consumption data you currently have? *	5-Scale Choice
Q18	How do you evaluate the resolution of the water consumption data you currently have? *	5-Scale Choice
Q19	How do you evaluate the accuracy of the water consumption data you currently have? *	5-Scale Choice
Q20	Have you ever been limited in your work by the lack of appropriate water consumption data? *	5-Scale Choice
Q21	Do you believe more detailed water consumption data would be beneficial to better fulfill your responsibilities? *	5-Scale Choice
Q22	If yes, what would be your preferable level of detail on a geographical level?	Nominal, Single Choice
Q23	If yes, what would be your preferable level of detail on a temporal level?	Nominal, Single Choice
Q24	What could real-time water consumption data be good for, in your view? *	Rate items on a 5-Scale

Table 13: Policy makers - Assessing your data

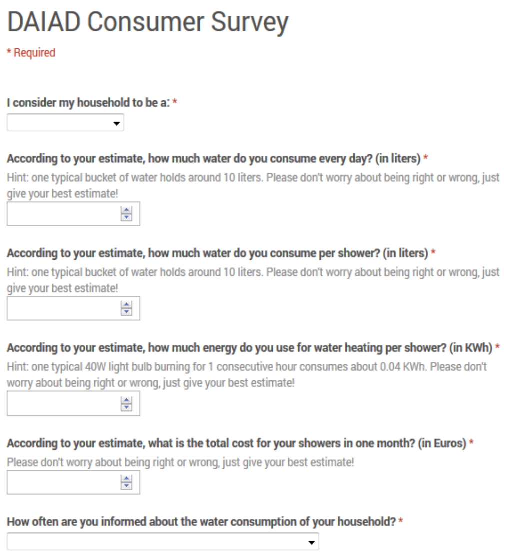
Citizens		
No	Question	Type
Q25	Are the citizens under your reach, sensitive in water efficiency and/or aware of how to become water efficient? *	5-Scale Choice
Q26	Does the geographical area you reach face any of the following challenges? *	Nominal, Multiple Choice
Q27	If you have performed awareness actions for water efficiency in the past, how would you describe their success?	5-Scale Choice
Q28	Is your organization involved in water pricing? *	Nominal, Single Choice
Q29	How was water pricing in your geographical area of reach designed? *	Nominal, Single Choice
Q30	Would you support personalized water tariffs per household? *	5-Scale Choice
Q31	Assuming citizens purchased a product that reduced their water consumption by 20% on average. Do you believe the purchase of this product should be subsidized? *	Nominal, Single Choice

Table 14: Policy makers – Citizens

2.1.2. Creation and distribution

For the surveys' creation, Google Forms was used. Google Forms allows collecting information from users via a personalized survey in an easy, streamlined way, ensuring the privacy and confidentiality of responses. Each Google Form is connected with a single Google spreadsheet, where all responses are automatically collected. Access to the corresponding Google spreadsheets is protected and available only to select members of the project's Consortium. These periodically extract the provided responses in Microsoft Excel format for analysis.

All surveys were available for participation on August 1st, 2014, with dissemination activities taking place for the subsequent two weeks.


DAIAD Consumer Survey

* Required

I consider my household to be a: *

According to your estimate, how much water do you consume every day? (in liters) *

Hint: one typical bucket of water holds around 10 liters. Please don't worry about being right or wrong, just give your best estimate!

According to your estimate, how much water do you consume per shower? (in liters) *

Hint: one typical bucket of water holds around 10 liters. Please don't worry about being right or wrong, just give your best estimate!

According to your estimate, how much energy do you use for water heating per shower? (in KWh) *

Hint: one typical 40W light bulb burning for 1 consecutive hour consumes about 0.04 KWh. Please don't worry about being right or wrong, just give your best estimate!

According to your estimate, what is the total cost for your showers in one month? (in Euros) *

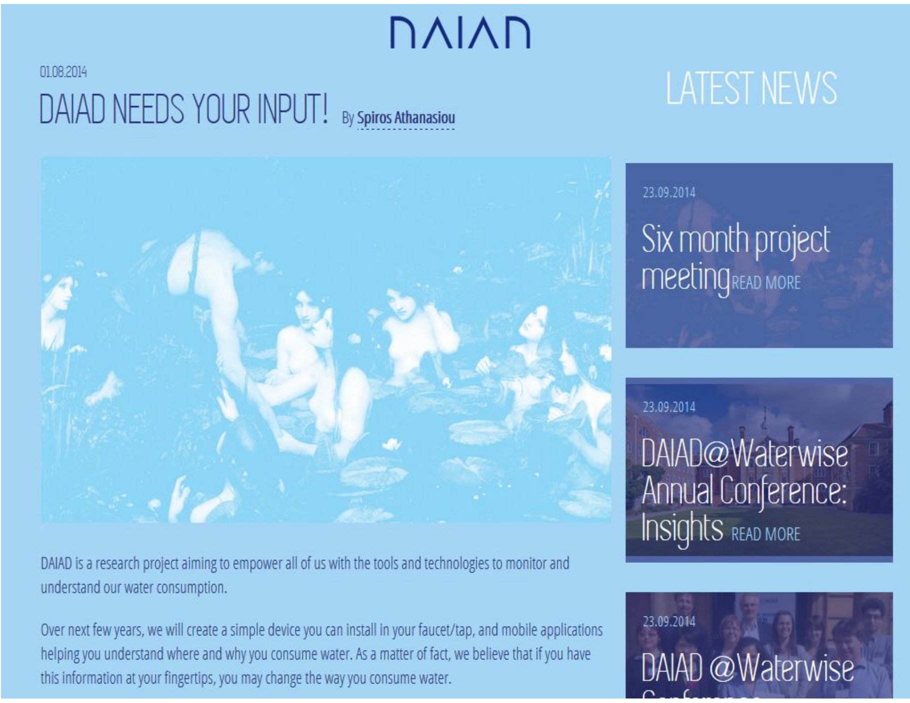
Please don't worry about being right or wrong, just give your best estimate!

How often are you informed about the water consumption of your household? *

Picture 1: Web survey for Consumers

Each survey was disseminated with a different manner, catering to the characteristics of the intended audiences.

- *Consumers*. The survey has been made publicly available in our website and disseminated through all project dissemination channels. Further, the survey was forwarded by all Consortium partners to their local/national networks, to EC officials, FP7 projects, and to our Advisory Board. Overall, we estimate that the survey reached ~5,000 consumers.



Picture 2: News article for disseminating the Consumer web survey (http://www.daiad.eu/?p=2999)

- *Utilities*. The survey has not been made publically available to ensure participation only from members of the target group. Consortium partners disseminated the survey *by email* to select stakeholders (*organizations, individuals*), inviting them to complete it and share it only with other individuals that fit their profile. Overall, we estimate that the survey reached ~500 users.

- *Policy Makers*. The survey has not been made publically available to ensure participation only from members of the target group. Consortium partners disseminated the survey *by email* to select stakeholders (*organizations, individuals*), inviting them to complete it and share it only with other individuals that fit their profile. Overall, we estimate that the survey reached ~250 users.

2.1.3. Overview of insights

In this document we analyze responses to the surveys provided until 10/10/2014. As already mentioned, the surveys will remain open for participation throughout the duration of the project. Overall, participation in the surveys *has been according to our expectations*. In particular:

- *Consumers*. We received 102 responses, i.e. ~2% of reached consumers participated in the survey. While the participation percentage is small, the number of participants is *satisfactory*, enabling us to derive useful insights. This is strengthened by our periodic analysis of responses during this period. After the first ~50 responses, our analysis results remained practically the same.
- *Utilities.* We received 12 responses, i.e. ~2% of reached stakeholders participated in the survey. We consider the number of participants to be *small* and the standalone analysis of responses not suitable for extracting significant insights. This low level of participation has been *anticipated* by the Consortium and validated during the requirements elicitation. For this reason we have planned in advance additional discussion panels and on-to-one interviews for this target group. In summary, the major reasons for this small participation, as extracted from direct communication with this group (*panels, interviews*), were:
    - *Confidentiality*. Members of utilities evaluated most questions in the survey as directly targeting *critical business functions* of their organizations, and as such protected by *confidentiality* clauses. Despite the provided privacy/anonymization guarantees, the audience did not want to provide responses to issues describing and/or affecting the operation of their organizations. In the context of the discussion panels and one-to-one interviews we have managed to somewhat curb this reservation and ensure a higher level of participation. However, we believe this insight to be critical for our future interactions with this community (*preference in direct communication*), and also relevant for future interactions from other research projects.
    - *Technical Background*. The number of personnel in utilities directly working on analyzing and extracting insights from consumption data is extremely small compared to their total workforce. In most cases, the role of the *Data Analyst* is absent; data analysis is most often subcontracted to third parties/experts bounded by NDAs and other confidentiality agreements. As such, most participants could not provide responses even for simple questions of the survey (e.g. size of their water consumption data), and thus entirely dropped out from the survey.
    - *Low interest*. A reoccurring theme, which also consists one of the major challenges the project aims to address, regards the low interest of utilities in real-time water monitoring and big data analysis technologies. The prevalent view is that the current status quo in

water monitoring is perfectly adequate to address the needs of utilities. Consequently, many members of this target group simply had no interest in completing the survey. Most importantly, the goal of water efficiency is not shared by a large number of utilities, as it directly affects their turnover.

- *Policy Makers.* We received 4 responses, i.e. <2% of reached stakeholders participated in the survey. We consider the number of participants to be *very small*, so we have not analyzed them further. This low level of participation has been *anticipated* by the Consortium and validated during the requirements elicitation. For this reason we have planned in advance additional discussion panels and one-to-one interviews for this target group. In summary, the major reasons for this small participation, as extracted from direct communication with this group (*panels, interviews*), were:
    - *Policy Targeting*. The vast majority of policy makers in the area of Water Management mostly focus on broader and mainstream policy challenges, not relating to real-time water monitoring. As such, the level of understanding for the project's goals, technology, and impact is extremely low. For most members of this target group the notions of real-time water monitoring from consumers, and the corresponding insights/stimuli for water efficiency was almost alien. Consequently, interest for participating in the survey was low.
    - *Technical Background*. The same observation regarding the *disconnect* of policy makers to the project's goals, is also materializing in the technical background of this target group. The data, tools and processes used to identify, plan, implement and monitor policies in the Water domain are quite simple in terms of technology used (compared to other domains). As such, many participants could not provide even simple responses to the survey (e.g. which data management system they use), resulting in high drop out from the survey.

In the following we provide an analysis of the responses received for each type of survey.

2.1.3.1. Consumer Survey

The online survey targeting consumers consisted of five question groups, as discussed in Section 2.1.1.1. Next, we analyze the responses for each question. The "*" symbol after a question denoted that an answer to the question was mandatory in the survey.

2.1.3.1.1. I consider my household to be a: *

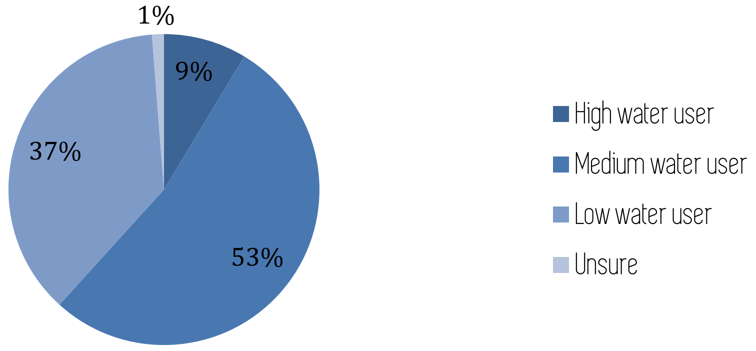


Figure 1: Responses on "I consider my household to be a:"

As we can see, end-users are opinionated on their general behavior regarding water consumption, with only 1% unsure of where they stand consumption-wise. There are two more observations that can be gained from the responses. First, one in two participants identifies their households as medium water users. Of course this cannot be true, and clearly demonstrates that half of the population considers themselves to be *average*, and as such with no real incentive to change their water consumption habits. Similarly, one out of three participants considers their household to be a low water user. Again, this is cannot be true for all responses, and exposes an already perceived barrier for improving water efficiency in a sizable percentage of the population.

2.1.3.1.2. According to your estimate, how much water do you consume every day? (in liters) *

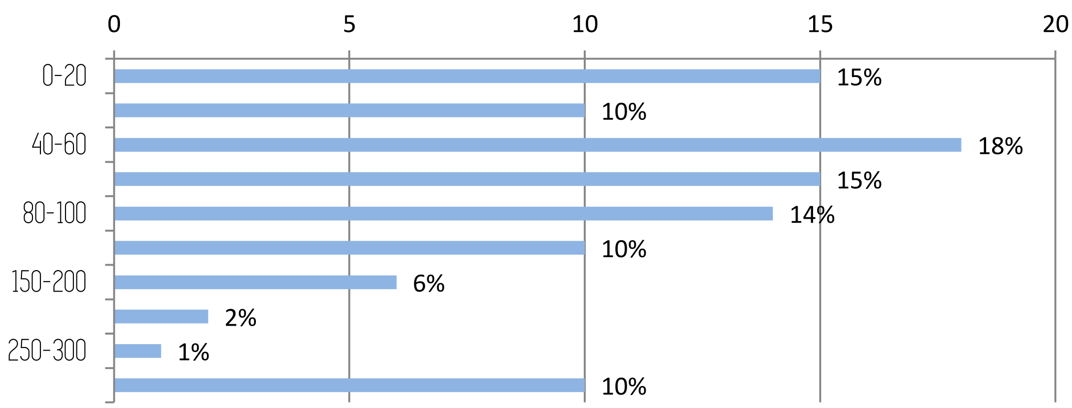


Figure 2: Responses on "how much water do you consume every day? (in liters)"

2.1.3.1.3. According to your estimate, how much water do you consume per shower? (in liters) *

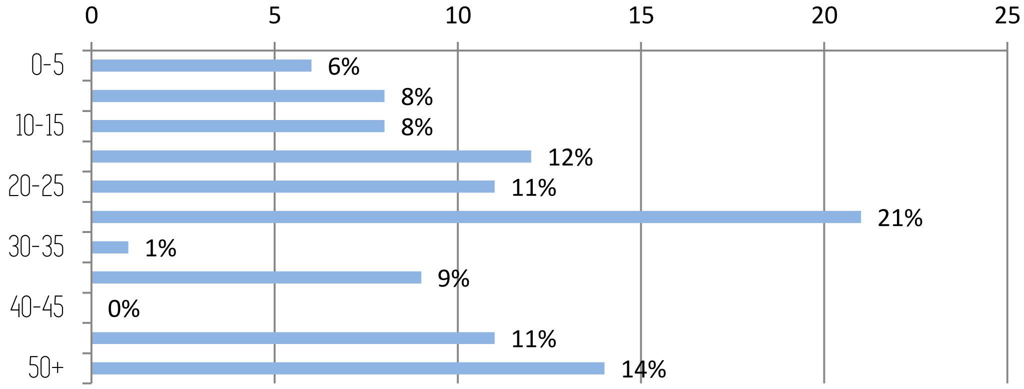


Figure 3: Responses on "how much water do you consume per shower? (in liters)"

2.1.3.1.4. According to your estimate, how much energy do you use for water heating per shower? (in KWh) *

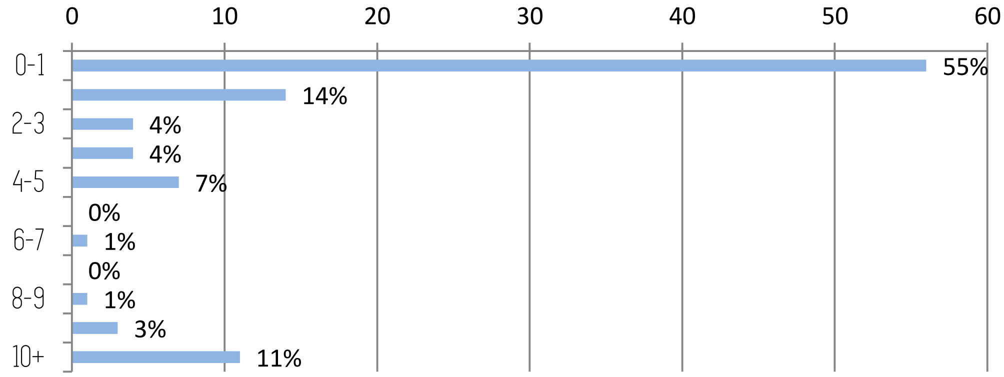


Figure 4: Responses on "how much energy do you use for water heating per shower? (in KWh)"

2.1.3.1.5. According to your estimate, what is the total cost for your showers in one month? (in Euros) *

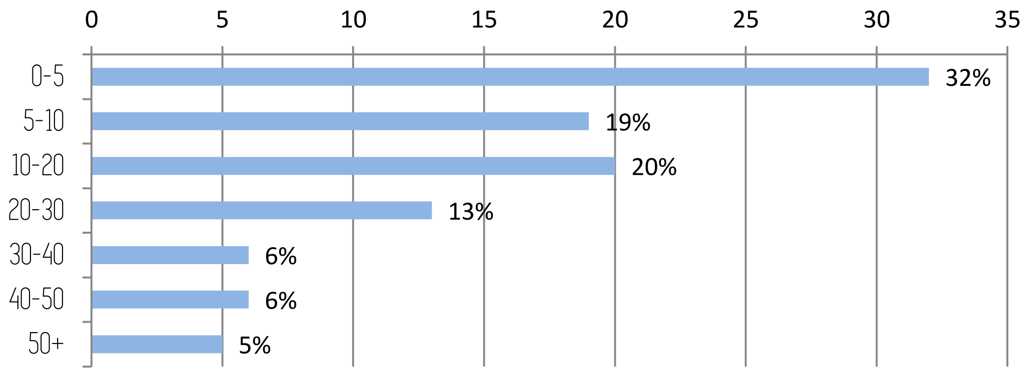


Figure 5: Responses on "what is the total cost for your showers in one month? (in Euros)"

From Figure 2 to Figure 5, we can see that consumers have very *dispersed estimations* about the amount of water, energy, and associated costs of their water consumption. For the majority of participants, their lack of understanding for their consumption behavior is evident (*e.g. percentage of unrealistically low/high amounts provided*). Quite simply, the vast majority of participants cannot quantify its consumption of water and energy. Another important insight regards the extremely low volume in liters users believe they are using in showers. Almost 90% of participants provide a number which is less than half of the volume required for a shower (~80 liters). As such, we can deduct that 90% of users already perceive their showers to be extremely efficient! A similar, but less dominant observation relates to the energy consumption and associated costs, again showing that participants underestimate their consumption.

2.1.3.1.6. How often are you informed about the water consumption of your household? *

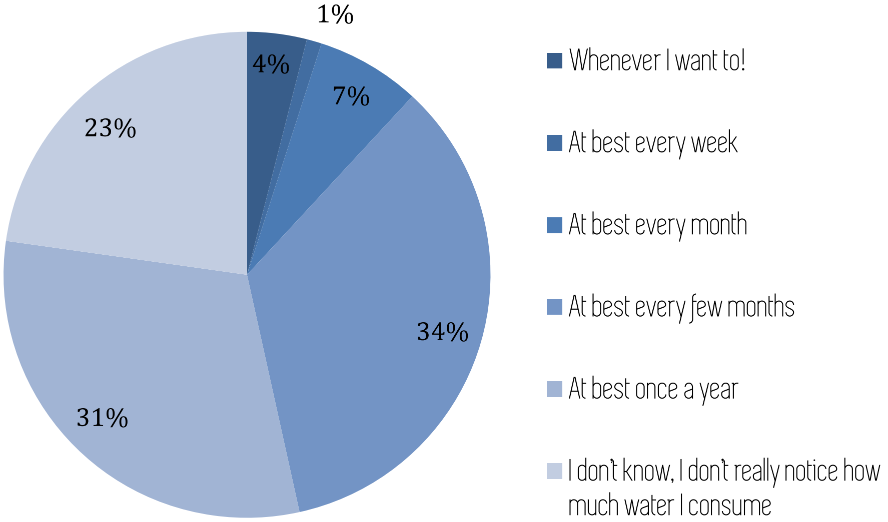


Figure 6: Responses on "How often are you informed about the water consumption of your household?"

The answers of the above question are expected: the majority (64%) is informed about its water consumption at best every few months or once a year. Interestingly, a large proportion (22%) does not care about how much they consume. Overall, 84% of participants are informed about their water consumption at best every few months.

2.1.3.1.7. I would consume less water if: *

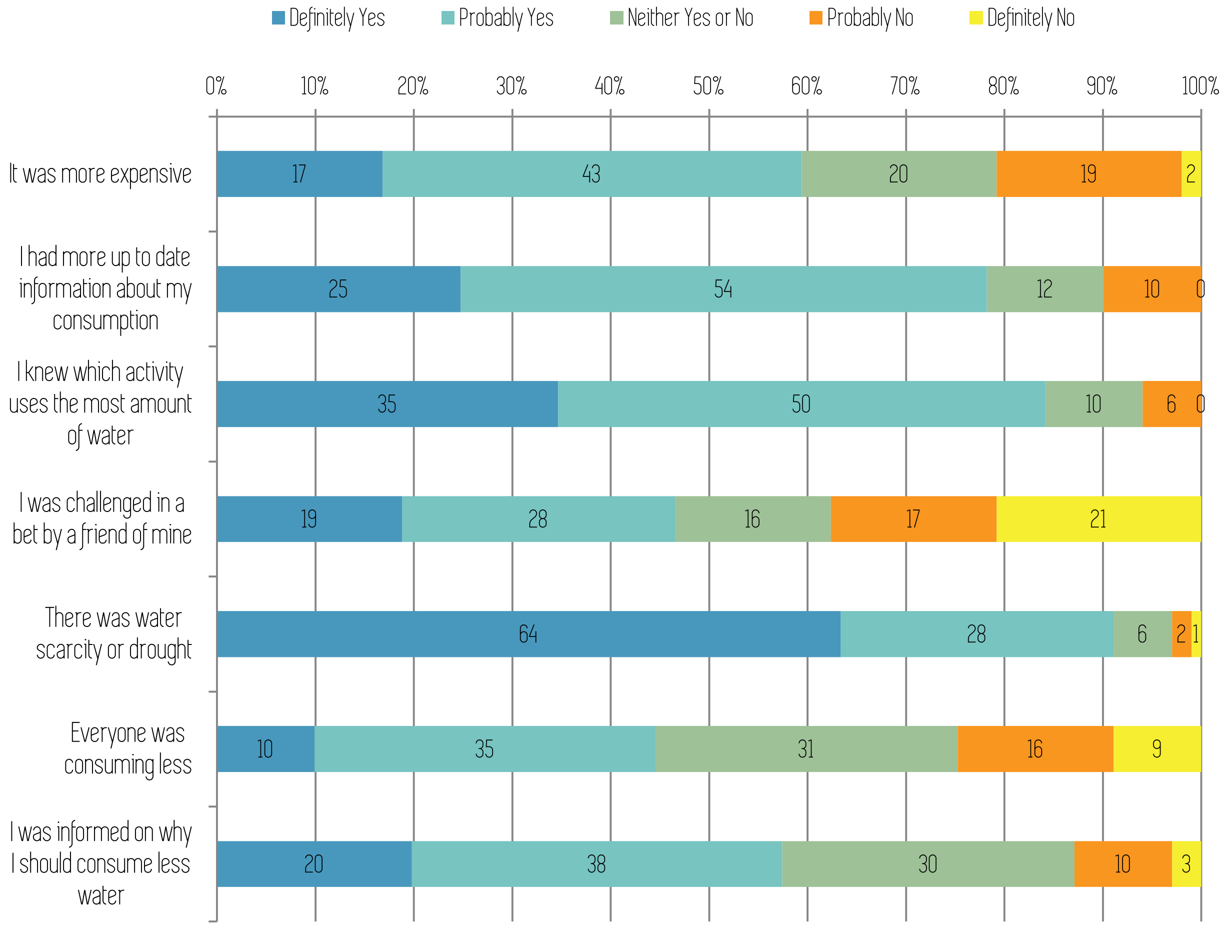


Figure 7: Responses on "I would consume less water if:"

Figure 7 provides an important insight on which are the most important factors for inducing reductions in water consumption. According to the provided responses, the most important factor is a *potential water scarcity or drought*. Consequently, we can deduct that half of the participants is willing to reduce their water consumption only in times of crisis, i.e. when a sustainability challenge has already manifested.

The next two important factors are related to users' awareness of their consumption. Consumers would be willing to reduce their consumption if they knew (a) which activities result in the most consumed water, and (b) had more frequent information regarding their water use. These two factors are directly related to the project's goals, which include, among others, increasing the frequency, the detail and the granularity with which users are informed about their consumption.

Interestingly, increase in price of water comes later as the fourth reason for reducing consumption. This implies that the majority of consumers do not consider water price as a strong motivator for reducing their consumption. Based on the other responses in the question, we can eliminate the notion of *consumption elasticity* as a reason (i.e. consumers *are* willing to reduce consumption for other reasons). Also, in conjunction with insights from the previous responses regarding water use, we can deduct that most participants consider water as a *low cost* resource; most of them are not even in a position to quantify their consumption.

2.1.3.1.8. If you had to, would you find it easier to consume less electricity or less water? *

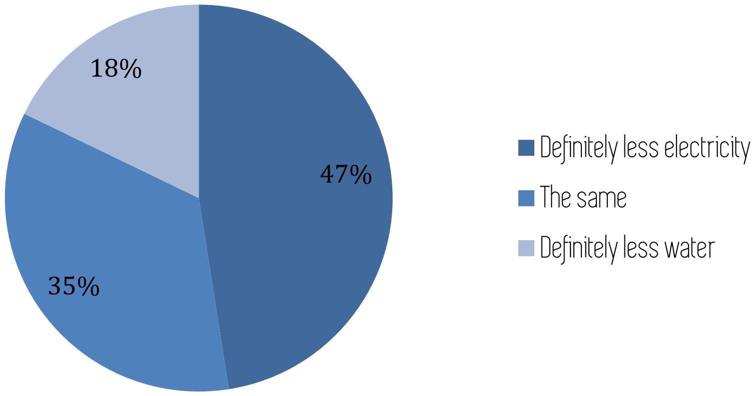


Figure 8: Responses on "If you had to, would you find it easier to consume less electricity or less water?"

Comparing water and electricity consumption, Figure 8 implies that users find it harder to reduce their water consumption. However, this may be partially attributed to the fact that they are poorly informed about their consumption and ways to reduce it. On the other hand, energy is in general most costly, so users are expected to be more informed on ways to decrease energy consumption, if required. We need to add, that if the users were better informed about the nexus of energy consumption and hot water consumption the results might be different.

2.1.3.1.9. Do you carry your mobile phone with you when you are inside your residence? *

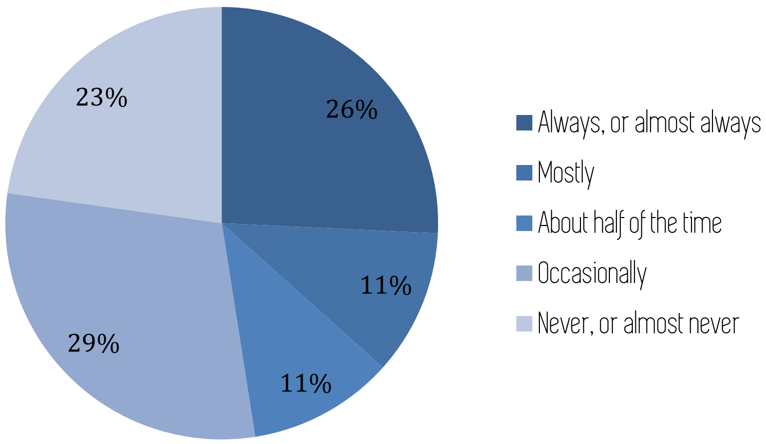


Figure 9: Responses on "Do you carry your mobile phone with you when you are inside your residence?"

Figure 9 provides some important insight regarding how consumers currently use their mobile phones. One in four almost always carries their mobile phones with them, while almost one in two has their mobile phone with them about half of the time. This means that mobile phones are *omnipresent* devices even within domestic environments, and as such suitable for conveying direct interventions and stimuli regarding water consumption.

Of course, the remaining population is equally important, meaning that the mobile phone alone is not enough. The rise of wearable devices may change this landscape and provide additional media for delivering information to consumers. However, and for the time being, interventions need to also be delivered to the point of consumption through suitable interfaces.

2.1.3.1.10. Is your mobile phone within reach or visual range when you: *

Figure 10: Responses on "Is your mobile phone within reach or visual range when you:"

A somewhat obvious, but nevertheless important insight is provided from responses to this question. Across all major water consumption activities, the mobile phone is at reach at best 50% of the time. The strong negative responses are also telling. For all activities, 29%-56% of the time participants do not have a mobile phone within reach. Again, we reach similar insights with the previous question.

2.1.3.1.11. Would you be able to replace the shower-head in your residence without anyone helping you?*

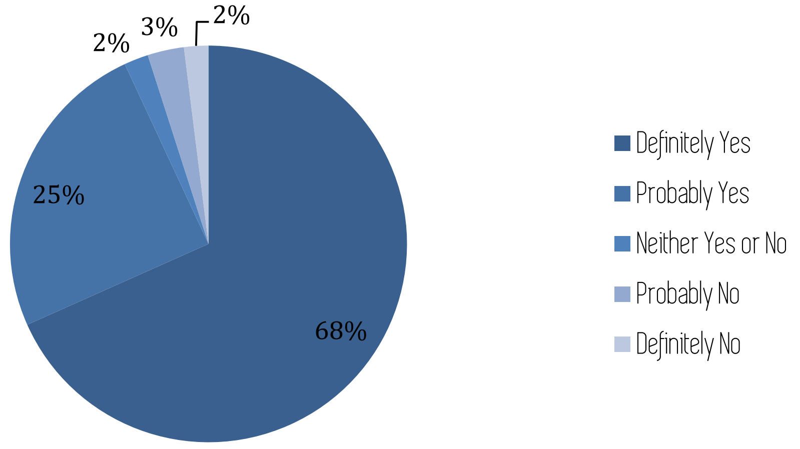


Figure 11: Responses on "Would you be able to replace the shower-head in your residence without anyone helping you?"

The results of the above question demonstrate the confidence of the consumer of being able to install the measuring device on their own. Only 7% of consumers would require assistance for installing a new shower-head. Consequently, integrating a display in the shower-head for conveying water consumption information is a packaging option that can be realistically adopted by consumers.

2.1.3.1.12. If you own both a mobile phone and a tablet, which one do you generally use more when inside your residence? *

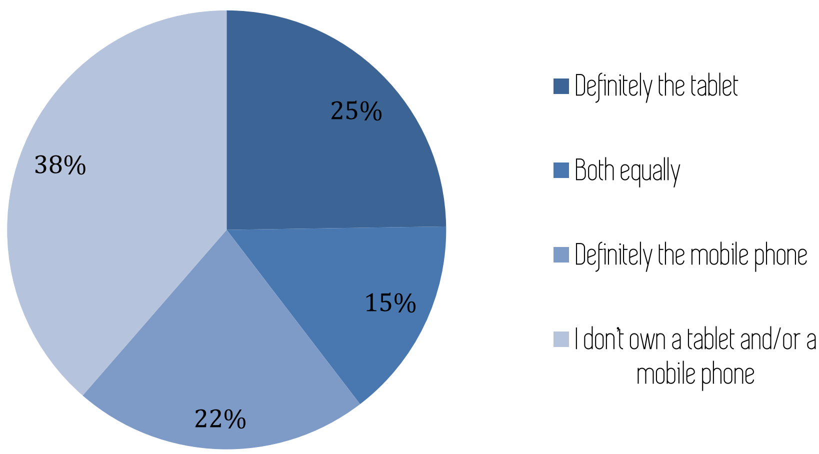


Figure 12: Responses on "If you own both a mobile phone and a tablet, which one do you generally use more when inside your residence?"

Several interesting observations can be made from responses in this question. First, in domestic environments where users have access to both a mobile phone and a tablet, preferences are almost *perfectly divided*. This means that equal attention should be given to both types of devices. Especially considering the current market trend of hybrid mobile phones with increased screen real-estate (*i.e. phablets*) a homogenized technical approach in terms of UI and functionality should be considered. Second, given that mobile phone ownership in EU/USA is greater than 90% [1,2], we can safely deduce that almost one out of three respondents does not own a tablet. Actually, this number is greater for the general population [3] and indicative for the *technology-inclination* of our participants. Consequently, for the majority of consumers, their mobile phone will be the only means for gaining knowledge regarding their water consumption.

2.1.3.1.13. Is Bluetooth ON in your mobile phone? *

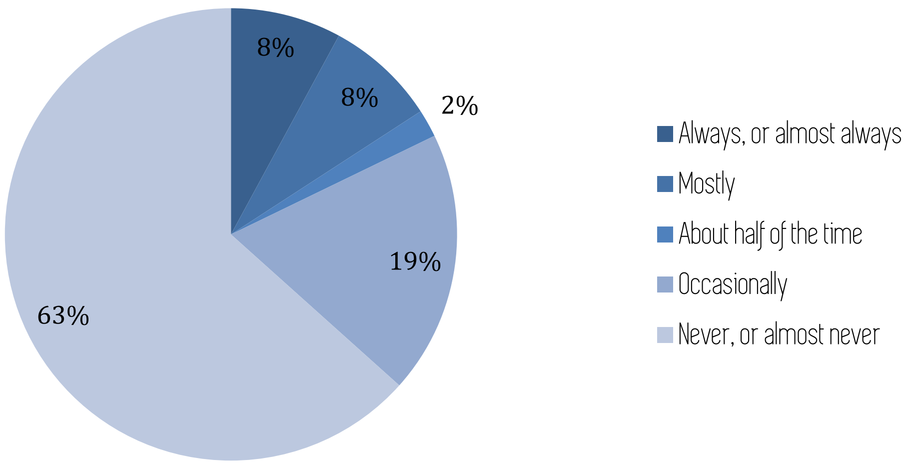


Figure 13: Responses on "Is Bluetooth ON in your mobile phone?"

The responses in this question are expected based on the current Bluetooth version of most mobile phones. While the low-energy Bluetooth 4.0 is available for more than a year now, and is a de facto standard for practically all new mobile phones, consumer perceptions are still dominated by the previous energy-hungry versions of Bluetooth. As a result, the vast majority of users (65%) almost never have the Bluetooth turned on. We expect this percentage to significantly decrease during the lifetime of the project as consumers get acquainted with the better energy efficiency of Bluetooth 4.0. However, the availability of Bluetooth cannot be taken for granted; data transmission should be designed as to accommodate this challenge.

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[1] http://www.eea.europa.eu/data-and-maps/figures/mobile-phone-ownership-in-four-pan-european-regions

[2] http://www.pewresearch.org/fact-tank/2013/06/06/cell-phone-ownership-hits-91-of-adults/

[3] http://techcrunch.com/2013/02/20/forrester-tablet-ownership-in-europe-to-rise-4x-in-5-years-55-of-regions-online-adults-will-own-one-by-2017-up-from-14-in-2012/

2.1.3.1.14. Do you own another device that connects to your phone over Bluetooth? *

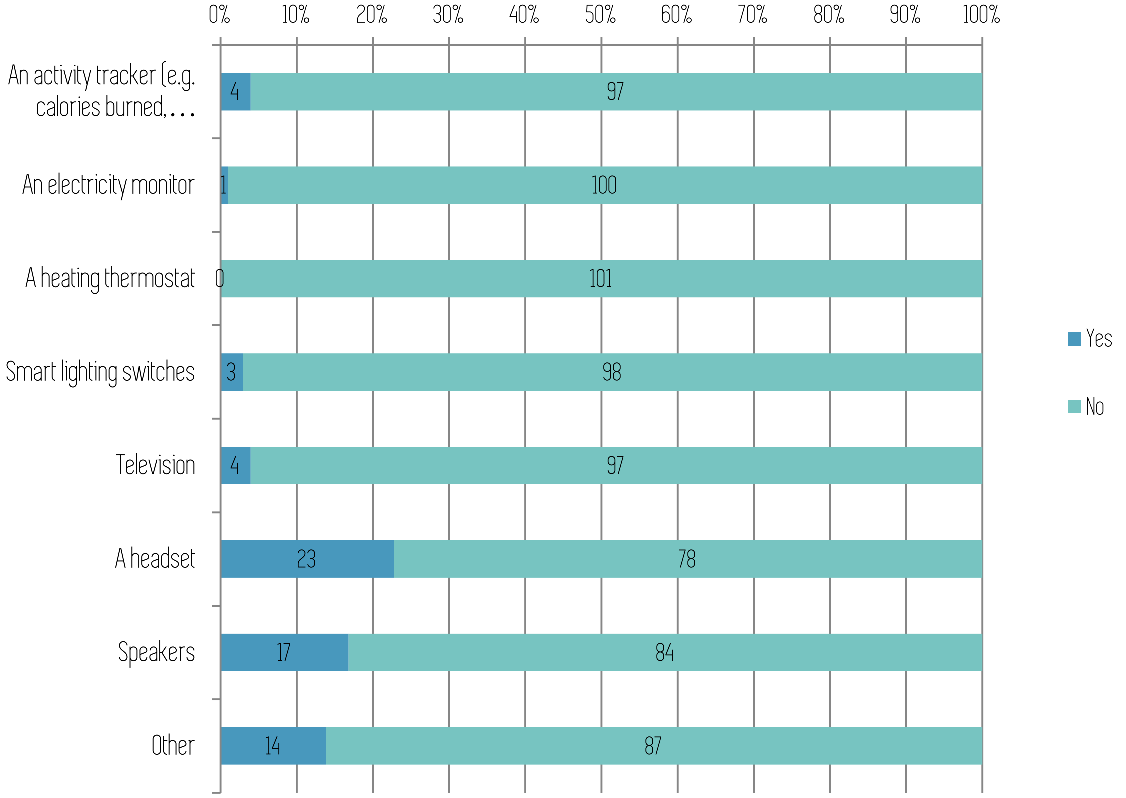

Figure 14: Responses on "Do you own another device that connects to your phone over Bluetooth?"

The responses in this questions were anticipated and do not provide any new insight. Most Bluetooth-owned devices are headsets/speakers. Also, current market penetration of smart home systems and activity trackers are extremely low.

2.1.3.1.15. Would like to have more information about your water consumption than your periodic water utility bill? *

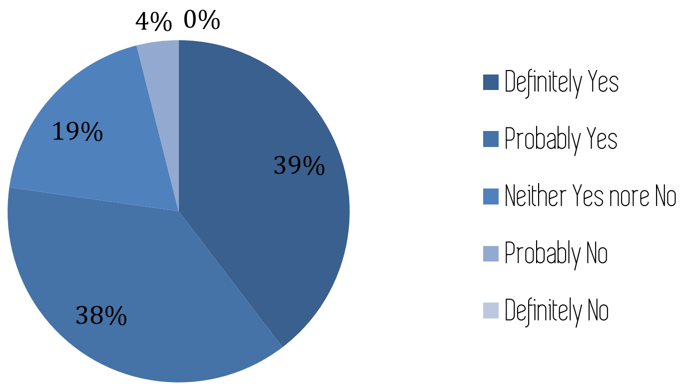

Figure 15: Responses on "Would like to have more information about your water consumption than your periodic water utility bill?"

Figure 15 verifies what was also implied by the answers in Figure 7. The majority of users are interested in learning more information about their water consumption. Specifically, almost eight out of ten users have replied “Definitely Yes” or “Yes”, while another 16% does not have a clear opinion about whether they would want such additional information. For this group of users we cannot assume a priori a negative or positive attitude towards acquiring more information. It is possible that these users are not aware of the actual benefits (e.g. consumption reduction) that can be achieved. Finally, only a 5% answered that they are not interested in this facility. However, none of them definitely reject it, so there might also be room for a shift in their point of view, given that they are provided with motivation or education on water consumption and saving.

