Combining Persuasive Computing and User Centered Design into an Energy Awareness System for Smart Houses

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***Abstract*—The environmental impacts of the usage of fossil fuels together with its limited supply has been pushing governments, industries and people to seek cleaner and renewable energy supplies and to adopt energy habits leading to a greater sustainability. While acquiring a Photo Voltaic solar panel (PV) is a big step in that direction, much can also be accomplished with changes in individual and collective energy consumption behavior. Moreover both strategies can be used together.**

This paper presents a software prototype capable of increasing the awareness of the energy consumption in a smart house and supporting a behavior change towards greener consumption habits. The software was developed following the design science research methodology anchored by the application of *User Centered Design* and the theories of persuasive computing.

The development of the User Interface (UI) was done following several iterations with both end-users and experts. In this work, we focus on the UI elements created in order to apply the concepts from different behavior change support methods and theories, such as *Feedback*, *Gamification*, and *Social norm* into energy savings and efficiency. The result was acclaimed during an expert evaluation and will now be trialed in two different trial neighborhoods.

I. Introduction

The unarguable effects of climate change triggered society to reflect on ways to reduce CO_2 emissions. The energy sector is responsible for about two thirds of the greenhouse-gas emissions responsible by human beings [1], where 40% of the global energy-related CO_2 emissions comes from residential electricity consumption [2]. Many countries started investing in solar energy and offering incentives to households to install PVs, enabling self-consumption and reselling of the energy back to the grid. The trend is such that solar power is expected to grow in Europe by 80% by 2019 [3].

While the installation of solar panels in households is very positive as their usage do not contribute to carbon emissions, the mismatch between energy production and consumption periods in households detriments the efficiency of the system. It is common to have peaks of domestic energy consumption in the morning and in the evening [4], and those are not the periods where PVs are generating most energy. Having users to change some habits in order to better align their energy consumption with their energy production would contribute to decrease greenhouse gas emissions. Such energy load shifting would reduce energy peaks, contributing to alleviate costs of grid operators with peak periods infrastructure and reduce the demand of fossil fuels (often used in backup generators for peak hours). Besides the load shifting, energy consumption behavior changes can contribute both to energy efficiency and energy conservation. In this work, we designed a system, called CoSSMunity, which can motivate the user to improve his energy expenditure habits towards higher energy efficiency. CoSSMunity is developed in the context of the European Union (EU) project CoSSMic (http://cossmic.eu/) where it will be used by the trial users of the project and is built on top of the CoSSMic baseline system.

CoSSMic is responsible for allowing a peer-to-peer energy management and sharing between users in a neighborhood [5]. This peer-to-peer energy management performs load shifting in a neighborhood level as neighbors can provide energy and storage (battery capacity) to each other. In other words, the CoSSMic baseline system operates in the background collecting energy data; and matching energy consumption and production between the households of the neighborhood as to maximize the usage of the produced energy on a neighborhood level. Meanwhile, CoSSMunity serves as the interface for the users to visualize theirs energy behavior, plan behavior change and take action, supported by smart devices. While CoSSMic's research question revolves around optimizing the usage of the available PV-generated energy on the neighborhood level based on the real-time energy levels, CoSSMunity focus on guiding the household owners to pursue habits that can collaborate to further energy efficiency and conservation.

The design work behind the production of CoSSMunity was done as an iterative process illustrated in Figure 1, where the blue and white rectangles describe the input information at the corresponding stage in the process and the resulting artifacts respectively. In our earlier work [6], [7], we documented the requirements gathering process through a series of workshops with the users (mapped to the first two stages in Figure 1). In those papers, we primarily discussed the application of *User Centered Design* methods and the resulting user requirements.

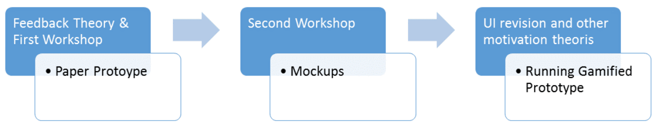

Fig. 1. Overview of this work's iteration process

In this paper, we describe the continuation of the design activity and the anchoring of the design elements into the persuasive computing theory. We detail how different elements from behavior theories (*Social Cues*, *Social Norms* and *Feedback*) were applied in the design in order to engage and help the owners of a smart house to change theirs energy consumption behavior.

