EnerSpectrum: Exposing the Source of Energy Through Plug-level Eco-feedack

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***Abstract*— This paper presents *EnerSpectrum* a standard wall electricity socket redesigned to present how much of the electricity being consumed is sourced from a renewable energy source. We build on studies that report an increase in consumer energy awareness and literacy when presented with the source of their electricity. The prototype was evaluated by 10 users using interviews, which found the concept interesting and valuable. We conclude this paper with an outline of the future work necessary to evaluate the *EnerSpectrum* in real live conditions.**

Keywords—Eco-feedback; Sustainability; User Interfaces; Prototyping

I. Introduction

Electricity consumption and the negative aspects associated with overconsumption of resources is still a big issue, and despite the advances in the efficiency of household appliances and the actual distribution grid, worldwide energy demand and associated carbon emissions continues to rise [1]. This has attracted the attention of both industry and several research fields, and one of the outcome were the so-called eco-feedback devices which provide feedback in individual or group behaviour with the goal of reducing electricity consumption, by informing and motivating users to change their consumption habits.

In a wider scale, the deployment of smart electric grid (commonly known as Smartgrids) proposes savings in individual and city consumption as well as in the electricity distribution by employing techniques such as load balancing, demand curtailment and automated agents in the household. Yet, while the room for savings is noteworthy, the deployment of the Smartgrid has been slow with only a few locations and energy providers living up to the initial expectations (e.g. [2],[3]). Nevertheless the electricity grid as we know it is changing, both physically, with distributed generation decentralizing the source of electricity, and conceptually with new legislation and services for rewarding micro-producers, and avoiding consumption in high demand periods. This change will not only affect the way we obtain electricity but also the way it is perceived.

In this paper we present the *EnerSpectrum* socket electricity feedback device. Our goal with it is to firstly inform consumers about the source of their electricity in real time, making them more aware and energy conscious. However our long-term goal with the proposed system is to incite knowledge within individuals aiming at demand side management, by rewarding consumers to use more electricity when higher percentage of renewable energy is available in the grid.

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II. Related Work

A. *Energy feedback at the plug*

Household electric plugs, and the action of connecting and disconnecting appliances is the closest individual consumers get to the electric grid. Therefore researchers have explored using these objects to provide real-time in-the-moment feedback about electricity consumption. Heller et al explored this concept with the *PowerSocket* a traditional power outlet redesigned to display energy consumption colour coded for low, medium and high consumption [4], [5]. The feedback was given via different modalities: a halo around the connector itself, a vertical or horizontal bar that changed its colour and size or the actual numeric consumption displayed in an LCD in the plug. A total of 14 participants using a software prototype evaluated the *PowerSocket* project. In general participants preferred the more ambient and abstract visualizations to the concrete data displayed by the LCD alternative. Similarly the *power aware cord* was a common power cord redesigned to show the consumption of the devices connected to it. The cord would glow according to the consumption and a small evaluation disclosed that individuals would quickly understand the concept behind the *power aware cord* [6]. A more abstract approach was proposed by Kim et al [7] in which a display placed near the socket would show the animation of a tree that would change according to the connected appliance consumption.

B. *Electricity production feedback*

Currently, consumers receive information about their consumption either through monthly bills or through dedicated devices. An addition is to present them with the source of their electricity as well. However, energy production data is hard to obtain and previous studies have been limited to micro-generations scenarios where consumers produce part of their electricity. An example of such device is the *Local Energy Indicator*, this prototype targeted at the household used the concept of energy metadata, to inform the source and location of the consumed energy [8]. The authors argue that micro-generation systems could be designed to be desirable not only by helping consumers save money but by appealing on user satisfaction of consuming their own “home-grown” electricity.

The same authors point that since electricity is an intangible energy source, normal consumers are mostly unaware of the effort necessary to produce it. To better understand this relationship between consumers and energy the authors designed and evaluated several prototypes capable of representing the intangibility of energy, one of these prototypes was the *Energy Lamp*, a desk lamp that changed its colour to display information such as the source of the energy or its age. This concept was tested with users who referred that they could change their routines in relation to the availability of solar or wind energy, the authors argue that electricity services based on micro production could be designed to appeal on the engagement between consumers and wind and solar energy [9].

The strategy of connecting electricity production and consumption fostering higher knowledge and engagement in the consumer has the end goal of motivating consumers to change their energy consumption routines, by shifting energy usage to periods of higher availability of renewable energy and reducing usage during periods of low renewable energy availability.

This phenomena is commonly known as peak demand shifting, and could result in a reduction in carbon emissions potentially larger than those promoted by eco-feedback devices (5~15%) [10], since production can be shifted to periods where more renewables are available or to periods where the thermal plants work with higher efficiency. Electricity providers also value this shift, since it often results in higher profits when expensive generators are disconnected [11].

III. THE ENERSPECTRUM

Our objective with the *EnerSpectrum* is to combine the engagement and knowledge revealed by consumers when presented with the source of their electricity, with the in-the-moment concrete feedback proposed by in-plug feedback. This study aims at contributing to the eco-feedback field since electricity production and plug level feedback are mostly unexplored areas of research and, to the best of our knowledge, the combination of this two techniques is truly innovative. Secondly, we aim to contribute to the broader Smartgrid initiative and more precisely demand-response research by intrinsically motivating consumers to use more electricity when the renewable quota in the grid is higher.

