Watt-I-See: A Tangible Visualization of Energy

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ABSTRACT

This paper describes a tangible visualization that explores the link between the impact of energy feedback on household consumers and the resource demand impact on energy production. Specifically, it positions a novel perspective attempting to move beyond the known limitations of current eco-feedback systems and contributes to enhance our understanding of how consumers comprehend energy production. The work is informed by a comprehensive study of an installation that displays the ratio of current power generation sources and the percentage of grid renewables. The paper provides design insights for creating novel eco-feedback visualizations that leverage the balance between user lifestyles and the desire to influence consumption behaviors and practices. Evaluation results show an increase in energy literacy and awareness as well as identifies high consumer preferences towards simple, representative interfaces and ubiquitous immediate feedback. Our study shows potential in terms of future scenarios for eco-feedback in distributed energy micro-generation and other inevitable disruptive changes for the energy utility.

CCS Concept

• Human-centered computing~HCI design and evaluation methods

Keywords

Sustainability; Eco-feedback; Public Installations; Visualization; User Study.

1. INTRODUCTION

Electrical energy is the cornerstone of our modern lives. Electrical devices support most of our daily activities as they power our social, governmental and health services. However, our society's increasing demand for electricity (and energy in general) is plainly unsustainable. Disruptive changes in this utility sector seem inevitable due to a convergence of factors, including economic downturn, falling costs of energy resources and public policy incentivizing the adoption of new energy technologies. These factors are making distributed microgeneration desirable and affordable by consumers, who gain independence from public utilities. In countries like Germany, Spain, Portugal, Australia, and the Southwest U.S., residential-scale solar production has already reached "grid parity" with average residential electricity prices. Still, the increased penetration of renewables poses many challenges for energy management systems and does not necessarily generate a more sustainable upcoming. In fact, the Jevons paradox effect reveals that the rate of consumption of an resource increases (rather than decreases) with technological progression and growth in efficiency of the resource in use [1].

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Regardless of these future scenarios, fuel based production still accounts for approximately 40% of the worldwide total energy production of which 28% is accountable for residential use, with an estimation to increase to 32% by 2040 [2]. The attempts to reduce residential consumption through increased efficiency are not reverting this tendency, as households now own more appliances than in the past. Small appliances proliferating in houses are currently estimated to account for half of the consumption, providing a significant margin for individuals to manage residential consumption. HCI research is looking at these phenomena typically from the perspective of encouraging sustainable energy consumption from end-users. Unfortunately the results are far from the initial expectations [3, 4].

This paper follows the conviction that "in order to assess the potential and effectiveness of HCI in environmental practice, it is necessary to inquiry into the contexts in which those practices arise, and to recognize the potential contradictions between the goals of our intervention and the forces that shape their deployments" [5]. We build on the state of the art in a twofold way. First we explore how HCI and design research envisioned energy and, in particular, the tension between the seamless and ubiquitous nature of energy as a service provided to consumers, and the inherent intangible and invisible nature of the underlying commodity [6]. Secondly we try to go beyond traditional eco-feedback visualizations by combining production and consumption information coming from a medium size closed grid with a high penetration of renewables. This material is particularly valuable as designs in this space must strike a complex balance between an awareness of the realities and complexities of user lifestyles, on one hand, and a desire to influence their use and consumption behaviors and practices on the other.

2. RELATED WORK

HCI research mostly focuses on raising awareness and promoting sustainable energy consumption. Four common methods have been used to make energy consumption accountable to consumers: i) comparing appliances [7]; ii) using an universal reference system (e.g. money, so called extrinsic motivators [8]), iii) comparing and referring to others' consumptions; and iv) exposing habits and past actions as a resource for accountability [9]. These approaches usually rely on some form of eco-feedback technology, i.e. technology that provides feedback on individual or group behaviors with the goal of reducing environmental impact [10].

Eco-feedback is proven to be efficient in reducing individuals' domestic energy consumption, with electricity savings ranging between 5 and 15%.

