Tailoring Feedback to Users' Actions in a Persuasive Game for Household Electricity Conservation

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Abstract. Recent work has begun to focus on the use of games as a platform for energy awareness and eco-feedback research. While technical advancements (wireless sensors, fingerprinting) make timely and tailored feedback an objective within easy reach, we argue that taking into account the users' own personal consumption behavior and tailoring feedback accordingly is a key requirement and a harder challenge. We present a first attempt in this direction, EnergyLife, which is designed to support the users' actions and embeds contextualized feedback triggered by specific actions of the user, called 'smart advice'. We conclude by showing the results of a four-month trial with four households that returned promising results on the effectiveness and acceptance of this feature.

Keywords: Sustainability, feedback, adaptive, context aware, design, energy awareness, persuasive technology, smart advice.

1 Introduction

Providing the individual consumer with information about the extent and consequences of his/her own energy consumption activity is considered an effective strategy to foster sustainable consumption practices [4, 5]. Experience accumulated with experiments and field studies shows that generic information is likely to be ignored since people prefer to avoid non-supportive information [2, 12]. Although the most common approach is still to present the user with information and general advice on the total energy consumption, financial measures, or through environmental footprints [10], current technology is also able to collect accurate data and provide the kind of vivid, salient and personal information [3] that is sought by consumers (e.g., [7, 16, 19]). EnergyLife, which is the focus of the present paper, is a mobile application that provides feedback to encourage electricity conservation practices. EnergyLife relies

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on real consumption data automatically fed into the application by individual electric devices, and returns consumption information along with tips, quizzes, historical data, and a social community. All features are integrated into a simple, usable interface and gradually disclosed according to a game rationale to sustain users' motivation in the long run.

The design of EnergyLife is fully oriented to make its feedback both *action-based and actionable* as a way to apply the principle of tailoring in persuasion (i.e., making persuasive information relevant to the specific characteristics of the recipient [1, 6, 12]) and as a strategy to make feedback more effective. In fact, feedback that helps to identify the relation between users' own actions and a pre-defined goal, e.g. saving electricity, is considered to be more successful [11]. EnergyLife feedback is tailored to the users' actions in three ways, identified through a field trial with an earlier prototype [8]. First of all, by following the users' stepwise increase of awareness when progressively releasing new features of the game. Second, by considering both the individual and the collective (i.e., household) agencies responsible for the game outcome and mapping them differently in the game rationale. Third, by providing tips that are contextualized on the users' consumption behavior (i.e., 'smart advice'). This paper focuses on this last and most original property of EnergyLife, namely the exploration of smart advice tips that are triggered by specific usage patterns and that include customized text. The goal of this paper is to describe the design of these tips, and to report the results of a four-month trial with four households investigating whether this tailoring strategy was well accepted by users and was effective in supporting electricity conservation. We will start by briefly describing EnergyLife and its interface. More specific information about design choices (feedback timing, format, content) can be found in [8, 17]. We will then explain the nature of smart advice tips and the way they were generated. We will then describe the field trial methodology and report the results on users' acceptance and smart advice tips effectiveness. We will summarize our contribution in the conclusion, pointing at possible future developments.

2 A Power Conservation Game in a Nutshell

EnergyLife is an eco-feedback game that provides next-to-real-time, device-based consumption information (i.e., saving and consumption information). The aim of the game is to increase users' awareness of their household's energy consumption.

The main interface consists of a three-dimensional carousel. Each card represents an electrical appliance whose consumption is monitored by sensors (Figure 1a); in addition, a household card represents the overall household and reports data from a sensor installed on the main meter. The fronts of the cards show the current electricity consumption of the device (or the household), and the saving achieved over the last seven days (Figure 1a). The cards can be flipped to access additional information and functionality for the given appliance (Figure 1b), i.e., advice tips, quizzes, and the consumption history for that device (or household) (Figure 2a). The application also offers information about current levels and scores in the game, and a consumption breakdown per device. Saving information and game scores represent two different kinds of feedback provided by the application, which rely on different agencies, household (i.e., consumption) and individual users (i.e. quiz, messages, …) respectively.