Our research focus in this publication is on: *How to design a software UI to support owners of smart homes to improve their energy consumption habits? How can we tap into behavior change theories to model UI elements for providing such support?* where we consider both the increase of energy efficiency and conservation as possible improvements of energy consumption habits. The research questions are answered in the development of the gamified prototype for management and monitoring energy in a household. The prototype was evaluated by two experts and will be trialed in the field by the CoSSMic project end-users later in 2016.

II. Research Methodology

The methodology followed in this work is based on the Design Science Research Framework from Hevner [8] and illustrated in Figure 2. We chose the design science framework because it fits with the iterative development process followed in the project: the combination of user input and theory for the foundation of the design, culminating with the production of a software artifact as part of the research process.

Hevner's framework defines the Design Science Research work in terms of design iterations fed by the understanding of the application domain and the research knowledge base. Those are applied in the design artifact and evaluated; subsequentially producing additional knowledge to the scientific field, refining the artifact in its design iteration and delivering a product to be applied back to the domain environment. He calls the cycle towards the domain environment as the *Relevance Cycle* and the one towards the theoretical base as the *Rigor Cycle*.

In this project, the *Relevance Cycle* is addressed through the familiarization with the application domain and stakeholders in the underlying project. Practically, that was done through

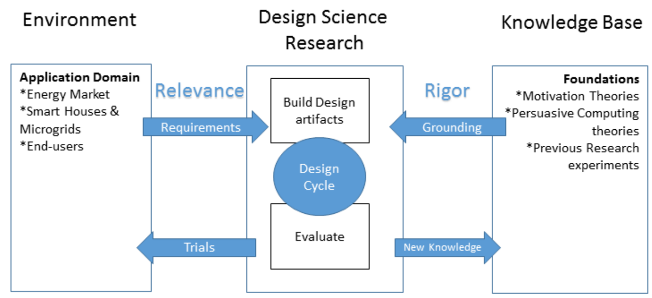

Fig. 2. Adaptation of Hevner's Design Science Research Framework [8] used in this work

focus groups and workshops following *User Centered Design* [9]. The *Rigor Cycle* is explored in the usage of the theories of persuasive computing for shaping our design choices together with the empiric findings of different research experiments on energy awareness and motivation systems.

The *Design Cycle* is realized through the three main iterations of design artifacts illustrated in Figure 1. In addition, it will be triggered again with the usage of the system in the field trials and the empirical findings resulting from it. Although the development of the user research and some of the theoretical grounding have been done in parallel through the above mentioned iterations, for the sake of clarity, we will be describing them separately in the two following sections.

III. Theoretical Background

ICT can be used to motivate people to modify an undesired behavior or adopt a new behavior. This usage of ICT is framed as *behavior change support technology* or *persuasive computing*. [10] reviewed almost 100 persuasive ICT technologies studies, including some on ecological behavior, and observed that they were capable of motivating the users and effectively triggering behavior change. In most cases, the user wanted to adopt the new behavior and just needed additional encouragement, which came through the ICT system. Improving energy consumption falls into this category as it is of interest of most people to pollute less and reducing costs (a consequence of energy savings). Applying persuasive computing to improve energy consumption habits in residences is a good case because (1) it amounts to more than 1/4 of all our CO_2 production, and (2) small changes in our energy consumption behavior can result in substantial impact [11].

The starting point for the definition of our behavior support change strategy was to use the widely cited Fogg Behavior Model (FBM) [12] into our scenario. The FBM describes that the individuals behaviors are dependent on the satisfaction of three conditions: (1) being sufficiently motivated, (2) being able to carry out the behavior and (3) having a trigger to perform the behavior. In our scenario, it is expected that the end-user already possess some level of intrinsic motivation as he decided to adopt an energy management system, such as CoSSMic, and possibly acquiring a PV or energy storage system. Therefore, we decided to explore the following behavior change and persuasive computing theoretical constructs: *Social Norm* as a contributor to additional extrinsic motivator applied together with *Feedback* and *Gamification* techniques as triggers and facilitators for the behavior and UI simplicity and *Social Cues* to enable it. In the next paragraphs, we describe those constructs and link them to other publications that have accessed theirs effects in information systems, and, when available, in energy efficiency or conservation scenarios.

