A Participatory Design Approach for Energy-Aware Mobile App for Smart Home Monitoring

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Keywords: Participatory design, User-awareness, User-Centered, Energy Aware, Smart Home, Smart Metering, Prosumer

Abstract: It is generally recognized that our behaviours affect the environment. However, it is difficult to correlate behaviour of an individual person to large-scale problems. This is usually due to insufficient ergonomy of available tools. The main cause is that most of user-awareness tools available are technology-centered instead of user-centered. In this paper, we present a participatory design approach we followed to design and develop an energy-aware mobile application for user-awareness on energy consumption for Smart Home monitoring. To engage end-users from the early design stages, we conduct two on-line surveys and a focus group involving about 630 people. Results allowed on identifying functional requirements and guidelines for mobile app design. The purpose of this research is to increase user-awareness on energy consumption using tools and methods required by users themselves. Furthermore in this paper, we present the technological choices that drove our implementation of an energy-aware application based on prosumers' requirements.

1 INTRODUCTION

Traditionally, technicians and engineers design systems with a technology-centered perspective. In recent years, there is a deep change in the design approach: from technology-centered philosophy to user-centered. In this way, new design challenges are projected on a new way to mold a system interface considering capabilities and needs of end-users. This philosophy aims at achieving optimal functioning of overall human-machine system (Endsley, 2011). The main principles of this design pattern can be summarized as follows: i) design technology around the user needs, tasks and abilities; ii) design technology to help users in easily achieve a goal and make a decision; iii) design technology to make aware the users.

In a dynamic and complex system, decision making depends on situation awareness; thus, knowing what is happening. In (Faruqui et al., 2010), the authors prove how user-awareness influences the energy savings at home and helps user to change their own habits towards green attitudes. Consequently, developers have to understand user-awareness as personalization of services delivered to consumers and prosumers[1] (Ritzer and Jurgenson, 2010). This is achieved by choosing proper data processing and transmission methods, according to functional and non-functional requirements stated by end-user. These requirements can be formulated explicitly or be a result of automatic recommendations that are based on application usage (Graña and Toro, 2012).

To actively involve consumers and prosumers on early planning and design stages of an energy-aware app for Smart Home monitoring, we carried out two on-line surveys and a focus group involving about 630 people in total. The subsequent results have been exploited to define guidelines on which the entire application is based, also it highlighted many issues and lacks. These results highlighted a general lack of awareness on energy consumption. Very often, users do not know consumptions and operating status of their appliances, while they perceive it as an essential information to know. Thus, users believe that a (near-) real-time energy-aware system is needed, even to promote green behaviours.

In this work, we aim at better understanding the importance of user-centered methodology to design and develop an energy-aware mobile application for Smart Home monitoring. We present the followed *Participatory Design* methodology to define functional requirements and guidelines to develop such a tool. The rest of this paper is organized as fol-

[1]Active consumer. New figure of producing consumer.

lows. Section 2 reviews literature solutions on user-awareness for energy consumption in smart environments. Section 3 describes the followed participatory design methodology. It also presents the results of two on-line surveys and a focus group we conducted to understand the functional requirements requested by users. These requirements have been taken into account to develop an energy-aware mobile app for Smart Home monitoring that is presented in Section 4. Finally, Section 5 discusses concluding remarks and future works.

2 RELATED WORK

There are a lot of research works in the field of user-awareness for energy saving. EnergyLife project (Jacucci et al., 2009) represents one of the first experiments where during the design phase the authors studied end-users' behaviors to realize a mobile platform close to users' needs. Two relevant projects developed with LinkSmart[2] are Energy Aware Smart Home (Jahn et al., 2010) and EnergyPULSE (Jahn et al., 2011). LinkSmart is middleware designed to create distributed applications and platforms to interact with Internet-of-Things (IoT) devices. Both Energy Aware Smart Home and EnergyPULSE projects develop smart energy efficient applications in heterogeneous environments. Energy Aware Smart Home includes smart metering and control of home appliances combined with novel user interaction applications. EnergyPULSE allows the monitoring of power consumption of appliances and other environmental values in the office domain (e.g. temperature, presence). It aims at providing a basis for new kinds of user-centered feedback systems in such an environment.

