Energy Consumer Knowledge Through Eco-visualization Evolution

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***Abstract*—This paper present energy consumer knowledge, through eco-visualization evolution in an attempt to identify how solutions, and their related technologies are evolving and what the perspectives for the future of the field are. Consumer awareness of energy use showed to be one of the roots to energy conservation. Technology, through digital artifacts, appears as an important factor to provide better feedbacks and, among with this, eco-visualization appears as one key enabler. The analysis was conducted by an ontological design and sustainable interaction perspective. This short paper presents this analysis and how eco-visualization solutions evolved through time in complexity and interactivity with features including, among other things, motivational and persuasive aspects and a tendency to use ubiquitous technologies.**

Keywords-Energy consumption; interaction design; eco-visualization; sustainability, eco-feedback.

I. Introduction

There is a need for cities worldwide to become smarter in how they manage their infrastructure and resources to cater to the existing and future needs of their citizenry - economic growth, technological progress, and environmental sustainability are the drivers for this new found urgency [1]. Focusing on global energy challenges, one important way of achieving sustainable behavior change is to provide better feedback on energy consumption (eco-feedback) [2]. People are often unaware of the extent of theirs immediate consumption of energy [3]. According to Sun [4], consumer awareness of energy use and their act in energy conservation are inextricably linked because the former enables informed decision-making and motivates behavior change.

How this information should be presented is not yet well understood, but apparently the digital artifact ability to provide meaningful information and usability are very important factors to increase energy consumer knowledge through eco-visualization [5]. Based on the problem of providing effective energy feedback to changing consuming behaviors in positive ways, the objective of this paper is to show energy consumer knowledge through eco-visualization evolution in the last ten years in an attempt to identify: (i) how solutions and their related technologies are evolving, (ii) what are the perspectives for the future of the field and (iii) what is the impact of time in the design of eco-visualization applications. The term "solution" is used in this work to indicate digital artifacts (prototypes and products currently on the market or not) addressed to fix the problem.

This paper is organized as follows: theoretical background on eco-feedback and ontological design ways of sustainable interaction are presented in Section II. The methodology used in this work is presented in Section III. Related work in energy knowledge consumer field is presented in Section IV. Relevant solutions comparative analyses and finding results are presented in Section V. Some final considerations and next steps are presented in Section VI.

II. About Eco-feedback Technologies and Ontological Design Ways

This section will depict some theoretical aspects of eco-feedback technologies (with focus in energy consumer knowledge) and a framework for ontological design sustainable intervention.

A. Eco-feedback Technologies

Eco-feedback technologies can be defined as: "technology that provides feedback on individual or group behaviors with a goal of reducing environmental impact" [2]. These are generic definitions that can be applied to many contexts (water, energy, and solid waste or carbon footprint, for example). In this work, the focus is energy, and the terms eco-feedback and eco-visualization are used most of the time as synonyms. Metrics, frequency, granularity and other factors play a role in the design of data feedback [6] and some possible ways to categorize these systems are by commitment (social or individual) [5], data visualization (pragmatic or artistic) type [7], or the support to the user behavior change (raise awareness, inform complex changes, and maintain sustainable routines) [8]. Few Human Computer Interaction (HCI) eco-feedback studies have attempted to measure behavior change [2]. In many cases, it is difficult to evaluate the efficiency of these artifacts in long-term usage because experiments reported in the literature were tested (validated) with a relatively small number of users, for a short period of time or both.

B. Ontological Design Ways of Sustainable Intervention

The solutions were analyzed grounded in the notion of an ontological design framework with the following aspects: Balancing (B), Prevention (Pv), Persuation (Ps), and self-Motivation (M) [9], as shown in Figure 1. Analyzing eco-feedback technologies through this view makes sense, since these solutions have the goal of reducing environmental impact. According to Kim [9]:

- Exploring design activity to synthesize technological effect, understanding users' practices and local environments as an ever-changing complex and applying appropriate technologies and services are some actions that can be performed to promote the balancing between now and the future (B);

- Prevention (Pv) of environmental problems involves, among other things, avoiding superfluous consumption and reducing the use of materials or energy;
- Understanding a digital artifact as a communicative possibility for transmitting sustainable meanings, indicating the efficiency of energy and materiality, and encouraging sustainable behaviors are some actions that can be performed to persuade (Ps) users to engage in sustainable practices;
- Self-motivation (M) involves, among other things, discovering how to empower and motivate users and groups or communities to organize their own thinking and act for ecological satisfaction.