2.1.3.1.16. Assuming you could have information on a mobile device about how much water you consume, which of the following devices would you prefer? *

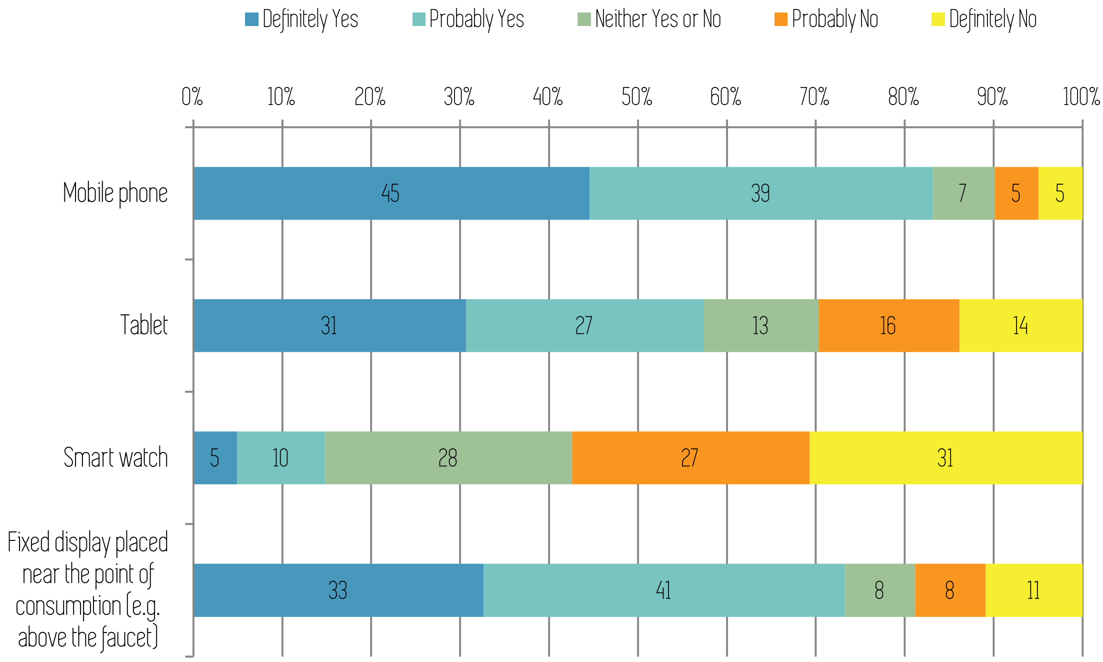

Figure 16: Responses on "Assuming you could have information on a mobile device about how much water you consume, which of the following devices would you prefer?"

Again, responses in this question are aligned with insights derived from previous questions, and validate the project’s targeting. The mobile phone is marginally preferred over fixed displays in the point of consumption for the majority of consumers. Both options for conveying knowledge to consumers enjoy significant approval, with ~85% and ~72% respectively of participants providing a positive response (Definitely Yes, Probably Yes). Actually, less than 10% and 20% of the participants, respectively, are negative with these solutions (Probably No, Definitely No). Regarding tablet devices, consumers are clearly less receptive. However, this observation must take into account the still growing share of tablet devices owned by the consumers. Finally, smart-watches are considered as a preferred medium by only

~15% of consumers. This was an entirely anticipated outcome, since smart-watches are still on their infancy. However, if we take into account that only 55% of consumers currently wear a watch and the anticipated market growth of smart watches in the next 3 years[4], the ~15% of positive responses conveys a critical insight. Despite the unproven technology, the very few manufacturers, and unfamiliarity with the capabilities of this new medium, consumers understand the potential themselves! Clearly, there is great potential for delivering timely consumption information using wearable devices.

2.1.3.1.17. What type of information would you prefer to be given instantly (i.e. in real time) as you consume water? *

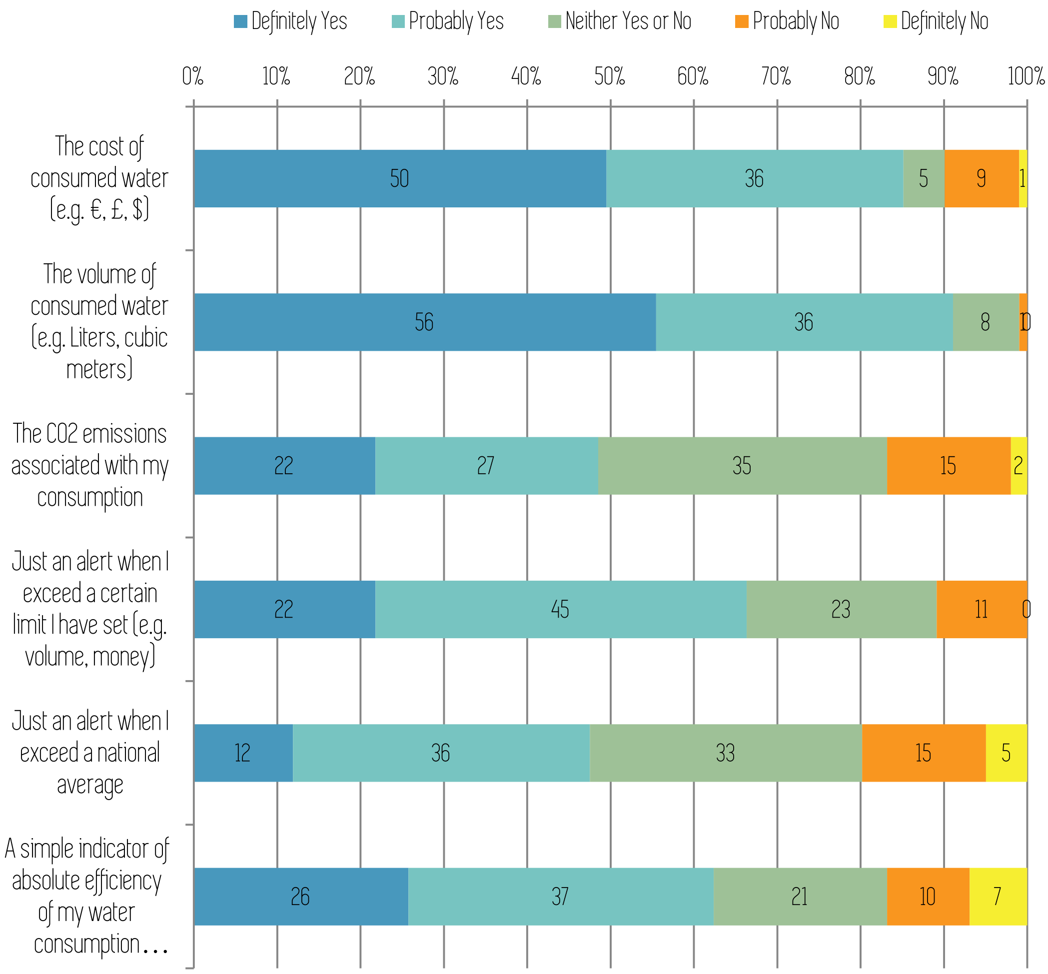

Figure 17: Responses on "What type of information would you prefer to be given instantly (i.e. in real time) as you consume water?"

[4] http://www.businessinsider.com/global-smartwatch-sales-set-to-explode-2014-3

2.1.3.1.18. Would you like to have access to your historical water consumption data? *

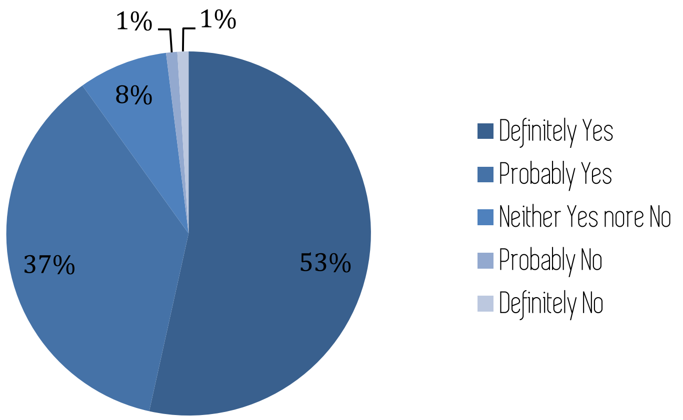

Figure 18: Responses on "Would you like to have access to your historical water consumption data?"

2.1.3.1.19. Assuming you had access through a web site to your historical water consumption data, what kind of information would you find useful? *

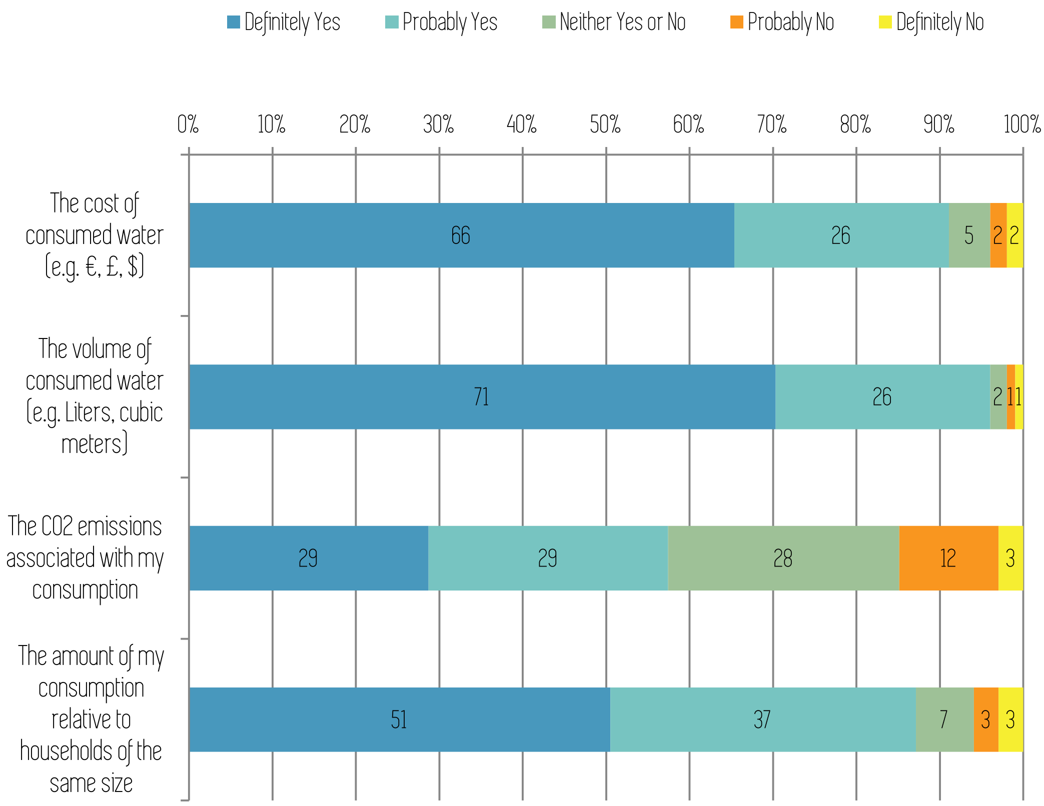

Figure 19: Responses on "Assuming you had access through a web site to your historical water consumption data, what kind of information would you find useful?"

Figures Figure 17 to Figure 19 present what types of consumption data users would prefer to be shown. Volume and cost of consumed water are the most important for most users, followed by alerts and efficiency indicators. Further, almost all users require to have access to historical consumption data (Figure 18), preferring, on top of volume and cost data, also comparative data with other households. The aforementioned results demonstrate the users' need for more fine grained and detailed information about their consumption, not restricted to simple indicators.

2.1.3.1.20. Assuming you had access through a web site to your historical water consumption data, how would you prefer this information to be presented? *

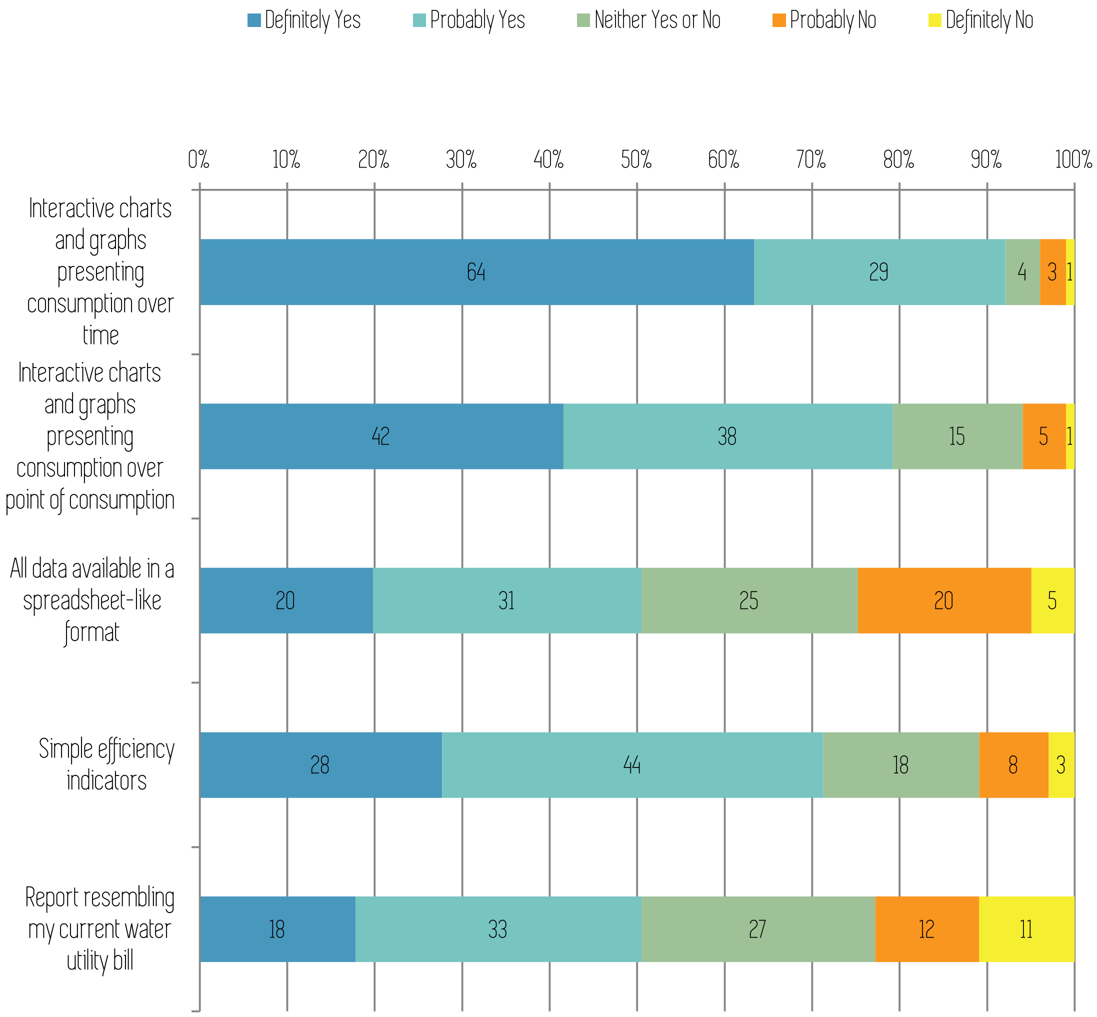

Figure 20: Responses on "Assuming you had access through a web site to your historical water consumption data, how would you prefer this information to be presented?"

According to Figure 20, the most preferable consumption data visualization methods are charts, followed by efficiency indicators. This is expected, since both tools present data in a more intuitive and user friendly way than spreadsheets and reports. Also, it is important to highlight that the current water utility bills are less preferable than all options. Despite consumers being familiar with their structure and content, they prefer other media providing them increased information and potential for exploration.

2.1.3.1.21. Assuming you could compare your water consumption data with others, which of the following groups would you prefer? *

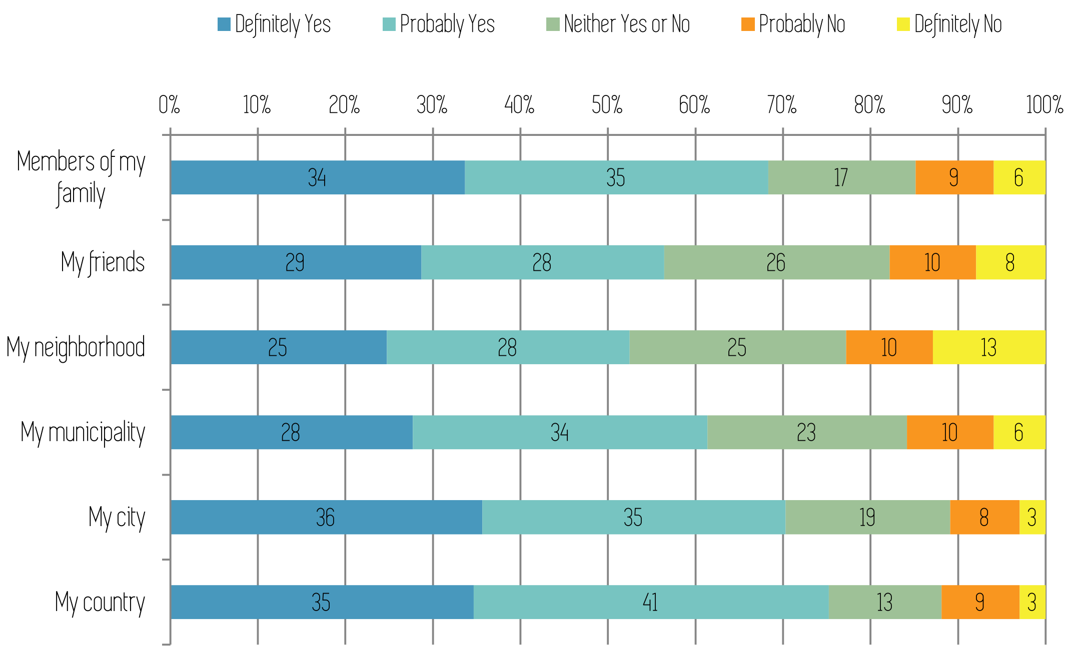

Figure 21: Responses on "Assuming you could compare your water consumption data with others, which of the following groups would you prefer?"

The responses of participants regarding comparison of their water consumption with other user groups provide two important insights. First, across all groups, negative responses (Probably No, Definitely No) range from 10% to 23%. This means that the vast majority of participants are positive towards comparing their water consumption with others. Second, it appears that users consider more important to compare their consumption with large scale aggregates (country, city, municipality), with positive responses reducing as the group decreases in size. Comparisons with friends and neighbors roughly enjoy the approval of neighborhood and municipality groups.

2.1.3.1.22. Would you share your water consumption information with others? *

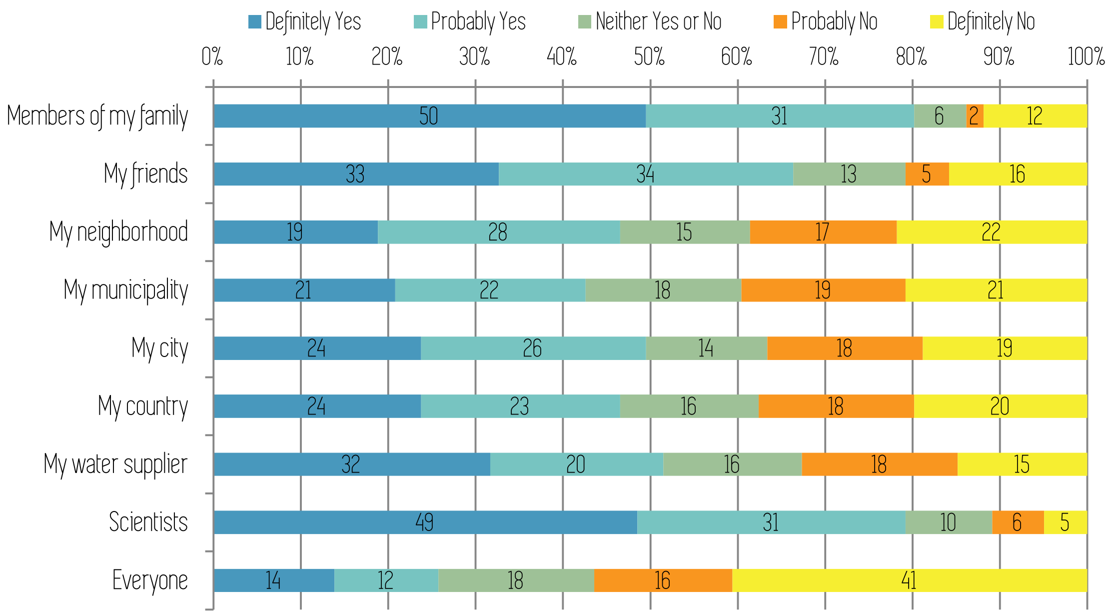

Figure 22: Responses on "Would you share your water consumption information with others?"

Responses in this question provide several interesting findings relating to perceived notions of privacy and trust. First of all, consumers clearly do not want to share their water consumption information with everyone, i.e. expose it in the public domain. Actually 40% respond with 'Definitely No', while ~25% are positive (Definitely Yes/Probably Yes). The number of positive responses is critical if we consider that one in four is willing to share their consumption with everyone, as it forms a very broad user base for designing bottom-up awareness campaigns and initiatives for motivating the general population. The number of negative responses imposes a critical requirement from consumers: water consumption should be private by default, with consumers having full control regarding who they share their consumption with.

It is important to highlight the positive view of participants in sharing their water consumption data with scientists. Positive responses are ~80%, and roughly the same with positive responses for sharing data with family members! Further, comparing with the responses regarding water suppliers (*which have de facto access to this data*), we can make the following observations. First, scientists enjoy the trust of participants. Consumers understand the needs of scientific research, and are willing to share their consumption data with scientists. This introduces a great opportunity for gaining access to water consumption information directly from consumers, and bypassing entirely the water utilities. Second, the trust awarded to scientists also implies great responsibility in maintaining it. Proper care and assurance should be given to ensure consumer privacy and application of data only for scientific purposes.

Finally, approximately ~45% of consumers are willing to share their consumption data with larger population groups (neighborhood, municipality, city, country). This is certainly a positive outcome; almost one in two would share their data, and thus provide multiple opportunities for analysis and broader water efficiency policies. However, the most interesting insight comes when comparing the responses for the groups 'My country' with 'Everyone'. Positive responses (Definitely Yes/Probably Yes) are ~45% vs. ~28%

respectively, despite the fact that sharing data with an entire country *more or less* means sharing data with everyone! This implies that the perceived notions of societal geographical boundaries regarding data sharing are important to consumers. When possible, these should be explored and promoted to the fullest degree to engage consumers.

2.1.3.1.23. Would you have any worries regarding sharing your water consumption data with others? *

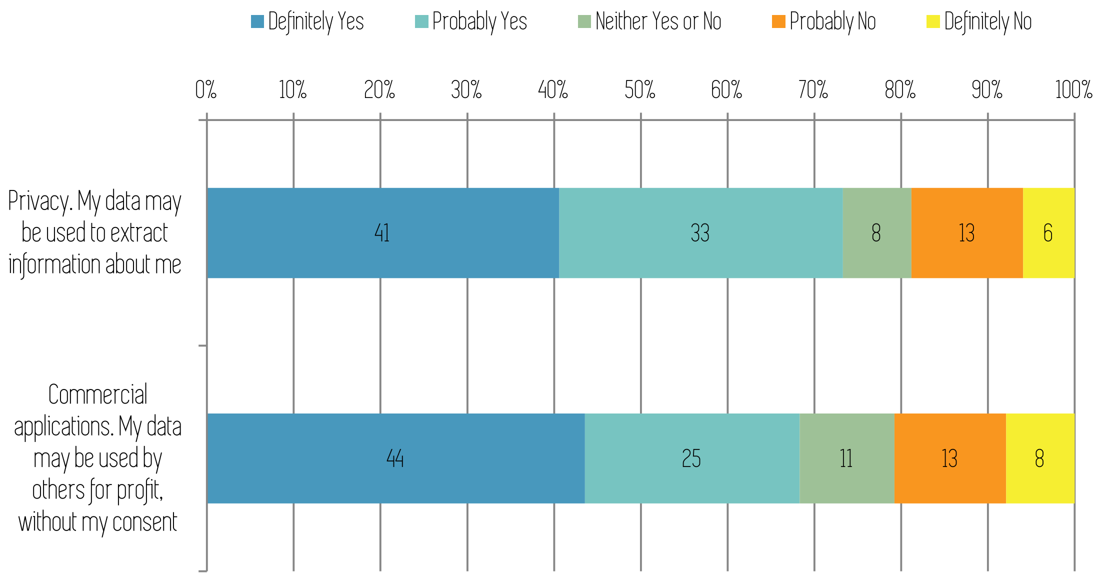

Figure 23: Responses on "Would you have any worries regarding sharing your water consumption data with others?"

Participants provide practically the same responses for both data sharing concerns, i.e. privacy and commercial exploitation. Almost 70% share these worries (Definitely Yes/Probably Yes), with only 20% of the participants not caring (Definitely No/Probably No). Clearly, these consumer concerns must be addressed on a technical level, providing users with complete control over their data and how they are used and/or shared by others.

Further, the positive responses in the previous question (*i.e. data sharing*) gain an even greater significance if we take into account the consumer concerns. Despite the fact that 70% of consumers are concerned about sharing their data, almost 80% is willing to share it with scientists.

2.1.3.1.24. How much money would you pay for a device enabling you to monitor and learn about your water consumption in real-time? *

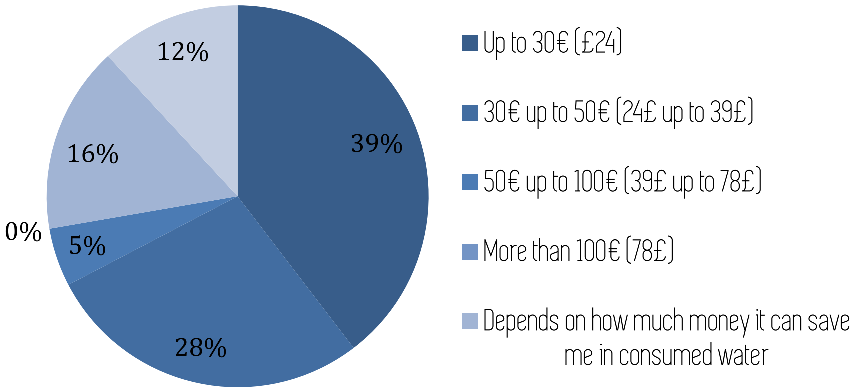

Figure 24: Responses on "How much money would you pay for a device enabling you to monitor and learn about your water consumption in real-time?"

2.1.3.1.25. If such a device was offered to you for free, would you use it? *

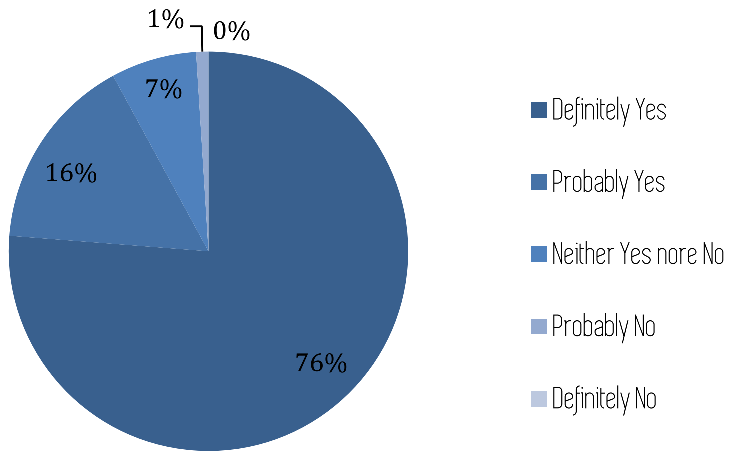

Figure 25: Responses on "If such a device was offered to you for free, would you use it?"

Figure 24 and Figure 25 demonstrate that the cost of a water consumption monitoring device is an issue. Although almost all users would use it if it was given them for free, two out of three users would not spend over 50€, while 14% would not buy it at all.

Clearly, the *price ceiling* for such a device is around 50€. However, it is important to mention that consumers make this estimate without taking into account the cost savings from the reduced water/energy use. Given convincing and validated benefits (e.g. 25% reduction), the price of the product could increase up to the point where its cost is amortized over a 1-2 years.

2.1.3.1.26. Let's assume you were in the market for a replacement shower-head and had three choices... *

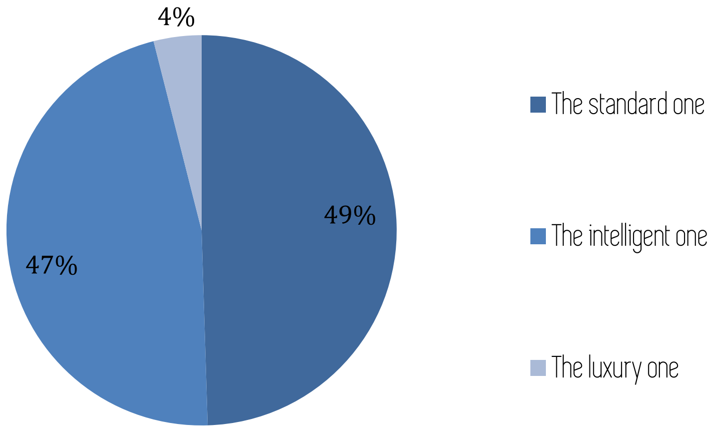

Figure 26: Responses on "Let's assume you were in the market for a replacement shower-head and had three choices...

In this question we introduce participants to a very specific consumer decision. Assuming they were in the market for a replacement shower-head, we asked from them to choose over a standard one (29€), a luxury one (79€), or an intelligent one, i.e. providing them with real-time water consumption information (79€). We have intentionally priced the 'intelligent' shower-head similarly to the 'luxury' one. From the responses, we can see that only 4% of participants would be willing to spend the extra money for a luxury device. Instead, they are polarized between the 'standard' and the 'intelligent' shower-head. Practically one in two participants would be willing to spend more than double of the money in order to enjoy more information over her water consumption. This is extremely encouraging, as consumers seem to understand, value, and ultimately select a novel product promoting water efficiency.

2.1.3.1.27. If I purchased a shower monitor that provides real-time water consumption information, I would do that because: *

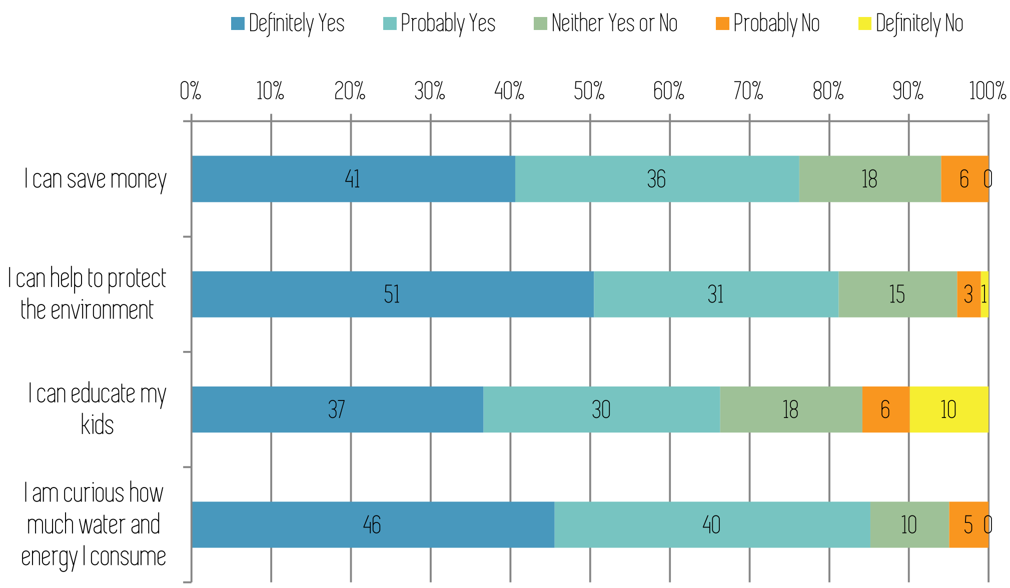

Figure 27: Responses on "If I purchased a shower monitor that provides real-time water consumption information, I would do that because:"

This question allows us to understand the reasoning behind the consumers' preference for a shower-head providing real-time water consumption information. The leading motivating factors seem to be environmental concern and actual interest for learning more about water/energy consumption. Cost savings come a close second, and the wish to educate younger family members last, but quite important as well.

2.1.3.1.28. Demographics questions

The final and *optional part* of the online survey included a set of questions regarding the demographic characteristic of the participants, and their broader views on environmental issues and technology receptiveness. An analysis of the responses for this group of questions is provided in Appendix II.

2.1.3.2. Utility Survey

The online survey targeting Utility users is analyzed next. The survey consisted of five question categories, as discussed in Section 2.1.1.2. Next, we analyze the responses for each question. The "*" symbol after a question denotes that an answer to the question was mandatory.

Note that as mentioned in 2.1.2, we consider the absolute size of the participants to *be small*. The reader is advised to take this into account regarding the generalization of the insights that follow.

2.1.3.2.1. What is your position in your organization? *

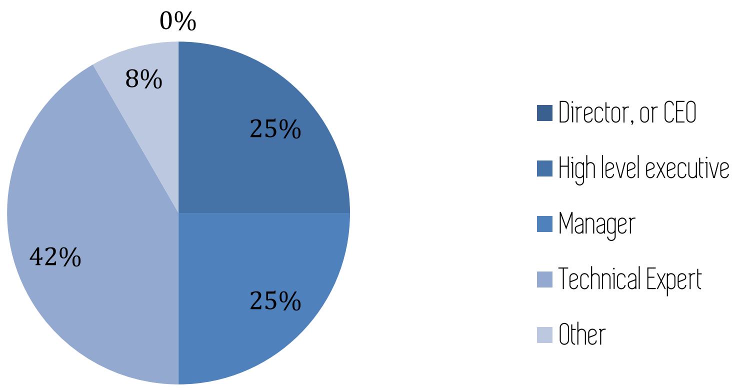

Figure 28: Responses on "What is your position in your organization"

The responses to the first question provide us insight on the composition of the utility employees that participated in the survey. Almost half of the participants were technical experts while the other half consists of high level executives and managers. Thus, our sample is balanced between people that can comprehend technical information and people that are in position to take decisions on strategies and policies.

2.1.3.2.2. Do you experience strong pressure to reduce the meter-to-cash costs? *

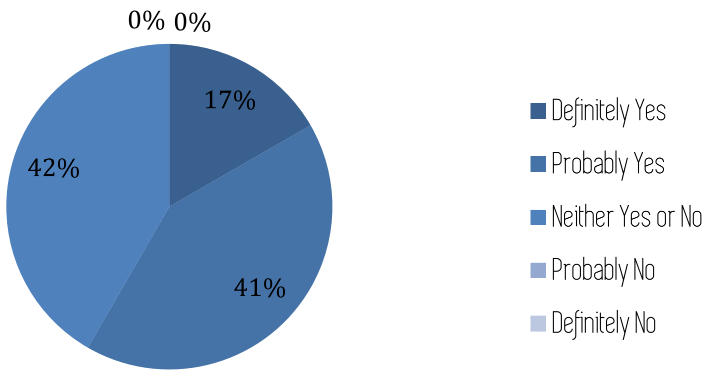

Figure 29: Responses on "Do you experience strong pressure to reduce the meter-to-cash costs?"

The responses indicate a strong pressure for reducing the meter-to-cash (M2C) costs: 58% replies that there is pressure to reduce the meter-to-cash costs, while the rest 42% does not have a clear opinion. This is an important finding, since it indicates a need from utilities to lower standard operating costs and increase profits. On the one hand, any solution that can reduce M2C costs (*directly or indirectly*) would appeal to utilities. On the other hand, the implied targeting towards cost-efficiency may act as a deterrent for long-term and/or big investments (*e.g. roll-out of SWM and data analysis tools*). Ideally, the industry would require quick wins, with a low entry barrier (cost, technical complexity), and benefits apparent as soon as possible.

2.1.3.2.3. Do you experience strong pressure to improve the quality of water demand forecasts for "next day" forecasts? *

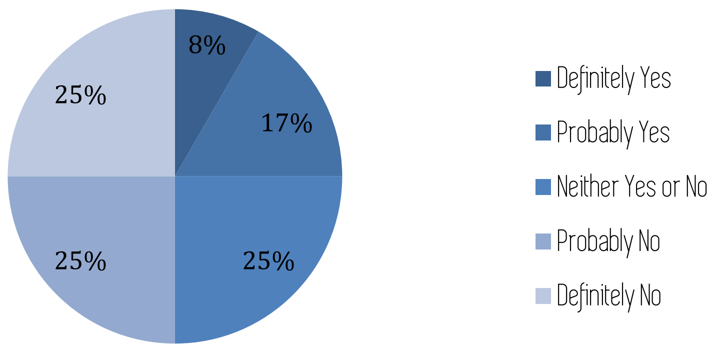

Figure 30: Responses on "Do you experience strong pressure to improve the quality of water demand forecasts for "next day" forecasts?"

2.1.3.2.4. Do you experience strong pressure to improve the quality of demand forecasts for time scales of several years? *

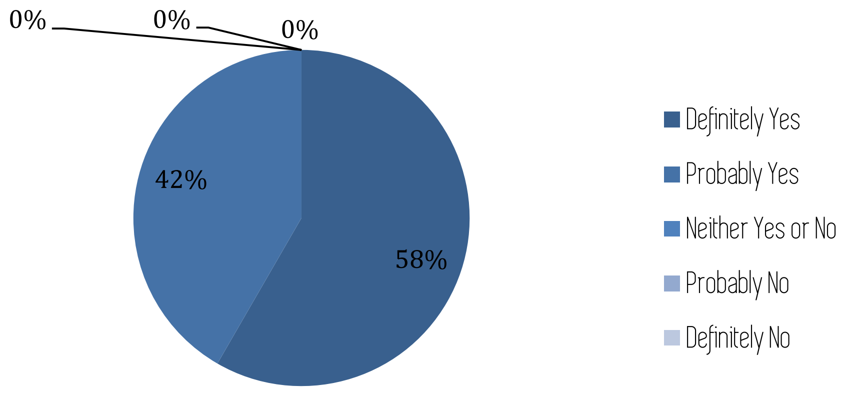

Figure 31: Responses on "Do you experience strong pressure to improve the quality of demand forecasts for time scales of several years?"

Questions 3 and 4 indicate the focus of utilities with respect to water demand forecasting: utilities are interested in long-term predictions of consumption (*all participants gave a positive answer*), while they are much less interested in short-term predictions (only 25% gave positive answers). This is expected, since long term, aggregate data would, in first sight, appear more fitting for utilities to base their services on. However, it is obvious that there is a lack of insight in the specific matter, since predicting and analyzing short term consumption could provide several advantages, both to the users and the utilities (e.g. increase of user interest/engagement in the respective technologies, user-personalized services by the utilities, etc.)