In Energy Aware Smart Home (Jahn et al., 2010), the authors deploy stationary and mobile interfaces that allow end-user to monitor and control smart homes. For each appliance the system User-Interface (UI) displays current consumption in watts, costs per hour, and costs projected over one year. As smart platform, they implement UbiLense (Reiners and Jentsch, 2009), an Augmented Reality (AR) (Carmigniani et al., 2011) system that aims at improving the user-experience. This application recognizes objects using image-processing methods and displays energy consumption information about the target device. This AR-awareness system improves the user-experience but in any case end-users must interact with pre-designed UI. This type of design is still technology-centered.

In EnergyPULSE (Jahn et al., 2011), the authors use Business Ethnography[3] (BE) (Stevens and Nett, 2009) approach to study if users understand the information collected by the system and if they perceive these information as useful for reducing the energy waste. Through three workshops, involving 12 people, the authors have defined and analyzed users requirements to improve their system. Specifically, they have understood some energy practices in work places and how they may affect on energy consumptions. Differently from our participatory design approach, Jahn et al. impose a default UI and data set. Only through a subsequent study, involving end-users, they evaluate possible design guidelines to consider in development of such systems. These improvements are not implemented but they represent the starting point for future developments.

3 IDENTIFICATION OF TARGET USERS AND FUNCTIONAL REQUIREMENTS

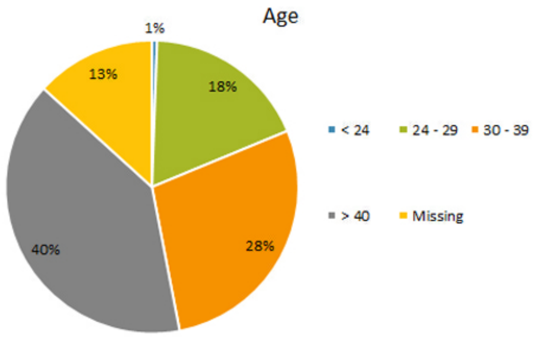
In (Faruqui et al., 2010), the authors emphasize how user-awareness on energy consumption can positively affect the energy savings at home. In particular, if end-users know their energy consumption in (near-) real-time, they can save around 7-17% of energy. Hence, a proper user-awareness and notification system is needed to promote green behaviours and convince users in changing their habits, which is not trivial. The rest of this section presents the results of two on-line surveys and a focus group we conducted. We exploited this results to identify functional requirements, strengths and improvements requested by users to design and develop an efficient energy-awareness application, presented in Section 4. Particular emphasis was given on gathering users' information, ideas, opinions and attitudes on energy consumption and efficiency.

3.1 Target user survey

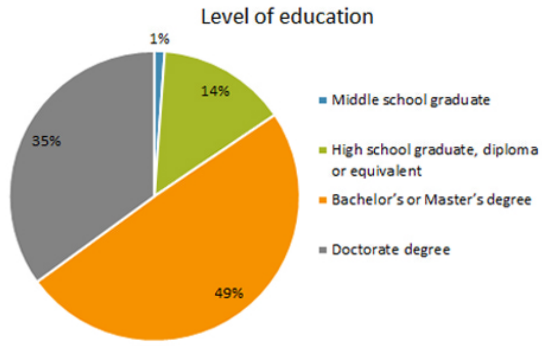
The first on-line survey was focused on identifying target user. It consists of ten questions regarding i) *Personal Information* and ii) *Energy Consumption Interests*, as reported in Table 1. It involved 528 persons and results are shown in Figure 1 and discussed in the following.