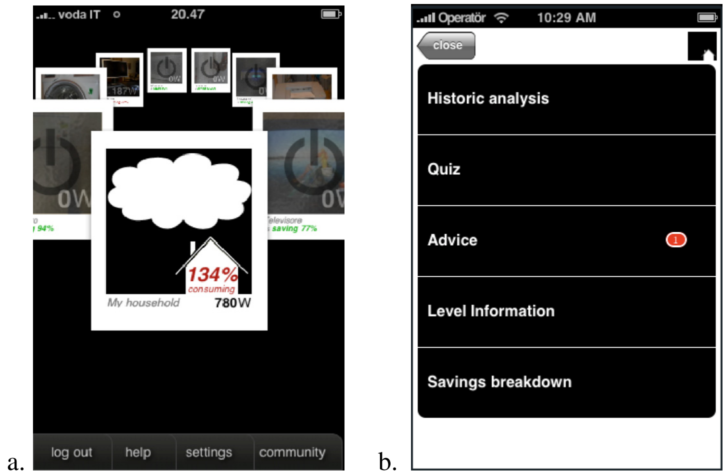
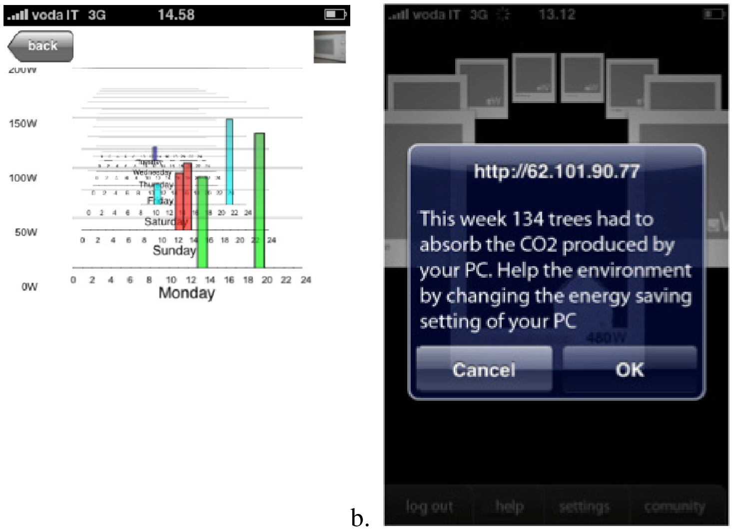


Fig. 1. a. 3D carousel with overview of monitored devices on cards. b. The card is flipped when selected, providing access to a menu.

EnergyLife tries to keep the user enticed and motivated once their initial curiosity drops by implementing game-like features (i.e., scores, quizzes) and by releasing its different features in four steps (i.e., 'levels' in the game) that are designed to fit the subsequent awareness stages of the user [8]. (i) At Level 0 only basic functionality is provided, which consists of saving/consumption feedback compared to a baseline calculated on the previous week. This level allows the users to familiarize with the goal (saving) and with the gap between household consumption and the goal. After 7 days at this level, users are automatically upgraded to Level 1. (ii) In Level 1 the user starts to receive generic advice tips, which direct the user's effort by suggesting energy conservation practices. This represents the knowledge acquisition stage prepared by the previous goal setting stage, and the actual start of the game, since by reading advice tips the individual user acquires points allowing them to advance to the next level. (iii) In Level 2 the user can test his/her knowledge by answering quiz questions that are regularly sent to the mobile phone, and can follow the collection of points in a dedicated page. Users also start to receive smart advice tips in addition to the regular tips activated (see Section 3). By successfully completing the quizzes and continuing to regularly read advice tips, the user progresses to Level 3. (iv) The features in Level 3 allow users to maintain their newly acquired conservation habits via community sharing and comparative feedback. Users can exchange messages within their own household as well as with users in other households, gaining points for each message, and can see individual and household rankings based on EnergyLife scores.



a. b.