2.1.3.2.5. Do you feel strong pressure to reduce residential water consumption? *

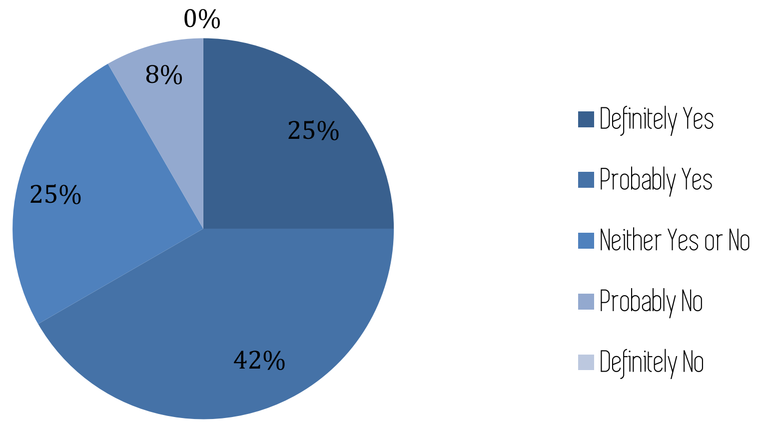

Figure 32: Responses on "Do you feel strong pressure to reduce residential water consumption?"

Figure 32 shows the importance of reducing domestic consumption for utilities. An overall 67% reveals a pressure towards achieving such a goal (Definitely Yes/Probably Yes), with 25% declaring strong pressure.

2.1.3.2.6. Do you feel strong pressure to reduce water consumption among commercial customers? *

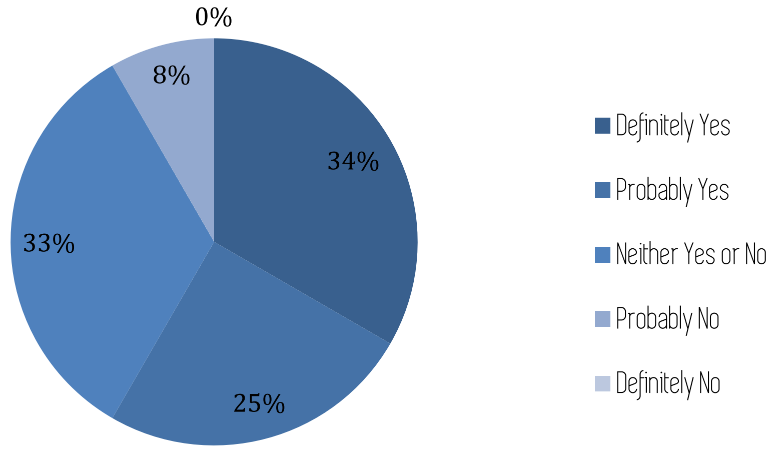

Figure 33: Responses on "Do you feel strong pressure to reduce water consumption among commercial customers?"

Figure 33 provides very similar result, with respect to reducing consumption of commercial customers: 59% answers positively, however, 34% declares a strong pressure. This might indicate a focus by the utilities to the commercial users, which are expected to consume larger quantities of water and/or require different services by the utilities.

2.1.3.2.7. Do you feel strong pressure to reduce residential energy consumption (due to water heating)? *

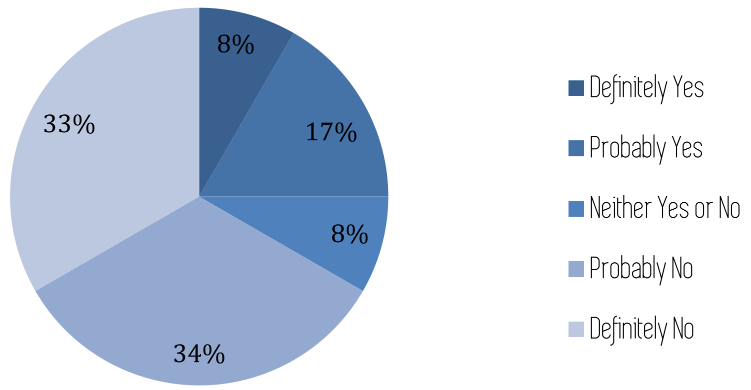

Figure 34: Responses on "Do you feel strong pressure to reduce residential energy consumption (due to water heating)?"

Question 7 shows that utilities do not share the same concerns, when it comes to energy consumption. Only 25% indicate that there is a need for reducing energy consumption due to water heating. This is also expected, since water utilities focus on their domain, without considering households as smart ecosystems where saving of resources is interwoven and includes energy, water, products, money, or air pollutants.

2.1.3.2.8. Is domestic water conservation of importance for your company? *

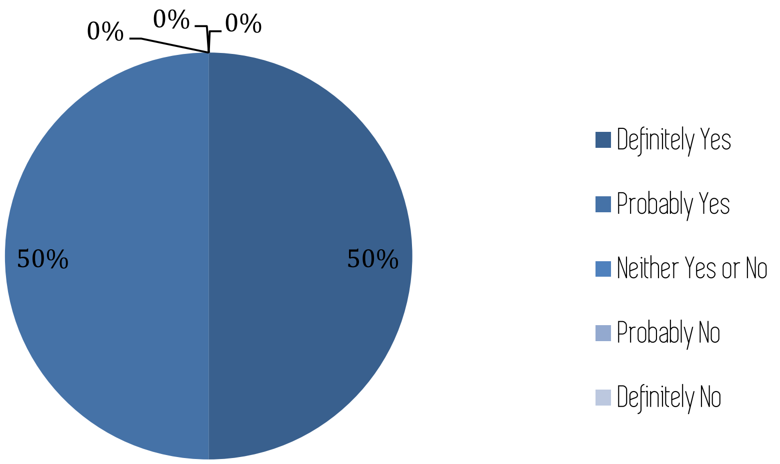

Figure 35: Responses on "Is domestic water conservation of importance for your company?"

The responses of the above question verify the results discussed on Figure 32. All participants consider domestic water conservation as an important goal of their utility (Definitely Yes/Probably Yes).

2.1.3.2.9. Do you feel there is a need to educate and assist consumers with reducing their consumption? *

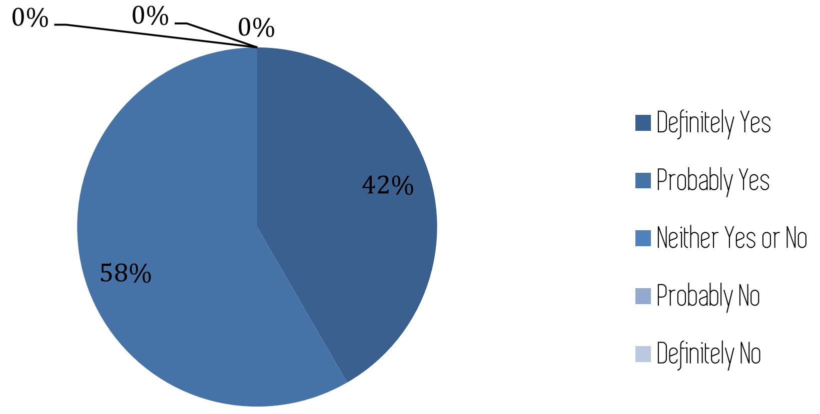

Figure 36: Responses on "Do you feel there is a need to educate and assist consumers with reducing their consumption?"

Another important finding is that utilities consider it necessary to educate consumers on water reduction practices. This finding strengthens the need for technologies and tools that will be implemented in DAIAD: systems that can provide consumers with real-time, both simple and more detailed/sophisticated information on their consumption and also allow them to compare their consumption and recommend them with ways to save water.

2.1.3.2.10. Does your organization apply smart water metering technologies? *

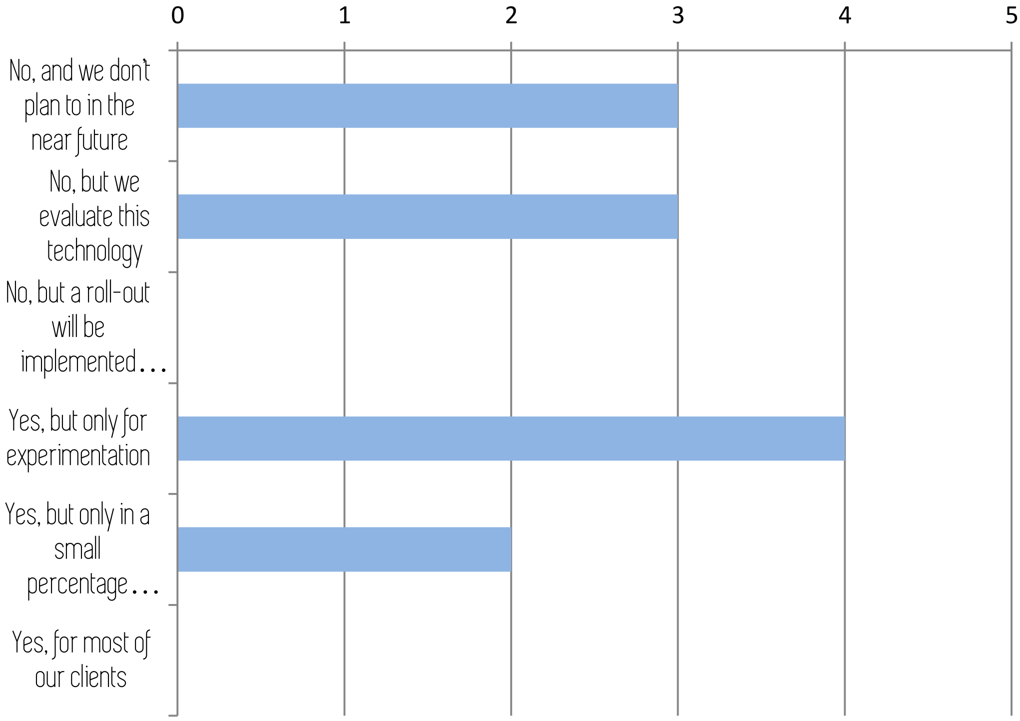

Figure 37: Responses on "Does your organization apply smart water metering technologies?"

This question shows the infiltration of smart water metering technologies in water utilities. Only half of them applied such technologies, but **only** experimentally or in a very small scale, while 25% are not even interested in adopting such technologies in the future. This might be attributed to shortcomings of current technologies (high cost of installation/maintenance, limited functionality, complexity), as well as to the lack of initiative and the technological gap within water utilities, as shown in the responses of question 11.

2.1.3.2.11. If you do not currently apply smart water metering technologies, what are the reasons? *

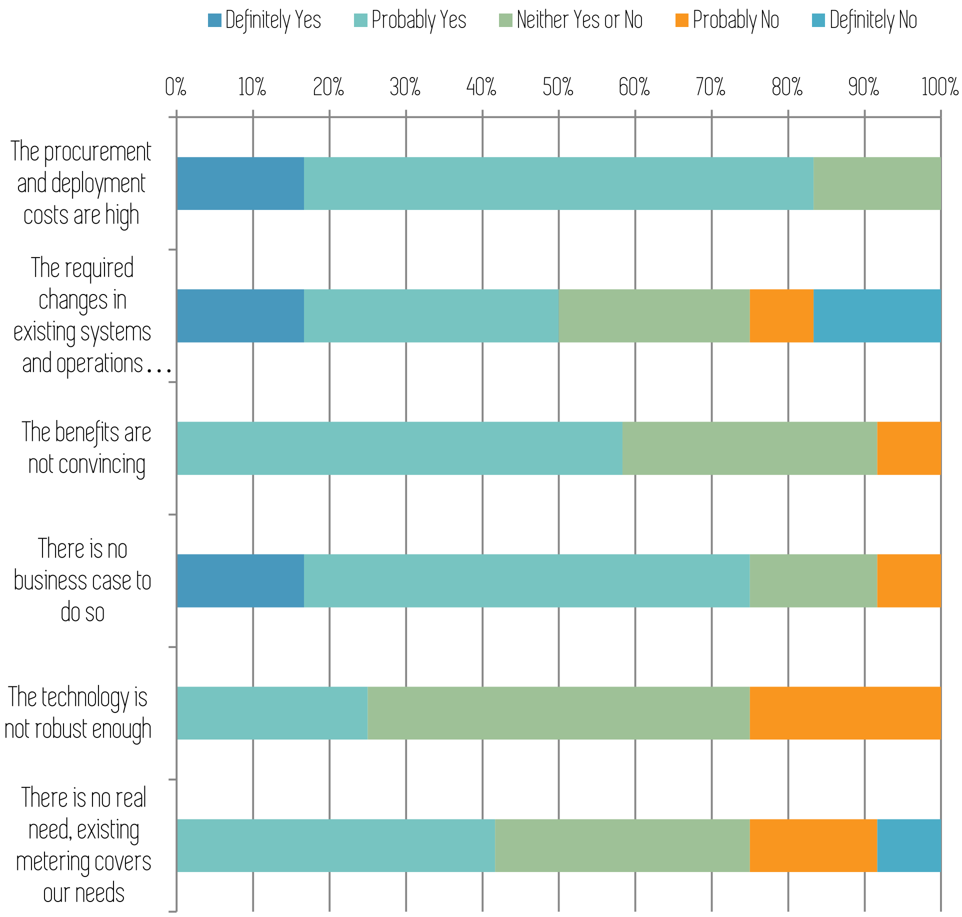

Figure 38: Responses on "If you do not currently apply smart water metering technologies, what are the reasons?"

2.1.3.2.12. What type of data management system do you currently have for storing water consumption data? *

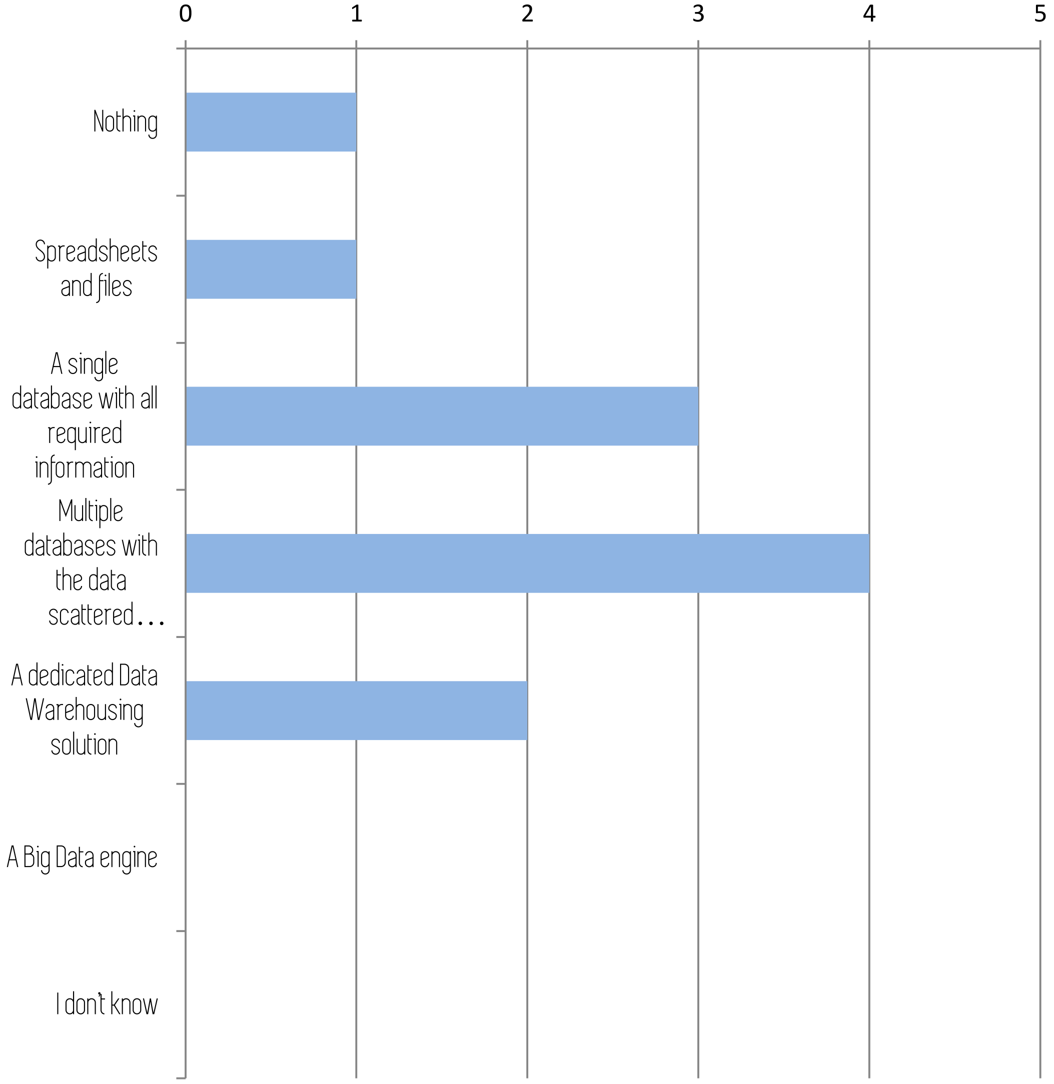

Figure 39: Responses on "What type of data management system do you currently have for storing water consumption data?"

From Figure 39 we can see that only one out of six participants have applied a dedicated data warehousing solution for storing WDM data, while *none* adopts a big data engine solution. This is clearly attributed to the lack of massive user consumption data, since current technologies and utilities policies do not allow the large scale deployment of data gathering, management and analysis systems.

2.1.3.2.13. What type of analysis software do you use for extracting insights from water consumption data? *

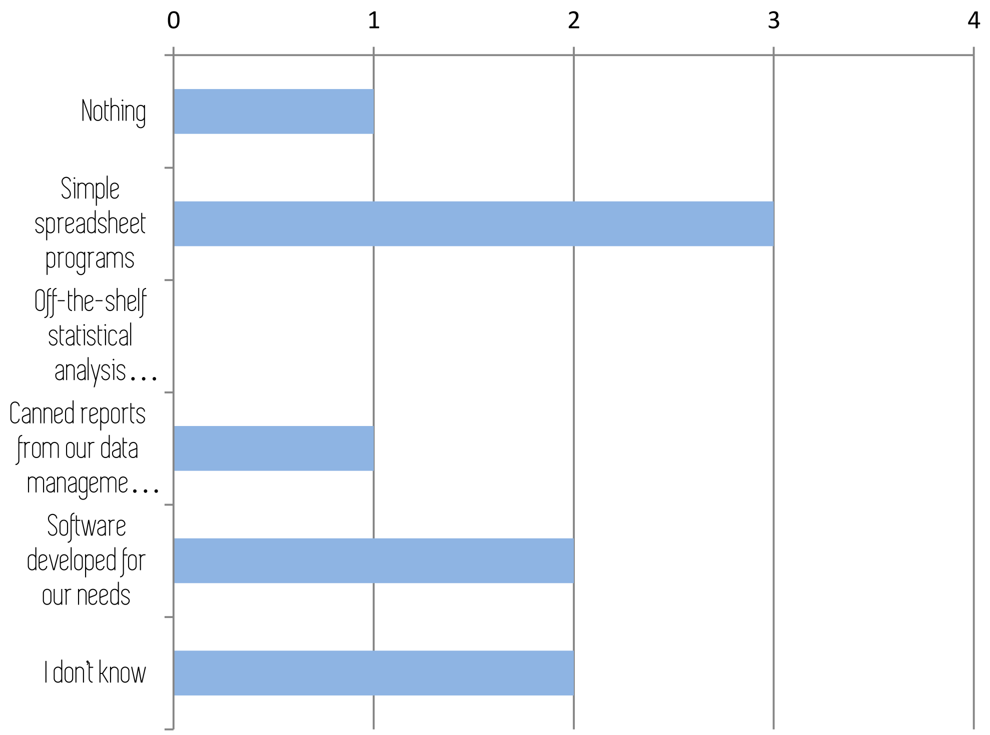

Figure 40: Responses on "What type of analysis software do you use for extracting insights from water consumption data?"

On the other hand, there is great dispersion on the means of analysis that are applied by the several utilities, varying from *no tools* to problem-specific developed software. However, only one out of six uses such software, where the most popular means of analysis are simple *spreadsheets*.

2.1.3.2.14. What is the most detailed information you have regarding the water consumption of a specific household? *

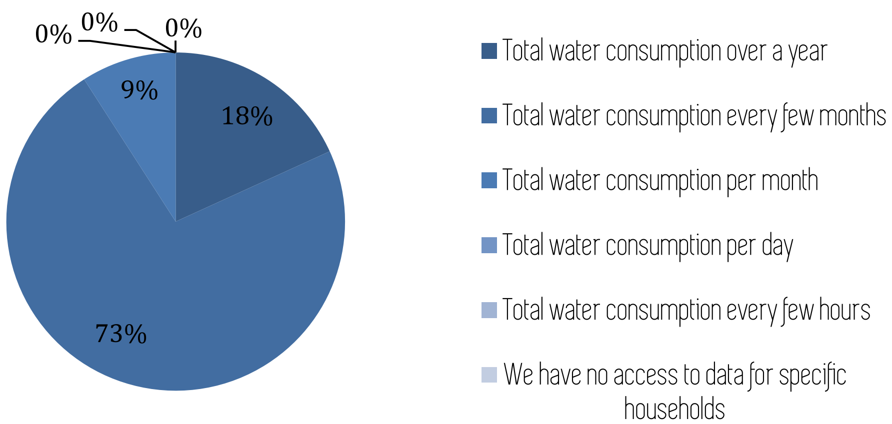

Figure 41: Responses on "What is the most detailed information you have regarding the water consumption of a specific household?"

2.1.3.2.15. What is the most detailed information you would like to have regarding the water consumption of a specific household? *

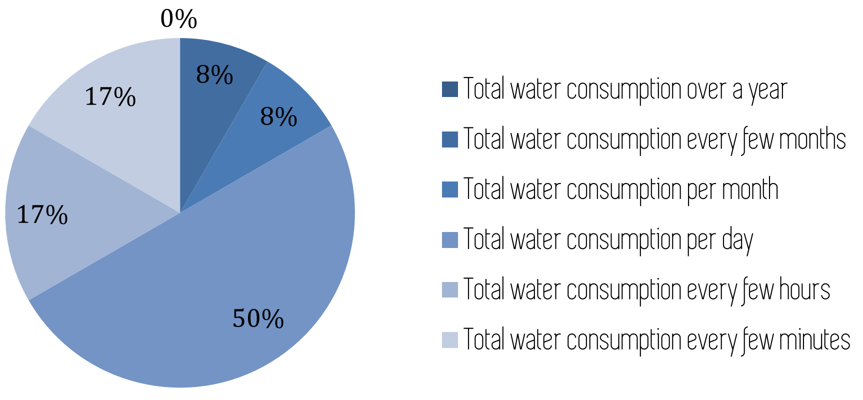

Figure 42: Responses on "What is the most detailed information you would like to have regarding the water consumption of a specific household?"

Questions 14 and 15 revolve around the existing and desired granularity of water consumption data that utilities can obtain. We can see that the most fine-grained data available to utilities is per-month and regards only a 9% of them, while the majority (73%) obtains data with a granularity of a few months.

It becomes clear that the current state *does not cover the utilities' need*; half of the respondents state that they would like to have data *with daily granularity*, while another 34% states that they would like to have even more fine-grained data. Of course, data of this scale require advanced storage, management and analysis solutions, which cannot be covered by the current state of the art.

2.1.3.2.16. What is the estimated size of your water consumption data? *

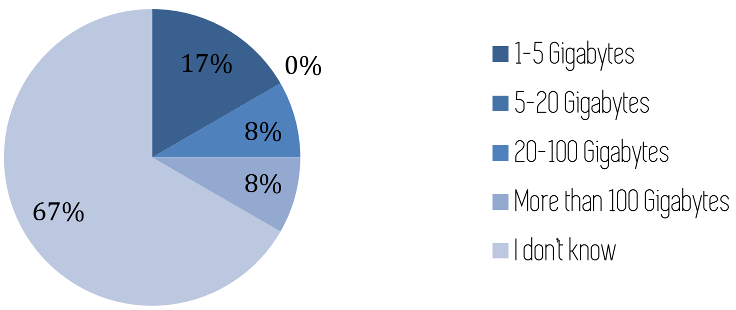

Figure 43: Responses on "What is the estimated size of your water consumption data?"

2.1.3.2.17. What is the earliest point in time of your digital water consumption data starts from? *

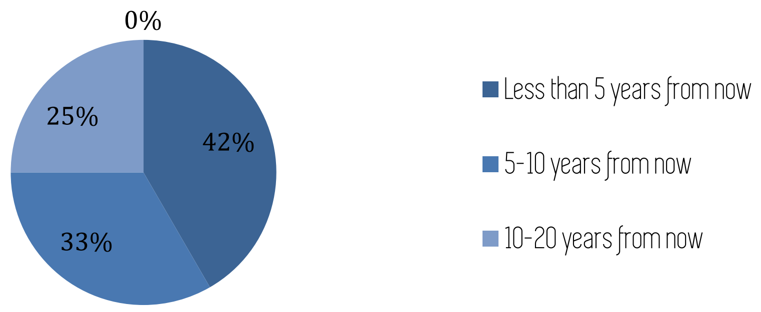

Figure 44: Responses on "What is the earliest point in time of your digital water consumption data starts from?"

Figure 43 and Figure 44 provide several insights. First, the majority of participants (67%) do not know the size of their water consumption data. Second, almost half of the respondents confirm the availability of data covering the past decade.

2.1.3.2.18. Besides water consumption data, what other data do you use in order to analyze water consumption? *

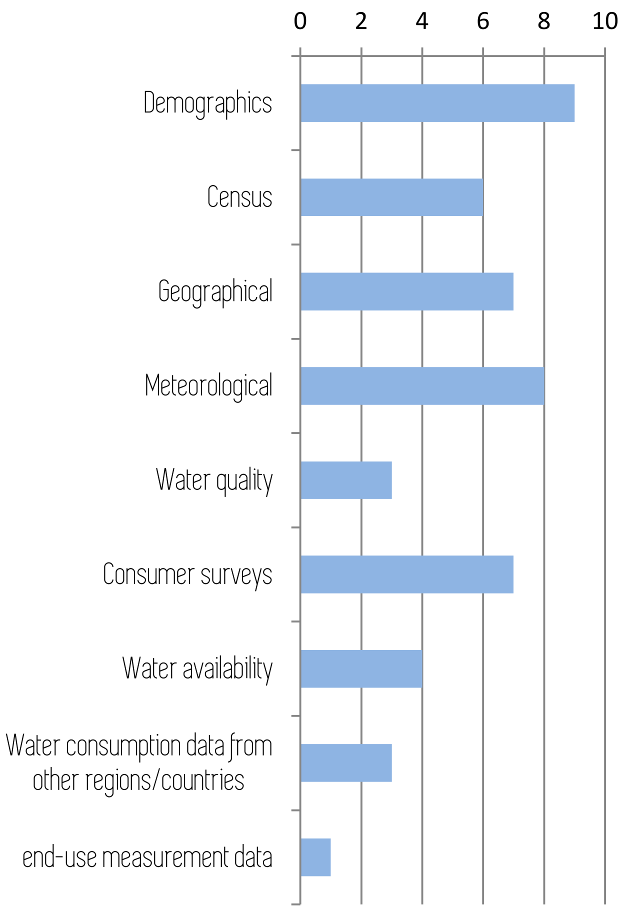

Figure 45: Responses on "Besides water consumption data, what other data do you use in order to analyze water consumption?"

The answers reveal the most important factors, according to water utilities, for analyzing water consumption. As expected, demographics and meteorological data have the highest rank, since they constitute determinants that influence water consumption. Geographical, census and consumer surveys come second. Finally, other factors such as water quality and water availability seem to be less important for most utilities.

2.1.3.2.19. Are there departments in your organization responsible for analyzing water consumption data? *

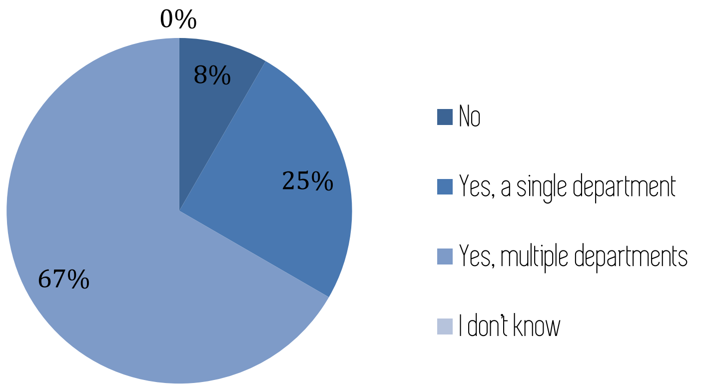

Figure 46: Responses on "Are there departments in your organization responsible for analyzing water consumption data?"

Question 19 reveals that most utilities have dedicated departments and personnel for analyzing consumption data. This demonstrates the importance of water consumption analysis processes for the utilities, as well as a possible lack of coherent collaboration tools to achieve it.

2.1.3.2.20. How do you evaluate the quality of the water consumption data you currently have? *

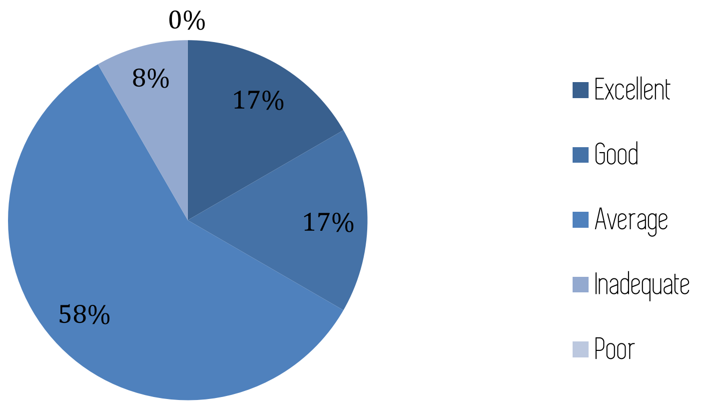

Figure 47: Responses on "How do you evaluate the quality of the water consumption data you currently have?"

Figure 47 shows that only a small percentage of utilities (24%) are satisfied with the consumption data they obtain, while the majority (58%) does not have a clear opinion. This figure, in combination with

Figure 41 and Figure 42 indicate the lack of highly granular, detailed and massive data in the current state of the WDM area. This finding is verified by Figure 48, where utilities seem dissatisfied by the resolution (detail-granularity) of their data: only 25% evaluates their data resolution positively.

2.1.3.2.21. How do you evaluate the resolution of the water consumption data you currently have? *

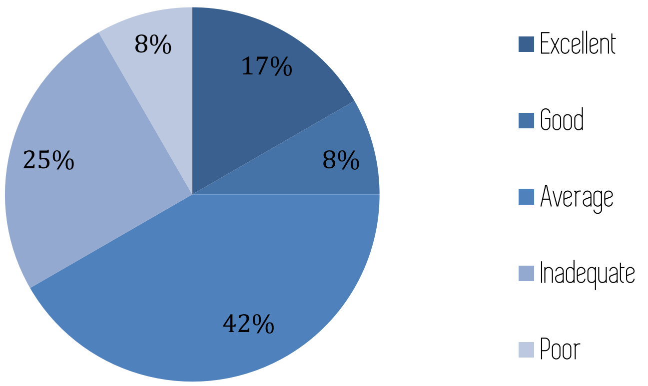

Figure 48: Responses on "How do you evaluate the resolution of the water consumption data you currently have?"

2.1.3.2.22. How do you evaluate the accuracy of the water consumption data you currently have? *

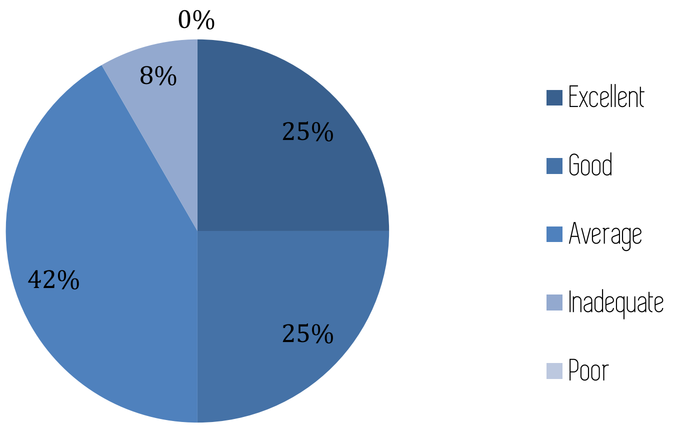

Figure 49: Responses on "How do you evaluate the accuracy of the water consumption data you currently have?"

Interestingly, when it comes to data accuracy, *only one in two* are satisfied. Since water consumption data are *de jure* used for billing purposes, one would assume that their quality would be great. However, this is not the case, with participants acknowledging quality shortcomings in their data.

2.1.3.2.23. Have you ever been limited in your work by the lack of appropriate water consumption data? *

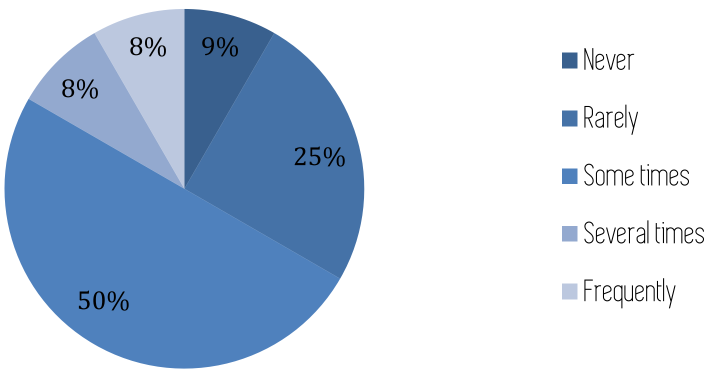

Figure 50: Responses on "Have you ever been limited in your work by the lack of appropriate water consumption data"

According to question 23, only one third of participants declare that their work has not been limited (or has slightly been limited) by the lack of better consumption data. This is on par with the results of previous questions with respect to the lack of high resolution data that limits the analysis capabilities of utilities and, thus, the quality of services they can offer.

2.1.3.2.24. Do you believe real-time water consumption data would be beneficial for your organization? *

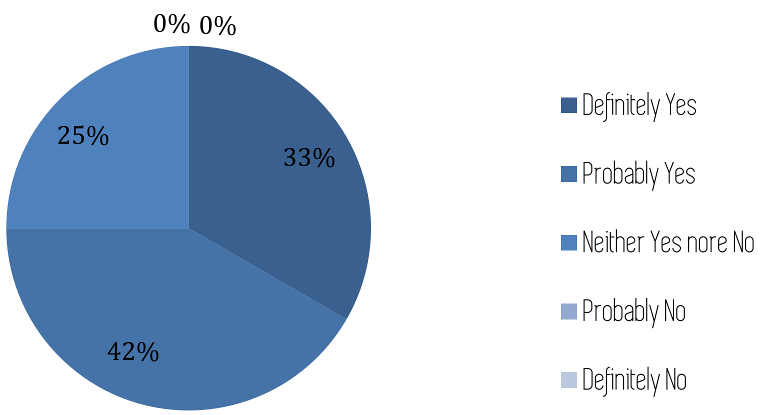

Figure 51: Responses on "Do you believe real-time water consumption data would be beneficial for your organization?"

This question reveals the great importance of real-time consumption data: three out of four utilities consider them important, although, apparently from previous questions, they hardly obtain such data.

2.1.3.2.25. What could real-time water consumption data be good for, in your view? *

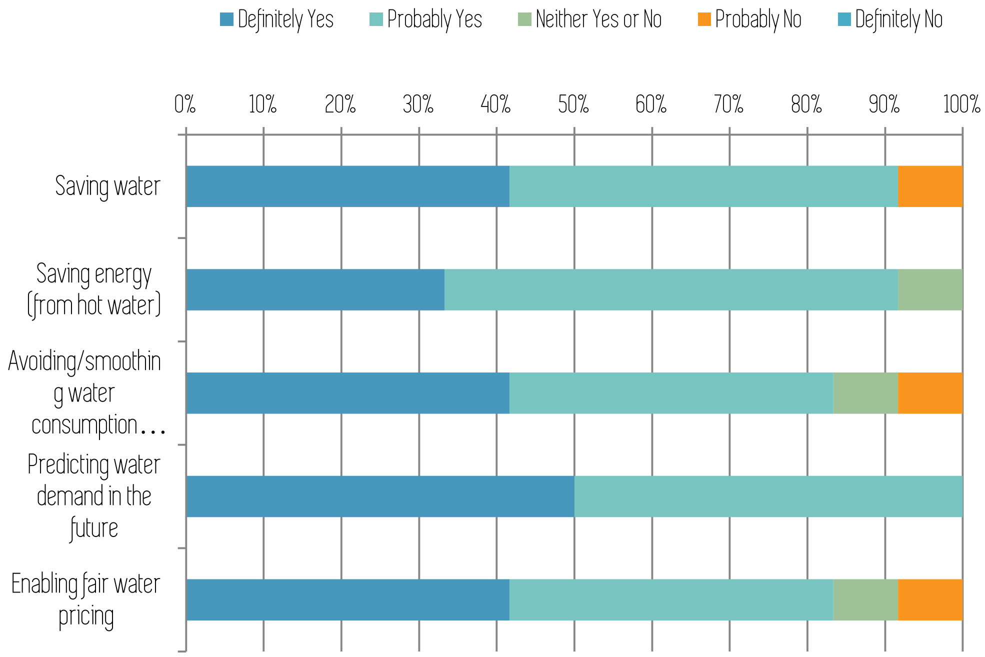

Figure 52: Responses on "What could real-time water consumption data be good for, in your view?"

This question complements the previous one, examining the reasons why utilities consider real-time data important. Interestingly, real-time data are regarded as important for all the goals presented in the question. These two questions verify the need for real-time monitoring systems like DAIAD, where both the consumer and the water stakeholders can gain insights and perform complex analysis tasks on the respective data.

2.1.3.2.26. Are your clients aware of water efficiency? *

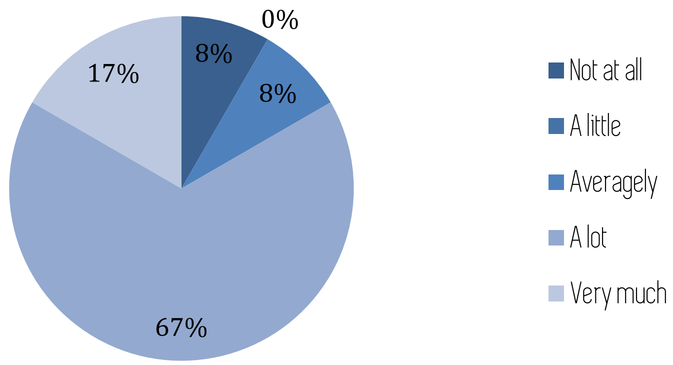

Figure 53: Responses on "Are your clients aware of water efficiency?"

This question reveals a great lack of awareness on the real status of end users-consumers, from the side of utilities: *only one out of six utilities considers their customers unaware of water efficiency*. However, as we have seen in the consumer survey (Figure 2 to Figure 5) consumers provide very disperse and unrealistic estimation on their daily/shower consumptions. This misconception of the current state by water utilities can be justified by the lack of proper tools to monitor and understand actual consumption behaviors from consumers.