[2] https://linksmart.eu/redmine

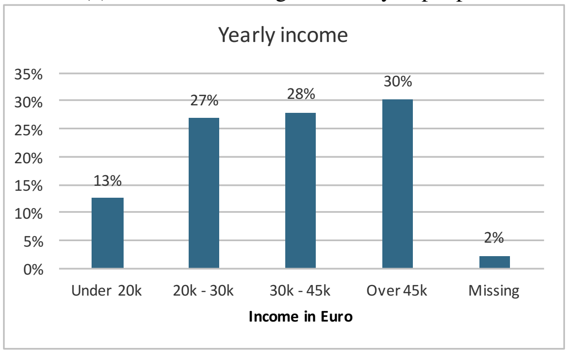
[3] The Business Ethnography is a supporting method to evolutionary design conceptions and relative forms of product finding.



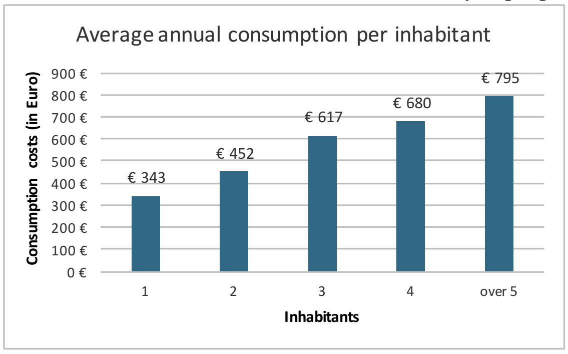
(a) Distribution of age of surveyed people



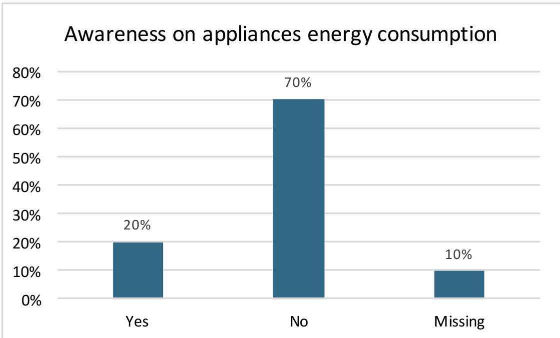
(b) Distribution of level of education of surveyed people



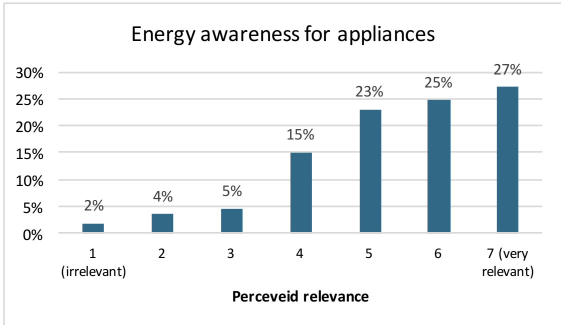
(c) Percentage of yearly income (in Euro)



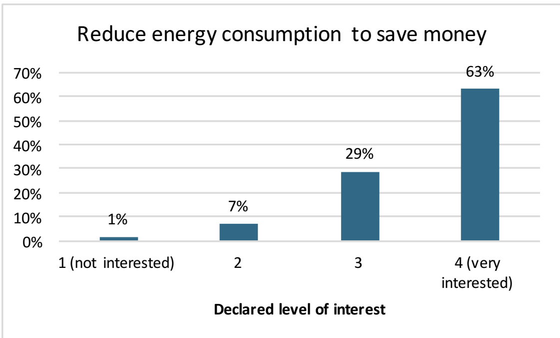
(d) Average consumption (in Euro) per inhabitant



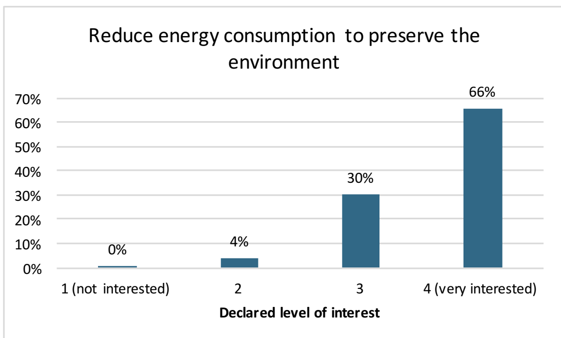
(e) Current awareness on appliances energy consumption