Regardless of the known shortcomings of eco-feedback systems [11], [12], research demonstrated several important findings in terms of guidelines for information presentation. For instance, the traditional kWh representation is not an adequate form of feedback, especially when presented as large aggregated data [13]. Likewise, displaying the collective or individual environmental impact is not a simple task. The information is normally depicted as pounds of CO2 emitted or by the number of trees necessary to offset the values of the emissions (e.g. Wattson, Kill-a-Watt, Orb). These emission values are normally estimations based on pre-set values and do not account for the different generation techniques used to produce the electricity consumed, i.e., is the current energy generated from fossil or renewable sources. Therefore these representations are too disconnected from consumers' routines and their environment (e.g. location, weather, time of the day) to provide meaningful awareness and accountability.

Research has disclosed that presenting consumers with the impact of their actions towards the environment is a strong motivator to reduce resource consumption [13]–[15], especially to consumers that are not concerned about how expensive electricity is [14], [15]. This lead researchers to explore other forms of eco-feedback that show the real-time exposure of the natural resources exploited to produce the electricity consumed in their households, and more long-term effects in terms of climate change and other weather or environmental impacts [16]. This approach is particularly relevant for distributed energy generation scenarios in particular for micro-producers who own small photovoltaic or wind generation equipment [18,19]. However, making the connection between production and consumption is hard in settings where consumers obtain their electricity from large distribution grids. This is the scenario where our contribution falls. Here, research efforts can be divided in two main groups: proof of concept and exploratory studies [6,20]; or traditional studies within households who produce (at least a portion) of the consumed electricity [18,21].

Exploratory studies [6,20] have focused on the intangible nature of electricity and reflect how cost is still a major factor inhibiting the adoption of micro-generation systems. Limiting the social acceptance of micro generation, which involves different deployment models with varying degrees of company and consumer involvement [21]. Regardless, participants commented on how they could change their routines in relation to the availability of solar or wind energy. This opens opportunities for new services and business models emerging from the disruptive nature of distributed energy generation. Another conceptual study [20] explored how families build mental models between their daily routines and resource consumption using metaphors like buckets of water, bags of coal and stacks of wood. This approach was also used in large public installations as in the Nuage Vert project [22] where the whole consumption of the city of Helsinky was projected on to the smoke emitted by a local coal energy power plant. Similarly, Wallebron et al [23] argue that energy should be depicted as a more "precious" commodity. This strategy would empower regular consumers to connect more with their electricity consumption. This conclusion arises from their observation that eco-feedback meters only really develop awareness is already informed consumers. Finally in [18] a broad qualitative study observed that owners of micro-generation system not only followed their production closely but also patterns related to weather conditions. Similarly, [17] observed that consumers using solar panels at home, utilized a weather forecast widget in conjunction with a production widget to predict and learn more about the energy production in their homes.

3. WATT-I-SEE: VISUALISING ENERGY

Watt-I-See (WISE) is an interactive installation concerned with raising awareness about energy production to average users. Our goal with WISE was two folded. First we wanted to explore a tangible design that could reconcile the seamless and ubiquitous nature of the electricity. Secondly we wanted to go beyond the conventional micro-generation scenario combining production and consumption information from the grid. Our ultimate goal was to provide actionable design guidance for creating novel eco-feedback systems based on real time consumption and grid power generation data.

Watt-I-See goes beyond exploratory attempts to feedback information from localized micro-generation scenarios. In this setup we usually have a household or small business, which corresponds to a small community of users. In WISE we explore a much larger ecosystems taking advantage of a closed circuit energy system of an island in Europe with more than 270 thousand inhabitants.

The island's electricity needs are fulfilled by 2 thermoelectric power 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). The average yearly electrical distribution is as follows: 78% of all energy is produced from thermoelectric plants, 11% from hydroelectric stations, 9% from wind parks and 2% from dispersed photovoltaic sources. During winter months the wind and hydro energy source quotas increase significantly, while during dry summer months the renewable quota is significantly lower. This unique setting provides an additional scale step from the existing studies of production and consumption in eco-feedback.

We argue that our deployment in an isolated grid anticipates several issues that go beyond micro-generation scenarios and where the complex balance between the production / consumption reality and the individual / collective behavior are closer to the disruptive scenarios we might envision in the future for larger grids. These are important issues that might compromise the goal to reduce the carbon dependency in the grid. Regardless of pricing structure and technological problems the important variables are the uncertainties induced by human activities (affecting demand) and unpredictable weather and environmental factors (affecting supply).