2.1.3.2.27. Does the geographical area you serve face any of the following challenges? *

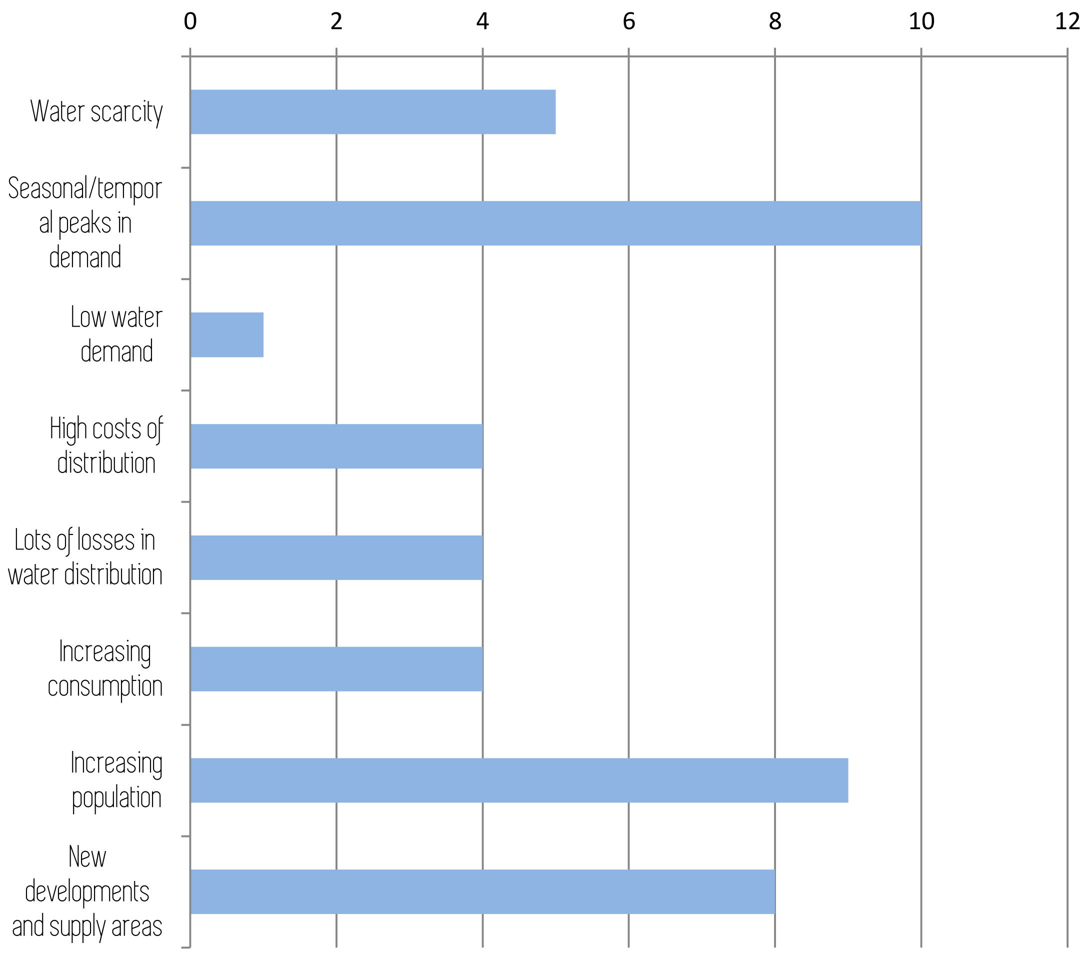

Figure 54: Responses on "Does the geographical area you serve face any of the following challenges?"

The responses are in line with the known challenges identified in the literature. For the majority of participants, the leading challenge is peaks in demand, with problems relating to population growth following.

2.1.3.2.28. If you have performed awareness actions for water efficiency in the past, how would you describe their success?

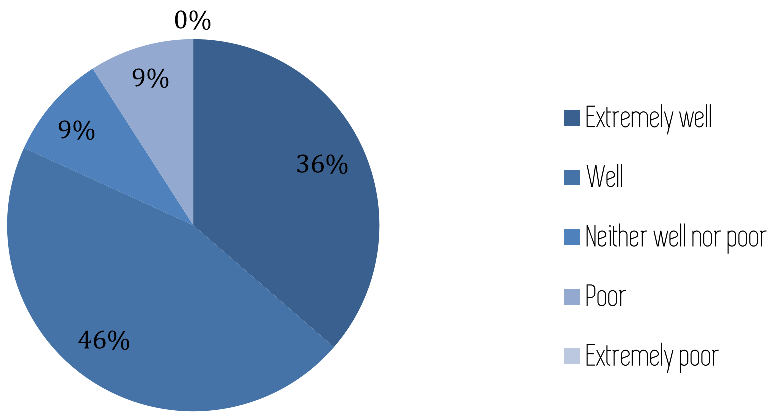

Figure 55: Responses on "If you have performed awareness actions for water efficiency in the past, how would you describe their success?"

Similarly to question 26, this question reveals the misconception of utilities about consumer awareness, since an 80% considers that consumers have been successfully educated on water efficiency on the past.

2.1.3.2.29. How was your water pricing policy designed? *

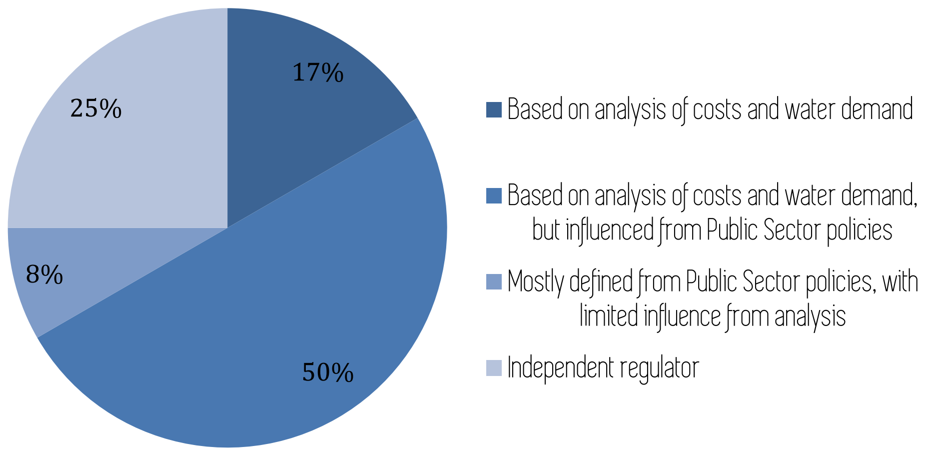

Figure 56: Responses on "How was your water pricing policy designed?"

2.1.3.2.30. Would personalized tariffs be feasible in the area you serve? *

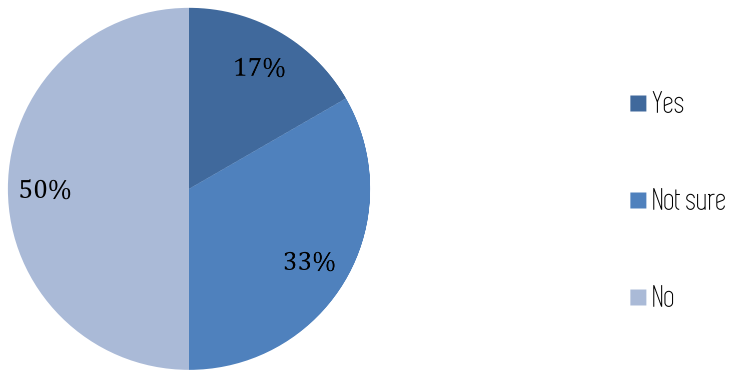

Figure 57: Responses on "Would personalized tariffs be feasible in the area you serve?"

2.1.3.2.31. How long would it take to change your pricing policy to support personalized tariffs for your clients? *

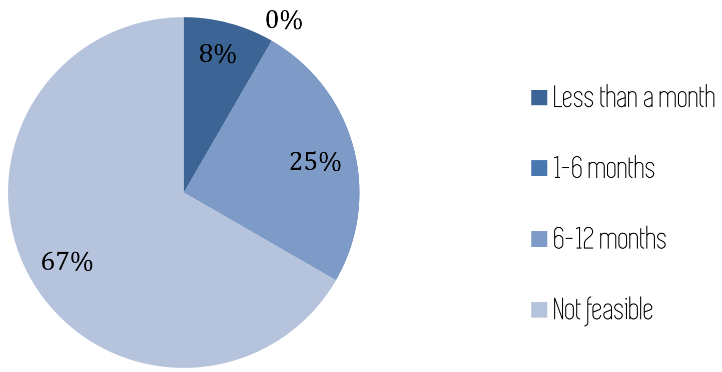

Figure 58: Responses on "How long would it take to change your pricing policy to support personalized tariffs for your clients?"

The two questions above reveal the rigidness of water utilities with respect to changing/personalizing consumption tariffs. Half of the respondents provide a negative response, with only 17% saying that providing personalized tariffs would be feasible. Further 67% states that it *is impossible* to change tariffs.

2.1.3.2.32. Which of the following actions would be required to change your pricing policy to support personalized tariffs for your clients? *

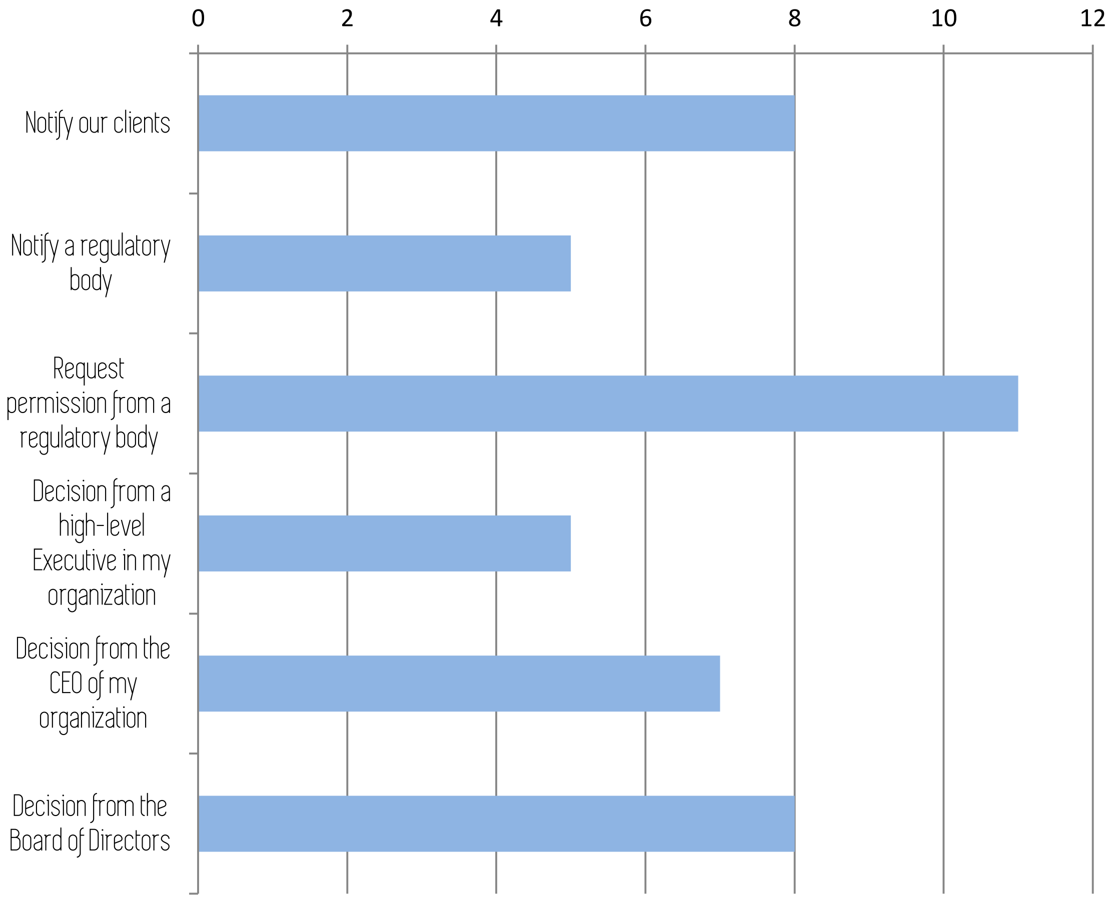

Figure 59: Responses on "Which of the following actions would be required to change your pricing policy to support personalized tariffs for your clients?

The responses of this question indicate the major reasons that cause the rigidness in changing tariffs. It is obvious that the reasons are mainly policy-related.

2.1.3.2.33. How do you evaluate the importance of data analysis of water consumption data and corresponding insights for the every-day operation of your organization? *

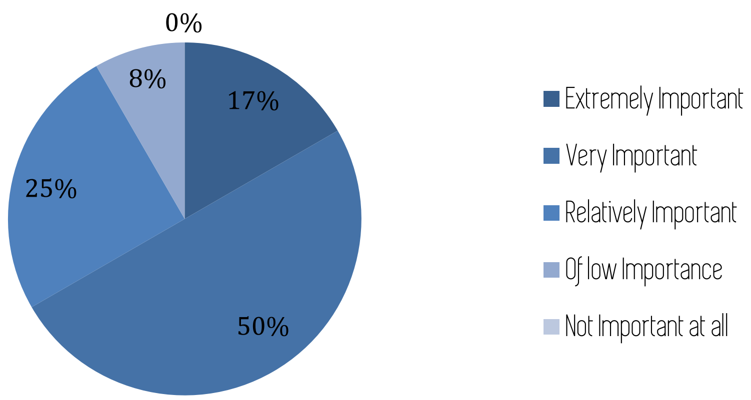

Figure 60: Responses on "How do you evaluate the importance of data analysis of water consumption data and corresponding insights for the every-day operation of your organization?"

2.1.3.2.34. How do you evaluate the importance of data analysis of water consumption data and corresponding insights for medium and long-term decision making of your organization? *

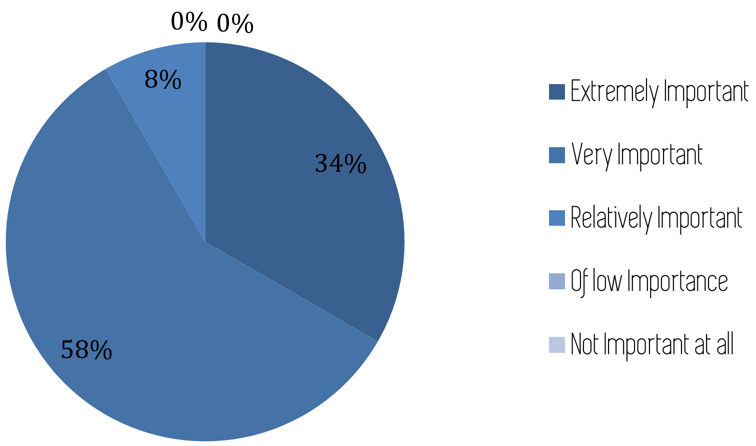

Figure 61: Responses on "How do you evaluate the importance of data analysis of water consumption data and corresponding insights for medium and long-term decision making of your organization?"

Questions 33 and 34 examine the importance of consumption data for the short-term and long-term operation of utilities. As expected, such data are considered more important for the long-term operation (92% against 67%), though the majority of utilities recognizes their overall importance.

2.1.3.2.35. Do you believe that having access to real-time water consumption data of your clients would be beneficial for your organization in terms of: *

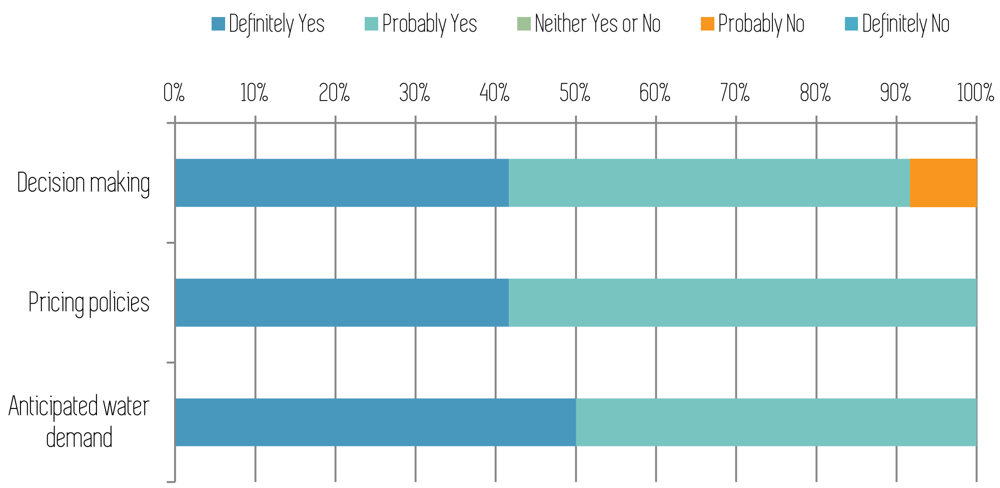

Figure 62: Responses on "Do you believe that having access to real-time water consumption data of your clients would be beneficial for your organization in terms of:"

This question examines the main benefits of real-time consumption data for water utilities. The results are not very informative, since all questioned benefits are recognized by the utilities. The definite positive attitude however is very encouraging; negative responses are almost absent.

2.1.3.2.36. Do you provide your water consumption data to public sector stakeholders? *

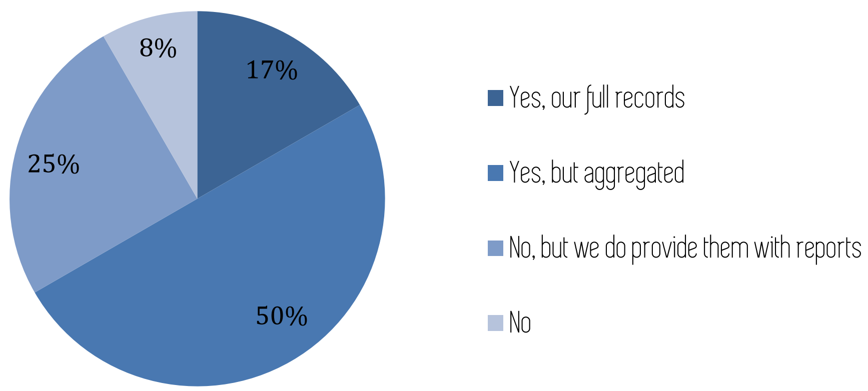

Figure 63: Responses on "Do you provide your water consumption data to public sector stakeholders?"

2.1.3.2.37. Would you object to having your organization's water consumption data publicly available? *

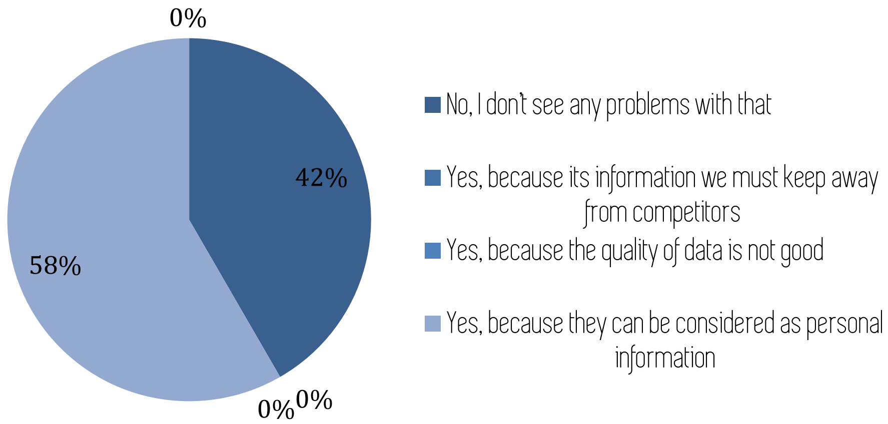

Figure 64: Responses on "Would you object to having your organization's water consumption data publicly available?"

Questions 36 and 37 reveal the divided viewpoints of utilities with respect to consumption data privacy. A 17% provides their full consumption records to public sector stakeholders while another 50% provides them aggregated. On the other hand, 42% agrees in making consumption data publicly available, against 58% that raises privacy concerns. The responses to these questions make it clear that systems like DAIAD should ensure privacy of consumption data and clearly communicate this feature, both to end users and to water utilities.

2.1.3.2.38. Assuming your clients purchased a product that reduced their water consumption by 20% on average. Do you believe the purchase of this product should be subsidized by your organization? *

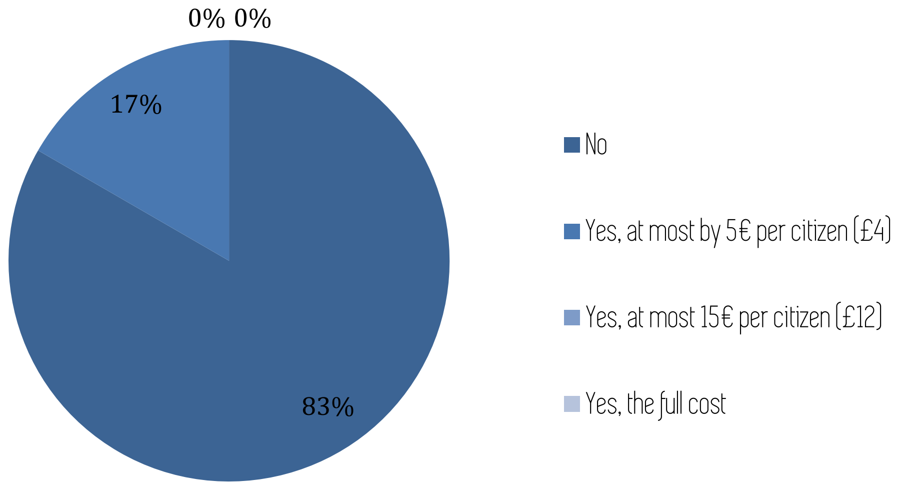

Figure 65: Responses on "Assuming your clients purchased a product that reduced their water consumption by 20% on average. Do you believe the purchase of this product should be subsidized by your organization?"

This question reveals the unwillingness of water utilities to subsidize products that facilitate water saving. This indicates that such devices and systems should be of low cost so that it is possible for end users to obtain them on their own.

2.1.3.2.39. Assuming your clients purchased a product that provided you with their real-time data water consumption, with an average error of 20%. Do you believe your organization would use this data? *

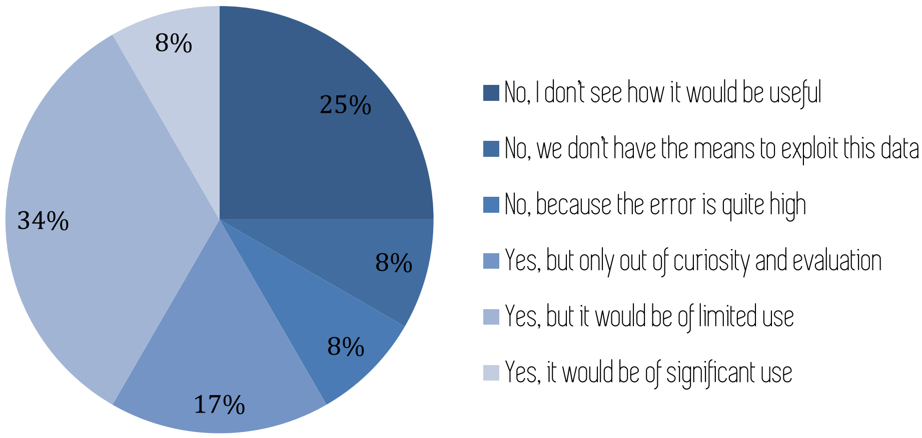

Figure 66: Responses on "Assuming your clients purchased a product that provided you with their real-time data water consumption, with an average error of 20%. Do you believe your organization would use this data?"

This question reveals the dispersed opinions of utilities about water monitoring systems with less than optimal accuracy. Around six out of ten utilities would use inaccurate data (with 20% error), however, only 42% would actually utilize them for non-experimental tasks.

2.2. Discussion panel

2.2.1. Methodology

The Consortium partners organized group-specific discussion panels on the functionality and services of DAIAD. Each panel consisted of homogenized groups of 5-10 participants from different domains: *consumers, researchers and utility representatives*. The purpose was to have an open discussion regarding the functionality and services of DAIAD. At the beginning of each panel, a short introduction to DAIAD was given and the participants were informed about the confidentiality of the discussion. Then a free discussion followed in order for the participants to express their opinions and preferences on several aspects of the DAIAD framework. The coordinator of the discussion was free to direct the panel based on its composition and area of expertise, making sure, however, that points presented in the surveys would eventually be discussed.

2.2.2. Participants

Three panel discussions covering three different stakeholder groups took place: a *consumer* panel with seven participants, a panel consisting of *researchers* in the domain of water resource management and a panel of five water *utility* employees, specialized in several domains: water efficiency, social media and communications and research and innovation. Due to the heterogeneity of the participant groups, we next separately present the major insights obtained by the discussions. Note that the complete minutes of the discussions are presented in Appendix I.

2.2.3. Overview of insights

2.2.3.1. Consumer Panel

The major insights from this discussion panel are as follows.

- The information on water usage could be integrated with energy/resource consumption information and visualized by in-home displays. The most desirable way would be on the smartphone (so no other device has to be installed).
- Integration with external (weather) and internal (heating) information would be welcome.
- Consumers express that they would principally spend money for a water monitoring system if the return on investment is significant.
- Direct feedback should be unobtrusive.
- Consumers would also like to see consumption information directly at the faucet, the showerhead, or on the tiles behind the faucet.
- Direct and indirect feedback is required. An aggregation of the whole information on the shower could be visualized afterwards.
- Persuasive and factual feedback forms are preferred as direct feedback.
- Saving tips are interesting but should be personalized.
- The willingness to share data depends on the audience and on the added value. For sharing information with a community anonymity is definitely required.

2.2.3.2. WDM Researcher Panel

The following list summarizes the major insights from the discussion panel on WDM researchers.

- The most important benefits from water metering are considered: water (and energy) saving and adjusting/controlling water demand. Though, several other benefits are also mentioned (see 7.1.2).
- Water metering devices should provide high resolution measurements and real-time feedback.
- Researchers are positive towards data sharing. They consider that water utilities and research institutes can be considered trustworthy by the consumers.
- There are concerns about users being willing to pay for the device/system.

- Meaningful and manageable amount of recommendations/interventions for water consumption can be conceivable/acceptable by the users. Direct and personalized feedback would be preferable.
- Mobile phones and fixed displays seem good means of interventions.

2.2.3.3. Utilities Panel

The following list summarizes the major insights from the discussion panel with water utility employees.

- Water utilities are positive on SWM for providing higher granularity data and encouraging consumption behavior changes.
- Management of water demand and consumer consumption by water utilities has issues and could be improved.
- High granularity data (e.g. per minute) is desirable, as long the tools to analyze them are also provided.
- A system like DAIAD would help study consumption and behavioral changes and educate people on their consumption.
- Data sharing in social platforms is considered important. Also, providing consumption related cost and emissions, as well as rewarding behavior changes could be useful.
- Concerns involve the fact that measurements need to be very accurate, the cost of the devices, the need to promote/motivate their use, privacy, compatibility issues and possible radiation.

2.3. One-to-one interviews

2.3.1. Methodology

The Consortium partners organized one-to-one interviews on the functionality and services of DAIAD. The participants came from different domains: *water supply and wastewater treatment, water supply companies' consultant, environmental policy regulator, water policy regulator and environmental agency*. The purpose was to have an open discussion regarding the functionality and services of DAIAD. At the beginning of each interview, a short introduction to DAIAD was given and the participant was informed about the confidentiality of the discussion. Then a free discussion followed in order for the participant to express her opinions and preferences on several aspects of the DAIAD framework. The coordinator of the discussion was free to direct the discussion towards the area of expertise of the interviewee, making sure, however, that points presented in the surveys would eventually be discussed.

2.3.2. Participants

Six interviews took place with one researcher, two representatives of water suppliers, two representatives of water regulators and a representative from an environmental agency. Next, we present the major insights in four subsections, corresponding to the four types of interviewees. Note that the complete minutes of the discussions are presented in Appendix I.

2.3.3. Overview of insights

2.3.3.1. Researcher Interview

The following list summarizes the major insights from the interview on water researcher.

- Smart metering can be useful for leakage identification, and less for load management and water saving.
- Data sharing with water suppliers, service providers and scientists will be acceptable by consumers.
- Willingness to pay is a concern; suppliers are expected to be more willing than consumers.
- Interventions will be acceptable by the users, especially via the monitoring device or the mobile phone.

2.3.3.2. Water Supplier Interview

The following list summarizes the major insights from the interviews on representatives of water supply companies.

- Smart metering can be useful for water saving. Though, extensive user/household profiling is required. Covering only one faucet is a disadvantage.
- Data sharing with water suppliers, service providers and scientists will be acceptable by consumers.
- Water suppliers are only willing to pay for water consumption analysis. Users are not expected to pay.
- Interfering/intervening with the consumers should be limited, discrete and careful. It could also be very expensive.

2.3.3.3. Water Regulator Interview

The following list summarizes the major insights from the interviews on water regulators.

- Research and innovation in smart metering are welcome. Currently WDM domain is left behind w.r.t. tools and apps, especially compared to energy domain.
- Customer engagement and companies' understanding of user needs and communicating with them, are important goals.
- Data collection and analysis only indirectly affects/interests water regulators.
- Water policies in general encourage smart metering technologies for water. However, there are both opportunities and barriers for smart metering projects.

2.3.3.4. Environmental Agency Interview

The following list summarizes the major insights from the interview on environmental agency representative.

- Financial incentives, detailed information on user consumption and user insight on their consumption are features that are missing from current WDM tools.
- Smart metering and projects like DAIAD can be helpful in the WDM/ water efficiency area.
- A smart metering system has to be easy to use and maintain, to allow consumption comparison, to provide simple-user friendly feedback, to be inexpensive and reliable and generic enough to be utilizable by several systems.
- Being able to extract high resolution consumption data from many users would be useful for WDM.
- It is unclear whether current policies favor smart metering technologies or whether such technologies will be widely adopted in the future.

3. Use Cases

In this section, we present the major use cases of DAIAD organized along the major deployment and exploitation scenarios. A high-level scenario description is provided for each group of use cases in order to identify: (a) the environment and assumptions under which DAIAD will operate, (b) the involved stakeholders and their relationships, and (c) significant key performance indicators and/or goal-setting that must be achieved. The provided use cases, in conjunction with insights gained from stakeholders that were presented in the previous section will be used for establishing the user requirements of DAIAD.

3.1. Consumer

Consumers include citizens who are concerned about their water and energy consumption as well as those who are fascinated by smart everyday-objects. Consumers may be driven by the desire to *curb their water and energy consumption*, to raise *awareness* among family and friends, or they may be simply interested in *quantifying* their own *behavior* and in being exposed to new technologies. Further, they may simply be provided with DAIAD in the context of a demonstration/trial or roll-out organized by a stakeholder (e.g. utility, local administration). As such, DAIAD is installed and used to meet one or more of these goals. In addition, all Consumers are considered as clients of water and energy utilities and acquainted with simple mobile devices.

3.1.1.1. Stakeholders

- *Consumer*. She has purchased a DAIAD kit (*or granted, or received co-financing*), installed it in her residence, and monitors her water consumption. She is assumed to own a mobile device (phone or tablet, with Internet connectivity and Bluetooth capabilities). Further, DAIAD may be installed in a single fixture, or multiple fixtures inside a residence. Similarly, multiple residence members my use DAIAD with the option of pairing their own mobile device or not.
- *Utilities* (Water and Energy). Access to customer data can help water utilities to *augment, improve, and evaluate* their water management practices. The key interest may differ between the companies, as some want to *increase* or *decrease* water demand, depending on environmental conditions and business targets formulated by their shareholders or local authorities. The same is valid for *gas* and *electricity* providers. However, as they mostly operate in more liberalized markets, they additionally have to focus on winning new and retaining existing customers as well as on *up-selling* (e.g. green tariffs with a higher margin) and *cross-selling* (e.g. add-on services). Therefore, these utilities want to use detailed consumer data for targeted marketing and enhanced business development purposes.
- *Privacy protection interest groups and related regulatory bodies.* These organizations advocate a careful usage of data that could possibly infringe consumer privacy. They promote aspects such as data ownership of the consumers, the right to delete data from files, and they aim to keep control

over personalized data in the hands of the consumers. Moreover, clear, easy-to-understand data protection policies are among their key objectives.

- *Citizen association/NGO*. These stakeholders include organizations that are active in sustainability issues. They want to promote sustainable consumption behavior and increase the awareness on the side effects of water consumption.
- *Local authorities*. These parties want to gain access to detailed consumption data (often in anonymized form to avoid privacy issues) in order to augment water management practices and to promote user participation regarding sustainability issues. As such, the motives are primarily rooted in existing/emerging issues regarding water and energy management.
- *Public authorities and regulatory bodies targeting water supply*. In addition to the reasons outlined for local authorities, public authorities and regulatory bodies have an interest in gaining better data to develop, evaluate, and select policy measures to implement fair and sustainable practices regarding water supply and billing.
- *Mobile apps and Internet of Things (IoT) developers*. Software and hardware developers want to disseminate and sell products and software applications that provide added value to the customers. For them, open interfaces to retrieve consumption data are important. Equally important are trusted mechanisms that allow the consumer to grant access to their consumption data.

3.1.2. UC1 –Installing DAIAD@feel

The consumer installs the DAIAD@feel in a fixture following the provided printed visual instructions, requiring no tools, nor calibration. In case the device includes an in-situ DAIAD@know component, as soon as water runs through the fixture, information is displayed in *real-time* to the consumer (*water and energy consumption, temperature, efficiency scale*). When a new extraction process starts after a pause longer than 2 minutes, the device resets itself, and again starts counting from zero. Any member of the household can use the device, without any action required.

In case the device does not include an in-situ DAIAD@know component, it first needs to be paired with a mobile device where DAIAD@home is installed.

3.1.3. UC2 –Installing DAIAD@home

The consumer installs DAIAD@home in the same manner as with any other mobile application, by sim ply visiting the application store available in her mobile device. The first time the application is installed the consumer has the option of signing in with an existing account (e.g. Facebook, Twitter) or create a set of credentials (email, password). Further, she is informed that with the same credentials she can have access to a version of DAIAD@home over the Web, providing a more analytical overview of her data and activities.

3.1.4. UC3 –Pairing DAIAD@home

The consumer has the option of pairing her *mobile* device with DAIAD@home, so that information from DAIAD@feel can be provided to non-integrated DAIAD@know interfaces, analyzed, or shared. The consumer must be in possession of Bluetooth-enabled (*BT 4.0 or newer*) mobile device (phone, tablet) and must previously have installed DAIAD@home to her mobile device. The consumer must open DAIAD@home in her mobile application and let water pass in the fixture where DAIAD@feel is already installed. Pairing is performed either with a sequence of *timed water on-off events*, or a PIN, according to provided instructions. The consumer verifies the proper pairing by viewing in real-time information from DAIAD@feel (*water and energy consumption, temperature, efficiency scale*).

The same process can be *optionally performed* with other mobile devices (e.g. tablet, mobile phones of other household members). This enables them access to real-time and historical information when they operate the fixture. Further, should the user have more than one DAIAD@feel devices installed at different fixtures, she is required to perform the same operation for each fixture.

3.1.5. UC4 –Data transmission

Data from DAIAD@feel are transmitted to DAIAD@home in an *opportunistic manner*. This happens completely opaque to the consumer, with the purpose of hiding potential connectivity issues. First, DAIAD@feel always maintains in a non-volatile memory data for a finite number of past water consumption events, uniquely identified. Then, if the mobile device is in BT-proximity with DAIAD@feel during a consumption event, *real-time* information is transmitted and stored to DAIAD@home, along with past water consumption events stored in the non-volatile memory. DAIAD@feel uses the unique identifiers of past events to maintain data consistency and non-duplication. The same process also serves the case where more than one mobile device is paired with DAIAD@feel.

Data from the mobile device are then sent over to the DAIAD@home web application whenever the mobile device has Internet connectivity.

3.1.6. UC5 –Alerts

The consumer may set alerts that help to keep track of saving targets, or be informed about events requiring her attention. The consumer may select from DAIAD@home a predetermined list of specific thresholds (*e.g. flow rate over a given limit, shower duration over 20min*) or events (*e.g. succeeded average water consumption lower than the national average*). Notifications are sent based on *user-defined* preferences to the mobile device, by email or in social media.

3.1.7. UC6 – Real-time interventions

The consumer is provided through DAIAD@know with real-time information regarding her water consumption (*volume of water used, temperature of water, energy consumption from hot water*), in addition to interventions visualizing in a *naïve* and easy to understand manner aspects of her consumption behavior. These stimuli are informative and educative in nature, aiming to enable the consumer to associate her consumption behavior with the actual impact in water and energy use. Further, the consumer may also receive automatic alerts/recommendations or user-defined alerts during an actual water consumption event in the case of the web and mobile versions of DAIAD@know.

3.1.8. UC7 – Exploring water use

The consumer has access through the *web and mobile versions* of DAIAD@know to historical water consumption data, simple exploration and analysis tools, automatically-extracted indicators, and recommendations for improving her consumption behavior. The consumer may explore this information at any time, and share the provided data/insights through social media. The mobile version of DAIAD@home provides a *concise* representation adapted to the smaller screen real-estate, with additional options and information being available in the web version of DAIAD@home.

3.1.9. UC8 –Sharing information

The consumer *at any point in time* may select to publicize over the Web her *water consumption* and *goals achieved*. Information may be shared *anonymously*, or associated with the user's *provided social identity* (e.g. Facebook, Twitter). In the first case, information is anonymized *by default* to protect user privacy; geographical location is obfuscated to the city-level and the only public set of demographics include age group (e.g. 18-25, 26-35) and household size (e.g. 1-2, 3-5, 6+). Further, information is not publicized in real-time, but after a *quarantine* period of 1 month (*e.g. September's data shared on December 1st*). The data are available through DAIAD's web services.

If the consumer has selected information sharing linked with her social identity, she has the following options per type of information. All sharing restrictions in granularity and accuracy are included in the system as a *failsafe* to protect the privacy of novice and uninformed consumers:

- *Water consumption* may be *periodically* and *automatically* shared in *1-month* aggregated data sets. The data are available through DAIAD's web services. Note that the consumer can always download her full water use data and share it in her own accord.
- Goals achieved (e.g. reduced water consumption by 20%, shower duration below the national average) may be periodically and automatically shared in social media after a 1-day quarantine period. The consumer has also the option to instantly share specific goals achieved through the DAIAD@home application with a simple selection (i.e. share-to button).

3.1.10. UC9 – Uninstall DAIAD

The consumer can remove DAIAD@feel from the fixture at any given time following the installation steps backwards. The device can be stored or moved to another fixture. Further, the consumer can uninstall DAIAD@home from her mobile device at any given time, and use only the in-situ DAIAD@know for monitoring her water use. The consumer is requested whether a copy of her data should be saved; if the response is negative, all relevant information is removed from DAIAD servers.

3.2. Commons

3.2.1. Scenario description

An arbitrary number of consumers (2-10,000) that have installed DAIAD in their residences decide to form a community (*Commons in DAIAD terminology*) and thus share their water consumption, generate insights, publicize and *gamify* their consumption behavior. A Commons is formed in the basis of local proximity (e.g. building block, neighborhood), environmental awareness (e.g. active citizens), participation in existing groups (e.g. Citizen Associations, NGO), or in an entirely ad hoc basis (e.g. consumers not even in the same country).

Consumers are supported in match-making for forming a Commons through a dedicated DAIAD's web-site (create a new, join an existing). A consumer can enter and exit (opt-out) from a Commons at any time, with a simple selection in her DAIAD@home device (mobile phone). Commons can also be consolidated (joined) and broken in its original members at any time. Further, Commons can decide to share its data with other stakeholders, or cancel a sharing agreement at any time. Self-regulation and moderation regarding the lifecycle of Commons and potential abusive behavior is handled entirely by the Commons members with no external intervention.