Social Norm was chosen as the extrinsic motivation element as it would fit with the aspects that users are already grouped in a neighborhood based on the usage of CoSSMic. *Social Norms* play a role in motivating the user by both the willingness to reach the assumed external expectations and in terms of looking upon others as models to be followed or surpassed. The materialization of social norm can be done by the implementation of rankings, peer-to-peer comparison, comparison towards an average user value or simply making the user information (such as the energy consumption) public within a group of people. Many electricity-saving experiments through both rankings of energy savings and peer-to-peer comparison between neighbors have yielded in an increase of energy conservation as observed in the articles reviewed by [13].

Giving *Feedback* consist of delivering insights as to why and how one should/can change their behavior. It can:

- enable users to carry out a behavior when they are unaware of their capabilities or of existing facilitating conditions
- be used for triggering the behavior when the feedback is given at the right moment
- be used in conjunct with social norm by providing feedback in relation to other peers

Feedback has been widely used in many energy consumption reduction studies, as it is relatively easy to be implemented. Simply providing to consumers a direct feedback in terms of an overview of theirs energy consumption habits were enough to trigger energy conservation in [11], [14]. Moreover, [13] presents that the direct energy consumption feedback of a household can lead to further energy saving when combined with the break-down energy consumption of the different appliances. Whereas [15] suggests that while direct feedback can boost energy conservation, energy efficiency is better tackled by indirect feedback.

Social Cues are mechanisms to provide indirect *Feedback*. It corresponds to verbal or non-verbal hints that indirectly influence the users. In [16], Fogg indicates the UI attractiveness as a social cue playing a central role in persuasive design. Combining positive colors and messages subconsciously induces the user to attribute a personality to the software, which can evolve to a relationship of trust. The work described in [17] exemplifies the indirect *Feedback* through *Social Cues* implemented as a virtual garden, Ubigarden. There, the virtual garden flourishes only if the users of theirs system sustain the habit of performing physical activities. Such concept was widely accepted and motivating for the participants of the study.

Gamification is not a behavior theory construct. It rather corresponds to the usage of game elements outside of the gaming domain [18]. The most commonly used *Gamification* techniques correspond to point/score systems, leaderboards and achievements (together with progress bars and levels). Those techniques map directly to the implementation of different motivational theories and triggers. Score systems and virtual rewards are linked to the provision of extrinsic motivation in the format of rewards at the same time that it facilitates *Feedback* by offering a quantification of the user's behavior. Leaderboards maps to *Social Norm* as it enables users to position between each other. On the other hand, achievements and level progression also fits into *Goal Setting* theory [19] which relies on a formalization and quantification of a behavior goal and the *Feedback* about advancing towards that goal.

Gamification has been used in many different domains, including energy saving [20] and fuel consumption saving [21], and observed to increase user engagement and motivation [22]. However, in order to be effective it is shown that the application of game elements must take in consideration the users' background, interests and needs. In order to do that, [23] suggests anchoring the *Gamification* design with *User Centered Design*. In fact, the user involvement and acceptance is proved to be an important factor determining the success of the previously mentioned motivation techniques [13]. The importance of user feedback for tailoring and optimizing behavior change support mechanisms sustain our application of *User Centered Design* methods [9] in the development, as it will be described in the following section.

IV. User centered design

As previously described in the introduction, the design work behind the production of CoSSMunity can be divided in three stages resulting in three iterative design artifacts: a paper prototype, mockups and a running prototype. In this section, we will summarize the design related findings of the first two stages without going in depth on them, since they were already described in our previous work [6], [7]. The third stage, where most of the influences from motivation theories come into play, will be described in the following section.

The first stage was marked by a workshop executed with members of the project CoSSMic. It included a range of software developers, energy market researchers, academics, solar energy researchers and energy policy decision makers from both trial municipalities. This heterogeneous group included owners of energy feedback systems, solar panels or electric cars. The workshop focused in creating a common vision of the CoSSMic product and impacts through a series of co-design exercises and games from [24] and [25] which included: *Tomorrow Headlines*, *Cover Story*, *Product Box* and *Business Model Canvas*. Then, the participants formulated their common understanding of the end-user interest in CoSSMic, its energy consumption habits, related motivations and its surrounding context. That was done through the development of *Personas* [26] and a first paper prototype (whose summary page is represented in Figure 3).