A. Electricity production data

The presented work is being developed in Madeira Island, Portugal. All the electricity is produced in the Island through a mix of 3 thermal stations 4 wind parks (located in the mountains), 10 hydroelectric stations (near the base of the mountains), and approximately 700 small and medium sized photovoltaic installations dispersed through the island. In average 28% of the islands electricity is generated from renewable sources, a value that tends to grow in the winter with the increase in rain and wind.

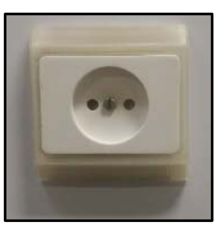

Fig. 1 *EnerSpectrum* socket disabled

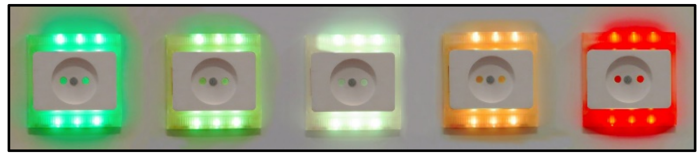

Fig. 2 Five possible states of the EnerSpectrum according to the grid status at a given moment

The electricity production values, updated every fifteen minutes, are obtained from the local electricity provider and stored online in a server that also provides an array of services to query the available data (e.g. real time production, average of day/week/month). Furthermore the local electric company provides the outcome of a model used to predict the production in the next 72 hours, which are also stored and available for querying.

B. The EnerSpectrum socket

The *EnerSpectrum* prototype is composed of a standard wall socket, from which the external shell was removed and replaced with a custom-made transparent one. Fig. 1 displays the power socket before being activated. Inside the outer shell there are six REG LEDs (3 on the top and 3 on the bottom), whose colour can be changed dynamically through a script running in an Arduino microprocessor. A Processing application is responsible for accessing the electricity production webserver and communicating the values back to the Arduino microprocessor, which adjusts the colour of the LED's based on the received data. The socket colours range from a bright green when there is a high amount of renewables in the grid to bright red when the electricity comes mostly from thermal sources (Fig. 2). Currently the prototype is installed in a wooden panel, the Arduino microprocessor is placed in the back of the panel, and connected via USB to a PC running the Processing application also placed behind.

After several tests we observed that the threshold used to select the colour of the socket could not be constant, other wise, in more extreme cases like a summer month with very little wind and rain the plug would always be red (this kind of negative reinforcement has been proven to be ineffective [12]). Therefore we developed a model that takes into account other variables to dynamically change the threshold values. In the current version of the *EnerSpectrum* the threshold used to decide the colour of the plug takes into account the current quota of renewables in the grid, the day week and month averages, and the prediction of the production for the next 8 hours. Fig. 2 displays the five possible states of the plug. An alternative approach would be to allow the user to control how the colours are displayed in the socket.

IV. EVALUATION

The prototype of the *EnerSpectrum* was evaluated in a pilot as part of a larger energy production display. To this end, ten individuals (five male and five female) were recruited and exposed to the plug displaying different levels of production based on previous days. After this all the participants were interviewed, which is a common technique originated in the Human Computer Interaction field, used to evaluate these type of devices (e.g. 8). In the remaining of this section participants are referred to as P1,P2,P3, etc. .

Overall, participants found the information easy to understand as pointed out by P3:*"The plug over there with the light I think it's the easiest way to view the information… it's always there… its immediate".* And they could easily relate the production quotas with the colour of the plug as observed by P7 "*Look at the plug all green and happy… now its not depressing*"

Participants also refereed that the plug displays new information to them, which is normally hidden as referred by P10: *"… Nowadays everything is so easy… with a plug like that we have an idea of the efforts necessary to obtain the energy",* the same participant referred that plug could be used to adapt their non-routine consumption: "… *not in our day to day routines, but in that consumption that we could shift, like the washing machine…*"

In general all participants found the information about the source of electricity is something useful interesting and valuable. It was even referred that the *EnerSpectrum* was something that they could see themselves using in their day-to-day routines.

V. FUTURE WORK

Motivated by our initial findings we are now planning a live deployment of the *EnerSpectrum* plug as described next.

A. Implementation

In a more advanced prototype targeted at a real world deployment the microprocessor will be placed in the hollow part of shell and obtain energy from it, the production data will be received wirelessly.

B. User control

We plan to implement an interface to allow users to control the information displayed in each socket. Users should for example be able to program a socket to be green when the renewable quota is higher than the average, and program a different socket to only be green when there is more than 50% renewables in the grid, these 2 sockets could then be used to power different appliances based on how important they are to the user. Furthermore if we combine the *EnerSpectrum* with the non-intrusive electricity sensing we used in [13], users could also configure their sockets based on the household consumption, or a combination of consumption and production.

C. User study

The most imperative next step in our research is to deploy the *EnerSpectrum* socket with actual consumers in their living spaces. We argue that for this type of device to be properly tested a long-term in-the-wild study is necessary since the household dynamics greatly affect how eco-feedback devices are adopted [14]. Furthermore the production of electricity is highly dependable in environmental variables such as weather or time of the day, thus, only a long-term study can assure that the users are exposed to different production quotas.

VI. CONCLUSIONS

In this paper we presented the first prototype of the *EnerSpectrum* plug, a standard household socket redesigned to display the source of electricity. An evaluation disclosed that consumers found this information valuable and rapidly understood concepts such as how the availability of renewable relates to the weather conditions.

After some initial evaluation we are now planning a live deployment of *EnerSpectrum*, such that one can understand how families embrace this type of products as well as gain insights regarding the potential of using this production information as triggers for enabling self-started demand - response strategies.

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ARDITI(002271/2014/131)
LARSyS (PEst-OE/EEI/LA0009/2015)