3.2.1.1. Stakeholders

- *Consumer*. She has purchased a DAIAD kit (*or granted, or received co-financing*), installed it in her residence, and monitors her water consumption. She decides to participate in a Commons either due to curiosity, self-belief, or third-party incentives.
- *Citizen Association/NGO*. It is an organization active in sustainability issues with an existing member or volunteer base. It wants to establish a Commons or have access to data of existing Commons. Insights from DAIAD will be used to acclimatize with water monitoring technologies, strengthen existing activities with actionable information, transfer and induce changes to the general population, or establish a new activity focused on water monitoring.
- *Local authority*. It wants access to Commons data in order to augment its water management practices, or promote personal responsibility and participation in sustainability issues. As such, its motives can be stem from simple curiosity/forward-thinking or existing/emerging issues in water/energy management.
- *Public authority/Regulatory body*. It is a body with a national/EU level reach in charge of policy or regulatory measures for water and/or energy resource management. It wants access to Commons data for similar intents and purposes with a Local authority. However, its extensive geographical reach introduces needs for tapping into Commons data and gaining insights on a massive scale.
- *Utility*. (Energy/Water). A water utility wants access to Commons data in order to augment, improve, or evaluate its water management practices. For an energy utility, its interest lies in reducing hot water consumption and thus energy demand/CO2 output (e.g. incentives to consumers, adjustments in pricing, introduction of solar water heating). In both cases, these stakeholders are not considered committed to the DAIAD system, and simply explore its potential uses and impact. Consequently, they do not have access to DAIAD@utility (*specialized big data analysis*) but must be encouraged to adopt DAIAD in a larger scale through simple pathways and options (e.g. co-finance/award DAIAD, trial access to DAIAD@utility, training courses).

3.2.2. UC1 – Commons creation

A consumer publicizes its intent to create a new Commons through the DAIAD@commons service. The consumer can have any official capacity (e.g. NGO representative, community coordinator), but this does not affect the provided facilities (i.e. *equal access to all consumers*). The consumer provides a targeting for the Commons (e.g. specific building, area, NGOs), additional information (*e.g. name, social/physical meeting points*) and publicity status (*e.g. data sharing by default, anonymous members, obfuscated geographical locations*). The Commons is created instantly, and instantiated with data from the founding consumer. The newly established Commons is available in a public catalogue in DAIAD@commons. Further, consumers are automatically notified based on geographical proximity and/or thematic preferences.

3.2.3. UC2 – Consumer enters a Common

A consumer visits DAIAD@home (*mobile app*) or DAIAD@commons (*web site*) and searches for an existing Commons through its catalogue service based on various criteria (e.g. *geospatial, thematic, number of members, creation date*). Further, DAIAD@commons provides recommended Commons based on the user profile (*match-making*). For each Commons, the consumer can gain an overview of its activity and compare it with similar (e.g. geographical, size) Commons. The consumer can join a Commons based on of a simple selection. A notification appears displaying in simple terms the acknowledgement of the membership (e.g. data sharing, self-regulation obligation), which the consumer must implicitly accept. Beyond this point, the consumer's data (real-time/historic) are instantly shared with the Commons group and DAIAD@commons provide a visible reminder of the membership. Finally, there is no limit regarding the number of Commons a consumer can simultaneously *participate* in.

3.2.4. UC3 – Consumer exits a Common

The consumer can exit a Commons she already participates in at any given time, either through DAIAD@home or DAIAD@commons. Justification for opting out is optional, and exit from a group takes place immediately.

3.2.5. UC4 – Commons insights and analytics

Any user (i.e. visitor, not a Commons member) can visit DAIAD@commons to gain an overview of the activity of existing Commons. This public information contains solely aggregated statistics and *gamified* indicators to solicit interest. Examples include: number of members and evolution over time, aggregated water consumption over time, water saving champions (*anonymized*), achievements-reached (e.g. 10% collective reduction) and experience gained (e.g. based on continuous participation of members), money saved over time (due to reduction in water/energy), compare activity with other Commons. At all cases, no personal information or data that can potentially lead to the identification of actual users is provided.

Members of Commons have more finely-grained access to the above facilities (i.e. at the consumer level) at their disposal, and means to motivate their peers. They can examine the exact performance and activity of other users (*again, without access to personal information*) per type of consumption and basic demographics, promote their achievements and participation through social channels (e.g. *share-it* functionality across analytics), and set collective goals (e.g. 20% more members, 30% less energy for showers). Further, they can share information with other users (*private forum*) to exchange experiences, issues, and ideas.

3.2.6. UC5 – Access to Commons data

An external stakeholder (i.e. non-Commons member) visits DAIAD@commons, identifies existing Commons and requests access to the data they generate. Depending on the conditions stated/agreed by the founders of the Commons (UC 1) the stakeholder must provide a short explanation regarding the request (e.g. commercial, scientific), assign a point of contact for any inquires the Commons members have, and accept standardized access terms (e.g. no reselling, no use beyond initial purpose, acknowledgement of the source). The Commons members are notified accordingly and the request is automatically granted if after a period of 24h at least 20% (or any other percentage defined by the commons members) of the group have not explicitly declined. The stakeholder has access to data through DAIAD's Data API (*anonymized*) and only regarding real-time information (historical data will not be provided). Access to the Common's data can be invoked at any given time when more than 20% of the Commons members have requested so.

3.2.7. UC6 – Commons management

Commons do not have any owners, including their founding member. Each member has access to her account, where she can edit personal information, vote on pending issues (e.g. oppose/invoke a sharing request), and remove herself from a Commons. Further, members can create one of the following standardized polls: (a) remove a specific user (e.g. abusive behavior), (b) shut-down the Commons, and (c) invoke data access to an external stakeholder. Other members are notified to participate and decisions are taken if YES votes exceed e.g. 20%, 50%, and 20% respectively.

3.3. NGO

3.3.1. Scenario description

A Non Governmental Organization (or Citizen Association), active on water efficiency and/or broader sustainability issues, is applying DAIAD across its members and/or active citizens. There are two major deployment and use directions, which can co-exist and complement each other. First, the NGO may simply *tap into existing Commons* groups and/or create a new Commons. As such, the NGO is simply repurposing data from existing consumers and has access to the DAIAD analysis facilities and knowledge extraction services. Optionally, the NGO may also distribute DAIAD kits to a *selected user population* and either monitor its data alone or in addition to data provided by existing Commons. The latter case supports focused studies and roll-outs of DAIAD which may also be co-financed or sponsored by a third party (e.g. government, local municipality, water utility, private company). In both cases, the NGO has access to the DAIAD analysis tools, for monitoring water consumption, extracting actionable insights, and collecting evidence for policy-making.

The purpose of applying DAIAD could be one or more of the following: (a) monitor and analyze a specific geographical area challenged by *water shortage* problems, (b) perform an *awareness* campaign for a local population, (c) gain highly granular data and demand models for given area.

3.3.1.1. Stakeholders

- *Existing DAIAD consumer*. She has purchased a DAIAD kit (*or granted, or received co-financing*), installed it in her residence, and monitors her water consumption. She is a member of one or more Commons, and thus sharing her water consumption data.
- *Citizen*. She is not a DAIAD customer, but is given a DAIAD kit to participate in an NGO-organized study and/or roll-out. She is required to install in her residence and join a Commons. The criteria

for selecting each citizen are unknown (e.g. *even a simple draw*), as are her technological literacy and sustainability sensitivity. As such, she is considered the *most challenging user* of DAIAD, as she will require the least amount of installation and use effort.

- *Volunteer/active citizen*. She is not a DAIAD customer, but is given a DAIAD kit to participate in an NGO-organized study and/or roll-out. She is required to install it in her residence and join a Commons. Her volunteer status implies a heightened level of awareness and thus motivation for installing and using DAIAD. However, technological skills may also be limited.
- *NGO/Citizen Association*. It is an organization active in sustainability issues with an existing member or volunteer base. It wants to apply DAIAD and integrate it in studies, awareness campaigns, or evidence-based policy making. Insights from DAIAD will be used to familiarize with water monitoring technologies, strengthen existing activities with actionable information, transfer and induce changes to the general population, or establish a new activity focused on water monitoring.
- *Third Party*. For the purposes of this scenario, all other stakeholders are considered as third-parties, and as such have no direct involvement over how DAIAD is being applied. However, they may provide indirect support in the form of: co-financing/sponsoring DAIAD kits, providing access to additional data (e.g. from smart water meters), support awareness campaigns, use insights gained for decision/policy-making.

3.3.2. UC1-NGO establishing a Commons

An NGO publicizes its intent to create a new Commons through the DAIAD@commons service. The NGO provides a targeting for the Commons (e.g. specific building, area, NGOs), additional information (*e.g. title, social/physical meeting points*) and publicity status (*e.g. data sharing by default, anonymous members, obfuscated geographical locations*). The Commons is created instantly. The newly established Commons is available in a public catalogue in DAIAD@commons and in a prominent position. Further, consumers are automatically notified based on geographical proximity and/or thematic preferences. The NGO has access to all data and services of its Commons.

3.3.3. UC2-NGO requesting access to data

In addition to creating a new Commons, the NGO may request data from existing Commons and/or existing DAIAD consumers. In the first case, the NGO simply follows the process established for external stakeholder access in a Commons. The exception is that Commons members may decide to share their historical consumption data, with each consumer taking that decision herself. For the second case, the NGO may also try to initiate and unite *different users* who might not necessarily be in the same Commons, (i.e. *very low water users with very high water users*), as a method to see how they interact and exchange knowledge but also to yield any positive outcomes this might have. The NGO visits DAIAD@commons, and provides a set of *predefined criteria* (*e.g. average water consumption, location, demographics*) for potential consumers and a population targets (e.g. min 20, max 100). The NGO must provide a short explanation regarding the request (e.g. commercial, scientific), assign a point of contact for any inquires the consumers have, and accept standardized access terms (e.g. no reselling, no use beyond initial purpose, acknowledgement of the source). The system automatically selects the appropriate consumers and notifies them for the request. Consumers must manually approve the request. If they have not responded over a 7-

day period, the request is implicitly considered as declined. Finally, consumers may invoke at any given time the access to their data.

3.3.4. UC3-Data analysis and knowledge extraction

The NGO (*as any non-Commons member*) can visit DAIAD@commons to gain an overview of the activity of existing Commons. When the NGO has initiated a Commons itself, and/or has been granted access in existing Commons, and/or specific users have granted access to their data, it has the more finely-grained access provided to all Commons members. Additional facilities include downloading historical data (*socio-demographics*, *consumer interactions* and *water consumption information*) in simple formats (e.g. MS Excel, CSV, SPSS) for further analysis. This information would be used to begin to draw out trends about consumers who use DAIAD.

3.4. Utility

3.4.1. Scenario description

Utilities comprise *water* companies as well as *gas* and *electricity* providers. Depending on the country, the utility itself or dedicated, independent metering companies collect and pre-process consumption data, either manually or electronically. Also depending on the supply area, utilities may sometimes provide both electricity and water (*and sometimes even gas and district heat*), and may use *synergies* in their meter-to-cash processes to keep the costs down. Yet another important difference among supply areas/countries relates to the degree of market liberalization and thus the possibility of the end customer to change providers. The latter fosters competition, and consequently advanced tariffs, better service quality, and additional product offerings become a major concern of the market players.

Our main target group is *water utilities* which need to offer attractive products to their customers, improve customer satisfaction, and aim at managing water supply in a sustainable way. Doing so, they are confronted with the challenge of supplying high-quality drinking water at low cost and, at the same time, manage the sources of their water sustainably, such that the supply can be maintained over a long period of time. Our secondary target group is energy utilities, which may also be interested in water conservation to the extent that *hot water* is concerned. This is the case since electricity providers – more often than their counterparts from the water domain – have to avoid extended (peak) energy consumption in times of low supply (e.g. no sun, no wind).

A utility may apply DAIAD in one of the following ways of *increasing involvement*:

- Request *access to data* from existing Commons in its geographical area of reach. Its purpose is to tap into highly granular water/energy consumption information, experiment with the provided analysis services and DAIAD's facilities.
- Purchase and distribute DAIAD equipment to a sample of its customers, either to evaluate the technology and its potential impact, or to study water/energy consumption in a representative population and extract insights that can be applied for its entire customer base.

- Subsidize DAIAD for its customer base, either to raise *awareness* on sustainability issue, or have access to highly granular water/energy consumption information.

3.4.1.1. Stakeholders

- *Utility.* It is a private or public company, offering water and/or energy to customers (*100K-5M*) in a given geographical area. It has a metering infrastructure in place and CRM/billing systems in operation. Beyond that, we make the assumptions of limited expertise in data management and a basic understanding of Water Demand Management. As such, we must support utilities operating *from and beyond* this low technical and knowhow foundation.
- *Utility customer*. She is a customer of the utility, with or without the option of selecting a different utility to serve her water/energy needs. She *at least* receives periodic bills presenting her water consumption and to the respective price. She is given a DAIAD kit to participate in a utility-organized study and/or roll-out. She is required to install it in her residence and join a Commons. The criteria for selecting each utility customer are unknown (e.g. *even a simple draw*), as are her technological literacy and sustainability sensitivity. As such, she is considered a *challenging user* of DAIAD, which will require the least amount of installation and use effort.
- *Commons*. Commons are groups of utility customers that have already purchased and installed DAIAD, and actively share their consumption information at their own accord. As such they share a common interest in using DAIAD, may serve as "*brand advocates*" and even offer customer support to other utility customers.
- *Privacy protection interest groups and related regulatory bodies.* These organizations advocate a careful usage of data that could infringe consumer privacy. They should be included in the development process at an early stage.
- *Local authorities*. Authorities are interested in innovative solutions offered in their region. They also want to improve the sustainability of demand and supply of water and energy and monitor the utilities' performance in accordance to this aim.
- *Public authorities and regulatory bodies targeting water supply*. Often in line with local authorities, public authorities and regulatory bodies have an interest in long-term sustainable and cost effective service provision while conservation and emission targets are met.
- *Mobile Apps and Internet of Things developers*. These developers want to disseminate and sometimes sell products and software applications that add value to the customers. For them, open interfaces to retrieve the data are important.

3.4.2. UC1 – Accessing DAIAD@utility

The utility may download DAIAD@utility and install it in a local infrastructure. The software must be initialized and populated with any required data. The utility has full control over the integration and migration processes of data, user management, performance, security and disaster recovery. Another option for the utility is to use DAIAD@utility as a cloud-based SaaS (Software-as-a-Service) deployment. In this case the utility maintains full control over its data and user management; all other aspects are handled automatically by the system.

3.4.3. UC2 – Evaluating DAIAD@utility

The utility wishes to evaluate DAIAD@utility analysis services without investing in DAIAD hardware and involving its customers. In this case, a utility representative creates an account in the SaaS version of DAIAD@utility, providing information regarding her evaluation intentions. She may also create credentials for additional users working in the utility which will also participate in the evaluation. The evaluation can be performed in two ways: (a) with *synthetic data*, provided by the system, or (b) with actual consumer's data provided by Commons. In the first case the user may select from several pre-defined synthetic datasets with parameters being population (100K, 500M, 1M), geographical location (South Europe, Northern Europe), and pricing (Greek, UK tariffs). In the second case the user must follow the process of requesting access to data from Commons; the system provides no guarantees that access to data will be given by Commons.

3.4.4. UC3 – Organize a DAIAD deployment

The utility has access to DAIAD@utility and *distributes* or *subsidizes* DAIAD kits to its customers. The acceptance of the equipment is explicitly escorted by the provision of their formal consent for (a) allowing the utility to store and analyze their data, and (b) accepting as *official* water consumption information the data generated by their water meter. The consumer is provided with detailed information as to which of her personal data are used, how this data is analyzed and what is done with the results. Further, it is explained who (including but not limited to the utility) will have access to the data/analysis results and in which form (e.g. anonymized, aggregated). Consumers then follow the processes described earlier regarding the installation and use of the system.

3.4.5. UC3 - Analysis

The utility applies DAIAD@utility in order to analyze water consumption information. Data sources may include any of the following: data from DAIAD users, historical water consumption data, third party data (*e.g. geographical, meteorological, demographics*). As such, the utility will be able to apply both highly granular data provided from DAIAD, as well as any other water consumption data it may have (e.g. from smart water meters). The utility applies the analysis and report functions in DAIAD@utility to extract water demand models for its population and perform what-if analysis across several parameters. Further, the utility can always extract reports from DAIAD and provide them as input to existing ICT systems and/or analysis processes.

3.5. Water Demand Expert

3.5.1. Scenario description

A water demand expert has access to DAIAD@utility and data and wishes to perform an arbitrary number of analysis steps. The expert may work under the capacity of a *utility* (permanent personnel or a commissioned service provider), a public administration (*again, similar working conditions apply*), or be an academic researcher. Consequently, the expert may have a specific targeting (*geographical, pricing, policy*), or simply explore the various parameters of water demand in search of important findings.

In order to carry out the analyses, the water demand experts need access to at least one part of the data stored in DAIAD@utility and of the results of all relevant analyses that have been conducted by the utility or other experts beforehand. The extent of this data access is subject to the capacity of the water demand expert; she may have access to actual utility's data, DAIAD data from utility customers, data shared from Commons, or a combination.

3.5.1.1. Stakeholders

- *Water demand expert*. She is considered highly proficient in theoretical and practical applications of water demand management. However, experience with big data collections and analysis services offered by DAIAD may be rather limited. Consequently, while she carries deep knowledge of methodologies and understanding of the goal of the analysis, she may not be familiar with full breadth of DAIAD capabilities.
- *Commons*. These are existing Commons approached by the expert with a request for accessing to their data, using the standard data-request processes.
- *Utility.* The utility is involved only when the analysis is performed on its behalf. In this case it is responsible to provide the water demand expert with the required data.
- *Privacy protection interest groups and related regulatory bodies* advocate a careful usage of data that could infringe consumer privacy. They should be included because data with restricted accessibility are given to a third party (i.e. the water demand experts) and analyzed by them.

3.5.2. UC1 – Initialize a study

In case the study is not supported by a utility operating DAIAD, the expert must create credentials in DAIAD@commons and send data sharing requests to Commons of her selection. The expert automatically has access to the SaaS version of DAIAD@utility, in which data from Commons become available when the access is granted. Further, the expert may reuse other public data integrated in DAIAD@utility, or upload her own data.

In case the study is supported by a utility operating DAIAD, the expert is provided with access to DAIAD@utility from the utility's responsible administrator.

3.5.3. UC2 – Analysis and exploration

Experts use data and DAIAD@utility analysis services to perform an arbitrary number/type of studies across a temporal and geographical span selected by them. The software supports them with analysis and reporting facilities, which may include identification of parameters influencing consumption, extraction of demand models, clustering population, etc. The expert has complete freedom over her analysis, can save intermediate results, and export them at any step of the process.

4. User Requirements

In this section we present the user requirements that will guide the development of the DAIAD system. The requirements were compiled by examining the online surveys, the discussion panels and one-to-one interviews.

Before we proceed, a high-level overview of DAIAD architecture is shown in Figure 67. The top level includes the DAIAD@feel module which provides real-time water consumption data. This data is used by the middle level that consists of three modules, namely DAIAD@home, DAIAD@commons and DAIAD@utility, which offer data analysis services to a single user, communities of users and water utilities respectively. Finally, at the bottom level, there is the DAIAD@know module that includes user interfaces for interacting with the DAIAD system.

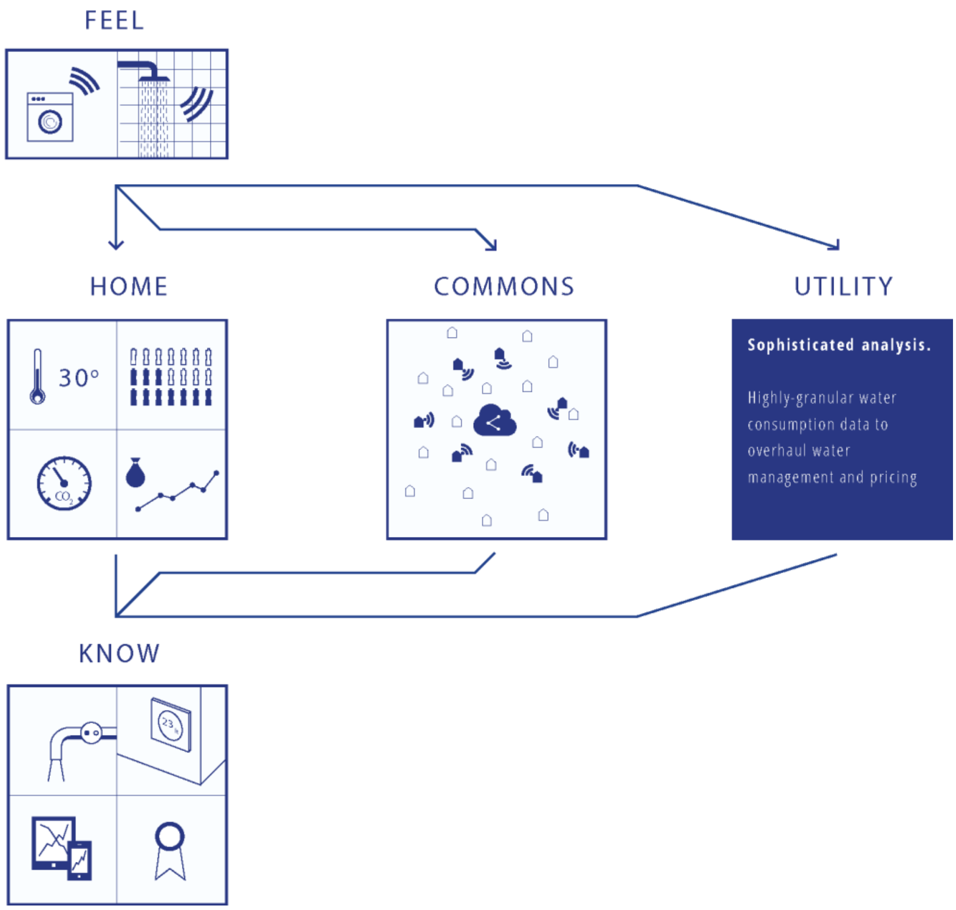

Figure 67: High Level Architecture Overview

4.1. DAIAD@feel requirements

Terminology	
Sensor idle state	DAIAD@feel sensor is in idle state when no water flow is measured for at least 2 minutes. DAIAD@feel sensor exits idle state whenever measurable water flow is observed.
Extraction Process	An extraction process is the time interval between two consecutive temporal events of exiting and entering the sensor idle state

DAIAD@feel	
Automatic resetting	When a new extraction process starts after a pause longer than 2 minutes; the device resets itself and starts a new measurement session.
Measurement: Water flow rate	DAIAD@feel will measure water flow rate in liters per second in real time.
Measurement: Temperature	DAIAD@feel will measure the temperature of flowing water in Celsius scale in real time.
Computation: Energy consumption	Using real time water flow rate and temperature measurements, DAIAD@feel will compute an estimation for the associated energy usage in kWh during an extraction process.
Computation: Water consumption	DAIAD@feel will compute the total water consumption of an extraction process.
Energy autarkic	DAIAD@feel will not require an external power source or integrated battery. It will generate the necessary power from water flow.
RF-connectivity	DAIAD@feel will support Bluetooth 4.0 (or newer).
Discoverability / Pairing	DAIAD@feel should be able to be discovered by and paired with other devices that support Bluetooth 4.0 (or newer).
Mobile device compatibility	DAIAD@feel will be RF-compatible with Android and iOS mobile devices.
Real-time data transmission	DAIAD@feel will transmit in real time measurements for water flow, temperature and associated energy usage.
Historical data	DAIAD@feel will maintain a record of at least the past 50 consumption events in non-volatile storage; consumption events will be identified uniquely.
Opportunistic transmission	A mobile device may request any subset of the historical data available during a current consumption event. The data are sent during the current consumption event, along with real-time data.
Localization	DAIAD@feel will be able to be localized w.r.t. measurement units and unit costs for different markets.
Autonomous operation	DAIAD@feel may operate autonomously when it is integrated with DAIAD@know, or RF-connected with an in-situ DAIAD@know component. In autonomous operation no data will be available to other DAIAD components; the user will receive information and stimuli only from the aforementioned DAIAD@know

DAIAD@feel	
	components.
Connected operation	DAIAD@feel may operate in a connected mode when it is paired with DAIAD@home. In connected operation data may be available to all DAIAD components; the user will receive information and stimuli from all available DAIAD@know components.
Data Transfer Security	Data will be protected with encryption to preserve user privacy.
Ease of use	DAIAD@feel will be easily installed by end-users, with no tools, expert assistance, or calibration required
Drinking water appropriateness	DAIAD@feel will have drinking water approval

4.2. DAIAD@know requirements

DAIAD@know	
Versions	DAIAD@know will be available in several versions of increased expressiveness, depending on its integration across DAIAD components. These versions are: (a) integrated display with DAIAD@feel, (b) in-situ component RF-connected with DAIAD@feel, (c) integrated with DAIAD@home (mobile/web), (d) integrated with DAIAD@commons (web), (e) integrated with DAIAD@utility (web).
Integrated display	The integrated display will automatically provide real-time consumption data and alerts from a set of pre-defined consumption events which are extracted from DAIAD@feel. The user will not be able to interact with the display.
In-situ component	The in-situ component will automatically provide simple stimuli to users, alerting them from a set of pre-defined consumption events which are extracted from DAIAD@feel. The user will not be able to interact with the display.
Mobile	Note: the relevant user requirements are integrated in the DAIAD@home section.
Web	Note: the relevant user requirements are integrated in the DAIAD@home, DAIAD@commons, and DAIAD@utility sections.

4.3. DAIAD@home requirements

DAIAD@home	
Availability	DAIAD@home will be available as a software for mobile devices (Android and iOS).
Supported devices	The UI and analysis capabilities will be adjusted accordingly to the available screen.
Installation	The consumer installs DAIAD@home by simply visiting the application store available in her mobile device.
Sign-in	The user will be able to create a new account or log in with an existing social media account. The same

DAIAD@home	
	credentials will be used for accessing all aspects of DAIAD@home.
Pairing	Pairing of DAIAD@home with DAIAD@feel will be performed either with a sequence of timed water on-off events, or a PIN. The user will provide information for the physical deployment of DAIAD@feel.
Multi-device support	Pairing of DAIAD@feel with different mobile devices operating DAIAD@home will be supported as to enable data access from different mobile devices and/or different users.
Multi-DAIAD@feel support	Pairing of DAIAD@home with different DAIAD@feel devices will be supported, as to enable monitoring across all points of consumption in a single residence, or across different residences.
Uninstall	DAIAD@home can be uninstalled at any given time. All user's data will be deleted upon the user's request; operation of DAIAD@feel is not affected.
Internet connectivity	DAIAD@home will require internet availability from the mobile device (WiFi or mobile network) in order to perform all cloud-based operations. Data transmission will be handled by the software depending on internet connectivity.
Localization	DAIAD@home will be automatically localized w.r.t. measuring units and UI language. The user may change localization preferences at any given time.
Local storage	DAIAD@home will locally store consumption data provided from the paired DAIAD@feel.
Cloud storage	DAIAD@home will support transmission and storage of consumption data to cloud storage for safekeeping, further analysis, and provision of web-based DAIAD@know interventions. The user will be required to provide her explicit consent, which may be revoked at any given time. In this case her data are deleted from the cloud storage.
Local Interventions	DAIAD@home will integrate local DAIAD@know interventions to inform users and induce changes in their behavior. These interventions will focus on immediate, real-time stimuli and exploration suitable for mobile devices.
Web Interventions	The user will have access to DAIAD@know web-based interventions to inform users and induce changes in their behavior. These will only be available if the user has enabled the cloud storage of consumption data. Web-based interventions will be of increased complexity and interaction, focusing on exploration and generating insights from historical consumption data.
Real-time data	The user will receive real-time information for her water consumption, water temperature and energy use. This information may be arithmetic, graphical, auditory or symbol-based, depending on the user's preferences.
Alerts	The user may select an arbitrary number of predetermined alerts, including thresholds, events and trends, which are automatically analyzed based on her consumption data. The alerts will be pushed to the user's mobile device, email, or social media, based on her preferences.
Recommendations	The user will receive recommendations for improving her water consumption. The recommendations can be provided in real-time, or presented at a later stage, depending on her preferences.
Indicators	The user will have access to statistics and indicators automatically calculated based on her water consumption. These will provide a '*one-glance*' overview of her consumption habits and may be arithmetic, visual or symbol-based.

DAIAD@home	
Trends	The user will be presented with automatically calculated trends based on her consumption, in addition to estimates of her future consumption.
Historical data	The user will have access to her historical water consumption data, with facilities enabling visualization and exploration.
Consumption classification	The user will be presented with information categorizing her consumption across several consumption events. The events will be identified automatically and will be accompanied with relevant recommendations.
User feedback	The user will be optionally requested to provide feedback on specific interventions. This information will be used to improve the analysis algorithms, recommendations, and personalization.
Profile	The user may provide information regarding her profile/preferences to improve the provided interventions
Multiple users	The user may indicate that she is not the only water consumer in the residence. In this case DAIAD@home will automatically attempt to identify individual users based on their water consumption habits and user feedback (if provided).
Data sharing	The user will be able to download and share her data/indicators through social networks. The extent of data sharing and anonymization will be decided by the user.

4.4. DAIAD@commons requirements

DAIAD@commons	
Availability	DAIAD@commons will be available as a web site, where the user will be able to search, create, register and unregister in several Commons groups.
Versatile group creation	Any user will be able to create a group at any time, with a simple selection in her DAIAD@home device. Also groups can be joined together and broken up.
Group participation	Any user can join and leave any group at any time. Terms of membership are shown to the user on registration. All user's data will be deleted upon the user's request, when leaving a group.
Membership eligibility	Any kind of user (consumer, active citizen, NGO, etc.) can create and participate in a group, with exactly the same privileges. A group will be managed by the members, no owner will exist and each member will be able to edit personal information, vote on pending issues, etc.
Sign-in	The user will be able to create a new account or log in with an existing social media account. The same credentials with DAIAD@home will apply.
Group initialization	The Commons group creator will provide information describing the group. These may include a targeting, additional information and publicity status.
Public group catalog	A catalog will provide a list with all available groups for users to join. Commons recommendations (match-making) will be available based on group and user attributes.
Localization	DAIAD@commons will be automatically localized w.r.t. measuring units and UI language. The user may change localization preferences at any given time.

DAIAD@commons	
Multi household/user/device support	DAIAD@commons will be able to access and process data from arbitrary DAIAD@commons members, upon their consent.
Group standardized polls	Members can create one of the following standardized polls: (a) remove a specific user, (b) shut-down the Commons, and (c) invoke data access to an external stakeholder. Decisions are taken if certain percentage thresholds are reached.
Parameterized group creation	A stakeholder will be able to create a Commons group by inviting users (already participating in Commons) that satisfy specific restrictions on a set of predefined indicators, including average water consumption, location and demographics.
Terms of use for parameterized group creation	The stakeholder-creator will assign a point of contact for any inquires the consumers have and accept standardized access terms. The users may accept or decline the invitation or revoke access to their data any given time.
Limited visitor data visibility	A non-member user can overview a group's anonymized activity and compare it with other groups. These data will include: number of members and evolution over time, aggregated water consumption over time, water saving champions, achievements-reached, and money saved over time due to reduction in water/energy.
Extensive members data visibility	Members of a group will have access to more detailed, but still anonymized, data. These will include exact performance and activity indicators of other users per type of consumption and basic demographics.
Extensive-anonymized members social functionality	DAIAD@commons will allow social facilities, including examination and comparison to the exact performance and activity of other users per type of consumption and basic demographics, promotion of their achievements and participation through social channels and setting collective group goals. Further, they can share information with other users (private forum) to exchange experiences, issues, and ideas.
Data API	A Data API will be provided to external stakeholders. The API will provide anonymized, real-time consumption information of the members.
Advanced Data API	Upon group members' consent, the Data API will further provide historical data regarding socio-demographics, consumer interactions and water consumption information.
Terms of use for Data API	Access to the Data API will be granted to external stakeholders if a percentage of group members do not decline it. Access can be revoked at any time by the members. The stakeholder will provide explanation regarding their access to the group's data and accept standardized access terms.
Cloud storage	DAIAD@commons will store and process consumption data in cloud infrastructures.
Web Interventions	DAIAD@commons members will be able to inform other members and induce changes in their behavior. Web-based interventions will be of increased complexity and interaction, focusing on exploration and generating insights from historical consumption data.
Motivation functionality	Means of motivation and gamification will be available to members of a group.
Private forum	A private forum will be available for members to discuss their goals, achievements, interventions, news, etc.

DAIAD@commons	
Data sharing	The user will be able to download and share her data/indicators through social networks. The extent of data sharing and anonymization will be decided by the user.
Recommendations	DAIAD@commons will provide recommendations on user consumption, based on collaborative analysis of consumption data from several users. Clustering techniques will be applied to identify subgroups of similar users in several levels (proximity, demographic similarity, similarity of consumption patterns, etc.) and produce the corresponding recommendations for consumption behavior changes.
Personalized recommendations and interventions	DAIAD@commons will explore user provided profiling information and group consumption data and metadata to provide personalized recommendations and interventions for the user.
Consumption statistics	DAIAD@commons members will be able to explore their historical consumption data and anonymized data from the other group members and extract aggregate data.
Indicators	DAIAD@commons will have access to statistics and indicators calculated based on her water consumption. These will provide a 'one-glance' overview of her consumption habits and may be presented in several visualization ways.
Trends	DAIAD@commons members will be provided with automatically calculated trends based on their consumption, as well as aggregate (average) or analytical consumption trends of other group members, allowing the estimation of their future consumption and the comparison with group members in several levels.
Historical data	DAIAD@commons members will be able to explore their historical consumption data and anonymized historical data from the other group members.
Advanced exploration and querying capabilities	DAIAD@commons members will be able to query the available consumption data, with a set of predefined-configurable queries and filter the results w.r.t. several predefined variables, including time, demographics and thresholds on consumption values.
Data visualization	DAIAD@commons will provide several data visualization options including charts, trend diagrams, analytical tables, symbols, faceted filtering of data.
User feedback	Optionally the user will be requested to provide feedback on specific interventions. This information will be used to improve the analysis algorithms, recommendations, and personalization.
Collaborative consumption classification	The user will be presented with information categorizing her consumption across several consumption events. Collaborative knowledge from several DAIAD@commons users will be used to achieve more precise event categorization and behavior comparison, thus inducing consumption behavior changes.
Forecasting	Forecasting and what-if analysis based on WDM models and historical water consumption and contextual data will be supported.
Results visualization	The system will be able to provide visualizations of the results in the form of (a) charts and graphs, presenting several facets different granularities of data and metadata, (b) simple and intuitive efficiency indicators, (c) tables containing analytical and aggregate consumption data, (d) symbols.
Privacy and anonymization of user data	The system should ensure privacy of user data, when required by the user. User location, demographics and time of measurement will be obfuscated to strengthen the anonymity of users.

4.5. DAIAD@utility requirements

DAIAD@utility	
DAIAD@common functionality	DAIAD@utility will incorporate DAIAD@common's functionality, w.r.t. data storage, processing and analysis, including trend identification, what-if analysis, forecasting, clustering and classification and group/user management. Further, it will extend several analysis functionalities to address the specific needs of water stakeholders regarding the exploration, design and validation of Water Demand Management strategies.
Installation/deployment options	DAIAD@utility will be available in two versions for installation: (a) local installation, where the software will be initialized and populated with any required data and the stakeholder-user has full control over the integration and migration processes of data, user management, performance, security and disaster recovery; (b) as a cloud-based SaaS (Software-as-a-Service) deployment, where the stakeholder-user maintains full control over its data and user management.
Dataset access	The user may obtain synthetic datasets with pre-defined parameterizations, such as population (100K, 500K, 1M), geographical location (South Europe, Northern Europe), and pricing (Greek, UK tariffs), or ask access to real user consumption data from DAIAD@commons.
Data integration	Integration of other third sources that may provide geographical, meteorological data, demographics or smart water meters data will be supported. Demographics should have higher priority.
Advanced analysis capabilities	The system will allow advanced facilities, including identification of parameters influencing consumption, extraction of demand models, clustering population, what-if analysis.
Advanced modeling capabilities	DAIAD@utility will provide services that allow stakeholders to explore the hidden correlations of the parameters that shape water demand strategies and water pricing, including interactive parameterization of processing algorithms and interactive selection of variables for building the WDM model.
Query functionality	The stakeholder-user will be able to submit custom queries to the data and the results of the analysis produced in a specified query language.
Predefined queries	A large set of predefined, configurable queries will be available to the stakeholder-user, including aggregate, filtering and join queries.

5. DAIAD Architecture

5.1. Introduction

In this section, we present the DAIAD architecture and explore possible solutions to the challenges enacted by the user requirements. Initially, we present an overview of the DAIAD logical architecture, identify the main DAIAD hardware and software modules, and establish the dependencies and data flow paths between them. Next, we provide a more detailed view of each module and investigate different architectural solutions, enumerating the advantages and drawbacks of each one. Finally, we describe the software integration practices to be applied, the deployment scenarios of the DAIAD system, and our test setup.

5.2. Logical Architecture

In this section, we introduce a high-level overview of the DAIAD logical architecture and identify the main data flow paths in the DAIAD system. The logical architecture of DAIAD is depicted in Figure 68 and consists of three layers, namely Data acquisition, Storage and Analysis, and Presentation.

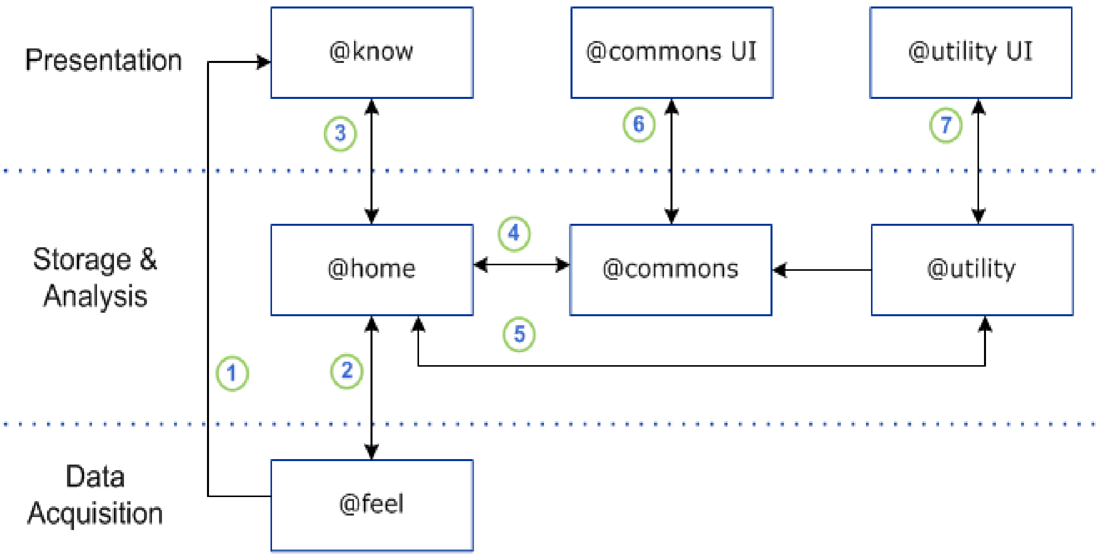

Figure 68: Logical Architecture

The first layer contains a single module, DAIAD@feel.

- **DAIAD@feel** is a sensor device installed at water extraction points that collects real time water consumption data. DAIAD@feel is the most critical module of the DAIAD stack since its proper functionality allows accomplishing the main goal of the DAIAD project, i.e. acquisition and analysis of highly granular real time water consumption data.

Data from DAIAD@feel is used by the next layer, which consists of three modules, namely DAIAD@home, DAIAD@commons and DAIAD@utility.