(f) Perceived relevance on energy awareness for appliances



(g) Declared level of interest on reducing energy consumption to save money



(h) Declared level of interest on reducing energy consumption to preserve the environment

Figure 1: Results of first survey

Figure 1(a) shows the age distribution of the surveyed people. 47% are under 40 years old. Respectively, 1% are under 24, 18% between 24 and 29 and 28% between 30 and 39 years old. On the other hand, 40% are over 40. The remaining 13% did not answer the question. Figure 1(b) highlights that 84% of users have a high level of education (respectively, 49% have a bachelor's or master's degree and 35% a doctorate degree). Then, 14% are high school graduated (diploma or equivalent) and almost 1% are middle school graduated.

Figure 1(c) reports the yearly income in Euro, grouped into four ranges. As it can be gathered from the figure, the distribution on the highest income ranges (respectively, 20k-30k, 30k-45k and over 45k) is almost uniform, between 27% and 30%. Only 13% of the users declared an income under 20k.

Figure 1(d) reports the average annual consumption expense in Euro. This Figure reveals that the expense rises proportionally with the number of inhabitants. Indeed, the impact of each additional inhabitant on the yearly consumption is about €100. This observation stems from correlating the outcomes of question 3 (*How many people live with you (including you)?*) and question 5 (*How much did you spend on electricity bills in the past 12 months?*).

Figure 1(e) highlights that 70% of users are not aware of their energy consumption and they do not know how much they spend for each appliance. Hence, knowing the consumption of each appliance is relevant for 75% of the total users, as revealed in Figure 1(f).

Table 1: Questions proposed during the first survey

	Question	Answers
Personal Information	1. What is your age?	under 24 years old 24-29 years old 30-39 years old over 40 years old
	2. What is the highest degree or level of education you have completed?	middle school graduate high school graduate, diploma or equivalent bachelor's or Master's degree doctorate degree
	3. How many people live with you (including you)?	1 2 3 4 5 over 5
	4. What is your yearly income?	under 20k 20k - 30k 30k - 45k over 45k
Energy Consumptions	5. How much did you spend on electricity bills in the past 12 months?	under 300 300 - 499 500 - 699 700 - 999 over 1000
	6. Do you know exactly how much you consume and how much you spend for your appliances?	yes, I do no, I do not know
	7. How relevant is it for you to be aware on energy consumption and costs of your appliances?	choose between 1 (irrelevant) and 7 (very relevant)
	8. Are you interested in reducing your consumption because you would reduce your monthly bill?	choose between 1 (not interested) and 4 (very interested)
	9. Are you interested in reducing your consumption because you would help reducing pollutant emissions?	
	10. Do you have any additional comment?	open answer

Finally, Figure 1(g) reports that 92% of users are interested in reducing energy consumption because they want to cut their monthly bills. This percentage raises to 96% if the reason to reduce energy consumption changes in decreasing pollutant emissions, as shown in Figure 1(h).

Correlating the answers on demographic variables (i.e. age, level of education, yearly income and yearly average consumption in Euro), the resulting analysis highlights that people are interested on having general information on energy consumption. In detail, 96% of the surveyed people with an age between 24 and 29 years old declared an high interest. Increasing the age, interest decreases. Indeed, in 93% of users with an age between 30 and 39 years old declared a medium-high interest for energy-related information. From the level of education viewpoint, energy awareness is perceived relevant for 94% and 95% of surveyed people with high school diploma and Bachelor's or Master's degree respectively. Considering the average annual consumption, the general interest is around 95% for users with yearly expense among €500 and €699 on electricity bills. This decreases to 88% for users in the range of €700 and €999. Focusing on having detailed information on the energy awareness for each single appliance, there is greater interest: i) among users between 24 and 29 years, about 82%; ii) among graduated, about 79%; and iii) among people with a yearly expense between €500 and €699, about 79%. On the other hand, disaggregated information raises less interest among people i) over 40 years old, about 69%; and ii) with a yearly income over 45k€, about 68%.