Fig. 2. a. Consumption history of a device b. Visualization of a smart advice tip

Technically, the application client of EnergyLife is a Web application adapted for touch-screen mobile devices. It was developed on HTML5, CSS3 and JavaScript and was deployed on the iPhone 3G and 3Gs. To measure the consumption of appliances in real-time, the system utilizes wireless sensors inserted in plugs. A base-station located in each household caches measurements in non-volatile memory and transfers them to the data storage in bursts. The base station supports both its especially designed 433 MHz wireless network and sensors, but also allows for interfacing with commercial ZigBee based networks. EnergyLife used high quality sensors for the measurements, while the analysis happens in the main computation cloud, for both historical data availability and also software upgradeability reasons – the delay for transferring data to cloud is small with modern IT network capabilities and it gives the system the ability to correlate data form several sources [13]. In a fully realized Internet of Things future, modern devices will contain a microprocessor able to determine the state of the device [18].

3 Smart Advice

Smart advice tips are triggered when exceptional usage of a device is recorded and they provide some tips on ways to avoid such overconsumption in the future. They merge two kinds of information, i.e., consumption information recorded by appliance sensors, and tips about electricity conservation practices taken from trustable sources (such as environmental associations data). Smart advice tips differ from the regular advice tips provided by EnergyLife in that they are triggered by the specific behavior of the user monitored by the BeAware system, and their content incorporates information on that recorded behavior, along with a tip. In this way, the final smart advice generated is tailored to the specific behavior of the household. Consumption is quantified in kW/h as well as in CO_2, trees compensating CO_2 and even miles on an average city car. For instance, the template "This week 134 trees had to absorb the CO2 produced by your PC. Help the environment by changing the energy saving setting of your PC" involves that a computer was on for longer than a certain amount of time. In the trial, three types of behavior triggered the generation of a related smart advice and its delivery to the phones of the household members:

1. high cumulative usage over a certain period of time: the smart advice was generated after the device was turned on for more than 84 cumulative hours over the last week or had an on-cycle[1] longer than 12 hours or had an on-cycle longer than 5 hours during nighttime;
2. increase compared with past consumption: the smart advice for a given device was generated if its consumption during 2 calendar weeks was higher than the consumption during the previous 2 weeks by 5%, or its consumption during the last 7 days was higher than the consumption during the previous 7 days by 5%;
3. prolonged use of stand-by mode; the smart advice was generated after the device had a stand-by cycle[2] longer than 5 hours or for more than 35 cumulative hours over the last week.

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[1] As many electrical devices, for example coffee makers and microwaves actually include short power off periods of a few seconds in their normal on-cycle, an on-cycle was defined using the following algorithm:

(I) On-cycle starts when the recorded power has been above a cutoff point of 0.1W for at least 3 consecutive measurements;

(II) (II) On-cycle ends when the recorded power has been below a cutoff point of 0.1W for at least 3 consecutive measurements.

The minimum number of measurements was chosen as a triggering criterion as several common household devices (e.g. microwave oven) exhibit a pattern where a non-maximal level is achieved by shutting down the motor or heating element for a short period of time. Thus the device might have periods of non-activity even when the device as such is in an active state. These measurements mean that the system has to remain on or off for at least 6 seconds to trigger a state change.

[2] Standby mode was detected via the following algorithm:

(I) Detect and identify all stable power states of the device;

(II) If there are more than 2 stable states and at least 1 of them consumes less than 10W, designate the lowest one as stand-by mode.

As the stand-by detection algorithm might fail for devices with particular consumption patterns, its accuracy was confirmed by a human expert for each device. This algorithm was used, as the system capability to fingerprint devices and their states was added relatively late in the project.

The system collected information about the time when the device was used; length of normal usage cycle; energy taken by normal usage cycle; standby pattern; length of standby cycle. This data was compared to all the triggering criteria once a day. If there was a match, the related smart advice was generated (or more than one, if more criteria were met) and sent to household members.

Although we had a larger database of smart advice templates, 13 templates were implemented for the trial, selecting those that related to the devices monitored in all households (i.e., computer, television, refrigerator, washing machine, microwave) and whose triggering conditions did not need any fingerprinting or any additional sensors (e.g. for temperature, light, etc) (Table 1). Each smart advice generated from one template differed from any previous one generated from the same template because it was based on the specific amount of consumption recorded in each case.