4. Design decisions

During the implementation of WISE, we followed the body of work pertaining to presenting consumers with their electricity (see section 2). Furthermore, we were also motivated by the work which communicated with individuals using metaphorical representation and tangible interaction. These techniques been proven effective to display group behavior and to promote learning of new concepts (e.g. [24], [25]).

4.1 Interaction

Participants can interact with Watt-I-See in three modes:

- *Physically engaging with the installation*: participants have to pedal on an exercise bike to surpass a micro-generation step to "power up" the installation. The energy produced does not influence the installation or the data it displays, rather its goal is to contextualize one's physical effort in producing electricity through a questionnaire on a tablet lying on the bike handle.

- *Acknowledging the visual interface*: learning about percentages of renewable versus fossil energy being produced in that moment on the island. The WISE presents viewers with the real time values for the electricity produced locally.
- *Querying the interface of the installation*: the third mode of interaction allows participants to construct different days through cards representing several weather conditions and time-of-day. The visualization is then updated with the view its corresponding (real data) production quotas for those conditions.

4.2 The Vortices: Disaggregated Production Quotas

Watt-I-See resorts to an analogy of "x-raying" a household wall, displaying four glass pipes containing a colored vortex, each representing an energy production source available locally: thermoelectric power stations, wind parks, hydroelectric stations and photovoltaic. The glass pipes contain distilled water and liquid paraffin. Each vortex is colored in order to represent a different energy source: dark purple for thermal energy, clear color for wind, dark blue for hydro and yellow for solar energy source. The size of the vortex, ranges from very low (between 1 and 3% quota) to maximum (these nine levels represent the quota in percentage. The highest level creates a more aggressive vortex to represent over 91% (limit selected by average maximum thermal quota) of quota from an individual production source. These levels represent the quota of energy produced and available to final consumers, thus the sum of all four vortices totals 100% (See Figure 1).

4.3 The Glowing Socket: Renewable Energy Feedback

In addition to the vortices, the power socket provides additional feedback on the overall quota of renewable energy in the grid. While the glass tubes and vortices display individual source production quotas, the power socket displays the cumulative quota of renewable energy in the power grid. Five renewable feedback levels were defined based on three years of disaggregated production quotas. Each level displays on the power socket a corresponding pulsing color (See Figure 2).

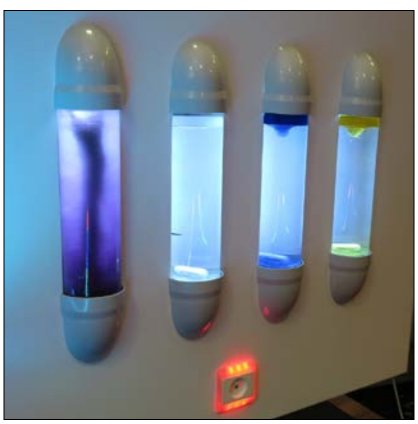

Figure 1: Fossil source over 91%, 0% wind, hydro and solar sources between 1-3%. The socket is glowing red.

5. IMPLEMENTATION

The electricity production data is obtained directly from the regional energy provider currently the primary entity responsible for the distribution of electricity in the island. Additionally, the regional provider distributes, through a prediction model, the estimate production quotas for the next 12 hours. The production and prediction data is then made available under a series of web services that can return the real-time, a multitude of statistical averages, and specific queries such as returning production data for individual days and hours.

5.1 Production Visualization

Watt-I-See measures 1.22m x 0.9m (without the stand) built from wood and covered in matte white vinyl. Four glass tubes (9x30cm) are used to represent the individual production sources. Vortices are created by DC motors controlled by an Arduino microcontroller. The DC motors rotate a large magnet that subsequently rotates a magnetic bar inside the glass tube creating the vortex. A smaller magnet and Hall effect switch is used to calculate the rpm's of each motor in order to leverage the rotation between the different tubes. Additionally, LED strips and drivers are used to retro-illuminate the glass tubes that are covered in tracing paper and contain the printed icons for each energy source (See Figure 2). A computer power supply is used to power the installation.