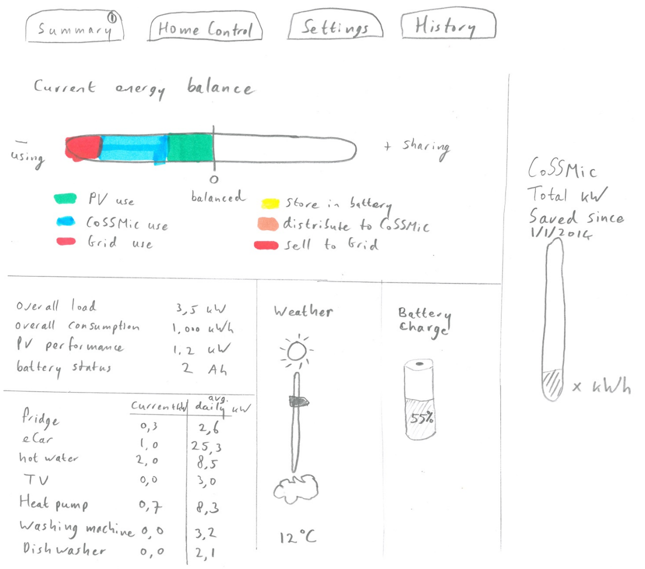

Fig. 3. First workshops resulting paper prototype

The paper prototype exposes feedback information related to energy production and consumption levels in the neighbourhood in the Summary page and household and appliance level in the Home Control and History pages. Although not illustrated in this work, the paper prototypes corresponding to those pages included graphs embedded with elements to zoom in time frames and compare appliances among each other. At last, both Home Control and Settings offered an interface for controlling the devices in the smart house.

The paper prototype at that point already incorporated some elements of *Feedback* mapped to [27] recommendations of multiple feedback options, interactive controls, history comparison and appliance consumption breakdown. Although those elements came from the user's suggestions since our theoretical behavior change research started only after the second workshop.

The second workshop consisted in a small and iterative series of focus group meetings performed with the trial end-users of the CoSSMic project. The trial users consist in a mix of private houses, schools and industrial sites powered with smart meters and devices. They are based in two different cities in Europe: Konstanz, in Germany and Caserta in Italy.

The focus group meetings with the trial users included: open questions group interviews, discussions and walkthroughs of the paper prototype followed by questionnaires. The workshops helped to confirm the end-users intrinsic motivation in pursuing "greener" energy habits. They also allowed us to refine some of the interfaces and confirm the participants' interest in observing energy consumption in both house level and device level.

At this stage, the participants draw the requirements about the scheduling and control of appliances which converged in the design of the Settings page (illustrated by the Heat Pump settings configuration mockup in Figure 4). They helped us identifying which type of appliances they would be willing to adapt theirs behavior in favor of higher energy efficiency; and which ones they would be interested in controlling via the UI. Those appliances included washing machines, dishwashers, clothes driers and others whose operation is based on the execution of a fixed timed task (in contrast to TVs, lights, etc). On top of that, they were positive about the shift loading of temperature and ambient devices such as heaters, air conditioners and water boilers as long as they could input their comfort preferences.

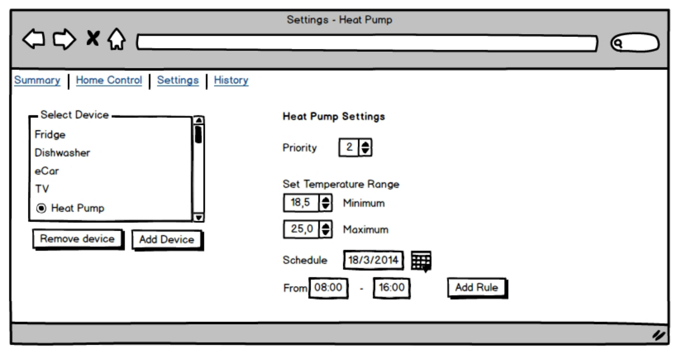

Fig. 4. Mockup of the Heat Pump settings

Schools and industrial users were also interested in using the system to schedule the turning on/off of certain appliances after the business hours. Besides that, a few new features were elicited, such as: the presentation of suggestions of energy efficient scheduling, different type of rule-set configurations for the difference appliances and the feedback of temperature information on rooms equipped with temperature regulating devices. The feedback of the workshops was recorded and used to create the next iteration of the design artifact: an interactive mockup created with Balsamiq[1]. As to present the contrast with the first workshop paper prototype, Figure 5 illustrates the refined version of Summary page.