Table 1. Templates used to generate smart advice during the trial and number of tips generated

The **computer** that you have left on on [*day*] for *[n]* hours made you consume *[n]* g CO2. Switch off the monitor if you plan not to use it for longer than 15 minutes	50
The **computer** that you left in stand-by for *[n]* hours, made you consume *[n]* kWh this week. Please remember to turn it off completely, to avoid wasting electricity	12
The **computer** that you left in stand-by mode for *[n]* hours this week, made you consume *[n]* g CO2 more than the previous week. Switch the computer off completely instead of leaving it in stand-by	16
This week *[n]* trees had to absorb the CO2 produced by your **PC**. Help the environment by changing the energy saving setting of your PC	30
This week *[n]* trees had to absorb the CO2 produced to provide energy for your **fridge**: you can help the environment by reducing the length at which the door is left open and do not insert food when it is still warm	6
This week your **fridge** spent *[n]* kWh more than last week. To save electricity reduce the duration of door openings and do not insert food when it is still warm	6
This week the **micro wave** oven spent *[n]* kWh more than last week. Please try to use it as little as possible to save electricity	4
This week *[n]* trees had to absorb the CO2 produced by your **micro wave** oven. Save electricity by defrosting your food naturally	12
This week you left the **microwave** on stand-by for *[n]* hours consuming *[n]* kWh. To save electricity, try to turn it off completely	3
The **stereo** that this week you have left in stand-by for *[n]* hours, made you consume *[n]* kWh more than the previous week. Remember to switch it off completely when you don't use it, to conserve electricity	6
On day *[n]* the **TV** left on for *[n]* hours made you consume *[n]* kWh. To save electricity switch it on only when you really watch it	116
On day *[n]* you used the **washing machine** *[n]* times. Was it always fully loaded? In this way you can save electricity and time	86
The day *[n]* you used the **washing machine** *[n]* hours longer than usual. Please try to use it only at full load	150

4 Trial and Evaluation

4.1 Method

A field trial was organized with four households located in urban areas in Catania (Italy), which used the application from January 9th to May 1st 2011. There were ten participants, four women and six men, aged 38 on average (*SD* = 12), and at least two participants belonged to each different household. None of the households included people working in the project. All participants had to own their house and include children since this increased the saving potential; some basic electric appliances (computer, television, refrigerator, washing machine, and possibly microwave) and a Broadband Internet connection was also needed. None had electric heating. Households were recruited through a web form and informal contacts; they were then selected based on an interview and a visit of the house to check the feasibility of the sensing system installation.

Seven sensors were installed in each house (connected to basic appliances listed below plus two devices chosen by the users). All participants were given a smart phone where they inserted their primary SIM card during the trial length, signed a general informed consent form, and an additional consent form at each data collection visit. Data on electricity consumption were collected continuously and automatically during the trial, separately from information on the users' identity. After the first visit when the mobile phones were configured and the users were trained to operate EnergyLife, the experimenters visited the households two more times: at the middle and at the end of the trial, to collect data, and a family interview investigated the users' experience in the trial. We will analyze here the access to the application, a few questions in the satisfaction survey and the household consumption. Some extracts from group interviews conducted during the last visit to the households will be reported, for illustrative purposes only.

4.2 Results

Acceptance and Comprehension

The users kept on accessing EnergyLife over the whole trial duration, gradually reducing the amount of access per day as familiarity with the application and its features increased. Overall access to the application changed (Mann-Kendall τ=-0.432, $p<0.001$) from above 20 login a day at the beginning to about 8 login a day the last day of the trial; the mean number of interactions with devices per login diminished from about 4 per login to 1 per login (Mann-Kendall τ=-0.396, $p<0.001$). This means that once users reach the maintenance phase in which the use of the application as well as the new consumption habits supported by the application got settled, EnergyLife was accessed to reach specific objectives (e.g. checking for new tips, quizzes, and messages).

Among EnergyLife features, the most accessed one was obviously the carousel (4298), followed by consumption history (2167 visits), community (1037), advice (1106) and quizzes (668) (Figure 3). The high number of visits to the consumption history pages shows that users were not only interested in features that were relevant to the game (advice and quizzes) but also in the consumption information that was instrumental to understanding and monitoring their consumption patterns.