The electricity socket is a common power socket where the outer bezel was 3D printed using a transparent plastic. The color of the socket is obtained by RGB LEDs and is based on several conditions queried in real-time to the database: 1) current real-time production quotas; 2) current day averages; 3) week averages; 4) month averages; 5) five hour prediction quotas. When providing feedback to consumers (or suggesting usage), Watt-I-See queries the database for the updated production data, to display through the vortices, and queries the database for a feedback value (between 1 red, and 5 green). The algorithm first compares if the current week is a good "greener" week within the current month. Then, the algorithm compares if "today" is a "good day" within the current week (last 7 days), adding or removing weight. Finally, it compares the current production data to the five-hour prediction data and attributes an even larger weight. These weights may influence the color of the socket positively (green) or negatively (red). The value (already weighted) is finally compared to the overall three-year production averages, where minimums, maximums, averages and standard deviations were calculated to define the five feedback regions (see Figure 2). An application was built in Processing in order to interface the Arduino and the web services allowing for additional interaction, such as choosing specific weather conditions and viewing real production data for those conditions and interaction with the exercise bicycle

5.2 Microgeneration

The microgeneration step was performed through a repurposed exercise bike. A stepper motor was attached along with a rectifier circuit (converts AC to DC current) and voltage divider to limited voltage to 5V (input to an Arduino microprocessor) - which is responsible for calculating the electricity generated. An android tablet placed on the handlebars displays the progress. Additionally a digitally addressable (60) LED provides interaction feedback, such as: 1) standby status; 2) production feedback with a flow of energy effect and simultaneous progress bar; 3) goal attained; 4) regress/reset.

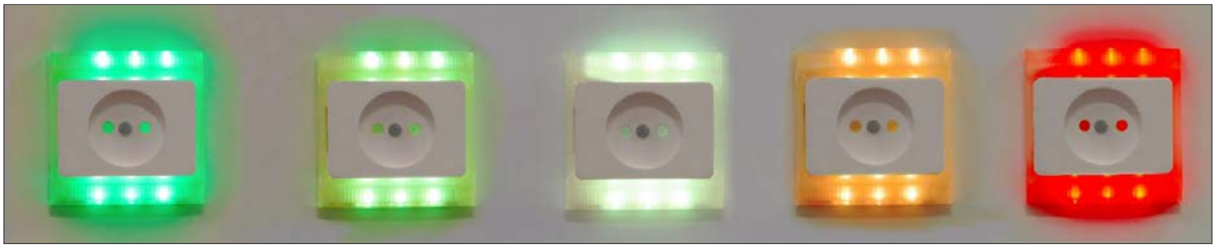

Figure 2: The power socket's five renewable energy feedback levels, from green (over 53% renewable) to red (less than 9%)

EVALUATION

We used a mixed method of surveys, observations after free exploration of the installation and semi-structured interviews at the end of the evaluation sessions. The study started by surveying electricity consumers in Madeira, then a subset of the respondents was selected to continue the study and interacting with WISE.

5.3 Electricity consumers survey

The study started with a questionnaire with 57 electricity consumers, 35 male and 22 female, with an average age of 29 (SD=8). Participants were recruited through social networks and word-of-mouth. They were asked to complete an online survey that assessed individuals pro environmentalism, through the New Ecological Paradigm scale (NEP[1]), and measured individuals' electricity production literacy.

Apart from the standard 15 questions of the NEP, the survey contained six multiple-choice questions regarding the local production of electricity, two multiple-choice questions relating to individual behaviors towards electricity consumption, and four questions where consumers were specifically asked to list and rank the local energy production techniques used. In the analysis of the questionnaire, we considered three sets of possible answers: correct; incorrect; and answers that only missed by one choice (only missing one production quota position incorrectly still represents a high level energy literacy).

5.4 Sub set selection

Ten responders of the survey were selected to undertake the remainder of the study and interact physically with Watt-I-See. Each participant interacted with WISE individually for the duration of approximately 50 minutes. The study included free interaction with WISE, a 14 question semi-structured interview recorded through the researcher laptop and a 20 question (five-point Likert scale) survey at the end. The study ran under the supervision of two researchers: an interviewer and a note taker. Audio of the interviews was recorded. The selection of this subsample was based on a set of factors. For once the availability of participants was crucial, additionally it was also preferable to gather a balanced of participants in relation to their gender. The practicality of the study itself also constrained the amount of participants we could recruit since each session would last approximately 2 hours.