- **DAIAD@home** is responsible for connecting to DAIAD@feel sensors and downloading any available data. Once data is successfully downloaded, DAIAD@home can perform analysis on local data collected from one or more sensors and generate recommendations and alerts for the user. Optionally, if the user has given her consent, data is uploaded to DAIAD@commons and/or DAIAD@utility.
- **DAIAD@commons** is a social and collaboration platform that allows users to form communities and share their water consumption data. DAIAD@commons exchanges data with DAIAD@home instances installed on registered user's mobile devices. It offers more advanced analysis features that generate recommendations and alerts based on data spanning the whole community. Moreover, DAIAD@commons provides reliable secondary storage for the user's historical data. Users can browse and download their historical data using any implementation of DAIAD@know applications.
- **DAIAD@utility** offers advanced functionality for supporting water demand management needs. DAIAD@utility collects data from both DAIAD@home installations for registered users and DAIAD@commons communities. Further, it integrates and manages several third-party datasets for analysis (e.g. geographical, SWM data, historical water consumption data).

Finally, the last layer is the presentation layer which is responsible for conveying stimuli regarding water consumption, and enabling knowledge extraction. This role is served by **DAIAD@know**, whose appropriate instantiations are integrated in the DAIAD@feel, DAIAD@home, DAIAD@commons, and DAIAD@utility.

5.2.1. Components

In this section, we present a more detailed view of all DAIAD modules. Each module is collapsed to its basic components and a description is given for their functionality, their relationships and dependencies with other components, their external interfaces and the associated design decisions and their rationale.

5.2.1.1. DAIAD@feel

DAIAD@feel in its simplest form is an energy autarkic sensor that measures real-time water consumption at the fixture level. In this section we do not examine the mechanical design of the sensor, but instead we focus on the *least functionality* a sensor should provide to external modules for satisfying the main use cases described in Section 4.1.

Since data transmission is opportunistic, DAIAD@feel should be able to store measurements of past consumption events to avoid data loss. Data will remain stored until a connection is established to DAIAD@home. To that end, non-volatile memory must be integrated into the sensor for storing historical data. This data will be kept until either it is safely uploaded to a paired DAIAD@home client, or until there is no more memory space for storing new measurements. In the former case, the DAIAD@home client may request the removal of stale data. In the latter, the oldest data will be overwritten. Every consumption event will be stored alongside a unique identification number generated by the sensor. This number will be unique per device and will allow DAIAD@home to distinguish redundant data transmissions.

DAIAD@feel will support the Bluetooth Low Energy (BLE) standard for uploading data. BLE provides functionality for discovering, pairing and exchanging data with other Bluetooth enabled devices with significantly low power consumption. If no suitable Bluetooth profile exists for water metering, a custom BLE profile will be developed that will offer services for uploading data to a client. Moreover, novel and well documented procedures will be established for pairing a DAIAD@feel sensor with a BLE enabled mobile device hosting DAIAD@home.

5.2.1.2. DAIAD@home

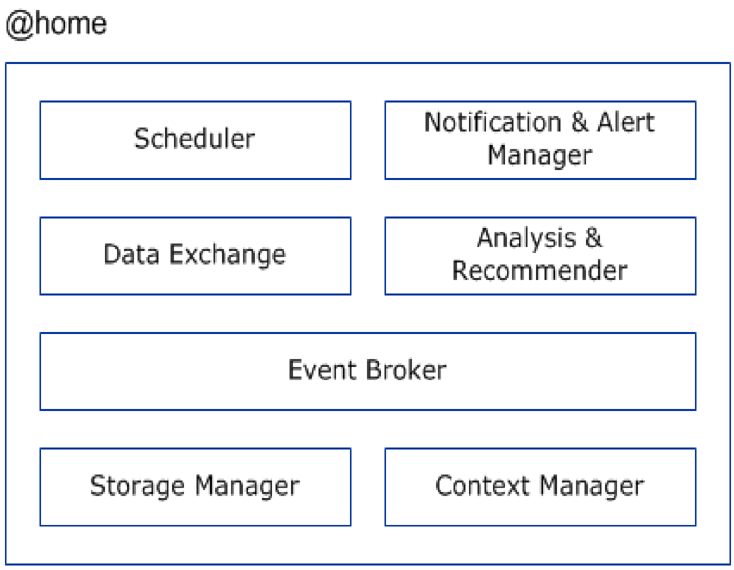

Figure 69: DAIAD@home architecture

The DAIAD@home architecture is depicted in Figure 69. The main components of DAIAD@home are:

- The **Storage Manager** offers persistence functionality to the rest of DAIAD@home components. It stores measurement data from DAIAD@feel devices, historical measurement data, application configuration settings and user preferences, intermediate and final results from local data analysis, user specific recommendations, notification settings, and server-side data that may be downloaded for enhancing local analysis and recommendation processing.
- The **Context Manager** observes Wi-Fi and Bluetooth connectivity status, battery status, device idle state and available storage space. When a change is noticed or a specific threshold is reached, it triggers appropriate events using the Event Broker. Other DAIAD@home components receive these events by subscribing to the Event Broker.
- The **Event Broker** implements a messaging system using the publish/subscribe pattern, that allows DAIAD@feel components to be loosely coupled. Instead of having every component registering callbacks to all the components it interacts with, it only subscribes for specific events from the Event Broker. The Event Broker simplifies event handling by centralizing the message exchange process. Among others, the events published by the Event Broker include: Wi-Fi connectivity status

changes, Bluetooth connectivity status changes, battery low status, sensor data exchange completion, server data download completion, analysis processing completion, and recommendation processing completion.

- The **Analysis** component provides lightweight implementations of the analysis and recommendation algorithms that will be developed in the context of the DAIAD project. It subscribes to the Event Broker for receiving events when (a) consumption data is uploaded from any paired DAIAD@feel sensor, (b) analysis results are downloaded from DAIAD@commons, (c) a user changes his preferences and notification settings and (d) battery low status is detected.
- The **Notification Manager** allows a user to create, enable and disable notification events by combining a set of pre-determined rules that use specific parameters computed either by the local analysis engine (*e.g. daily total water consumption of the user*) or by the server analysis engine (*e.g. weekly average water consumption compared to other users*). Moreover, system alerts are supported in order to inform the user about recommendation results or events that may require her attention (*e.g. unusual spikes in water consumption*). The Notification Manager subscribes to the Event Broker for receiving events when analysis and recommendation results are available.
- The **Data Exchange** component encapsulates all the logic for data transfer operations required by DAIAD@home. Data transfer operations include discovery, pairing and data exchanging with BLE enabled DAIAD@feel sensors, measurement data uploading to DAIAD@commons and DAIAD@utility, and downloading analytical results/recommendations computed at the DAIAD backend for enhancing the local analysis and recommendation engine. Whenever any of the aforementioned tasks is completed, an appropriate event is published to the Event Broker.
- The **Scheduler** is responsible for supervising the execution of asynchronous tasks. The scheduler's primary job is the initialization of data exchange tasks at specific intervals set by the user preferences or when specific events occur (*e.g. the free storage space is running low or Wi-Fi connectivity has been detected*). The Scheduler will subscribe to the Event Broker for receiving events from the Context Manager.

5.2.1.3. DAIAD@commons / DAIAD@utility

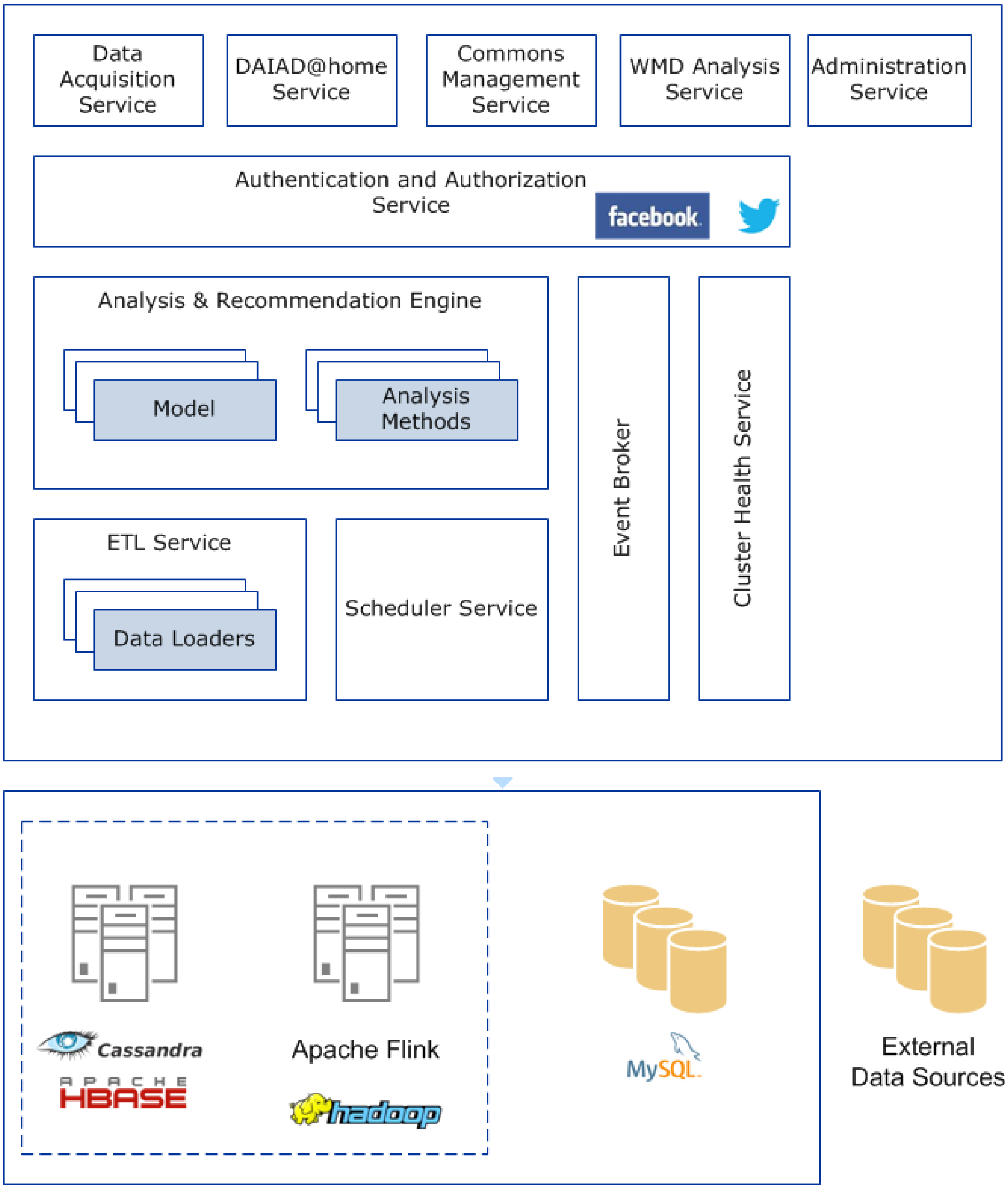

Figure 70: DAIAD@commons and DAIAD@utility architecture

DAIAD@commons and DAIAD@utility share the same architecture but differ on the analytical functionality they offer and the user interface they present. The main components of the architecture are depicted in Figure 70.

- The **Authentication and Authorization Service** controls user access to DAIAD offered functionality by managing user accounts and assigning permissions. Users can either create an account using an email address and password, or sign-in with an existing Facebook or Twitter account. For DAIAD@utility only the first option will be available. Moreover, when a user creates an account for

DAIAD@utility, the account is not activated immediately. Instead it is activated after the intervention of an administrator who validates and acknowledges the account creation.

- The **Data Acquisition Service** handles data uploading requests from DAIAD@home clients and stores water consumption data in a NoSQL database. In order to upload data successfully, the clients should present valid credentials and each measurement should be tagged with a unique DAIAD@feel device identifier.
- The **ETL Service** is responsible for executing all data curation tasks including data archiving and data pre aggregation. Additionally, if workload isolation is implemented (i.e. storing real-time data from DAIAD@feel and analysis data from DAIAD@commons and DAIAD@utility in different stores), the ETL Service will synchronize the two stores. The ETL service will also use various data loaders in order to consolidate data from external data sources, like demographic and meteorological data, into the DAIAD database.
- The **Scheduler Service** schedules and orchestrates the execution of maintenance tasks including ETL tasks. The Scheduler service will use information from the cluster's health service (see below) to throttle task execution.
- The **Analysis and Recommendation Engine** is responsible for executing analysis requests like Hadoop Map Reduce jobs or what-if queries. It implements algorithms for analyzing data and stores information about analysis models. Analysis results are stored in the DAIAD NoSQL database.
- The **Event Broker** implements a messaging system using the publish/subscribe pattern, that allows DAIAD services to communicate in a loosely coupled manner. For instance, if the cluster health service detects that computing resources drop below a specific threshold, it can inform the scheduler service to adapt its scheduling policy.
- The **Cluster Health Service** collects data from different components of DAIAD and provides a unified view of the cluster status. This information can be used by the administration service to generate notifications. Likewise, DAIAD@utility UI can use this information to compose insightful dashboards for system administrators. In general most systems like HBASE, Cassandra, MySQL that are presented in Section 6.2 provide a service for reporting system status. Nevertheless, for day to day operations, a mashup of these services is more productive.
- The **DAIAD@home Service** handles requests from DAIAD@home clients. Among others, the requests handled by the DAIAD@home service include: downloading historical data, fetching analysis results and notification data from DAIAD@commons, managing DAIAD@commons operations etc.
- The **Commons Management Service** is responsible for managing all DAIAD@commons administrative tasks and providing DAIAD@commons analysis functionality. The exposed API has access to a subset of the algorithms and analysis models supported by the analysis and recommendation engine.
- The **WDM Analysis Service** provides full access to all algorithms and analysis models supported by the analysis and recommendation engine to DAIAD@utility. The knowledge discovery workbench application is built on top of the API exposed by this service.
- The **Administration Service** provides an API for managing DAIAD@utility deployment, exposing cluster health service information and controlling scheduler service tasks and policies. The

exposed API will be used for implementing a separate DAIAD@utility portal section for cluster administration.

Most of the described functionality of the top level components will be published by implementing HTTP Web APIs using JSON for exchanging data. These APIs will be used for implementing the DAIAD web applications functionality. Moreover, in order to increase interoperability with 3rd party web applications and services, the web APIs will support Cross-Origin Resource Sharing (CORS). CORS allows web resources to be requested from different domains than the one that hosts DAIAD.

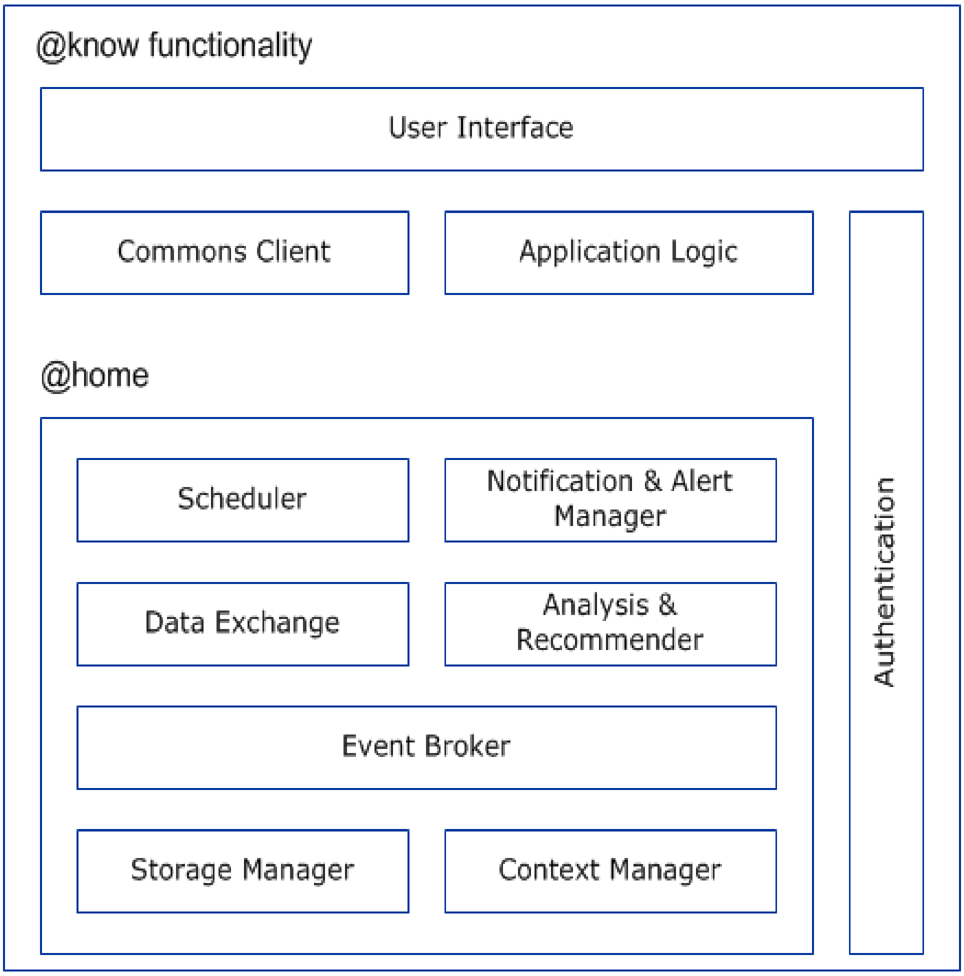

Figure 71: DAIAD@home mobile application architecture

5.2.1.4. DAIAD@home mobile application

The components of the DAIAD@home mobile application is presented in Figure 71. The user interface and application logic components will be implemented using the Model View Controller (MVC) pattern that allows the clear separation of the application logic and model from the user interface. Application Logic component will interact with the following DAIAD@home components through appropriate programmatic interfaces:

- It will configure notification rules for DAIAD@home notification & alert manager

- It will subscribe to event broker for receiving events from all DAIAD@home components in order to provide appropriate visual feedback to users.
- It will store user preferences and application data to the storage manager component

Finally, the commons client will offer a subset of DAIAD@commons functionality to the mobile application like browsing communities, joining communities or retrieving community analysis results.

5.2.1.5. DAIAD web applications

The DAIAD system includes the following web applications:

- DAIAD@home web client, optimized for both desktop and mobile browsers
- DAIAD@commons portal that will provide simple analysis tools and community management features
- DAIAD@utility portal that will host the knowledge discovery workbench and user administration
- DAIAD@utility administration portal for monitoring the cluster status and managing DAIAD deployment and provisioning.

In order to enhance user experience, all applications will be developed as Single Page Applications (SPAs) by using the DAIAD@commons and DAIAD@utility HTTP Web APIs. Moreover, the Model View View-Model pattern will be used to facilitate a clear separation between the user interface and any application logic, including calls to DAIAD Web APIs.

5.3. Physical Architecture

In this section, the physical architecture of DAID is presented. The architecture is described in the context of a *cloud-based* installation using either physical servers or virtualization. Additional details about other deployment alternatives are provided in section 5.5. Next the data storage architecture is explored in more detail and important design decisions and the rationale for them is explained.

5.3.1. Overview

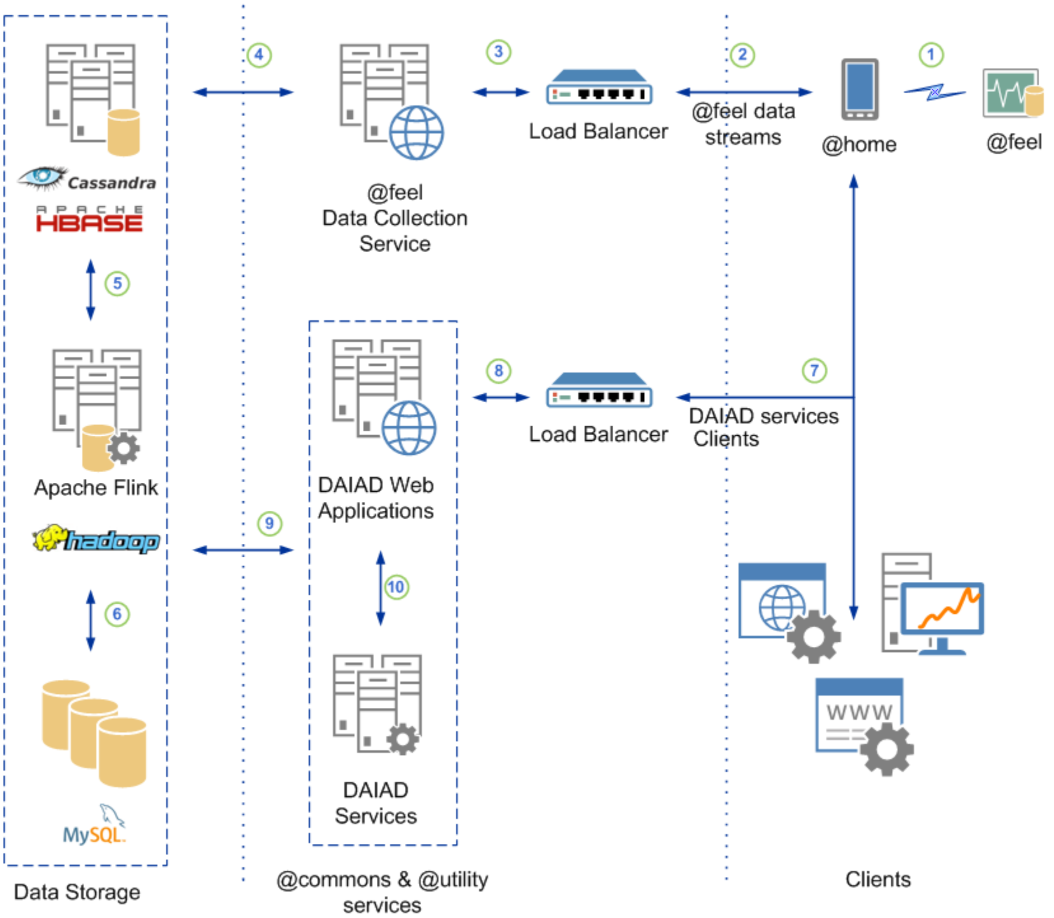

Figure 72: DAIAD physical installation

The DAIAD physical architecture overview is illustrated in Figure 72.

- Highly granular real-time water consumption data is initially collected from DAIAD@feel sensors. The gathered raw data of one or more sensors is transferred to a paired mobile device running iOS or Android operating system with DAIAD@home installed.
- DAIAD@home transfers water consumption data to DAIAD@commons and DAIAD@utility. During data transmission, DAIAD@home attempts to minimize the computing, bandwidth and energy overhead of the hosting device by employing fluent heuristics.

- Incoming data streams of water measurements are processed by one or more dedicated web application servers. In addition, load balancing is used to attain higher throughput. Using dedicated servers prevents mixing different requests types and API calls, which can complicate performance issues tracing.
- Measurement data is stored in a low latency, high write throughput NoSQL database. This database will act as an active data archive for DAIAD data, offering both safe storage and easy access to highest granularity water consumption data. At this point the data collection cycle is complete and data is stored safely in the DAIAD infrastructure.
- Granular sensor data is extracted, transformed and loaded to a secondary NoSQL data store either in real-time (see section 5.3.2) or by executing batch processing. During this phase data quantization and aggregation may be performed based on the required analysis scenarios. For example, real-time consumption data is split and aggregated in temporal slots of one or five minutes intervals depending on the required accuracy.
- During the phase of data cleansing, additional data may be retrieved from a relational database. The relational database is used for storing frequently changing data, like DAIAD@commons community memberships, user profiles and preferences, application metadata, cluster management information, etc. The goal of using a different store for this type of data is to minimize the delete operations on the NoSQL databases.
- Except for water consumption data uploading requests, external requests to DAIAD include, web client requests, mobile application data API calls, DAIAD@utility and DAIAD@commons data API calls. All these requests are handled by a separate cluster of web application servers in order to achieve workload segregation as explained earlier. Moreover, loading balancing is implemented which can further isolate the request workload.
- Finally, one or more application servers will be deployed for handling high latency requests, e.g. execution of Map Reduce jobs and running services like cluster monitoring and administration.

5.3.2. Data Storage

Data Storage is one of the most important aspects of the DAIAD architecture, guaranteeing optimal performance, high availability and low latency query responses. Although using a mixed persistence model will increase redundancy and deployment complexity, it will also achieve query workload isolation. In DAIAD we expect mainly four query workload types:

- A continuous stream of write only queries with sensor data from DAIAD@home. As long as no extensive read queries are submitted simultaneously, key value or wide column NoSQL data stores tend to handle such workloads efficiently.
- Numerous read only queries that request a small portion of the stored data. For example, a user requests to download historical consumption data for a specific interval, browses analysis results and recommendations about her own consumption behavior, or views information about the DAIAD@commons communities she participates to.
- Numerous read/write queries that update user preferences and settings, configure notifications, manage DAIAD@commons communities and memberships, initialize analysis jobs and retrieve administration information.

- Read queries that involve scanning large portions of the stored data at a high granularity level. Such queries are usually part of the execution of complex analysis algorithms and Map Reduce jobs.

For the first three workload types, responses are expected to have low latency. Otherwise, user experience may decrease significantly. The last workload is expected to have high latency but this is acceptable since it involves querying vast amounts of data. Nevertheless, if interactive analysis is expected (e.g. implementation of the what-if analysis module), hierarchical pre-aggregation and data filtering may be further applied to limit the size of input data.

Running both low and high latency workloads against a single data store may result in unpredictable performance behavior, especially for the queries that require low latency responses. For instance, load spikes are expected to be highly probable for queries originating from DAIAD@home. Starting a resource expensive Map Reduce job simultaneously may force DAIAD@home clients to resubmit failed uploading requests. A scenario like this is quite likely to occur and opposes to DAIAD's principle of collecting measurements data timely with the minimum impact on user devices. Moreover, adding more servers to the cluster will scale the cluster's performance uniformly for all workload types. Thus, it will be hard to quantify the benefits for each workload type separately. In contrast, it is preferable to scale specific workload processing, e.g. add additional servers for handling data analysis only.

Hence, we propose using two distinct NoSQL stores in the cluster, one for handling continuous streams of measurement data and one for handling the rest of the workload types. Optionally, analysis results may be written to the latter store too. However, the suggested configuration increases redundancy and disk space requirements. To alleviate this problem, analysis performance can be traded for disk space by lowering the replication factor of the second store. The performance tradeoff is due to the fact that the fewer data replicas are, the less parallelization is attained.

Data migration from one data store to the other will either be performed using batch jobs executing in regular intervals or dynamically by using appropriate cluster topology and configuration. For an example of the latter solution see section 6.2.4.

During the development phase, we plan to do extensive testing of different configurations using data from the Synthetic Data Generator. We plan to create representative query sets for each workload type and test different storage schemes, including both different NoSQL implementations and single or multiple data stores installations.

Finally, we will use a relational database management system (RDBMS) for storing frequently changing data such as user profiles, DAIAD@commons community memberships and application metadata in order to provide low latency responses to DAIAD@commons / utility and DAIAD@know web clients.

5.4. Integration

During the DAIAD development lifecycle several tools will be used to coordinate and accelerate the development process. A project Wiki[5] will be used for sharing architecture and design documents among partners. A GitHub repository[6] will be used for source code management, task management and bug tracing. Finally, we plan to employ Continuous Integration in order to simplify the deployment and streamline the evaluation of the developed software. The proposed Continuous integration flow is shown in Figure 73. Initially, an automated build operation will be executed after a new code commit. Next, static code analysis will be performed for detecting potential bugs. Finally, the generated software artifacts will be packaged and stored in a build repository, ready to be deployed to the DAIAD test servers.

Figure 73: Continuous Integration flow

5.5. Deployment

In this section, we present DAIAD deployment scenarios and the options each of them offers.

5.5.1. In-house deployment

This is the most flexible DAIAD deployment scenario and applies to (a) service providers who want to provide DAIAD as a service, or (b) to water utilities who want to have an in-house DAIAD deployment. In both cases, we will refer to the service provider or water utility as the *owner of the installation*.

The owner of the installation is responsible for all aspects of the system, including security, availability, scalability, cluster management, disaster recovery, resource distribution, etc. Once all DAIAD modules are configured, the owner of the installation can enable DAIAD@utility and/or DAIAD@commons features through the administration panel, manage users, and import data.

Finally, the DAIAD@utility owner will have to either upload a pre-configured DAIAD@home mobile application version to Apple iTunes and Google Play, or guide his customers (or commons members) to configure their existing DAIAD@know installations for uploading data to his infrastructure.

5.5.2. Software as a Service

DAIAD@utility as a service is the simplest deployment scenario. A water utility may contact a service provider and request the creation of a DAIAD installation. The service provider will allocate resources, install DAIAD components and perform any required configuration. Once the installation is completed, the

[5] http://wiki.daiad.eu

[6] https://github.com/daiad

water utility can access the administration portal to manage users and import data. The water utility will have access to the whole DAIAD functionality except for the cluster administration portal.

The DAIAD@utility provider will also have to offer a pre-configured version of the DAIAD@home mobile application for the customers of the water utility to download.

5.6. Test Environment

In order to assess DAIAD functionality and performance, a cluster of virtual servers will be deployed. By default, each virtual server will have 4 logical cores, 4 gigabytes of memory and 200 gigabytes of disk space. These specifications may vary depending on the role of the virtual server. Several types of virtual servers will be instantiated, including:

- Five or more servers for hosting HDFS DataNodes and HBase RegionServers.
- One server for hosting HDFS NameNode and HBase Master Server.
- One optional server for hosting HDFS secondary NameNode.
- One or more servers for hosting ZooKeeper (required by HBase).
- Five or more servers for hosting Cassandra nodes. Cassandra node installations may share the same virtual servers with DataNodes and RegionServers.
- One application server for hosting DAIAD@know, DAIAD@commons and DAIAD@utility web applications.
- One application server for handling data acquisition of water consumption data from DAIAD@home.
- One server for running the synthetic data generator.

The aforementioned configuration represents the minimum requirements for DAIAD development and testing. During the trials, more servers will be required in order to attain availability and fault tolerance. To that end, additional servers will be deployed including:

- A HDFS secondary NameNode server.
- A secondary HBase Master Server and
- Two ZooKeeper nodes.

5.7. Synthetic Data Generator

5.7.1. Introduction

The Synthetic Data Generator (SDG) is a software application that will generate big water consumption data given a set of parameters. The novelty of the SDG is its ability to produce water consumption data of high granularity i.e. resembling the output generated by a large DAIAD@feel install base (*ranging from* *hundreds of thousands to millions of devices*). The SDG will evolve over the course of the project to produce more accurate data by utilizing the water consumption models and analysis results introduced in WP6.

5.7.2. Relevant Work

Big data generation is currently a hot research topic due to the increased interest in big data management and the fact that most real big datasets are *proprietary and not available to the public*. To circumvent the lack of big datasets, several attempts have been made to create synthetic data generators. In the following sections we present two state-of-the-art systems.

5.7.2.1. Yahoo! Cloud System Benchmark

Yahoo! Cloud System Benchmark[7] (YCSB) implements an extensible framework for benchmarking systems. YCSB supports different workloads and implements interfaces for the most commonly used NoSQL databases. The YCSB architecture is depicted in Figure 74. YCSB accepts two parameter files, one for configuring the workload (e.g. % of read, write and scan operations), and one for configuring the database interface (e.g. connection parameters for a specific NoSQL database). The Workload executor is responsible for generating the data, loading it to the data store and executing the workloads. Workload execution is performed by one or more threads and execution statistics are collected by a separate module.

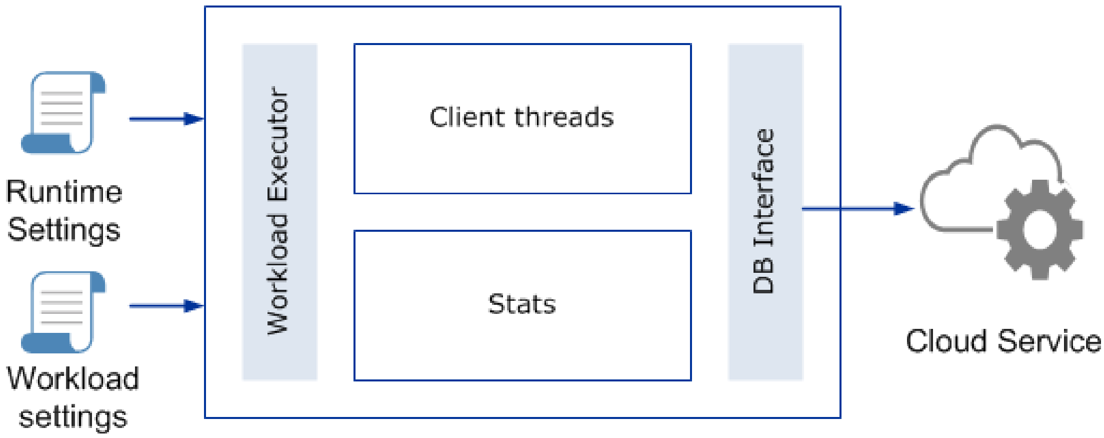

Figure 74: YCBS architecture

In order to execute data operations, a store-specific database interface layer is implemented that translates simple data operations into database specific calls. The main extension points of YCSB are the workload executor and database interface layer. The default workload executor can be replaced with a new implementation that offers more complex operations. Moreover, a new data store can be tested by implementing the appropriate database interface layer.

[7] https://github.com/brianfrankcooper/YCSB

5.7.2.2. BigDataBench[8]

BigDataBench is a holistic solution for generating data and benchmarking data management systems. It provides parallel and distributed data generation and workload execution. In contrast to YCSB that uses simple distributions like uniform and Zipfian, BigDataBench utilizes data models extracted by real datasets to enhance the data generation process. Moreover, BigDataBench allows the creation of flexible benchmark scenarios by abstracting data operations and workload patterns. In particular, data operations are abstracted into three categories, namely the single element, single set and double set categories. Each category includes typical operations i.e. put, get, delete, filter and project, aggregate, order by for single element and single set categories respectively. Likewise, the abstracted operations can be combined to form different workload patterns like single operation, multiple operation and iterative operation workloads. Currently, BigDataBench supports search engine, e-commence, and social network application domains and produces text, graph and table data.

5.7.3. SDG Roadmap

In the context of the DAIAD project, we have selected to extend the BigDataBench framework in order to support the water consumption application domain. The current version of SDG available in our repository is a basic port of the BigDataBench. We plan to extend SDG in three steps. Each step will increase the complexity and accuracy of the SDG and will add new features to it.

- Initially, we will focus on generating big data in size. A small set of input parameters will be used, including the size of dataset, time span, area and population. Correlations and other factors that influence consumption will be ignored (*i.e. uniform data distributions will be assumed whenever random values are required*). Moreover, we will make a preliminary attempt to develop and loosely integrate water models in the data generation process.
- In this step, we will focus in increasing the accuracy for low granularity data over a large area and time frame. To this intent, water consumption models and analysis results (*such as age and income distributions*) will be integrated in the data generation process. Moreover, small scale real data will be used as input to enhance the overall data accuracy.
- Finally, we will attempt to increase the accuracy of high granularity data by using (a) personalization and clustering and (b) parameters, models and dimensions from WP5 and WP6 respectively.

[8] http://prof.ict.ac.cn/BigDataBench/

6. Tool stack

6.1. Overview

In this chapter we present the libraries, frameworks and tools we are going to evaluate for implementing the software components of the DAIAD system as well as the software systems and applications that we will deploy, extend and incorporate in the DAIAD architecture. First, we present data management systems and processing frameworks for managing and analyzing big water consumption data. Next, we briefly enumerate mobile application development approaches and present two distinctive frameworks. Finally, we discuss web application development and present web development libraries and frameworks organized in two sections, targeting client-side and server-side development respectively.

6.2. Data management

As pointed out in Deliverable 1.1, NoSQL databases are not always replacing existing database or data warehouse solutions, but instead complement them, resulting in mixed persistence models. Moreover, depending on the anticipated query workloads, a solution may be more appropriate than another. In section 5.2 we have presented the DAIAD architecture and proposed a diverse persistence model using both NoSQL and relational database solutions. In this section we are presenting the most important storage solutions and processing frameworks we are going to evaluate and use during the DAIAD development.

6.2.1. MySQL

MySQL[9] is one of the most popular open source relational databases that delivers high performance and scalability. It is compliant with a broad subset of the SQL 1999 standard and is released under both a commercial license and the GNU General Public License (GPL). MySQL offers distributions for many operating systems including Linux and Microsoft Windows and provides APIs for many programming languages including Java, Microsoft C# and Python.

Moreover, the MySQL Fabric framework supports high availability and scalability by combining data replication and partitioning (sharding). Availability is achieved by employing a master slave replication architecture in a set of servers, forming a high availability (HA) group. Scalability is attained by partitioning data across multiple HA groups. It is important to notice that administrators should decide how data are partitioned in contrast to automatically data partitioning offered by NoSQL databases. Nevertheless, partitioning is transparent to the end users and no proxy is required for routing requests to the appropriate servers. The latter is accomplished by having the connectivity API manage routing.

[9] http://www.mysql.com/

Finally, MySQL offers a unified visual tool, namely MySQL Workbench that allows database administrators and developers to easily inspect and manage database instances.

6.2.2. Hadoop Distributed File System (HDFS)

Hadoop Distributed File System (HDFS) is a distributed, highly available and scalable file system, designed to run on commodity hardware and is an integral component of the Hadoop ecosystem. HDFS splits files in blocks which are replicated across a set of servers. The storage servers are called DataNodes. A single server in the cluster, namely the NameNode, is responsible for managing the file system namespace (directory structure), coordinating file replication and maintaining metadata about the replicated blocks. Every time a modification is made e.g. a file or directory is created or updated, the NameNode creates log entry and updates metadata. Clients contact the NameNode for file metadata and perform I/O operations directly on the DataNodes. A high level overview of the HDFS architecture is depicted in Figure 75.

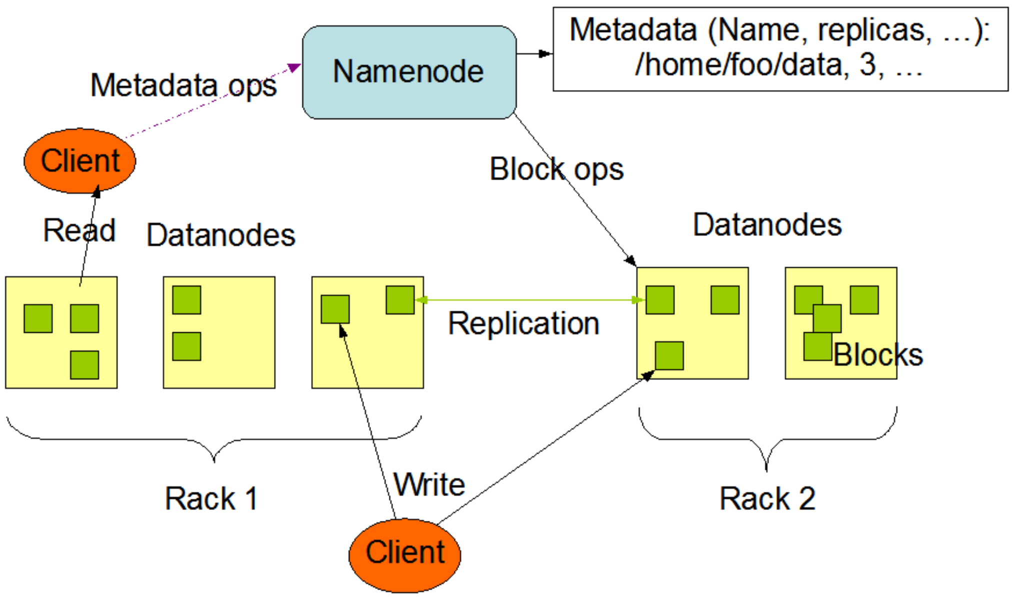

Figure 75: HDFS architecture

The NameNode is a single point of failure in a HDFS cluster. In order to increase availability, the NameNode maintains multiple copies of the metadata and log files. Moreover, an optional secondary NameNode can be deployed for creating checkpoints for the metadata and log files. Creating checkpoints allows for faster recovery times. In addition, HDFS can be configured to use multiple independent NameNodes, thus implementing many autonomous file system namespaces. The latter feature increases I/O operation throughput and offers isolation between different applications.