Finally among the last question replies (*Do you have any additional comment?*), many people suggested to include information about energy production of their renewable plants (e.g. Photovoltaic systems). They also would like to be recommended on optimizing self-consumption, thus maximizing the use of their renewable systems.

3.2 Requirements focus group

The second step of our research was a face-to-face focus group that involved six graduated people between 30 and 35 years old. It has been organized as an open discussion among the participants with a moderator. The purpose of this focus group was to deepen qualitative information that were difficult to identify with on-line surveys. Thus, the moderator addressed the discussion on topics about i) consumer habits, ii) perception and awareness on energy consumption, iii) interest in energy efficiency and iv) relations with the energy provider.

The focus group highlighted that participants are not aware of monthly and yearly energy consumptions. However, they know approximately the average bill expenses. Indeed, they refer to their bills to roughly verify if energy consumptions are coherent with the amount to pay. Furthermore, the participants stressed that bills are difficult to read. Sometimes, consumers distrust their energy providers. For example the electricity market is perceived as something very complex. The energy provider is seen as a distant entity that should limit its role to strictly provide electricity.

Regarding energy-awareness, participants think that such solutions should not be invasive and end-users should choose the notifications to receive and their frequency. A good compromise, raised during the discussion, is receiving a weekly update of main notifications, again chosen by users. Moreover, participants consider useful that such notifications guide them into a gradual change of their habits towards virtuous behaviours. To facilitate this changes, they also underline that notifications should encourage users with positive reinforcement rather than negative without stressing incorrect habits.

Finally, from this focus group raised that participants are not concerned by privacy issues. They declare to be almost resigned in providing their sensitive information. However, they would not like to receive advertising messages, for example, by their energy supplier.

Table 2: Questions proposed during the second survey

Give a rating between 1 (not interested) and 10 (very interested) to the following services	
Knowing in real-time and in every moment what my appliances consume and how much I pay for them	Having a novel and innovative tool
Knowing the energy consumption (and spending money) of my appliances on a daily basis	Protect the environment by reducing energy consumption
Knowing the energy consumption (and spending money) of my appliances on a weekly basis	Evaluating if my supply contract is the best for me
Having during the month a forecast of the cost of the next bill	Receiving offers and promotions from my energy supplier
Receiving reports on malfunctioning or inefficient appliances	Having the chance to join purchasing groups with people who have my same needs
Receiving personalized tips to figure out how to better consume and spend	Checking if my bill match my consumption
Understand if my consumption are in line with those of other similar families	
Select notifications you are interested in (max 3)	
An appliance is faulty or operates incorrectly	My spending threshold has been exceeded for the current month
I am going to reach the maximum power threshold	A particularly inefficient appliance has been identified
There is a new custom hint to save money (e.g. Switches from 4 to 3 weekly washes with your washing machine to save 80 in one year)	Washer/dishwasher finished washing or the food is ready (microwave/oven)
There is a device unusually turned on by too many hours	There are interesting news from the world of energy
I am not at home and an unusual electrical activity was detected (e.g. lights on)	There are commercial offers for me about tariffs, energy efficient appliances, tools and technologies
Select notification frequency you prefer (max 1)	
Daily	Weekly
Never	I choose