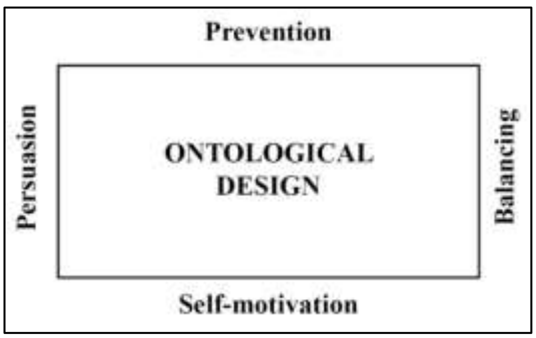

Figure 1. Ontological Design framework [9]

Originally, the framework presents a design perspective, but it can be applied during the entire process of new products creation.

III. METHODOLOGY

To achieve the objectives, a literature review to form a theoretical basis and a benchmark was conducted. The goal of this activity was to find previous works related to the issue of providing effective energy feedback. The intention was not to collect cases in terms of quantity, but to choose cases in a representative way according to their impact, creativity and diversity.

Following the criteria mentioned before, five solutions were selected - some of them are currently on the market (Cloogy [15] and Power2Switch [12]) and other represent early experimental functional prototypes (The Ténéré [11], Power-Aware Cord [10] and PowerViz [7]). They are presented in chronological order pointing in many aspects to an evolution along the years. After that, we analysed each one of those solutions, in order to validate and gather how they changed, or did not change, the way in which an energy assessment is done.

The findings from previous step were analyzed through the concept of an ontological design and a sustainable interaction framework [9] following these aspects: Balancing between now and the future (B), Prevention of environmental problems (Pv), technologies that Persuade users to engage in sustainable practices (Ps), and empowering self-Motivation (M). In order to perform the evaluation, these aspects were linked to some eco-feedback relevant characteristics that might be present or not in the selected solutions, such as: commitment, data visualization, support to user behavior change and the additional electric power consumption the solution could cause.

Finally, an analyses was conducted comparing one solution with another, to better understand how this field is evolving and how the next generation of eco-feedback digital artifacts is expected to be and cover.

The implementation and creation of a new approach to this matter was not part of this work.

IV. EXISTING SOLUTIONS

This section will depict the main features of existing solutions for analysis.

A. Power-Aware Cord

Power-Aware Cord is a re-design of a common electrical power strip that displays the amount of energy passing through it at any given moment. It uses dynamic glowing patterns produced by electroluminescent wires molded into the transparent electrical cord, as shown in Figure 2. By using this functional prototype, the authors of the project investigated how ambient displays could be used to increase the awareness about energy consumption [10].

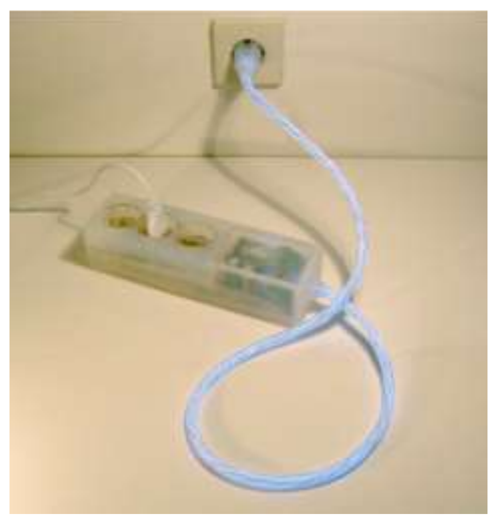

Figure 2. Power-Aware Cord prototype [10]

The system uses individual commitment, feedback and abstract data visualization to increase awareness. It causes additional electrical use and long-term use may reduce the effect of meaningful and emotional appeal. According to Gustafsson and Gyllenswärd [10], the prototype was validated by fifteen users in the original study.

B. The Ténéré

Ténéré is a power wall tap and power extension cord that connects end products to energy source to measure and

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indicate the power use, as shown in Figure 3. It was designed to support people's energy conservation behaviors, focusing on providing appropriate energy awareness information in meaningful and emotional ways while products are being used [11]. A narrative of tree (which names the project) was used to indicate energy use, symbolizing the environmental consequences of human activity.