During a presentation and appraisal of the mockup with an external group of UI design researchers, it was noticed that the main energy source feedback component in the mockup Summary page, the top energy bar, was relatively abstract and difficult to understand (see Figure 5). The bar was supposed to present the ratio of energy sourcing among the PV, Grid and neighborhood, but many aspects of it were not intuitive. The period of the data in the bar was unclear. The appraisal group did not understand the "-, 0 and +" signs. In addition, the bar did not convey the values of energy or legends, leading to many possible interpretations. At this moment we decide to revise the user interface for making it clearer and introduce UI elements based on the research on *Gamification* and the behavior change constructs described in the previous

[1] https://balsamiq.com/

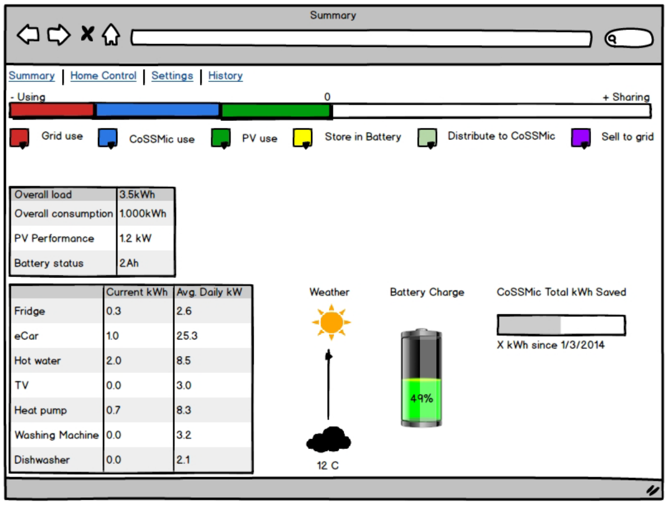

Fig. 5. Second workshop resulting mockup

section. This step coincided with the artifact iteration from the mockups to a running prototype. The running prototype and the anchoring of its UI elements in the aforementioned theories is described on the next section.

V. THE GAMIFIED UI

A *Gamification* concept was implemented in the prototype in terms of score system and a leaderboard. The scoring of a household was built based in up to four parameters linked to the behaviors to be stimulated in the user.

- Scheduling Score: this score is computed based on the flexibility of the user when setting the periods of execution of his appliances. It rewards users for making an effort to enable the system to shift the execution (and its energy load) to period of high energy supply.
- Sun Score: this score also aims to motivate the user contribution for shifting his consumption to high supply periods (when the sun is shining). However, in this case, it is computed based on how much of his energy is consumed in this period. Therefore, it takes in consideration both appliances that can and cannot be scheduled.
- Saving Score: this score is computed based on the energy savings the user achieves in comparison with his previous behavior.
- Sharing Score: this score is present only in households that own batteries. It reflects the amount of sharing of the energy storage.

The implemented Summary UI (illustrated in Figure 6) presents the user score together with a new design for representing the energy source feedback, the schedule of devices, the estimated PV efficiency based on the weather and the trend of energy production and consumption in the neighborhood. Those elements were chosen to be placed at the Summary UI because they all relate to factors that can influence the shifting of energy consumption and provide feedback about the user's contribution in the neighborhood grid. The current schedule plan of the devices, for example, can be seen together with sun and neighborhood energy availability allowing the user to reflect on the impact of his schedule based on those external elements.