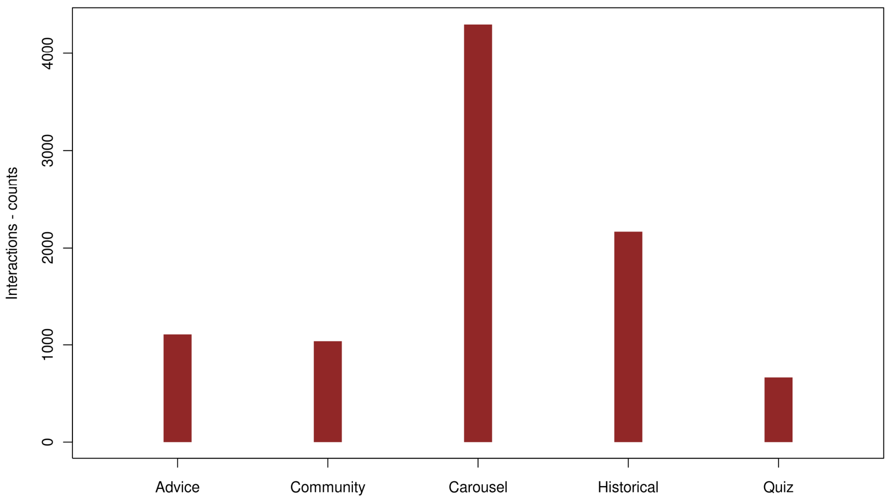

Fig. 3. Number of visits to EnergyLife features during the trial period

A total of 326 smart advice tips were sent and read during the trial (since they occupied the foreground of the screen, the usage of the application was not possible until they were read, see Figure 2b). Each household received an average of 110.24 smart tips (*SD* = 22.35), generated from the same 13 templates. Participants' interest in smart advice was measured on a scale ranging from 1 to 6, where 6 was the highest positive evaluation; the score received was high (mean = 5.00 - first bar in Figure 4). Users also agreed that tips should be (even) more specific, showing their eagerness of receiving detailed information (mean = 4.80 - second bar in Figure 4). Both items were significantly above the middle point of the scale, $t(9) = 2.90$, $p = 0.02$ and $t(9) = 3.34$, $p < 0.01$ respectively. In the interviews users confirmed their interest in the link between their behavior in the house and the comment received in the advice. ".... I wasn't aware about how much CO_2 we produce". We also found that participants were surprisingly neutral about receiving the same kind of tip repeatedly, $t(9) = -0.68$, $p = 0.51$ (mean = 3.20 - third bar in Figure 4). This topic was raised in the interviews, which confirmed that repetitions were noticed but were ultimately considered helpful "…some tips were already applied, but through the suggestions they were strengthened".

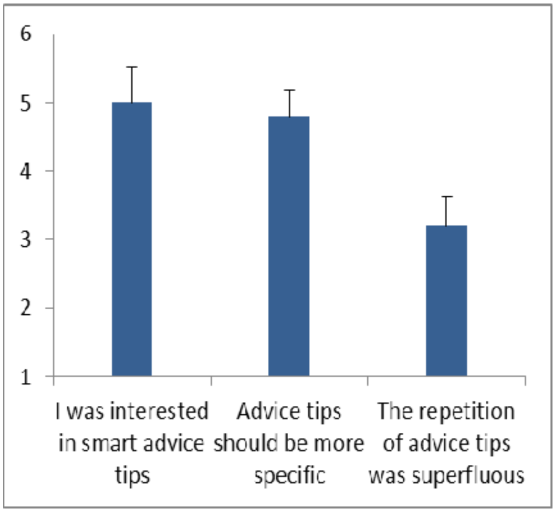

Fig. 4. Answers to four specific items on advice and smart advice tips. Errors bars represent the standard errors.

Participants' comprehension was tested by seven items asking the users to rate the clarity of messages, advice tips and rules from a visual, linguistic and structural point of view. Mean score was 4.80 on a scale ranging from 1 (not at all) to 6 (totally), significantly above the middle point of the scale, thus in the satisfaction range, $t_{(9)} = 5.25$ $p < 0.01$. Learnability was tested with three items such as "*I learned Energy life with some difficulty*", in which users gave positive rates (mean score = 5.13; $t(9) = 7.93$ $p < 0.01$).