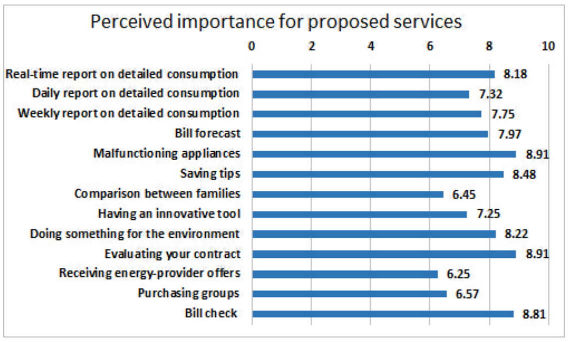
3.3 Requirements survey

The last step of our research was a second on-line survey to identify the main features requested by end-users. Table 2 reports this second survey that involved 100 persons. Questions are grouped in three macro-areas. Regarding the first macro-area, the participant had to give a rating between 1 (not interested) and 10 (very interested) among the thirteen possible services such user-awareness system could provide. Figure 2(a) reports the results of this question. It depicts that all proposed services are perceived as important by users. Indeed, the average rank is over 6 with a maximum of 8.91 for *Malfunctioning appliances* and *Evaluating your contract*. As regards the second macro-area, participants were invited to select a maximum of three out of ten notifications they perceive as useful. The achieved results are shown in Figure 2(b). They range from 1% to 22%. In our analysis, we chose to neglect notifications below 10% of interest rate. The perceived most important are: i) *Faulty appliance* (22%), ii) *Inefficient appliance* (16%) and iii) *Unusual activity* (16%). Finally, the third macro-area required to select the preferred notification frequency among: i) *Daily*, ii) *Weekly*, iii) *Never* and iv) *I choose*. As shown in Figure 3, participants prefer to choose by themselves the notification frequency.

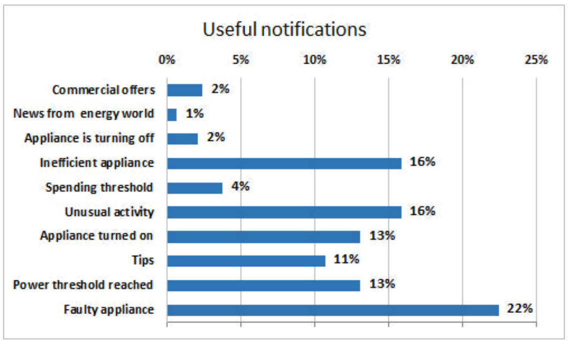
From the presented results of the focus group and both on-line surveys, we identified the functional requirements exploited to design and develop the Android application for energy-awareness in Smart Home presented in Section 4.

4 ENERGY-AWARENESS APP FOR SMART HOME MONITORING

The identification of end-users' needs and requirements are done through a participatory design approach allows defining guidelines to implement an ergonomic energy-aware application for Smart Home Monitoring that leverages upon our distributed Software Infrastructure for Smart Metering called FLEXMETER (Pau et al., 2016). FLEXMETER is distributed platform that i) integrates heterogeneous information of multiple energy vectors (e.g. electricity, water, gas and heating); ii) correlate and post-process data of different utilities; iii) provide advanced services to different stakeholders. In this view, smart meters send data to FLEXMETER through the Internet, thus becoming IoT devices (Schultz et al., 2015), (Bahmanyar et al., 2016). To achieve our pur-



(a) Decalred perceived importance for proposed services



(b) Declared preferences on useful notifications

Figure 2: Results of second survey

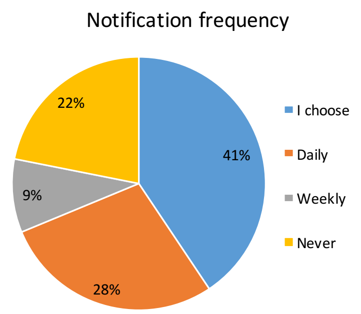


Figure 3: Declared preferences on notification frequency

pose, we deployed our prototype Smart Meters at customer premises. They are based on a Raspberry Pi enhanced with an additional board to measure every second both active and reactive power and send these collected data every 15 minutes.

Figure 1(a) shows that 47% of users surveyed are under 40 years. Thus, we developed an application for mobile smartphones and tablets equipped with Android operating system. This app address the functional requirements identified in Section 3 through a participatory design approach.