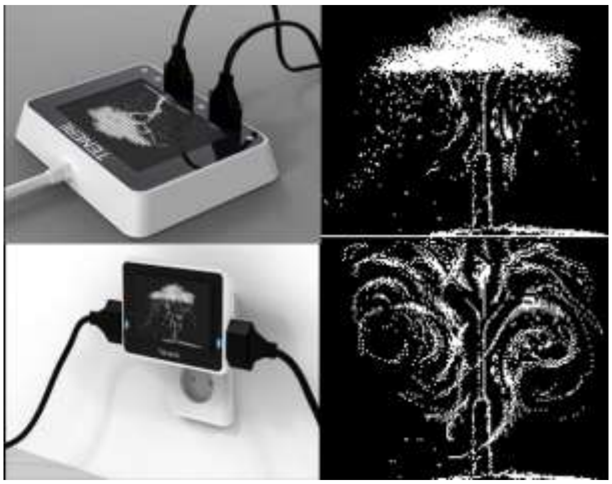

Figure 3. Ténére extension cord extension cord and wall tap type; Screen transitions that reflect current power usage [11]

The system uses individual commitment feedback and abstract data visualization to raise awareness. It causes additional electrical usage and long term usage may reduce the effect of meaningful and emotional appeal [11].

C. PowerViz

PowerViz is a prototype to an always-on eco-feedback display, which provides information about people's power usage in their homes at an appliance level [7]; as shown in Figure 4. The system draws its data from a smart home energy metering system, obtaining usage data from each outlet in the household. User interface consists of four individual screens: current usage (screen saver), usage history, appliance usage, and appliance history.

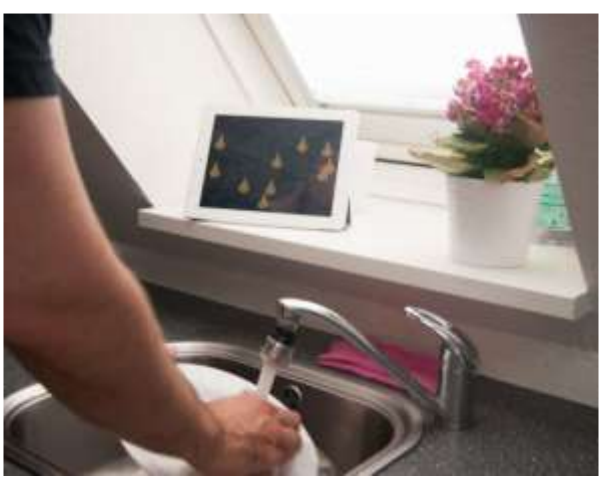

Figure 4. PowerViz usage [7]

The system uses individual and social commitment feedback and abstract and pragmatic data visualization to raise awareness. It causes additional electrical usage. According to Pierce et al [7], the prototype was validated with 3 end users (a very low number) in the original study.

D. Power2Switch

Power2Switch is an American startup that offers as service the account bill redesign and helps to find the best supplier (in many American cities consumers can choose the energy company) [12]. The redesign uses color, variation in font sizes and graphics that help to emphasize the most important information in the account and also to reduce noise and little relevance information [13]; as shown in Figure 5.