5.4.1 Feedback from Real Time Power Generation Data

The study kickoff involved the microgeneration task in which participants had to pedal on an exercise bicycle and generate 200 watts (cumulative). A tablet installed on the bicycle displayed the amount of generated energy while a one meter 60 LED strip displayed the produced energy as a progress bar. Once the progress bar (LED strip) was fully lit, Watt-I-See powered up. Upon completion, the tablet presented participants with five (three multiple answers) questions relating to microgeneration and everyday consumption habits in an attempt to contextualize different device/appliance consumption characteristics to physical effort, e.g., "For how long do you think you would need to pedal to charge your phone" versus "How many kWh power supply is needed to charge you phone".

5.4.2 Interaction with WISE

The next interaction step led participants to view the current energy production for the island's electrical grid followed by the third step of the interaction: or "day building" procedure. This experiment was designed to allow participants to build knowledge on the combined effects of renewables, distributed production and the balance of grid demand and supply. Participants were presented with four sets of three cards that depicted several weather conditions in normative terms such as, "sunny", "partially sunny", "breeze", "very windy", etc., and a set of six cards relating six different time periods (e.g. breakfast, work hours) (Figure 3). Participants could then combine the cards freely. Once a combination was created, WISE would query the database containing one and half years of historical meteorological data and four years of electricity production data, selecting a day that best fitted the archetypical day. Watt-I-See then displayed the real production quotas for a day that matched such conditions.

5.4.3 Post study evaluation

In order to assess the impact of the interaction with the Watt-I-See installation, a follow up questionnaire was sent to the participants eight days after the on site evaluation. The questionnaire included eight questions that were present in the initial survey, which allowed to compare participants' initials conceptions and awareness before and after exposure to the WISE installation, as well as three questions pertaining to renewable energy awareness within daily routines.

Figure 3: Cards used to manipulate the variables during the evaluation.

[1] http://www.pearweb.org/atis/tools/52

6. RESULTS

The average scores for the NEP were, on scale from 1-Very pro-Environmental to 5-Not pro-environmental, 2.16 with a (SD=2.17) - which tended to be more on the pro-environmental spectrum. Respondents averaged, on a scale from 1 to 5 (1 being Strongly Agree and 5 Strongly Disagree), low scores pertaining to energy production: scored 1.2 (SD=0.6) on the existence of different techniques to produce electricity and a score of 1.3 (SD=0.7) on the impact different production techniques have a different on the environment. When queried on the awareness of the origin of their electricity at home respondents scored 2.1 (SD=1.1). Regarding the enumeration production techniques 23% of the answers were correct, 35% missed by one and 42% missed by more than 2. In the task of ranking production sources in terms of presence in the grid, 6% of the answers were correct, 38% missed by 1 source and 56% missed by more than one. More than 98% of the respondents were not able to correctly order the sources by cost for the region. Regarding which sources have the largest impact on the environment correct answers were also low (6% of the answers were ordered the sources correctly), while 78% of the answerer were capable of identifying thermal sources as the largest pollutant.

6.1 Watt-I-See Energy Production Feedback

Ten of the 57 individuals that undertook the pro-environmentalism survey were selected to perform a study about the relationship between consumers and their energy sources, 5 male, 5 female, average NEP classification of 2, ages between 26 and 37 (31 average), this sample included students, professors, salespersons and programmers. Participants interacted with WISE then undertook a semi-structured interview and then responded to a questionnaire.

6.2 Energy Consumption Misconceptions

Five multiple choice questions pertaining to everyday household consumption routines were displayed on the tablet and presented to the participants after they generated the 200 watts (cumulative) goal on the modified exercise bike. Forty percent of respondents' underestimated household's consumption routines and 28% over estimated. The questions answered most correctly were: "For how long do you think you would need to pedal to charge your phone" (50%) and "How many people pedaling would be needed to light an incandescent light bulb" (50%). The questions answers least correctly were: "How many people pedaling would be needed to power your kettle" (10%) and "How many people pedaling are needed to light an economic light bulb" (20%).