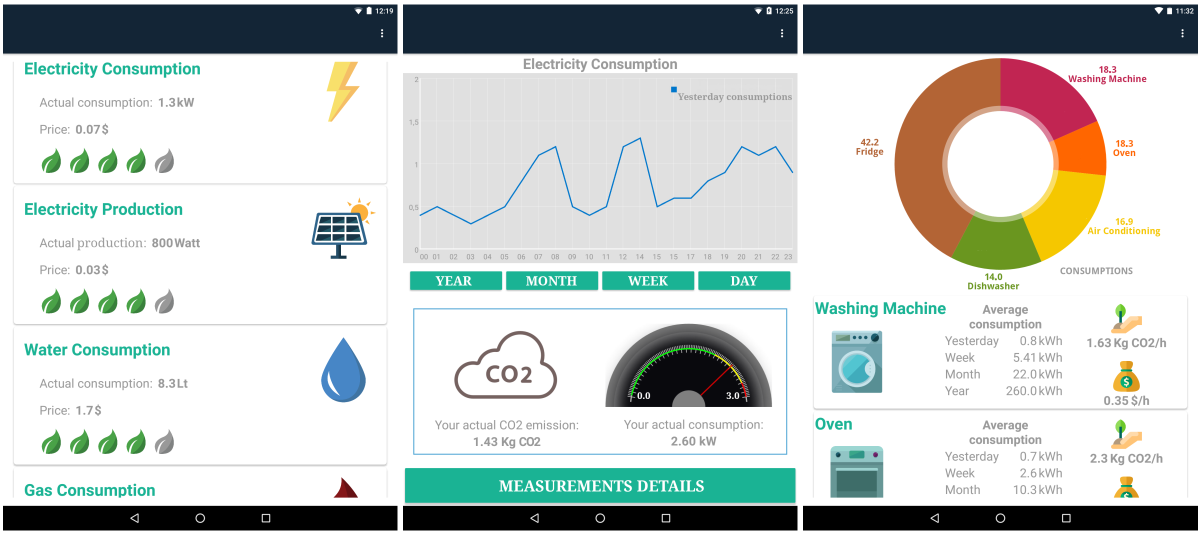
The purpose of this application is to increases user-awareness and promotes green behaviors allowing end-users to have a complete overview of their energy profiles. Knowing the itemized consumption means having the necessary actionable feedback information to propose for reducing the energy waste (Faruqui et al., 2010).

As shown in Figure 2(a), generally benefits for end-users are summarized in the following: i) having a complete control of their energy profile through simple and intuitive interface; ii) knowing the energy production from renewable sources; iii) comparing the energy production of renewable sources among different weeks, months or years; iv) knowing the disaggregated energy of the household appliances; v) discovering which appliance is the most inefficient one; vi) comparing the disaggregated appliance consumption among different weeks, months or years; vii) observing the energy consumption in (near-) real-time to monitor the apartment and receive alarms whenever the energy situation is not as expected.

Through a simple and intuitive interface, compliant with the Android development standards, users can access to all provided data by i) a Non-Intrusive Load Monitoring (NILM) platform (Zoha et al., 2012), which is a service provided by FLEXMETER and ii) smart meters or appliances (e.g. smart plugs). These data refer to electricity consumption and production. To provide a complete overview of all energy consumptions in a Smart Home, we extend both FLEXMETER and the Android app to other energy vectors (i.e. gas, water and heating). These energy vectors are part of the considered case study. FLEXMETER flexibility allows the integration of any other energy measure. Therefore, adding services related to new energy vectors is possible to characterize a complete energy-profile for each customer. Information is retrieved by FLEXMETER through REST web services (Fielding and Taylor, 2002) and all the communication flows are authenticated through a token-based mechanism.

After the user authentication, the *Main Activity*[4] (Figure 4(a)) shows the logged user energy-profile. The user energy-profile is represented as a collection of energy vectors monitored through smart meters in apartments. In detail, this activity presents instantaneous consumption and production for each monitored energy vector. Such information is shown to users using different indexes (unit of measurement, costs and emitted CO_2 footprints) to involve and sensitize the end-user (Wiedmann and Minx, 2008) (see Figure 1(g) and Figure 1(h)).

[4] An Activity in Android is a software window that is usually displayed in full-screen mode.