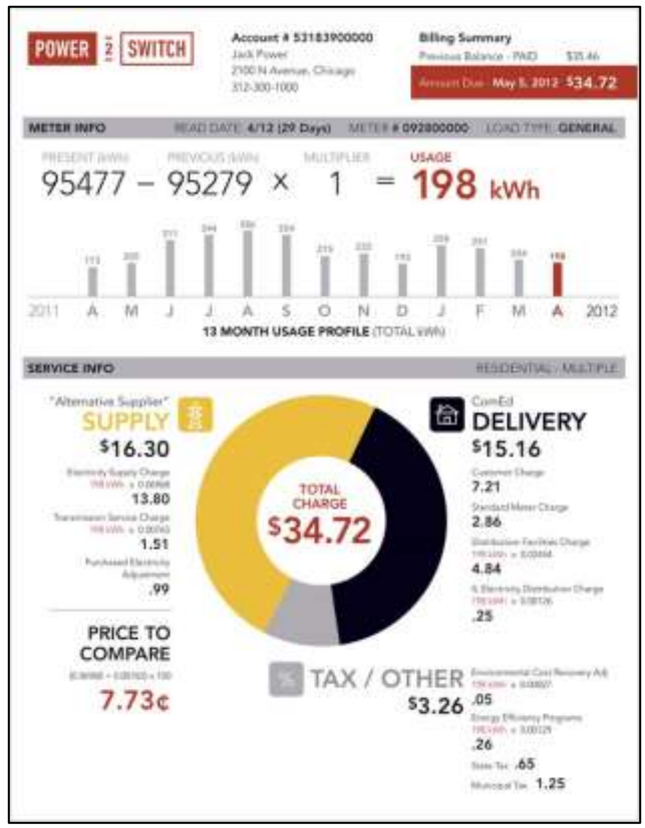

Figure 5. Account bill redesign sample [13]

It gives a better understanding of how much is paid by electricity (Supply), how much is paid to energy delivery and how much is paid in taxes [14].

E. Cloogy

Cloogy is an energy management solution that allows monitoring energy consumption. The device is Portuguese and was launched in late 2012. It promises savings of up to 25% on energy bill. Some system features are: simulate tariffs, set personal goals, create user profile, obtain forecasts of consumption and comparison between periods of times, control equipment remotely in real time and schedule the equipment operations [15]. The system uses individual commitment feedback and pragmatic data visualization to raise awareness, inform complex changes, and maintain sustainable routines.

V. ANALYSIS

It would be difficult to provide an in-depth comparison between the commercial and prototype solutions presented. This is due to the fact that, despite having the same purpose they have distinct characteristics and use different technologies. But, using a framework, as described in Section II, could help in the analysis. The main characteristics considered in this evaluation were: commitment, data visualization, support to user behavior change and the additional electric power consumption the solution could cause.

Motivation can be interconnected with many elements. Although, for simplifying, commitment was related to Motivation in this analysis: social commitment was considered more motivating than individual commitment. Data visualization types were related to Persuasion: offering both pragmatic and abstract visualization modes or mixing up both was considered more persuasive than using just one kind. Support to user behavior change was related to Balancing and Prevention. If a solution uses a lot of electric power it can contribute negatively to Balancing and Prevention.

As shown in Table 1, the analysis of the selected solutions states a tendency to combine the multiple factors listed before in order to achieve greater effectiveness. The findings also state a tendency to eco-visualization solutions adoption in homes, along with the use of ubiquitous and pervasive technologies [7][12][15] to control and monitor power consumption remotely from devices with internet connection.

TABLE I. SUSTAINABLE INTERACTION

Year	Sustainable interaction				
	Solutions	***B***	***Pv***	***M***	***Ps***
2005	Power-Aware Cord	✖	✖	✔	✔
2009	Ténéré	✖	✖	✔	✔
2010	PowerViz	✖	✖	✔	✔
2010	Power2Switch	✔	✔	✔	✔
2012	Cloogy	✔	✔	✔	✔

The latest solutions presented, especially Power2Switch and Cloogy have several improvements in usability and show consistent Balancing (B), Prevention (Pr), Persuasion (Ps) and self-Motivation (M) by mixing forms of abstract and artistic visualization. They involve different types of commitment and can be more economic in power consumption compared to earliest artifacts that serve as the foundation for this evolution indicating somehow the impact of time in the design of eco-visualisation applications and the field development .

VI. FINAL CONSIDERATIONS

It is already known that meaningful information and usability are very important factors to increase energy consumer knowledge through eco-visualization [5]. Legibility of energy data in real time (or not) thought information systems with or without big data helps users to control, define goals and improve energy use contributing to sustainable behavior. In some cases, the available solutions analyzed expose to the user a consumer profile, turning power information more transparent and knowledgeable [12][15].

Energy consumer knowledge through eco-visualization evolved thought time in complexity and interactivity with features including, among other things, motivational and persuasive aspects. The related work analysis shows a great solutions range: pragmatic and abstract data visualization [7][10][11], narratives to meaningful and emotional ways [11], with social and individual commitment [7], energy management [15] and account bill redesign [12]. It is interesting to observe that the research field extrapolated to and generated new business and products with end users. It is possible to notice consistent and useful products currently on market.

As future works, it is intended to improve validation techniques from the framework factors of the conducted study and use it as metrics to better evaluate and design eco-feedback technologies. That may contribute to developing more sustainable digital artefacts and user experiences.

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