Finally, HDFS is optimized for managing very large files, delivering a high throughput of data using a write-once, read-many-times pattern. Hence, it is inefficient for handling random reads over numerous small files or for applications that require low latency.

6.2.3. HBase

Apache HBase is a free, open source, distributed and scalable NoSQL database that can handle tables with billions of rows consisting of millions of columns. HBase is built on top of HDFS and enhances it with real time, random read/write access.

The architecture of HBase is similar to that of HDFS. Table data is organized in regions that are managed by a set of servers, namely RegionServers. Usually a RegionServer is installed on every DataNode of the underlying HDFS storage cluster. By default, each region is served by a single RegionServer. Still, HBase can be configured for region replication if availability is more important than consistency. Fault tolerance is attained by storing HBase files to HDFS. Likewise, an HBase Master node is responsible for monitoring RegionServers and load balancing. Usually, the HBase Master is installed on the same server with HDFS NameNode. In addition, more than one HBase Master may be present in a master/salve configuration in order to circumvent single point of failure issues. Finally, Apache ZooKeeper is used for coordinating and sharing state between master and region servers. Clients connect to ZooKeeper for submitting requests and read and write data directly from and to the region servers.

HBase integrates seamlessly with Hadoop Map Reduce framework since they share the same underlying storage. Moreover, since rows are sorted by row key, HBase scales well for both fast row key scans across tables as well as single row read operations. Hence, HBase can be efficiently used both as a Hadoop Map Reduce source as well as a data store for ad-hoc querying and low latency applications.

6.2.4. Cassandra

Apache Cassandra is a massively scalable, open source NoSQL database designed for managing large amounts of structured, semi-structured, and unstructured data across multiple data centers. In contrast to HBase, Cassandra employs a master less architecture with no single point of failure. Node failures are handled by the cluster automatically and no external systems, like ZooKeeper, are required. In Cassandra all servers in the cluster are equivalent and clients can connect to any of them to perform read and write operations.

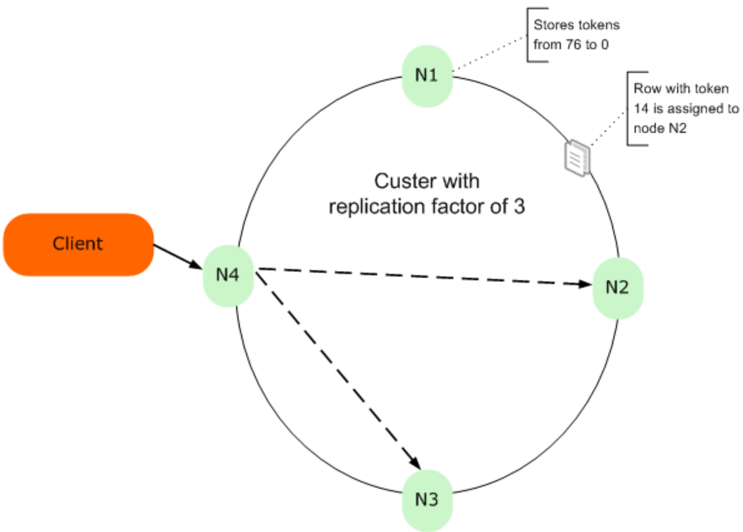

Figure 76: Cassandra replication example

Data in Cassandra is stored as rows organized into tables with a required primary key. Cassandra uses consistent hashing for partitioning the rows by the first component of the primary key. Inside each partition, rows are clustered on the remaining columns of the primary key.

Nodes are also assigned a unique value (token) in the range of possible hash values and are logically organized in a ring, positioned in ascending order of this value. A node is responsible for the range of hash values starting from the token of his predecessor (exclusive) to its own token (inclusive). The only exception is the node with the lowest token which gets both all keys less than that token, and all keys greater than the largest token in the ring. Hence, a node's value determines what keys it is the first replica for.

Once a row is stored in the appropriate node, it is replicated to N-1 more nodes where N is the replication factor of the specific table. The selection of the N-1 nodes is performed using a predefined replication strategy. For instance, the simplest available strategy places additional N-1 replicas on the next nodes clockwise in the ring without considering topology. It is important to remember that the first node that stores a row is only acting as a proxy for the client and is not special by any means. All replicas are treated equally.

Figure 76 demonstrates the partitioning and replication strategy described earlier. In this example, we assume that there are four nodes and the hash value range is from 0 to 100. Moreover, a replication factor of two is used and a simple replication strategy is employed. Therefore, for the configuration in this example, a row key with hash value equal to 14 is assigned to nodes 2 and 3.

Cassandra also allows tunable tradeoffs between consistency and latency. This is feasible due to the method Cassandra uses for reading and writing rows. In particular, when a client reads or writes a record, it specifies the required consistency level, which is the number of nodes that the read or write operation should be successful before returning. The lower the consistency level, the lower the response latency will be.

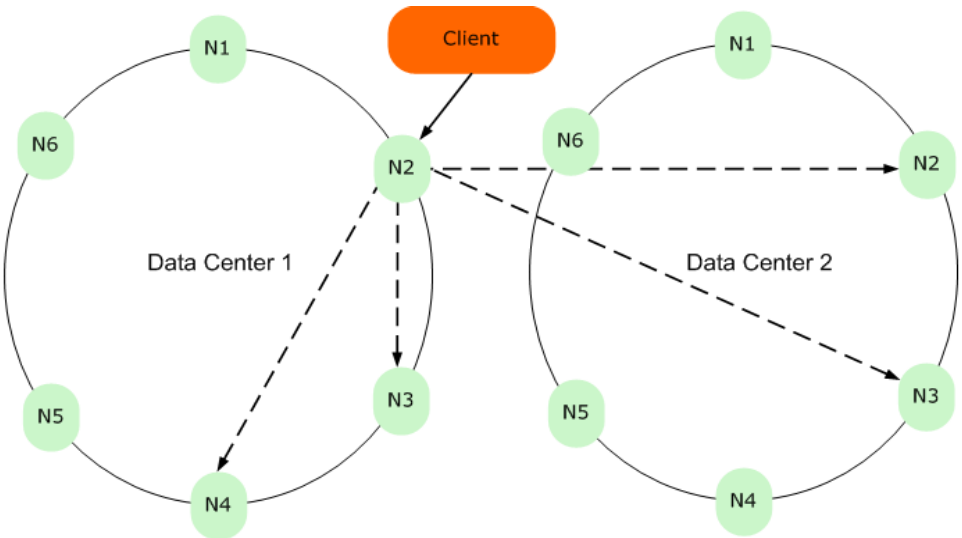

Figure 77: Workload isolation using Cassandra configuration

Finally, Cassandra supports workload segregation. That is an administrator can assign different sets of Cassandra nodes for serving different workload types e.g. real time and analysis processing can run side by side without the latter affecting the performance of the former. This is achieved by using more complex replication strategies that consider the network topology. An example of such a configuration is demonstrated in Figure 77. In this configuration twelve servers are logically separated into two groups, namely data center one and two. The two groups are configured with a replication factor of three and two respectively. Clients connect to servers of Data Center 1 to write new records. Likewise, clients who execute analysis queries, connect to Data Center 2. Data are synchronized between the two clusters automatically. However, analysis query workload does not interfere with real-time, low latency writer requests.

6.2.5. Hadoop Map Reduce

Hadoop Map Reduce is a big data processing framework that simplifies the development of highly parallelized and distributed programs. Developing distributed programs requires handling many tasks including data replication, data transfer between servers, fault recovery, management of many parallel executing tasks etc. Hadoop abstracts the complexity of developing parallel and distributed applications by making all the aforementioned tasks transparent, allowing developers to focus on the problem under consideration.

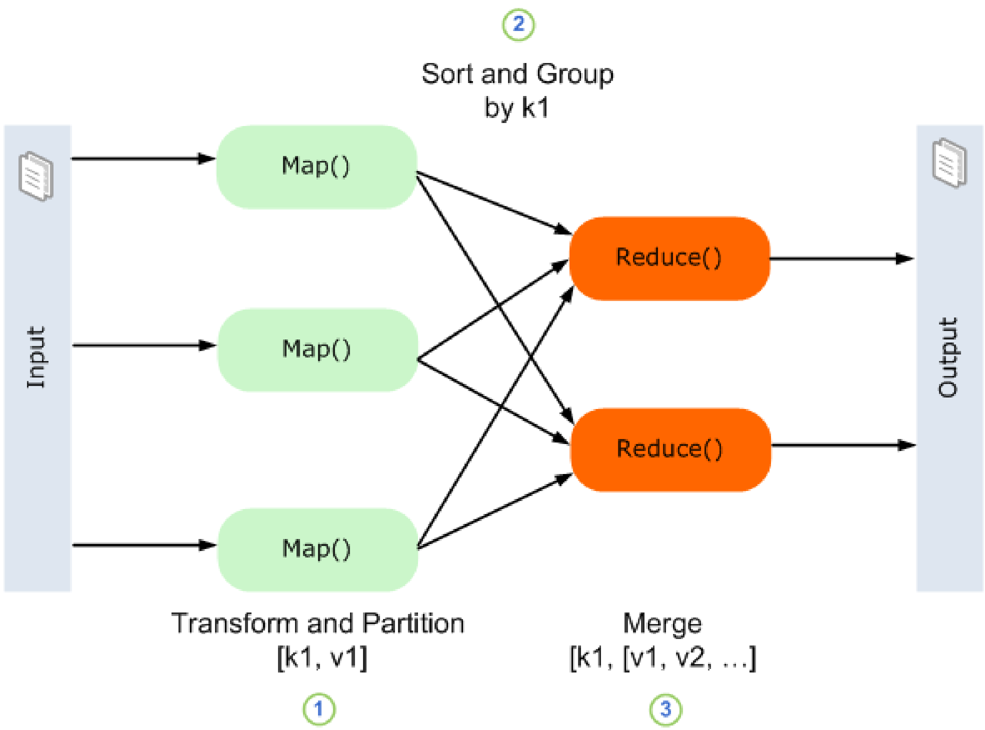

Figure 78: MapReduce computing model

The Hadoop Map Reduce initial version shared an architecture similar to HDFS. In particular, a TaskTracker resided on every DataNode that was responsible for performing computations on the specific server. Similar to the NameNode, a JobTracker was acting as a master node that performed resource management and job scheduling and monitoring. In newer versions of Hadoop Map Reduce, resource management and job scheduling has been assigned to a new component, namely YARN [10]. Therefore, the implementation of other distributed computing models, such as graph processing, over a Hadoop cluster is possible and also Hadoop Map Reduce focuses exclusively on data processing.

The computing model of Hadoop Map Reduce is depicted in Figure 78. A Map Reduce program requires the implementation of two methods, namely Map and Reduce. The Map method transforms input data to a set of intermediate key value pairs which are partitioned on the generated key. Then, the intermediate partitioned key value pairs are sorted and grouped by the generated keys. Finally, the created groups are processed by the Reduce method and the final output is produced. Both intermediate and final results are stored on HDFS.

6.2.6. Apache Flink

Apache Flink (*formerly Stratosphere*), is a general purpose, distributed and efficient data processing framework that provides an extensive set of operators for expressing complex algorithms. Flink operators are designed to work in memory and gracefully fallback to external memory algorithms once memory resources become scarce.

One of the most prominent features of Flink is the support for iterative operators. Many algorithms relative to machine learning or graph processing require multiple executions over a set of data. Implementing such algorithms with Hadoop Map Reduce is not efficient since the latter saves intermediate and final results to HDFS (during, and after each iteration). Moreover, another important aspect of Flink is that it applies job execution plan optimization similar to what relational databases do for query execution plans. Hence, instead of just executing a job expressed as directed acyclic graph (DAG) of operators, Flink optimizes the job execution by reordering operators and selecting appropriate implementation algorithms for each of them. The goal of the optimization is to reduce both data shuffling and computation time.

Finally, although Flink is independent of Hadoop, it implements support for HDFS and YARN, JDBC data sources and HBase connectors.

6.3. Mobile framework

6.3.1. Overview

One of the most important modules of the DAIAD system is the DAIAD@home mobile application, which will be responsible for collecting detailed water consumption data from DAIAD@feel devices. Hence, its successful implementation is of critical importance for delivering the promised functionality of the whole DAIAD system.

We are planning to develop the mobile application for two platforms: Apple iOS and Google Android. Currently the two aforementioned platforms account for 90% of smartphone sales for 2013 according to Gartner[11]. In general, there are three prominent development options for mobile applications, namely, Native, HTML5 and Hybrid.

[10] For a more detailed presentation of YARN and Hadoop Map Reduce architecture refer to Deliverable 1.1

[11] http://www.gartner.com/newsroom/id/2665715

6.3.1.1. Native

Native applications are specific to a given mobile platform and are built using platform-specific tools, e.g. Eclipse for Java[12] and Android SDK[13] for Android or Xcode[14] and Objective-C[15] for Apple iOS. Native applications achieve the best performance and have full access to all hardware-specific features like GPS, Bluetooth, wireless connectivity, etc. The main drawback of this approach is that two different implementations have to be developed and no code reuse can be attained.

6.3.1.2. HTML5

HTML5 applications are implemented using standard web technologies like HTML5, JavaScript/CSS, and are *device agnostic*. Users access the applications using a browser; hence it is easy to develop cross platform applications that work on multiple devices. Moreover, the distribution and upgrade of the application is simplified, since no native code resides on the device. Their main disadvantage is the troublesome access to device-specific hardware features (e.g. Bluetooth or GPS) and to provide secure storage or offline session management.

6.3.1.3. Hybrid

Hybrid applications attempt to combine the best features of the previous approaches by embedding HTML5 applications inside a native container. Rich user interfaces can be easily constructed using HTML5 and the native container gives access to device hardware features. Moreover, the application has to be written once and be executed on many platforms. Finally, using JavaScript as the programming language, the developer has access to all libraries and frameworks presented in section 6.4.

Nevertheless, there are some important shortcomings associated with the hybrid approach. Firstly, since the application is executed as a web page inside a native container, performance is not optimized. Secondly, allowing users to navigate between different web pages, may result to poor user experience since the application may be unresponsive during the page loading phase. The latter problem can be alleviated by implementing Single Page Applications (SPA). For more information about SPA see section 6.4.1.

Next we present two frameworks for developing hybrid and native mobile applications, namely, Apache Cordova[16] and Xamarin[17].

6.3.2. Apache Cordova

Apache Cordova is a framework for developing hybrid mobile applications. The application is implemented using HTML5, JavaScript and CSS. Developers can either implement the user interface (UI) from scratch or use one of the many available touch optimized JavaScript UI frameworks like jQuery Mobile[18], Sencha

[12] https://www.eclipse.org/downloads/
[13] http://developer.android.com/sdk/index.html
[14] https://developer.apple.com/xcode/
[15] https://developer.apple.com/library/mac/documentation/cocoa/conceptual/ProgrammingWithObjectiveC
[16] http://cordova.apache.org/
[17] http://xamarin.com/platform
[18] http://jquerymobile.com/

Touch[19], Kendo UI[20] and AngularJS[21]. In the first case, developers must be watchful and account for implementation differences in the web rendering engines each operating system offers, in order to achieve parity for the UI appearance across multiple devices. In contrast, using a UI framework substantially alleviates this problem.

Moreover, Cordova offers a set of JavaScript application programming interfaces (APIs) that allow access to the most common native device APIs including geolocation, storage and network functionality among others. More significantly, these APIs are consistent across multiple platforms, hence, code has to be written only once. In the case that the developer requires access to a native API that is not supported e.g. Bluetooth connectivity, Cordova offers a plugin architecture for implementing JavaScript bindings to expose the required native functionality to the JavaScript code. Furthermore, Cordova community already offers hundreds of plugins accessible from the Cordova plugin registry[22].

Moreover, a Cordova application is packaged in the native device format e.g. for Apple iPhone an iOS application archive is created. Likewise, for Android an Android Application Package file is created. A user can install the application through the corresponding platform application store e.g. Apple iTunes or Google Play, as she would with any other native application.

Cordova is currently available for the following platforms: iOS, Android, Blackberry, Windows Phone, Palm and Symbian, it's free and open source software and distributed under the Apache License, Version 2.0.

6.3.3. Xamarin

Xamarin is a framework for developing native mobile applications for Google Android, Apple iOS and Windows Mobile and is powered by Mono[23], an open-source version of the .NET Framework. Applications in Xamarin are coded in Microsoft C#[24], a modern programming language that offers many productivity features like simplified asynchronous programming, easy to code lambda expressions and type inference.

Developers can share most of the business logic by using the same programming language, APIs and data structures across all development platforms. In addition, if Xamarin UI components library is used, namely Xamarin.Forms, code reusability across different platforms can reach nearly 100%. In every case, platform specific builds use the platform native UI controls which retain the appropriate look and feel, resulting in optimal performance and better end-user experience.

Moreover, Xamarin offers a cloud based testing service that allows developers to easily test their applications on hundreds of physical devices. Developers can write tests that emulate user behavior by scripting tap, swipe, rotation and other interaction events. The test results are visually presented accompanied with screenshots that allow developers to discover problems and UI differences quickly and efficiently.

[19] http://www.sencha.com/products/touch
[20] http://www.telerik.com/kendo-ui
[21] https://angularjs.org/
[22] http://plugins.cordova.io/
[23] http://www.mono-project.com/
[24] http://msdn.microsoft.com/en-us/vstudio/hh341490.aspx

Finally, Xamarin allows developers to access numerous components through the NuGet [25] package repository, including UI controls and web service APIs.

6.4. Web applications

In the context of DAIAD project, a set of web applications and services are going to be developed. In this section we present the various frameworks we are planning to evaluate and use during the development process.

6.4.1. Client Side Development

In order to offer increased UI usability that is in par with desktop applications, the DAIAD web applications will be developed as Single Page Applications (SPAs). In contrast to common web applications, a SPA application is initialized by loading a single web page and further needed resources, content and scripts are loaded dynamically on demand using Asynchronous JavaScript and XML (AJAX) requests. Moreover, code responsible for handling events, manipulating DOM elements, executing AJAX requests and business logic will be implemented using controllers that separate views (content) and models using either the MVC or the MVVM pattern.

Next we present JavaScript libraries and frameworks that offer many of the aforementioned features. More than one of them may be applied in order to achieve the desired functionality in our applications.

6.4.1.1. RequireJS [26]

RequireJS is a JavaScript library for loading files and modules dynamically that improves application performance. Developers declare dependencies in their modules and only reference RequireJS library in their web pages. RequireJS resolves all dependencies and ensures that all required scripts are loaded before executing any code that depends on them. Moreover, RequireJS provides an optimizer for merging and minifying JavaScript files based on the declared dependencies. Finally, since RequireJS can manage dependencies centrally, it allows to easily change a library’s version or to completely swap its implementation.

6.4.1.2. Backbone [27]

Backbone is a JavaScript library that simplifies the implementation of two way data binding between application models and views. Developers do not have to write and maintain cumbersome code for event handling and DOM element manipulation for synchronizing models and views. With Backbone, Model-View-Controller solutions can be easily implemented without resorting to more complex frameworks that may pose additional constraints to the application structure.

[25] http://www.nuget.org/packages
[26] http://requirejs.org/
[27] http://backbonejs.org/

6.4.1.3. jQuery

jQuery is a lightweight, CCS3 compliant, fast JavaScript library with rich functionality that simplifies tasks such as HTML elements traversal, manipulation and styling, event handling and AJAX request execution. jQuery API supports most modern browsers and hides browser specific implementation details for event handling and AJAX requests.

6.4.1.4. jQuery UI

jQuery UI is a set of user interface controls built on top of jQuery library. It offers implementations for both widgets and interactions. Widgets are visual controls such as buttons, menus, progress bars etc, while interactions implement behaviors like resizing, sorting, drag and drop, etc. jQuery UI is fully extensible allowing users to extend existing widgets and interactions or implement new ones. Finally, it supports the creation of custom distribution packages and widget styling through the download builder and theme roller applications.

6.4.1.5. jQuery Mobile

jQuery Mobile is a touch-optimized user interface framework, built on top of jQuery that simplifies the development of applications accessible to smartphones, tablet and desktop devices. It supports the development of responsive and single page web applications and offers a rich set of widgets for page layout, page navigation and data input. Finally, custom distribution packages and styling can be configured through the download builder and theme roller applications.

6.4.1.6. AngularJS

Developing a web application usually involves writing static HTML pages and adding JavaScript code for manipulating DOM elements and executing AJAX requests. AngularJS is a web application development framework that adds new constructs to HTML5 that allow the declarative definition of tasks, otherwise developers should have implemented manually such as two way data binding between DOM and models, attaching events to DOM elements, managing form validation, etc.

AngularJS thrives when it comes to the development of CRUD applications by removing most of the cumbersome code for callback registration, marshalling data from and to the user interface and updating DOM. Nevertheless, AngularJS may not fit well when developing applications with fairly complex graphical user interfaces.

6.4.1.7. Sencha Ext JS

Sencha Ext JS is a holistic web development framework for creating business grade desktop and tablet applications. It provides a class system for adding object oriented capabilities to JavaScript, a rich set of extensible components for building complex user interfaces, a routing mechanism for managing site navigation and application state and a powerful event system that supports both custom events and event normalization across different browsers.

Ext JS also offers a rich data library that allows developers to implement both Model View Controller (MVC) and Model View View-Model (MVVM) solutions. Moreover, Ext JS allows easy theming of the application. Theming differs from classic styling by allowing an application to switch user interface visual aspects dynamically.

Finally, Ext JS learning curve tends to be quite steep, especially when it comes to extensibility. In addition, when user interface controls are rendered, numerous DOM elements are created. The latter problem though has been improved in the latest releases. Ext JS is distributed under both a commercial license and GNU GPL license v3.

6.4.1.8. Kendo UI

Kendo UI is a complete framework for implementing web and mobile applications with HTML5 and JavaScript. It is built on top of jQuery and offers an extensive suite of user interface components, a MVVM framework and customizable themes.

The user interface components feature responsive capabilities and touch support that offer an enhanced user experience on both desktop and mobile devices. At the same time, the MVVM framework declarative two way data binding reduces the code required for syncing UI components with data models significantly. Finally, Kendo UI offers more than ten pre-defined professional themes which can be easily altered using the ThemeBuilder[28] application.

Kendo UI is distributed under both a commercial license and Apache v2 license. However, the latter distribution contains only a subset of the user interface components.

6.4.2. Server Side Development

In this section, we enumerate various server side web development frameworks. The evaluation of a web framework usually depends on multiple criteria such as productivity and ease of use, framework complexity and learning curve slope, available documentation and support, security, testability, scalability and throughput, easiness of maintenance, framework ecosystem, etc. While all frameworks aim at delivering robust web applications, each of them favors different qualities like testing, rapid application development, or simplicity over others. Moreover, applications usually prioritize features like security and scalability higher than others. For DAIAD applications and services, scalability, security and testability are the primary required qualities.

In the next sections, we focus on Java frameworks, since most of the open source systems we are going to use in DAIAD, are developed on the Java platform or support Java programmatic interfaces.

6.4.2.1. Spring[29]

Spring is the most popular and mature web development framework for Java, featuring a vast ecosystem of projects for developing applications from the mobile to the enterprise and cloud. Spring's vertical tool stack handles almost any programmatic task like security, data access, transaction management, social service provider integration, etc. Yet, its modular architecture allows using only these features required by the solution being developed.

[28] http://demos.telerik.com/kendo-ui/themebuilder/

[29] http://spring.io/

Spring also offers features such as messaging that allow the creation of scalable applications. For instance a distributed application may be hosted on several servers that communicate using a Java Message Service implementation. In addition, it offers a highly customizable security module featuring authorization, authentication, web session protection, cross site request forgery (CSRF), etc. Finally, it provides an integrated development environment (IDE) based on Eclipse[30], namely Spring Tool Suite, that allows implementation, debugging, testing and deployment of Spring based applications.

Despite its complexity and steep learning curve, Spring is the most prominent choice for server side development for DAIAD, since it offers functionality that spans all the aspects of the DAIAD architecture.

6.4.2.2. Apache Struts[31]

Apache Struts is a free and open source web development framework. It implements a pure MVC architecture without any extra components that may increase complexity. Developers are allowed to use the presentation technology of their choice e.g. using a view engine like Velocity[32] or a combination of JSON and AngularJS. Moreover, Struts integrates seamlessly with other technologies like Spring framework. Still Struts does not offer any special security or scalability features. However, Apache Struts has an easier learning curve than Spring or JSF and allows developers teams to start writing code faster.

6.4.2.3. Java Server Faces[33]

Unlike other web frameworks, Java Server Faces (JSF) is a specification and a member of the Java Platform Enterprise Edition (EE). JSF is used for assembling user interfaces for web applications using components which encapsulate most HTML and JavaScript code. These components allow preserving state between requests over the stateless HTTP protocol, and implement client events that are executed at the server side. The latter two features are doing exactly the reverse of what most modern client web development frameworks, like AngularJS, do. JSF was getting criticism for being stateful but newer implementations support stateless components too. JSF can be used separately e.g. using Apache MyFaces[34] implementation, but the true benefits about performance do come when it is executed as part of Java EE stack.

[30] https://www.eclipse.org/
[31] http://struts.apache.org/
[32] http://velocity.apache.org/
[33] https://javaserverfaces-spec-public.java.net/
[34] http://myfaces.apache.org/

7. Appendix I

7.1. Panel discussions

7.1.1. Consumer Panel

7.1.1.1. Major insights:

The following paragraphs outline point by point the discussion results for DAIAD requirements by seven panel members who represent the stakeholder group of "consumers".

7.1.1.2. Information about the panel members

1. The panel members don't actively save water or know about their water consumption. Consumers have a rough idea about how long their shower takes (about 4-5 or 5-10 minutes) but they don't know how much water they spend. One member checked the water meter once but cannot tell exactly how much the person spent.
2. Panel participants attest restricted usage of tablets and smartphones for feedback visualization. Only 30% of all panel members own a tablet. The distribution of smartphones is much higher (about 90%). Nevertheless consumers rarely move the device from one room to another (such as to the bathroom).

7.1.1.3. Insights on requirements for DAIAD

1. Personalized feedback information at the fixture level. Consumers would prefer to gain access to individual consumption information. Identification is suggested by an ID card or with the smartphone. However, only a few consumers take their smartphone to the bathroom. The idealistic version includes feedback information in every faucet/fixture with a quick password-based identification directly on the faucet.
2. Feedback technologies embrace mainly in-home displays, laptops and smartphones. Consumers do not see any usage of smart watches or Google glasses for visualizing water consumption. The information on water usage could be integrated with energy/resource consumption information and visualized by in-home displays. The most desirable way would be on the smartphone (so no other device has to be installed).
3. Data enrichment. With the help of further devices other all day activities can be tracked and matched in order to identify. In a smart home scenario the data should be integrated with external (weather) and internal (heating) information. For that reason, temperature suggestions and water consumption estimations can be improved.
4. Willingness-to-pay depends on the savings. Consumers express that they would principally spend money for water management system if the return on investment is significant. For the amphiro a1

device estimates imagine a price of 80-120€. However, only few could imagine to spend 100€ for the whole DAIAD system. Some were interested in the system out of technological interest for testing modern technologies (a vital condition is connectivity).

5. The desire for installation depends on the status of the apartment. For tenants there is no real interest in investing in DAIAD. They would not want to change anything (shower hose or head, often they never changed it as soon as provided by the landlord). In the case consumers own their home they could imagine opting for DAIAD.
6. Direct feedback should be unobtrusive. Consumers would like to see consumption information directly at the faucet, the showerhead, or on the tiles behind the faucet. They would only purchase a new faucet in the case they own the apartment/house. The weight of external displays (such as amphiro a1) should be limited as much as possible.
7. Direct and indirect feedback is required. An aggregation of the whole information on the shower could be visualized afterwards on the mirror.
8. Persuasive and factual feedback forms are preferred as direct feedback. 60% of all panel members prefer factual feedback for individual consumption. They can imagine audible feedback.
9. Saving tips are interesting but should be personalized. A general question is about the way water savings can be achieved. Saving tips may play a role for providing information on that subject. However, the information should not be too obtrusive. Most of the consumers have the impression that they can gain access to saving tips more appropriate on Google.
10. The willingness to share data depends on the audience and on the added value. Data sharing on the household level can be unrestricted. Some consumers claim complete anonymity. For sharing information with a community anonymity is definitely required. No one is actually interested in sharing information on water consumption via facebook or twitter. The added value could be represented by comparisons with other individuals or utility cost savings (when data is shared with utilities). On the national level consumers do not perceive a real advantage. Only on the international level (for countries with far more problems on water consumption) there seems to be an advantage.

7.1.2. Researcher Panel

Next, the panel discussion for DAIAD requirements with German researchers in the domain of water resource management, executed by Fraunhofer, is presented. After a short introduction into the DAIAD-system, the following questions and topics were discussed. Under each question, the answers given are provided:

1. What is regarded as the benefits of smart metering in general?
   Answers:

i. Saving water and thus, from the perspective of consumers in Germany, in particular saving costs (additional property expenses)

ii. From an expert point of view, saving water also seems to be a relevant benefit with regard to water scarcity which temporarily occurs in some German regions

iii. Demand side management → reducing peaks of consumption (however, this is not as important as for energy consumption, as water can be stored and the water infrastructure is rather oversized, e.g. to supply enough fire fighting water in case of fire)

iv. In the commercial and industrial sector demand side management seems to be more relevant → beside households also enterprises should be assessed, as peaks of consumption and load are relevant for tariff structure.

v. Gaining informed scientific evidence on detailed water consumption (in particular distribution of residential water consumption over different points of use)

vi. Interesting for consumers/users who like to manage/monitor personal data (cf. "Body monitoring"),

vii. Integration into smart homes possible (automatic management of different residential functions)

viii. From an energy point of view, reducing water consumption is very relevant - not only reducing consumption of warm water - in particular due to consumption of indirect energy for transport and treatment of water, etc.

ix. Monitoring of leakages in the pipe network via online metering at different (also small) metering points. Detection of leakages also within households/companies in case of sudden unexpected changes of consumption profiles (e.g. increased consumption during the night).

x. For hotels possibly interesting for implementing incentive schemes to promote water saving behaviour.

xi. Management of water allocation (e.g. in case of block pricing or droughts), also interesting for remote buildings (e.g. mountain huts)

2. Which requirements does a smart metering system have to fulfill to provide these benefits? Answers:

i. High metering time resolution (to the split second), in order to relate water consumption to specific behaviour; alternatively implementation of meters at different points of consumption

ii. For detection of leakages: it is sufficient to measure and forward via online transfer continuously total water consumption (preferably metering at point of entry)

iii. For consumers with regard to change of behaviour: Rapid feedback which is easy (without much effort, easily to understand) to read and given close to behaviour

   iv. Rationing of water (e.g. in hotels, mountain huts, on campsites): Point-of-use metering; high metering time period is not necessary, but feedback mechanisms

3. Which of the abovementioned benefits can be reached with DAIAD/Amphiro?

   Compare answers to Question 2.

4. DAIAD/Amphiro aims to collect data of many users and report data back to them after processing. For this aim, third parties have to get access to the data.

   a. Is this exchange of data principally conceivable and would it be accepted in Germany? Answers:

      i. In principle interesting, in particular direct smart metering within an apartment for own analysis, so that it is the own decision which data are shared with third parties

      ii. Data sharing with water utility or independent energy and water consultants is conceivable (legitimation). By no means, data should be used to provide commercial offers which are not related to the topic of water consumption

      iii. System is interesting to promote awareness for water consumption, e.g. of teenagers

      iv. Willingness to pay depends on interest in saving water/money or in managing residential water consumption and on the benefits (e.g. amount of savings); consumers who enjoy taking a shower might be little interested

      v. Perhaps mainly renting of water metering systems such as DAIAD/Amphiro will be interesting, as attention might decrease or target is reached after some time.

      vi. In case of water scarcity or limited capacities for water treatment, when certain amount of water could be allocated or special tariffs could be introduced with prices which increase drastically after certain amounts of consumption, device could be interesting to manage amount of water/ /distribute it on different purposes.

   b. Which institution could come into consideration as third party (water utility, public or private, researcher, independent service provider, NGOs)?

      Answers:

      i. Water utilities seem trustworthy, if anything, with regard to use of data, as they have an inherent interest into the data which is related to water provision; also independent energy and water consultants seem trustworthy

      ii. Research institutes and statistical offices are also conceivable, if use is clarified and data are anonymized

      iii. Conclusion: it has to be clarified, who gets which data and what will be done with the data?

   c. Do water utilities have an interest in the data to be collected?

      Answers:

   i. With regard to future water provision exact distribution of specific consumption of all consumers is interesting, in particular for newly laid up regions and infrastructures

d. Who will pay for this? Which willingness to pay exists?

   Answers:

   i. Willingness to pay and interest depends on the target group. Device seems interesting in particular for younger people, which are used to/ interested in measuring „everything“ and willing to give data to third parties. They could be willing to use such a service or device.

5. DAIAD finally aims to influence water consumers by means of the collected data, i.e. change water consumption behaviour of consumers in a sustainable way or according to the aims of the water utilities (e.g. by corresponding tarifs which might be individualized).

   a. Is such an intervention conceivable / would it be accepted by water consumers? Answers:

      i. Comparable to energy topic: Advice, provision of appliances and communication of reference values is conceivable, also interventions via price / special tariffs (e.g. increased prices in times of water scarcity and consumption peaks)

      ii. For acceptance of interventions, understanding of their reasons and awareness for problems motivating the interventions are important.

      iii. Meaningful and manageable amount of recommendations is conceivable

      iv. In case of infrastructures which are smaller dimensioned or specifically adapted to consumption needs, need to manage consumption would exist and fixed costs of water provision would be lower.

      v. Display of tariffs close to point / time of consumption would be conceivable (e.g. via signal lights).

      vi. Could be important that within a household feedback related to a specific user is only reported to that person (and not to other members of the household), e.g. via identification via mobile phone.

   b. Which kind of interventions seems conceivable? How should information be delivered? (via mobile phone/ computer/ email / post mail?)

      Answers:

      i. Via mobile phone conceivable rather for usages other than taking a shower, (e.g. providing tariff information when doing laundry), mobile phone is not necessarily in the room when taking a shower

      ii. Central display at a place which is well visible, e.g. in the corridor.

iii. Direct management of intelligent appliances, e.g. programming for use of washing machine according to tariff

iv. Mobile phone conceivable for transfer of personal, individualized data, e.g. by entering a PIN to receive data.

7.1.3. Utilities Panel

On the 12/09/2014 at 10.30 – 12.00 a panel interview was conducted at a UK water utility with five participants. The participants were from departments such as; water efficiency, social media and communications and research and innovation. A set of 10 questions were asked and a semi-formal structure was used to allow to flexibility if points of interest came up and further questions were required. During the interview notes of the key points were kept, which are detailed below, P1 stands for participant 1 and so on for all those present.

To introduce DAIAD a brief 10 minute overview was provided which outlined the projects aims and how these were going to happen as well as information about the trials.

1. [LD] Are you looking to use smart technologies in the near future? Do water companies want a smart metering solution like DAIAD?

   -[P2] We are looking to use smart meters in the future, not the smartest but what the water industry terms as a smart meter.

   -[All] Further discussion about what a smart meter actually was and how the term means different things to different groups was discussed. It was agreed that a smart meter was one that sends data frequently and lets people interact with it.

   -[P3] Yes, would like to use smart technology but it has been getting the technology onto the meters that has been the issue. We would want the better granularity of data.

   -[P5] We would want smart technologies in the future, especially if they can help to encourage behaviour change, do like the idea of devices such as the Amphiro shower device.

2. How do you currently manage and monitor water demand and consumer consumption?

   [Going to consult WDM team – further explanation to come]

   -[P1] Mostly through modelling

   -[P4] Sometimes we have got consultants in to work out this consumption, this cost around £1million

   -[P1] The DMAs weren't mapped very well in terms of supply, demand a leakage though.

3. What resolution data does this give/ what resolution would you want?

-[P5] With our new metering roll out we will eventually be able to get monthly data

-[P4] I would want at least daily data and even more granular than that

-[P1] It might not be practical to have minute data and having more granular data could make it more difficult to store lots of data.

-[P3] I agree, there is no point in having data if unless you take some action from the data

-[P2] It would be good to have GIS/ Analytics in near real time and make sure it is used in near real time as possible

4. How often do you think your average consumer would log on and use DAIAD?

   -[P1] Only when they have a problem…

   -[P4] I think there will be pockets of people who will use it and others who wont, you will get people like environmentalists who would be into it but those who money is not an option to might not be interested

   -[P5] If you could make it easy in app form you could add push notifications for weekly updates about their consumption levels. They could choose to have a popup asking them if they want to know their consumption, could choose how often they were asked.

5. How would you want to use DAIAD and where do you think it could have the biggest impact?

   -[P4] It would provide the opportunity to provide more data than we are currently able to give, there wouldn't always be ways to get this level of information otherwise.

   -[P3] It would bring it up to real time and allow you to manage it yourself, it helps to bridge the gap between customer expectation and what we are able to provide

   -[All] Discussion about technology and how customers demand more in everyday life and the information they have access to, saying this carries on through to all areas of their lifestyles.

   -[P2] it would help us as a water company internally as we would be able to do more research behind behavioural change and find out more information about consumption usage and the factors that affect it.

   -[P2] It helps us to determine what people actually use to tailor behavioural change campaigns

   -[All] Discussion about how consumers have no idea how much water they are typically using and how often those who think they are low water users are often the worst offenders and vice versa so having more data would help to clear this up!

   -[P1] Its educational and people would take notice, it would make them more aware and provide them with the information to look at. You could use it in schools as it would be really good to provide data for schools verses other schools, or even counties and businesses.

   -[P5] Through using maps it could help us to identify which areas are the worst offenders so we could target these areas first to make improvements.

-[P4] It would provide something for people to do for a couple of minutes, in those minutes they might not usually think about water on a daily basis, this might help them to relate to it and take it for granted less than they already do.

-[P1] We need people talking about the messages themselves instead of from the water company, it's a case of letting people think about it for themselves. People do not trust water companies, they would rather use online forums and ask strangers!

-[All] Discussion about how water companies are often less trusted than banks. Some of the panel shocked at this.

-[P5] People want to have information and gamification is a good element as there is competiveness in everyone, think this would help on a bigger scale.

6. Are there any specific features you would like from DAIAD?

   -[P3] It would need to be made as easy as possible to share your household info on social media automatically and across as many different devices as possible.

   -[P2] Would be good if it was compatible with your Facebook account so you didn't have to make another username/ password to log in with a separate account.

   -[P4] it should also be able to move with the different social media platforms being created

   -[P1] All of the hardware and software should be moveable because people move all the time

   -[P5] It would be interesting to show consumption and how it equates to money for people or show cumulative savings over time from baseline consumption so they can see how much they have saved since using it.

   -[P4] It would be good to have heating and CO2 so people understand the embedded energy. It would also be interesting to have a comparison to show what the money spent on a shower could do somewhere else in the world/ what you could buy or how many buckets of water have been used.

   -[P5] Having medals and rewards or telling them they are above average would be useful, like giving them a digital tap on the back, or telling them they are the captain of water efficiency in the street – could do a verses of the average consumption of people in your area if you choose to link with GPS.