(a) Main Activity (b) Consumption Activity (c) Detailed Consumption Activity

Figure 4: Example of activity views visualized with the Android mobile application

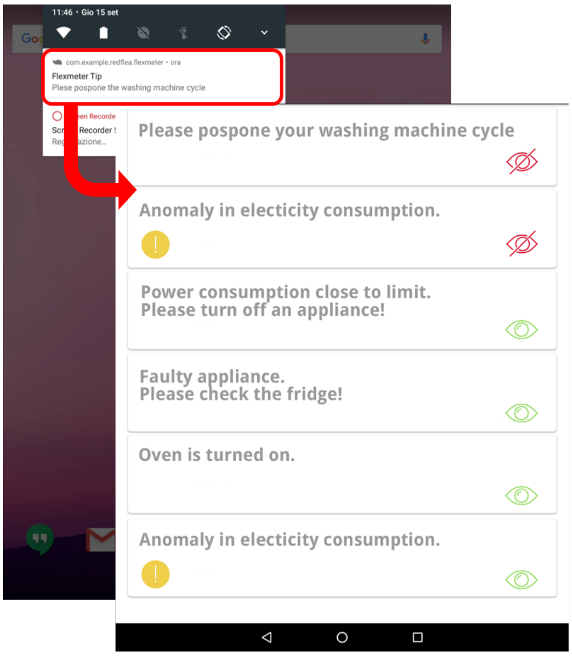


Figure 5: Tips and Warnings Activity

Figure 6: Video of the present Android App for User-Awareness

Selecting an energy vector on the *Main Activity*, the user accesses to the relative *Consumption Activity*. As shown in Figure 4(b), this activity presents widgets to provide a detailed overview on energy consumption and pollution using different indexes. The same activity is used in case of renewable energy production (e.g. photovoltaic systems) and data are updated accordingly. Furthermore, FLEXMETER provides historical data for each energy vector. To better know the energy performance, these data with different granularity: daily, weekly, monthly or yearly.

The *Detailed Consumption Activity* (see Figure 4(c)) provides disaggregated data for each home appliances retrieved from the NILM module and/or smart appliances via FLEXMETER. Through an appropriate conversions, this feature allows knowing energy consumption in costs and pollution indexes to have a complete control of home appliances. Just at the first visual impact, user knows the whole energy consumption for the appliances through a pie chart. Then, a list details more specific information for each appliance is given (e.g. i) daily, weekly, monthly and annual average consumption, ii) hourly pollution and iii) hourly consumption expense), also to provide information on their operating status at any time.

As shown in Figure 5 through a notification system, the user receives tips and warnings from FLEXMETER. During both on-line surveys and focus group, participants have expressly requested a tool to optimize self-consumption by maximizing the use of their renewable energy systems (e.g. Photovoltaic panels). The proposed app is ready to notify prosumers, recommending the best time-slots to turn on appliances according to electricity self-production. Finally, based on the requirements reported in Figure 2(a), Figure 2(b), and Figure 3, during the first application set-up, users can choose the receiving notifications frequency. This functionality is empowered by Google Firebase push notification system[5] that allows developers to organize a flexible notification platform. In addition, the *Tips and Warnings Activity* shows all tips received, highlighting unread messages (see Figure 5).

Finally, to provide a demo of the proposed app, a video is available on YouTube: just scan the QR code in Figure 6 and click on the resulting link[6].

5 CONCLUSIONS AND FUTURE WORKS

In this paper, we presented the participatory design methodology we followed to develop an energy-aware app for Smart Home monitoring. We discussed the results of two on-line surveys and a focus group to identify the functional requirements for the proposed app. These kind of interviews are needed to design software to promote green behaviours, which is not a trivial task. We also introduced the developed app that leverages upon a Smart Metering Infrastructure. Such infrastructure is needed to collect energy-related data before providing post-processed information to end-user apps. As future work, we spread this solution to citizens to evaluate the acceptance level of user on proposed suggestions, tips and alerts to promote virtuous behaviours.

Acknowledgments

This work was partially supported by the EU project FLEXMETER, by Siebel project "POWER AWARE - Lights off, brains on" and by the Italian project "Edifici a Zero Consumo Energetico in Distretti Urbani Intelligenti".

[5] `https://firebase.google.com/`

[6] `https://youtu.be/JdwzvpgvOeQ`

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