Table 1. Comparison of consumer energy production literacy

Questions	Before	After
There are different ways of producing electricity for consumer use	1.1	1
Different production techniques have different levels of impact on the environment	1.1	1
I'm concerned about the environmental cost of the electricity I consume	1.7	1.4
I'm aware where the electricity I consume comes from (how it was produced)	2.2	2.4

6.3 Real Time Energy Production Feedback

Prior to visualizing the real time production data, participants were asked to recall the current weather conditions and described them to the interviewer. The results pertaining to their expectation of the current quotas for each individual production sources, 8/10 participants expected solar power production to be higher. Comments referenced how the island has a lot of solar panels and how on average it's a sunny place. However, 2/10 expected solar power to be lower than displayed. A participant commented on how he does not see a lot of solar panels and compares it to a source he sees most, the wind turbines. Six participants expected wind power to be higher, again comments based on visual awareness - and relate production directly to the high number of wind turbines. Overall, for some sources such as hydroelectric, participants commented on know very little they know about it, and how it is less common to see a hydroelectric station. As one user put it, hydroelectric power might not be related to the "now", but heavily influenced by passed weather conditions such as, if has been raining for the past days. In conclusion, during the interview 5/10 participants expected a much higher production of renewable energy.

6.4 Building Renewable Energy Awareness

The card query prepared for the evaluation study was instrumental in order to foster discussion and uncover misconceptions about energy production. The discussion was captured during the query and in the subsequent semi structured interviews. Results are summarized and described below. The majority (6/8) of participants referred to the "Rainy day" card combination as the most memorable/interesting. Participants commented on how they did not expect, or though it was not possible, to produce so much energy from hydroelectric stations. A participant found "clear summers night (no wind)" as the most interesting, commenting on his unawareness that during those pleasurable nights the grid could be up powered up by 99% of thermoelectric energy. Overall, 9/10 participants felt confident that they could estimate the availability of renewables.

6.5 Feedback Immediacy

Participants valued the power socket for its feedback immediacy and 6/9 answered that if they could have only one WISE feature it would be the power socket.

Participants noted the benefit of the power socket due to its location at the point-of-interaction, where the consumption activity is undergoing. However, 7/10 participants commented on the benefits of a similar interface to WISE on mobile devices due to their ubiquitous presence in one's daily activities and commodity. A Participant mentioned a similar interface to WISE to be used on the phone, with bars describing disaggregated energy quotas and a similar function to the power socket feedback light.

6.6 Curiosity as a motivator

All participants agreed Watt-I-See was useful while six mentioned how curiosity and interest were primary motivation drivers. Four participants mention how the power socket gives an idea of the effort that is behind providing us with energy. Seven participants commented how Watt-I-See is informative, helps understand one's impact and aids in knowing that one is consuming. One participant related the exposure provided by Watt-I-See to recycling, both are hidden information and how until you engage in it you are unaware. Another participant displayed curiosity on an energy production projection with a 5 or 12 hour forecast and how it could help him decide whether to consume energy now or wait a couple of hours.

6.7 Follow up questionnaire

Eight days after contact with Watt-I-See participants were asked to fill a survey about their perception of the islands electricity production. Eight of the questions present in this post questionnaire were also included in the original questionnaire, which allows the comparison of individuals' perceptions before and after exposure to the Watt-I-See installation. Table 1, presents the results from the 10 participants that tested the WISE installation answered the first 5 questions before and after (answers ranked from 1 - strongly agree to 5 - strongly disagree).

During the follow up survey participants tended to improve their answers towards more pro-environmental. In listing the energy production sources the number of correct answers doubles (from 3 to 6). Improvements were also evident during the rank the sources, where before interacting with the Watt-I-See two participants ordered the sources correctly one missed by one source and seven order them incorrectly while in the post questionnaire only one ordered the sources incorrectly, six missed by one, and three participants ordered the sources correctly. At the end of this interaction participants were asked if they thought about the electricity production in the past week. Seven of the ten participants answered yes and were able to recall the weather conditions for that particular day, describe the activity undertaken, and estimate (in relative terms, i.e., a is higher than b) the electricity quotas for those particular conditions.