7. Do you foresee any barriers to using DAIAD? How do you think DAIAD would intergrate with you current metering system and would any requirements need to be fulfilled?

   -[P3] Might be concerns around GPS and tapping into other peoples networks if they aren't the leader, would need to decide tolerances of what is acceptable [Participant further expanded and stated that they had heard about this happening on other apps]

-[P1] The accuracy of the data needs to be near perfect. Concerns about increasing contact if it isn't which would damage ratings if the call centre was experiencing a higher call content. Could be an issue if predictions of cost is totally different to the customers bill.

-[P2] The lack of incentive to use it, there needs to be a buzz created around it for people to take it off and run with it, such as a big marketing campaign.

-[P4] The cost of buying it – if people were to purchase it there would need to be a fast payback within weeks or months. On the average bill £50 is quite a big portion so it would have to be cheap, free would be helpful!

8. Which aspect of DAIAD interests you the most?

-[P2] the name and meaning behind it.

-[P1] The competitive and community element behind, that there will be an app with social media aspects involved

-[P4] The ease of being able to monitor the consumption and actually showing people what they are using.

-[P5] Giving the empowerment to customers, so far water efficiency has been based on a top down approach of giving out devices, this is another route for customers to take power of their consumption and subsequently take action.

-[P3] The new technologies that will come out of it and a different approach to understanding household water consumption

9. What concerns would you or do you think customers might have about using a system such as DAIAD?

-[P5] The radiation from meters and health concerns, know it has been proved not an issue but the average person might not be aware of this.

-[P3] That the meters that we install at households aren't specific for these devices, so compatibility issues.

-[P2] The privacy and customer information, that its secure and cant be accessed or hacked.

-[P1] There is a lack of trust of the water industry and government, this could be seen as an invasion into homes. This is becoming a bigger area of contention for people.

-[P4] If there was a discrepancy between meter readings from DAIAD and ours. There have been cases (such as Anglian Waters in house display that didn't work because of accuracy issues]. The margins of error need to be low and overall it needs to be super accurate.

10. Who do you think would use it?

-[P1] It would be cool for families who have kids who then drive the family to use it

-[P3] There are different ideals within family and the older generation have different appreciation and values about what is scare and what isn’t.

-[P4] I think it would mostly be families using it or younger people who are part of the app generation.

7.2. Interviews

7.2.1. Interview 1

Next, the interview for DAIAD requirements with a researcher in the domain of water supply and wastewater treatment in Germany, executed by Fraunhofer, is presented.

After a short presentation of the DAIAD project and the Amphiro device and its intended modification, the following questions were discussed:

1. How can smart metering of water be useful in general?

    i. In Germany, water saving is not a big issue, at least not from the suppliers' perspective. The latter even argue that, if the users reduce water consumption, they have to flush the pipes with additional fresh water to avoid hygienic problems.

    ii. Load management (i.e. achieving as smooth a flow as possible). Basically, the capacity of pipes is large enough to accustom large flows, moreover there are buffering capacities, but pumping larger quantities requires disproportionally more energy for the pumps. Also, for new systems the pipes could be dimensioned smaller (i.e. less costly). But: many systems also serve as fire water supply (with higher capacity needs)

    iii. Leakage identification: If the supplier knows exactly how much and when he supplied water and how much and when the water users used it, he can calculate where the difference was lost. The same is true within a house or an enterprise once water is used at very unusual times (e.g. during the night)

    a. What are the requirements a smart metering device has or meets for this purpose?

    iv. Load management requires demand-side management → need to provide feedback to the water users; time resolution high enough to identify peaks

    i. Leakage identification requires a comprehensive network of meters covering all outlets → a point-of-entry meter is more useful than a point-of-use meter; time resolution high enough to distinguish different times of the day

2. Which of these uses can be served by DAIAD/Amphiro?

i. Load management as timely feedback is important

3. DAIAD/Amphiro intends to collect data, evaluate them and return them to the water users. This requires access of a third party to the respective user data.
   a. Is this exchange of data acceptable?
      i. Yes, if data are used by the water supplier
   b. Which institution could serve as a third party? (water supplier, public/private? (independent) service providers? scientists? NGOs?)
      i. Water supplier; service providers and scientists to the extent that they support the water supplier
   c. Are water suppliers interested in the type of data provided by DAIAD?
      i. They are not so much interested in the high time resolution; also, DAIAD covers only one part of the consumed water
   d. Who pays? How much?
      i. Willingness to pay for most water users is rather small (exception: monitoring freaks); depends on whether users are ready to change their water use behavior at all
      ii. Willingness to pay among water suppliers is higher, but not so much for the data supplied by DAIAD/Amphiro device

4. Eventually, DAIAD aims at intervening with the water users' behavior on the basis of the collected data such that their water use scheme becomes more sustainable, shortages are better managed or peaks are flattened.
   a. Is such an intervention acceptable from the point of view of the water users?
      i. Basically, any price or block tariff represents an intervention.
      ii. If water price responds to a situation of scarcity (e.g. drought), higher prices are acceptable, but the conditions have to be transparent
      iii. In situations of emergency even more drastic measures such as embargoes are adopted (e.g. interdiction to water the lawn or wash a car)
   b. Which way of intervention is acceptable? (Via mobile? Via computer? Via Mail?)
      i. The closer to the point of (water) use the better (Amphiro, mobile phone)

7.2.2. Interview 2

Next, the interview for DAIAD requirements with a consultant for water supply companies in Germany, executed by Fraunhofer, is presented.

After a short presentation of the DAIAD project and the Amphiro device and its intended modification, the following questions were discussed:

1. How can smart metering of water be useful in general?
    i. Online water meters are frequently used in the distribution network to control for leaks. In households, they have been tested in series of trials, but it is still unclear to which end they could be used. They are too expensive for the benefit to exceed the cost. In the power market, there is a need for demand side management, because energy cannot be stored easily. In the water sector, by contrast, many distribution systems were designed and built around the 1970s, when increasing water demand was foreseen. Now, in times of decreasing demand, these pipes have a rather large capacity with no need for any kind of sophisticated load management.
    ii. For this and other reasons (e.g. the existence of plenty of water), there is also no need to save water or to help water users doing so. In the energy sector, power suppliers supported power users in using less electricity. This strengthened the ties between supplier and customer and prevented the latter from changing to a competing supplier. In the water sector, by contrast, there is no competition between suppliers; therefore, there is no need for customer-binding measures.
    iii. The higher cost of smart meters does pay for large, industrial customers, who are billed for the total quantity of water used and the quantity per time (i.e. size of the fixture)
    iv. Compared with energy, a household's annual cost for water is so small that most people do not care and even do not know the water price. As a consequence, price differentiation would hardly be recognized and, all the less, have any impact.

    a. What are the requirements a smart metering device has to meet for this purpose?
        i. —

2. Which of these uses can be served by DAIAD/Amphiro?
    i. General weakness: only one water flow in a household is measured

3. DAIAD/Amphiro intends to collect data, evaluate them and return them to the water users. This requires access of a third party to the respective user data.
    a. Is this exchange of data acceptable?

i. Yes, the issue is subject to the conditions of the contract between the wa-ter supplier and the water users. Minimum standards for this are estab-lished by the water suppliers' associations.

b. Which institution could serve as a third party? (water supplier, public/private? (independent) service providers? scientists? NGOs?)

   i. Water supplier; service providers and scientists to the extent that they support the water supplier; conditions need to be specified in the contract between both parties

c. Are water suppliers interested in the type of data provided by DAIAD?

   i. Not really

d. Who pays? How much?

   i. No willingness to pay on the part of water suppliers

4. Eventually, DAIAD aims at intervening with the water users' behavior on the basis of the collected data such that their water use scheme becomes more sustainable, shortages are better managed or peaks are flattened.

   a. Is such an intervention acceptable from the point of view of the water users?

      i. —

   b. Which way of intervention is acceptable? (Via mobile? Via computer? Via Mail?)

      i. —

   c. What is the water supplier's stance to this?

      i. If it was beneficial for the water supplier, there would be no reason why not to interfere with the customers. Any change of water prices (or price schemes) represents such interference. But at this moment, there is no need to interfere.

7.2.3. Interview 3

Next, the interview for DAIAD requirements with a representative of a German private water supplier, executed by Fraunhofer, is presented.

After a short presentation of the DAIAD project and the Amphiro device and its intended modification, the following questions were discussed:

1. How can smart metering of water be useful in general?

   i. Source of more information about the customers of water supply, especially with future perspective. Water suppliers need to plan their infrastructure requirements. In order to do so, they need to know the water users with regard to demography and socio-economic parameters (e.g. age, in-come, education).

ii. A difficulty in this context: Learning from user → User pays more attention to water usage → User saves water (This is not the supplier's aim). More acceptable: Saving of hot water instead of water as such. Water saving not only for economic reasons, but in order to have environmentally a good conscience.

iii. There is a small group of water users, who love to measure and evaluate everything around them and use devices like Amphiro to do so (about 5 to 8 % of all users). They can easily be convinced to participate in the information exchange between water supplier and user. With all others this is much more difficult.

a. What are the requirements a smart metering device has to meet for this purpose?

  i. In addition, more individual information is necessary. Some information can be derived via the contract between water supplier and the customer (Where is house located? How many inhabitants?). But the customer and the user are often not the same (landlord vs. tenant). More user-specific information can in principle be collected by smart meters. But smart me-ters are stupid; in order to gain information, the data need evaluation. This requires high-resolution data and a close interaction with the customer to learn about the meaning of specific use profiles in the first place.

2. Which of these uses can be served by DAIAD/Amphiro?

  i. Amphiro can facilitate the information exchange between water supplier and water user owing to its smart phone-mediated communication capacity. Also the high-resolution water metering is an advantage. Unfortunately, Amphiro covers only one part of household water use (showering).

3. DAIAD/Amphiro intends to collect data, evaluate them and return them to the water users. This requires access of a third party to the respective user data.

  a. Is this exchange of data acceptable?

    i. Most of today's smart meters are point of entry meters (for entire houses), which is also the limit for the traditional responsibility sphere of water sup-pliers. Other recipients of water data are those service providers who measure and split (cold and hot) water consumption of entire houses to specific flats.

    ii. If data are exchanged electronically or even wireless, strong data protection standards are applied to avoid misuse of the data. Otherwise burglars could find out from water use profiles whether the inhabitants are in or out; or insurances could derive information about the medical condition of their customers.

b. Which institution could serve as a third party? (water supplier, public/private? (independent) service providers? scientists? NGOs?)

   i. See above

c. Are water suppliers interested in the type of data provided by DAIAD?

   i. To analyze the water consumption and learn more about the consumption behavior of specific user groups: yes. To screen the major part of all water users: no.

d. Who pays? How much?

   i. To the extent that water suppliers want to learn about their customers they will pay. The number of customers that are ready to pay is rather limited (5 to 8 %, see above)

4. Eventually, DAIAD aims at intervening with the water users' behavior on the basis of the collected data such that their water use scheme becomes more sustainable, shortages are better managed or peaks are flattened.

   a. Is such an intervention acceptable from the point of view of the water users?

      i. To some extent, this interference already happens based on price schemes. Other existing intervention: Prohibition of garden irrigation and car washing in times of drought. So, interventions are commonplace.

      ii. The latter type of intervention is not exerted by the water supplier, but by local government (politically). For the water suppliers, it would not be advisable to interfere too intensively with the customer (e.g. commenting every aspect of his/her behaviour).

   b. Which way of intervention is acceptable? (Via mobile? Via computer? Via Mail?)

      i. Via mail and computer this is already state of the art.

   c. What is the water supplier's stance to this?

      i. Interference with all users individually would be too expensive. However, social interaction between users could be effective and less costly and without the supplier's need to interfere with all of them.

7.2.4. Interview 4

Next, the interview for DAIAD requirements with a UK Governmental department responsible for policy and regulation on environmental, food and rural issues, executed by Waterwise, is presented. Their priorities are to grow the rural economy and improve and safeguard the environment.

Initially a telephone interview was conducted with two representatives from the department. This lasted for 30 minutes, of which 10 of those were to provide an overview about DAIAD and is aims and trial scenarios. Following going through the questions both participants asked if they could have the list of questions to consult with other colleagues who might have more expertise.

1. Currently do you think there is anything missing in WDM tools? This could be from both or either the consumer or utility side?
    i. Government welcomes innovation in the water sector and this can be either on the consumer or the utility side.

2. Is there a place for smart metering and projects like DAIAD to assist in the WDM/ water efficiency area?
    i. Research is always useful. Water companies are responsible for introducing smart metering where it is needed or is cost beneficial.

3. From your perspective, what requirements would you like from a smart metering system, such as DAIAD? This can relate to both Water Company and household side.
    i. This question would be better directed to water companies.

4. What type and resolution data do you think would be required/ you would like to see? And why?
    i. Again, this question would be better answered by water companies.

5. How do you think having higher resolution data would impact your work? WDM perspective
    i. Data collection is a matter for water companies – government does not require very granular data from water companies' customers. Data collection by water companies can be fed in to Water Resource Management Plans.

6. Do you think policy currently encourages smart metering technologies for water?
    i. There is scope within WRMPs to adopt innovative approaches. Government policy, via the Water Act, is introducing competition for non-household users by 2017. Large water users might look for a water supplier that provides them with better data on their water usage, smart metering, online support and advice on water efficiency to help them reduce waste. This offers obvious environmental benefits as water companies seek to attract new customers though new water efficiency services and advice. For example, in Scotland a water supplier helped a caravan park reduce their consumption by 20% through installing rainwater harvesting. In another example, Business Stream estimates their water efficiency services in Scotland have saved customers over £13 million and saved 7.4 billion litres.

7. How do you think this could be influenced inline with the smart metering advancements?
    i. The Water Act is creating the environment where innovation can push through and increase uptake of smart metering.

8. What opportunities and barriers are there for smart metering and projects like DAIAD?
    i. Responsibility for smart metering is a matter for water companies.

9. Do you think smart metering will become ubiquitous in the future?
    i. We do not have an answer to this question at the present time.

7.2.5. Interview 5

This interview was conducted on the 18/09/2014 with an individual from the UK Water Regulator. The area of expertise for this person is in the policy and governmental affairs but has an in depth knowledge and level of experience in the water sector as a whole. The questions were tailored to accommodate this as innovation is currently highly relevant to UK water utilities and their business plans as a whole. The interview was composed of 8 questions and lasted for 30 minutes.

To introduce DAIAD a brief 10 minute overview was provided which outlined the projects aims and how these were going to happen as well as information about the trials.

1. Is there a place for smart metering and projects like DAIAD to assist in the WDM/ water efficiency area?
    i. Yes, this currently ties in with approach for PR14 and beyond (PR14 is a large report that is produced by individual water companies, it sets out how water companies are going to keep prices affordable as well as the service package that customers will receive)
    ii. We want customers to engage directly and understand what they want whilst building this into how they work
    iii. Want the companies to talk and understand what customers want and need and take an innovative approach to this communication.

2. Currently do you think there is anything missing in WDM tools? This could be from both or either the consumer or utility side?
    i. Gap at the moment is we all have smart phones but don't have water on these.

ii. There is a gap between old fashioned engagement and the social world – and apps would help to bridge this.

iii. Need for water to catch up with energy

iv. Water companies need to drive innovation for customers' supply and demand and their management.

3. From your perspective, what requirements would you like from a smart metering system, such as DAIAD? This can relate to both Water Company and household side.

    i. Would like for the water companies to be able to speak to the customer

    ii. Want the kit (hardware - relating to Amphiro devices) for households but don't necessarily want everything (i.e. information and data) on a smart phone, might want old methods or alternatives to see this information

    iii. Where it ties in with what customers want, so if its bottom up and what customers want and what works for them and want to use it

    iv. Risk in the water companies attached to demand management – different risks that people might not know about

4. What type and resolution data do you think would be required/ you would like to see? And why?

    i. 15 minutes sounds right but it also depends on what customer would want

5. Do you think policy currently encourages smart metering technologies for water?

    i. Government policy, the fact its not mandated but there is space in terms of business plans means that water companies now can, it is not up to the water companies to rise to it

    ii. Ofwat regulate – space for companies to innovate, with the Price Review methods that have been running for a couple of years

    iii. Water Companies don't think that there is space for innovation but the barriers have now gone

6. What opportunities and barriers are there for smart metering and projects like DAIAD?

    a. Opportunity:

        i. Through the Price Review process there is the opportunity to reward the water companies for innovation, water companies are looking to be more innovative

        ii. There are more ambitious water efficiency plans – have to deliver what they have agreed as they are dependent on customers engaging with the behaviour change

b. Barriers:

   i. Skills barrier with the people who could deliver it

   ii. Typically people in companies wouldn't have this as at one time there was a need for engineers

   iii. There are different skills and challenges with that now

7. If this type of technology were to become mainstream, who should take the cost for this?

   i. It would be down to the water companies understanding customers – some water companies might not pay and some would be willing to pay

   ii. It would also be down to the customers' views about whether they would want this

   iii. For example, Wessex water, in their business plan have community scheme which means if they save water the local schools get books for the money.

   iv. If the community save money – water company save money

8. Do you think smart metering will become ubiquitous in the future?

   i. Yes, but I don't know how long it will take there, eventually it will get to that stage

7.2.6. Interview 6

This interview was conducted with a representative from the Environment Agency. Due to availability of the participant an overview was given via email and questions answered in the same manner.

1. Currently do you think there is anything missing in (Water Demand Management) WDM tools? This could be from both or either the consumer or utility side?

   i. I think there are three main things missing:

      - The financial incentive – even though this may not have to be big - so linked to that is;
      - Information for people on how much water they actually use which can only be provided effectively through metering and possibly by a system such as DAIAD
      - Understanding how much water people really use themselves i.e. even if people have a meter do they really understand how much a cubic meter really looks and feels like? So some form of effective visualisation tool or picture is needed. I don't think the Olympic swimming pool analogy works at all.

2. Is there a place for smart metering and projects like DAIAD to assist in the WDM/ water efficiency area?

   i. Yes

3. From your perspective, what requirements would you like from a smart metering system, such as DAIAD? This can relate to both Water Company and household side.
    i. Easy to use for customers
    ii. Engaging enough so the novelty doesn't wear off and people stop using it which I think is common for many apps
    iii. The ability to do comparisons with similar households so it needs to be able to be customised by individuals to show their family size etc.
    iv. Ability for individuals to compare their own use over time and maybe automatically download data to a spreadsheet in Excel or Numbers – maybe this is a low priority but will appeal to the geeks amongst us
    v. Leak warnings via text and email
    vi. Targeted and simple data and information requirements/provision for both companies and customers
    vii. Zero maintenance for customers. It's no good having to change the batteries like you do on an Owl energy meter
    viii. Low cost and maintenance for water companies, otherwise it won't be funded or they won't be interested
    ix. Adaptable so it can be easily added on to water companies' existing systems
    x. Reliable – for both companies and customers
4. What type and resolution data do you think would be required/ you would like to see? And why?
    i. Ideally the user should be able to chose. Daily as a minimum but users could select event driven data especially as individual appliances are being monitored. So maybe it could provide a readout if someone uses the shower for more than 5 minutes. Perhaps it could provide 15 minute or appliance level data for the current day or two days then drop down to daily after that. If the system stores 96 readings (15 minute data) per day, this could add up to a huge amount of data when you get a few thousand households onto the system. I'm not sure if water companies would want to hold this much data. However the ability for water companies or consultants to grab high resolution data for specific studies would be very useful.
5. How do you think having higher resolution data would impact your work? WDM perspective
    i. It would be most useful for short individual studies and understanding components of demand. Samples of high resolution data could be taken and used to track changes in water use behaviour over time and in response to events like droughts and Temporary use bans. For the EA's work this would be for specific studies and water resources planning rather than an ongoing data archive. We would probably want the water companies to do a significant part of this work. The results of these studies would

improve demand forecasts and enable demand management messages to be better targeted.

6. Do you think policy currently encourages smart metering technologies for water?
    i. Not directly, but water companies are expected to look at the costs and benefits of approaches to WR planning including metering and can select smart meters where these are beneficial.
7. How do you think this could be influenced inline with the smart metering advancements?
    i. No comments
8. What opportunities and barriers are there for smart metering and projects like DAIAD?
    i. If the system is found to be cost effective to install and maintain as well as delivering real water savings from customers then it will be used. If it hits the sweet spot for customers then they may ask for it.
9. Do you think smart metering will become ubiquitous in the future?
    i. Difficult to tell. It depends on whether metering becomes ubiquitous, whether it is shown to be cost effective by water companies who are using it now and future costs. It will also depend on customer views. Some companies have found that customers do not want smart metering.

8. Appendix II

The final and *optional part* of the online survey included a set of questions regarding the demographic characteristic of the participants, and their broader views on environmental issues and technology receptiveness.

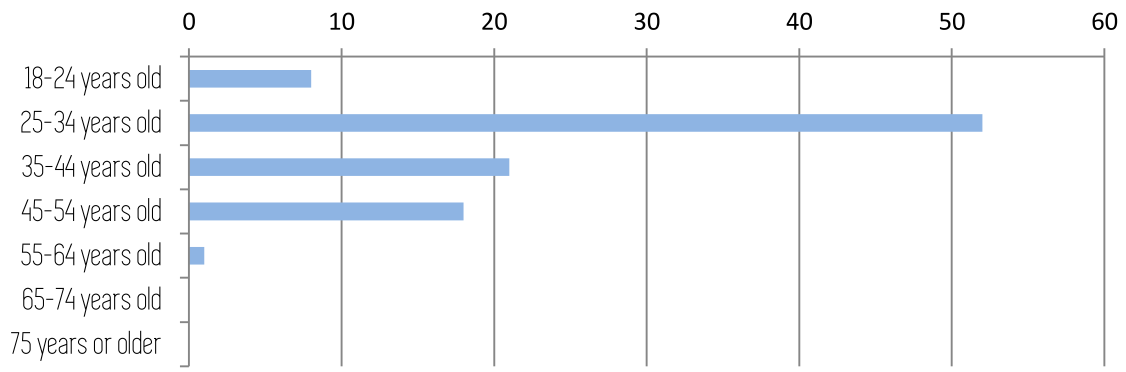

Figure 79: Responses on "What is your age?"

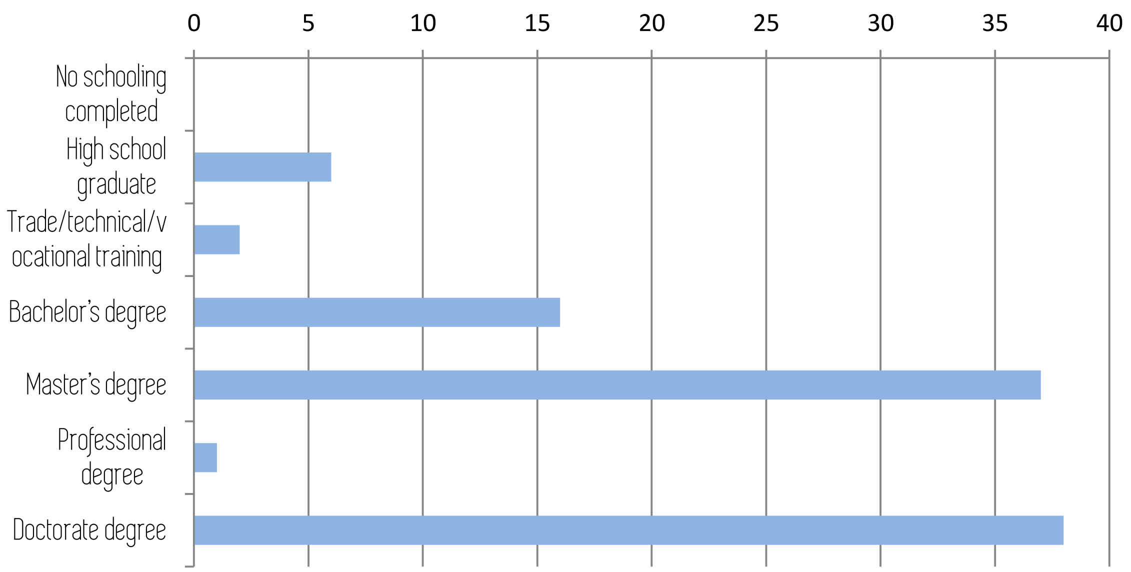

Figure 80: Responses on "What is the highest degree or level of school you have completed? If currently enrolled, highest degree received"

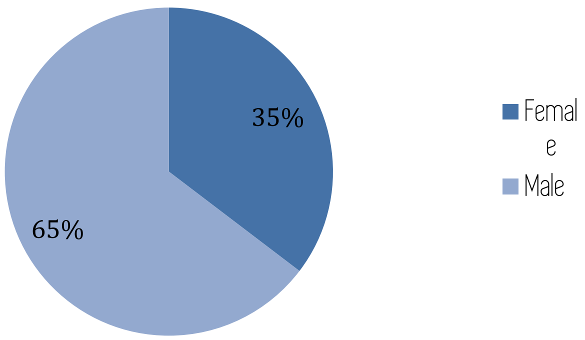

Figure 81: Responses on "What is your gender?"

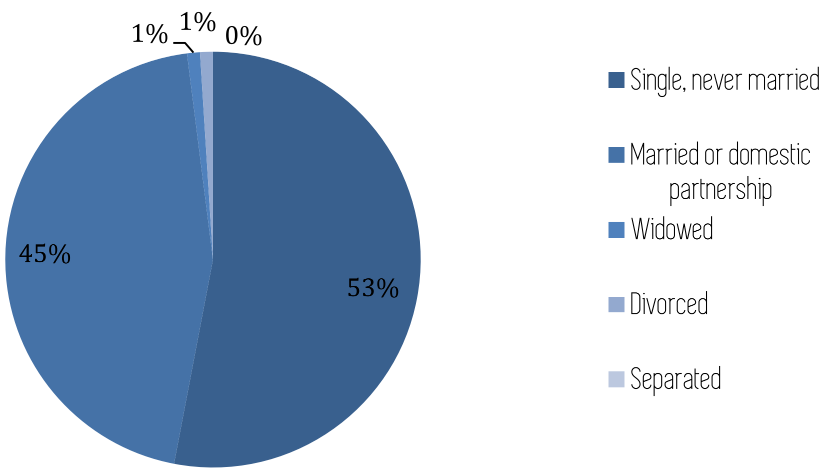

Figure 82: Responses on "What is your marital status?"

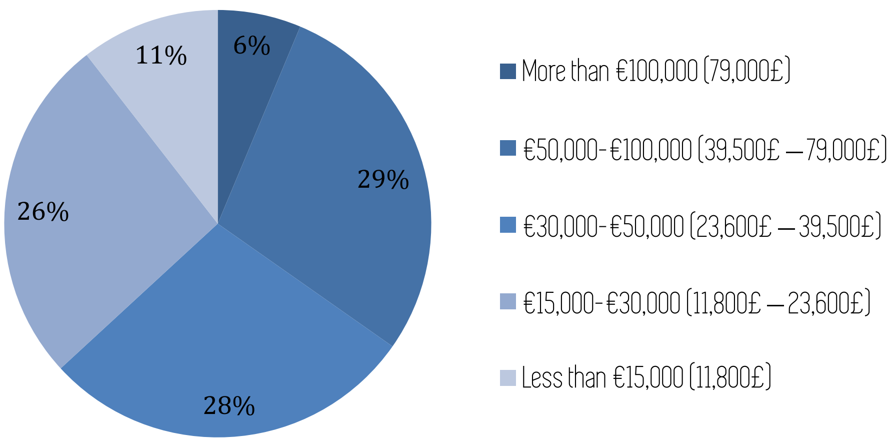

Figure 83: Responses on "What is your total household income?"

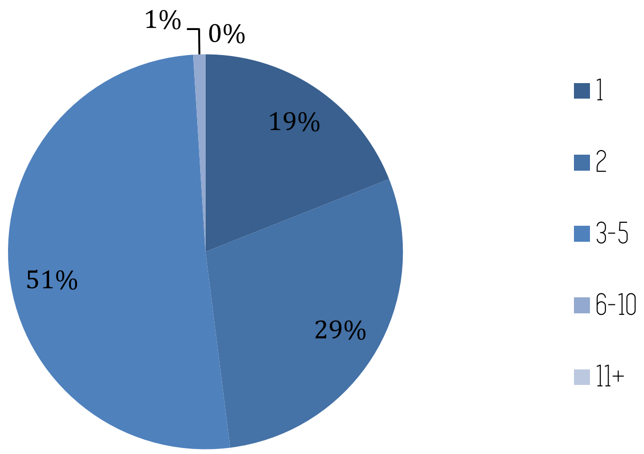

Figure 84: Responses on "How many members are there in your household?"

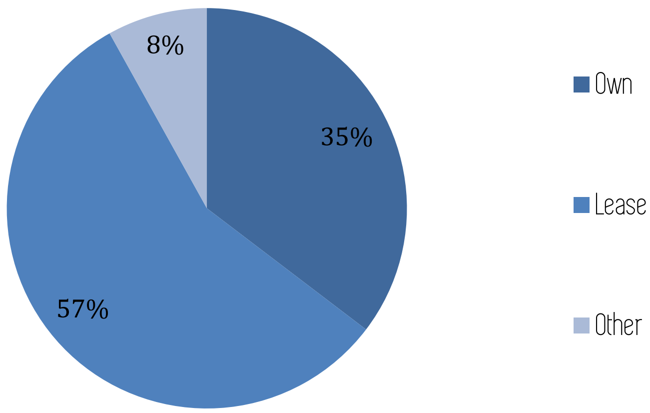

Figure 85: Responses on "Do you own or lease your residence?"

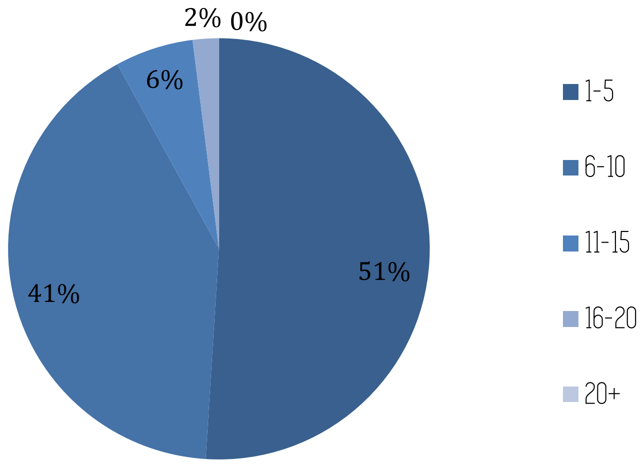

Figure 86: Responses on "In total, what is the total number of fixtures and appliances consuming water in your residence (e.g. faucet/tap, shower-head, dishwasher)?"

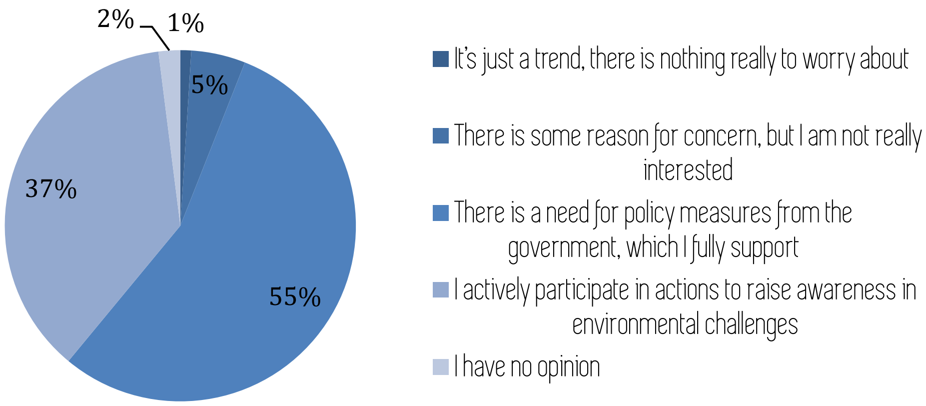

Figure 87: Responses on "What is your opinion of environmental issues?"

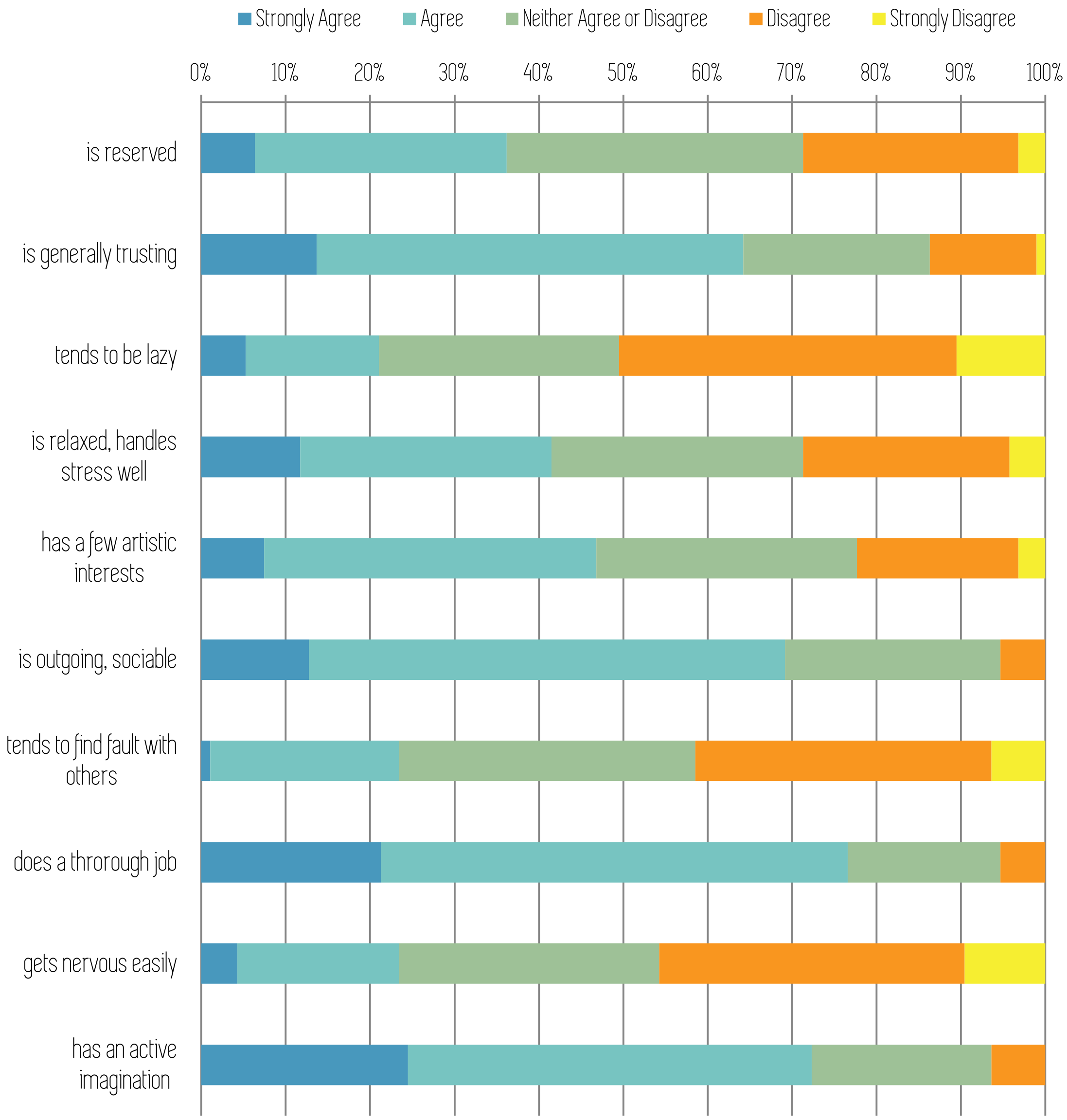

Figure 88: Responses on "How well do the following statements describe your personality? I see myself as someone who:"

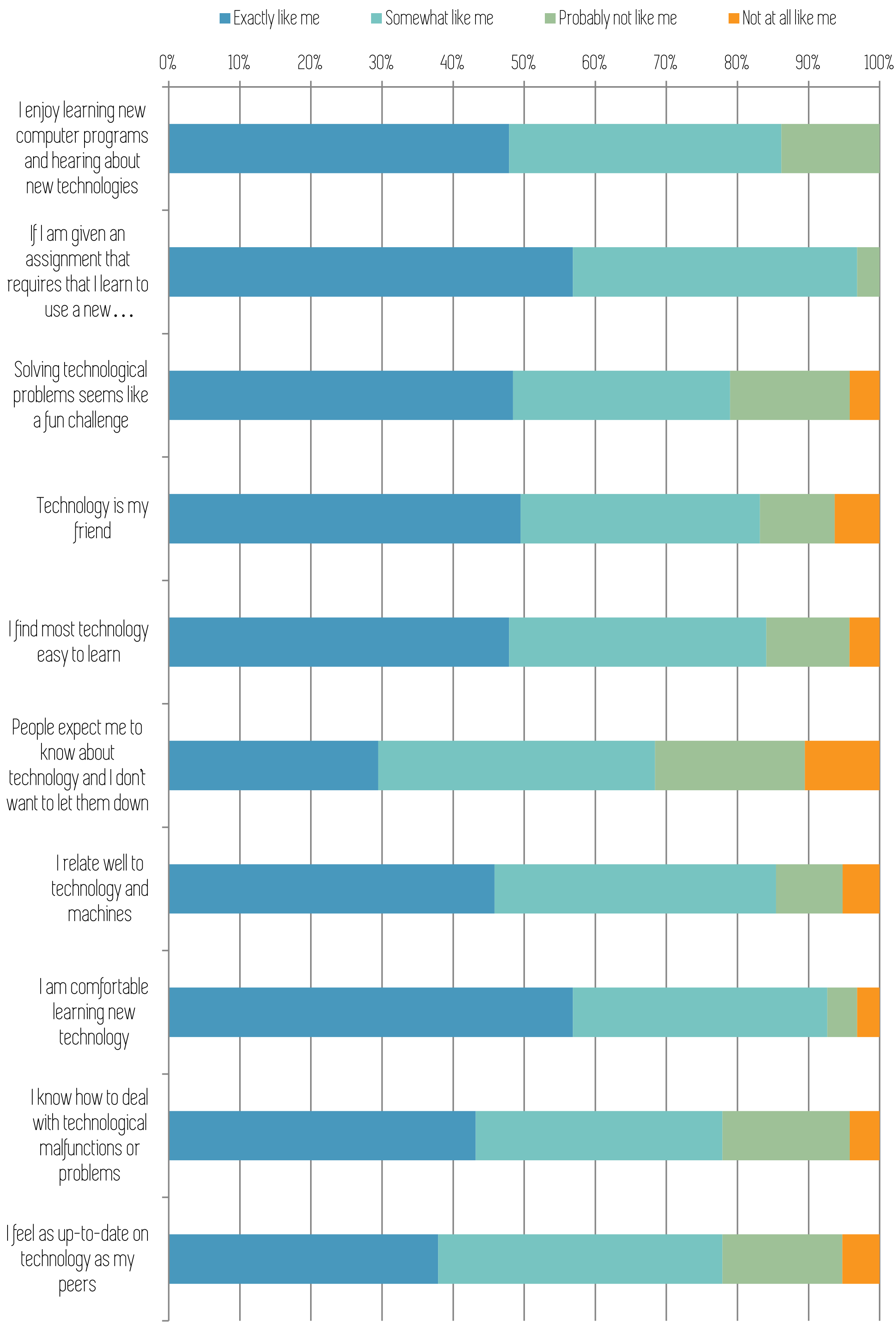

Figure 89: Responses on "Please rate how well the following statements describe you."