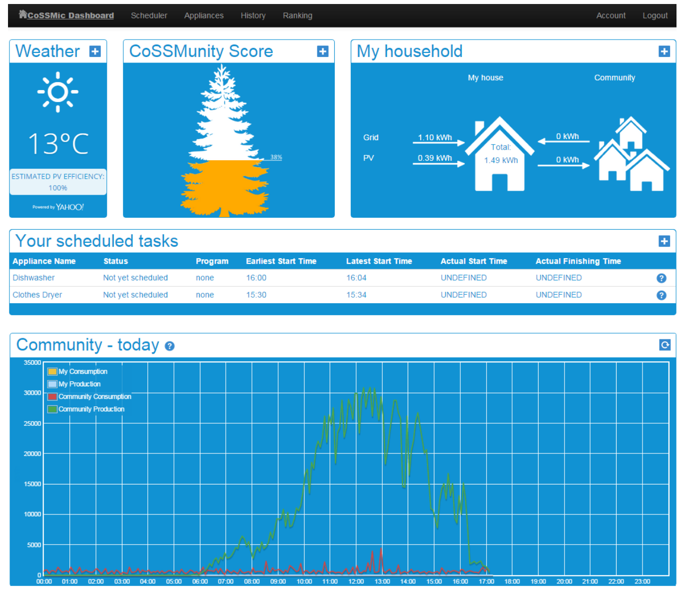

Fig. 6. Summary UI

The whole design was inspired on Fogg's observations of motivating social cues in interface designs [16]. The different elements of the page were split in aligned and consisting panels based on a few selected colors in order to transmit a feeling of simplicity and harmony. They are also primarily represented through images that offer immediate feedback in a understandable way:

- the PV efficiency is presented in percentage, together with a weather forecast symbol.
- the energy sourcing is shown in directional arrows between the supply and demand sources connected to the house.
- the user score is reflected into a tree that becomes greener as his points increase (inspired in Ubigarden [17]).
- the panels are embedded with a plus button on the top corner which triggers theirs expansion (see the example of the Score panel expansion in Figure 7) into a more detailed view and conveying more information about the element.This both allows the user to get more detailed feedback related to the element of his interest and introduces a playful interaction in the UI.

The expanded score panel (Figure 7) reveals the detailed scoring of the user and it contrasts that with the scores of the neighborhood, represented in the bar charts and forest image on the right. Putting both personal and neighborhood scores side by side enables the user to benchmark his behavior in relationship with his neighbors as to trigger the desire or pride (depending on his scores) of being a relevant contributor to the energy efficiency of the group. Besides, *Social Norms* are also explored through a leaderboard in the ranking page.

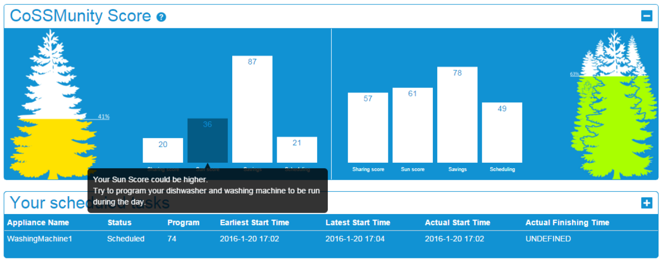

Fig. 7. Expanded Gammification Panel

Back to the CoSSMunity Score panel, the hoovering of the mouse in a specific score triggers a tooltip with hints. Those hints describe personalized measures the user can take in order to improve that score, boosting the ability of the user to adjust his behavior. The question mark/help button on the side of the panel title triggers the explanation of the scoring system and metrics.

Besides the Summary and the Ranking, the system has three other UI pages (as depicted in the top bar in Figure 6): Scheduler, Appliances and History. The Scheduler page presents a list of the appliances of the household whose operations can be programmed. Once the appliance is selected, it's corresponding rule-set configuration options are listed so that the user can program it, similarly to what was described in the mockup artifact (and illustrated in Figure 4). Depending on the user's choices and the estimated energy demand and supply in the neighborhood, the UI provides a suggestion of alternative settings that can achieve a higher energy efficiency (just as it was suggested by the end users in the second workshop).

Both Appliances and History pages are responsible for providing zoom and navigation capable graphs with real-time information of the household energy consumption and production. Each page has a graph panel with four tabs mapping to the daily, monthly, yearly and total energy graphs. The History graph shows the overall household energy. It superimposes the energy consumed locally over the energy consumed from the grid and the energy fed to the neighborhood over the self-consumed. That easily illustrates the ratio of PV generated energy used locally and shared. On the other hand, the Appliances Graph show the consumption of each one of the connected devices. The graph has a lines graph per device monitored and each line can be toggled, allowing the user to directly compare a customizable set of devices. Those different levels of *Feedback* converge with the wishes manifested during the user workshops and with the best practices in terms energy monitoring *Feedback* [27]. Table I summarizes the application of the different motivational aspects described in the theoretical study into the design of the prototype.