7. DISCUSSION

7.1 Energy Literacy and Awareness

Results from the New Ecological Paradigm survey point out to consumers' awareness about the sources of energy, the different generation techniques and natural resources. However, during the study a majority of participants overestimate the impact of some renewable sources such as solar energy and widely underestimate the presence of hydroelectric and wind energy in the grid. Energy awareness, especially pertaining to renewable sources, seemed to have an almost direct relation to participant exposure to the mechanisms used to produce them. As p3 commented, "*I though the sun [solar energy] would be stronger [higher quota]…the island has a lot of solar panels…and a lot of sun (…)*". Similarly, p6 commented for wind power, "*we could have also a bit more Eolic [higher quota for wind power] since we have so many [wind turbines] is could be put to better use.*" For less "visible" renewable source productions such as hydroelectric consumers were mainly unaware of its impact in the grid and were especially surprised selecting rainy days as the most memorable and interesting energy production archetypical day they constructed. Overall, 9/10 participants felt confident they could estimate the availability of renewables based on time of day, season and weather conditions.

The follow up survey, performed 8 to 10 days after the short exposure to Watt-I-See, found improved energy awareness results. Respondents were more aware of the source of their electricity and showed improved knowledge regarding how local electricity is produced and which sources are present in the grid. Seven of the ten participants throughout the week thought specifically about renewable energy and were able to recall the weather conditions for that particular day, describe the activity undertaken, and estimate the electricity quotas for those particular conditions. Again, rainy and windy weather conditions triggered their recall of renewable energy, linking back to their experience during the Watt-I-See study and how it was one of the most memorable/interesting conditions.

The microgeneration procedure found a general lack of knowledge on the efforts needed for producing the electricity for domestic consumption. Forty percent of all answers pertaining everyday consumption activities were underestimates and 28% were overestimates. Low power longer usage appliances and devices seemed easier to understand and produced more correct answers, while high power appliances such as kettles yielded the most number of incorrect assumptions. It was clear that the notion of electrical power (watt hour) was complicated to grasp. The majority of participants reckoned that they could power the kettle with the microgeneration bicycle, resorting to more effort and longer durations, however, it is not possible to power an 1800W kettle through the bicycle.

7.2 Exploring Materializing Energy through Movement

Watt-I-See was defined as realistic representation of energy (p5, p9 and p10). Movement showed a significant effect on the engagement of participants. As participant p3 explained "*…I like the colors [of the vortices], I like the fact that it is a whirlwind because it has to do with energy something always in movement, being produced (…) people need to know that it is energy and that energy manifests itself in many ways…it is something in movement or puts in movement.*" As a result, the simplistic representation of the energy production quotas thought the size of the colored vortex allowed for an attractive, understandable, almost mesmerizing effect, that was suggested to be faster to check and more intuitive. A stronger impact at times was noted. Participants felt somewhat worried when viewing the fossil vortex at its maximum scale how aggressive it looked "*that looks worrying*" the comments of a female viewer when she realized that there was approximately 85% of thermal (diesel production) energy being produced. Others commented on the difference between fossil and renewables as depressive, something that needed to be dealt with.

7.3 The Importance of Feedback Immediacy

One of the preferred aspects of Watt-I-See was feedback immediacy. Providing immediate feedback was found as a twofold design concern:

- Immediacy of feedback: Easy to understand, "at a glance" information. The glass tubes and vortices provide just enough information to inform a decision.
- Immediacy of interaction: As close to the point of consumption. The feedback power socket is as close to the point-of-interaction as possible, however, possible at times not the most visible due to the location of power socket. On this point, five participants commented on mobiles phones as an "easy to reach interface" that is always present (or near) consumers.

While a twofold design issue, p2 commented on "*it could be interesting, if it was possible on the phone possible on a widget with the production levels of each energy, using symbols and bars to show the relation among them,.*" Another confirmation that sometimes less information is more. It seems that a simple relation between different energy sources and its quotas provide enough renewable information for the average consumer's curiosity.

7.4 Motives for Energy Reduction and Resource Demand

While not designed as a core aspect of the study, throughout the evaluation of Watt-I-See participants often began to reflect on their daily household energy consumption routines. We identified three key issues:

Participants commented on how they already strive to minimize energy consumption and waste at home. Participants rhetorically asked what could one do with this information and what else could one do at home to help or change. There are things cannot be changed just because the plug is red. Participant p1 summarizes the lack of extrinsic motivators further referring to a pro environmental motivator as a solution: "*We are paying the same only if it were to further protect the planet. Probably after some time I could understand my routines and plan some changes*".