Effectiveness of Smart Advice

The average delay between the generation and the reading of a smart advice tip was about 1.5 days, since users did not check the application every day. Therefore, to test the effectiveness of smart advice tips, we compared the electricity consumption of each device the day before and the day after the users read a specific smart advice tip[3]. Since there is not a clear way to determine the identity of the person actually using a device in the analysis, we decided to aggregate the advice per family: the data on smart advice tips reading were aggregated across households. A linear mixed model was used for this comparison. Fixed effects (i.e., the variables actually explored in the analysis) were the consumption time (i.e., the day before or the day after the reading of a smart advice tips) and the trial day. The trial day was included in the model to calculate the effect of the smart advice over and above the global reduction of consumption due to the monitoring per se and other persuasive features of Energy Life. Both household and devices were included as random effects like participants in a repeated measure ANOVA. The results show a significant reduction in the electricity

[3] Therefore, in the case of multiple consecutive smart advice tips about the same device, we compared the consumption of the day before the reading a first smart advice tips with the consumption of the day after the reading of the last tip.

consumption of a device following the presentation of smart advice ($\chi2(1)=6.75$ $p < 0.01$). On average the day after reading of one or more smart advice tips the consumption of the specific devices dropped of the 38% (Figure 5).

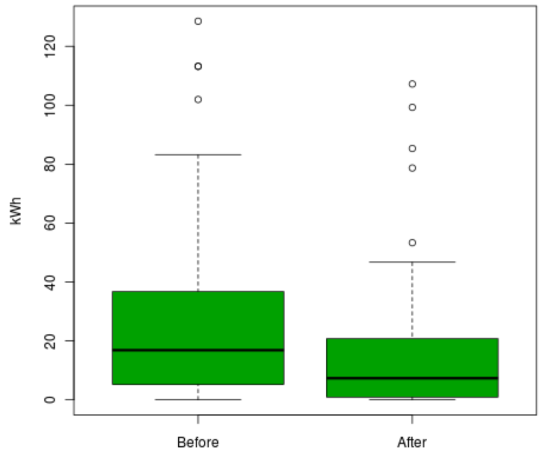

Fig. 5. Box plots of electricity consumptions the day before (left) and after (right) reading a smart advice tip. Isolated dots represent outlier observations.

We also explored the interaction between the effect of a smart advice tip and the trial day (i.e., the variation in the effect of smart advice tips during the trial) with an additional linear mixed model. The interaction was not significant, $\chi2(1) = 0.02$ $p = 0.88$. This result indicates that the effect of the smart advice tips remained stable across the trial, without an effect of habituation or boredom.

Finally, we considered the role of a small series of smart advice tips about the same device read in consecutive days in the same household. This series could unveil a failure of smart advice in reducing consumption. If another smart advice tip was received the next day about the same topic, these series could be due to contingent reasons (i.e., household members did not open the application daily or a high consumption that triggered both a week-related tip and a day-related tip). Participants were considered separately, entered as a random effect in the model together with households, and the consumption the day before and the day after the reading of the first smart advice tip in the series were compared. Again, consumption decreased significantly, $\chi2(1)=10.66$ $p < 0.01$, suggesting that the decrease already reported in Figure 5 is not an artifact of the method adopted to measure consumption at the household level.

5 Discussion and Conclusion

We have described a persuasive eco-feedback game that offers real time, tailored electricity consumption feedback accompanied by tips on energy conservation. This solution was designed to address crucial challenges, namely making feedback actionable, adapting to the users' varying needs as his/her awareness changed, and maintaining the formation of habits in the long run. We have focused in particular on the role of the smart advice feature, which epitomizes the EnergyLife strategy. Smart advice offer contextualized information and related tips at the device level, whose delivery and content depend on the users' actual consumption behavior. The results of our study indicate that smart advice was well accepted and effective in supporting electricity conservation behavior. Building on these results, the 'smartness' of a tailored, contextualized advice could be improved exponentially to match the accuracy that users expect from a digital sensing and feedback system. They can be based on triggering conditions that take additional information into account (e.g., external temperature, lighting, number of people in the room, automatic recognition of device mode and type of use) to better capture critical users' action patterns.

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