TABLE I
MOTIVATIONAL ASPECTS ON THE PROTOTYPE

Motivational Aspect	**Feature**
Social Norm	Score comparison with the neighborhood and ranking
Feedback	Real-time feedback of energy through graphs and of energy efficient behavior through scores
Triggers to perform the behavior	Scheduling suggestion and tips to increase the scores
Gamification	Scoring system and ranking
Social Cues	Attractive design, playful interaction, positive messages within suggestions given by the system and tree/forest metaphors

VI. Experts Evaluation

The evaluation was executed through a semi-structured interview session with two experts followed by a likert questionnaire based on the Technology Acceptance Model (TAM) [28]. The experts consisted in a researcher within business development of solar energy systems, and a researcher on Human Computer Interaction applied to carbon neutral lifestyles. Both experts had long experience from other projects looking at consumer electricity behavior and from existing energy information and management systems. They were not involved in the design process or familiar with the prototype.

The objective of the interview session was (1) to assess if the user interface elements are clearly understandable and consistent and (2) to validate that the motivational aspects present on the prototype (summarized in Table I) were well applied in the context of improving one's energy behavior. While, the TAM-based questionnaire included quantitative questions to assess the perceived ease of use and usefulness of the elements in the context of changing behavior. Moreover, we wanted to obtain feedback regarding possible refinements of the UI before deploying it to the trial users.

The session started with a general presentation of the system, including the capabilities of CoSSMic, the visual aspects of the UI and the rationale behind them. Participants were encouraged to interact and make questions during the presentation, while we would steer the discussion to answer our concerns if the participants did not bring them up. The meeting ran with an intensive involvement of the experts in providing feedback to the system.

Overall, the participants agreed that the UI was attractive and easy to understand. They also thought that the score system and motivational cues attached to it were a good introduction into educating the user in improving his energy consumption habits. However, they were afraid that motivation and engagement with the UI would wear out after some time. They suggested that the system should adapt with time and introduce new suggestions and triggers in order to captivate in the long term.

When it comes to the representation of the scores, both were satisfied with the tree metaphor and tooltips. They suggested that the timeframe corresponding to the scores should be made it explicit in the UI and customizable so that users can interact with it. The experts were unsure that the social comparison and competition aspects would motivate users. They thought that it would motivate some users, but demotivate others. In that sense, one of them suggested the system to focus more on the suggestive feedback and triggers to act, rather than the social comparison. They proposed that suggestive feedback could be further embedded in the Summary page panels representing the PV efficiency and the consumption/production trend in the neighborhood. A concrete suggestion on that regard was to connect the scheduler system with the neighborhood energy trends panel as to show the impact of those in the energy balance, instead of leaving the user to infer such impact.

The results of the questionnaires pointed towards the same results of the interview: the researchers agreed that the UI and its elements were attractive and easy to understand, but they have some reservations on whether the elements will be useful towards motivating the users to change theirs behaviors. They graded around 7 (in a range from 1 to 7) to the usability aspects of the UI and from 4 to 7 in terms of usefulness.

VII. Conclusions and Future Work

Already through the usage of the *User Centered Design* we have been able to include features that the users deemed important and that would drive them to use the system. Now, through this work, we enhanced the UI design with components inspired on behavior change constructs, in order to foster energy savings and efficiency based on the three behavior change support conditions described in the Fogg Behavior Model (FBM) [12]. Following the FBM, the UI stimulates the extrinsic motivation through *Gamification* and *Social Norm*; facilitates the performing of the behavior through *Feedback* information presented in an aesthetic and captivating *Social Cues*; and triggers concrete energy efficiency actions by means of *Suggestive Feedback* placed together with reflective and active elements of the UI.

The feedback from the experts showed that the UI has a high usability and that the motivational aspects are easy to understand and well applied in the energy behavior context. The evaluators suggestions for further *Suggestive Feedback* and theirs reserves about the long-term motivation of the users are currently being addressed. We started working on the development of *Gamification* badges and achievements together with the possibility of launching thematic and fixed duration competitions in order to stimulate long-term usage and motivation. Given that the trials will start before that, those new concepts will be presented to the users in a mock-up and concept level at the same time that we introduce the current UI as it is.

The usage of the current UI in the trials should be enough to help us investigate how the users will react to motivational aspects, and, more specifically, how is their behavior influenced by them. Meanwhile, as the trial progresses, the new aspects triggered by the experts (badges, achievements and competitions) can be put in place in order to study the long-term behavior change within the system.

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