Participants felt somewhat responsible about raising the quota of renewable energy as p7 comments "*my problem is…that I feel like I cannot affect the display, this is, I cannot make it rain*". This participant comments of how there is nothing she can do to affect the visualization, i.e., it's not in her control to generate more power from wind, solar or water, she cannot directly influence the data like if it were consumption data. However, for two participants there could be other solutions such as installing solar panels or saving energy through the use of more natural light.

The fact is that some daily household activities cannot be shifted; they will happen regardless of the energy required. However, some activities were mentioned as more flexible, such as washing machines and ironing. Yet, these activities are still affected by other factors, for instance weather conditions to dry cloths. Withal, sporadic consumption routines were mentioned to be more able for shifting than daily routines.

Extrinsic motivators such as monetary rewards from consumption reduction are not expressed through the WISE feedback. This way the study seemed to invoke more intrinsic motivators from the participants such as feeling worried or depressed when viewing the fossil vortex at its maximum scale. Participant p6 further reinforces the idea: "*I would probably have only the first tube because it is possible to know what we are doing wrong…while the others are good I do not need to worry about reducing them.*"

7.5 Practical Implications

The analysis in eco-feedback studies typically examines the reduction effect in energy consumption, down to a single figure expressed as a percentage of energy reduction. It became evident that several of the established guidelines for eco-feedback are also applicable for production feedback.

Immediacy was the most important feature for consumers pertaining to energy production and possible resource demand activities. Consumers found the power socket as a useful feedback feature allowing for real-time, immediate and near the point of decision interaction. The impact of viewing real time production values for the first time was a striking eye opener. For some, to see how much fossil fuel was being produced (and subsequently consumed) was a wakeup call.

However, consumers still display high levels of misconception in terms of effort in producing energy for different appliances or devices (high power compared to low power). Consumer exposure to production information (and the convergence of factors leading to up to production) led to increased levels of awareness, measures 8-10 days after the single exposure to WISE. More so, consumers reflected on certain activities on the house that could be rescheduled to maximize their use, however, indicating others impossible to shift. This observation is in line with work in HCI [4] and peak demand field, thus suggests an opportunity for technology to aid consumers in making decisions, either by helping the planning of activities to maximize renewables usage, or going a step further automating certain home activities.

The study found further evidence that consumer gratification can be a strong motivator, as observed by Pierce and Paulos [6]. This should be taken into account in the future Smart Grid services, where, for example, consumers can choose between two tariffs or providers solely based on the source of electricity.

8. CONCLUSIONS

Electricity is the cornerstone of modern society. However, in this study we can hypothesize that consumers are still poorly informed and unaware of where their energy comes from, the costs and efforts in producing it and the dynamics of household consumption.

In addition, we argue that HCI contributions in the domain of energy awareness and sustainable energy consumption, in particular, conventional eco-feedback, are detached from the wider political and economic contexts in which the utility business is evolving. The various disruptive challenges facing public utilities have different implications, but they all create adverse impacts on revenues, investor returns and ultimately energy price and usage and hence environmental impact.

The Watt-I-See installation is a first attempt to physically represent grid production sources and quotas with an overall feedback mechanism. As such it was generally well accepted by our sample of users. The study showed evidence about increased awareness and stimulated a dialogue about the different sources of energy, their relationship with weather and other context conditions and finally the consumption patterns in households. Here we attempt to provide design insights for creating eco-feedback displays that strike a complex balance between the awareness of the realities and complexities of user lifestyles on one hand, and a desire to influence their use and consumption behaviors and practices on the other.

The strong connection between movement and electricity production and easily accessible information increased consumer energy literacy and awareness towards the production of renewables. This led to consumers reflecting on their energy consumption routines and questioning possible changes to increase renewable energy consumption efficiency. Our study shows potential in terms of future scenarios for eco-feedback in distributed energy micro-generation and other inevitable disruptive changes due to a convergence of factors, including economic downturn, falling costs of energy resources and public policy incentivizing the adoption of new energy technologies.

In sum, this paper provides evidence of the benefits of providing consumers with information from where their energy is coming from and in turn how "green" the energy is. Results show an increase in energy literacy and awareness as well as identify high consumer preference towards simple, representative interfaces and ubiquitous immediate feedback revealing intrinsic motivations within consumers.

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