A PARTICIPATORY APPROACH FOR CONSTRUCTING ENERGY RESILIENCY

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by
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Abstract

Energy production is typically a regional enterprise, with the majority of energy produced far from the main areas of demand causing tremendous problems in terms of lack of resiliency and flexibility in handling the ever-changing demands at the users' end. On the other hand, microgrids as local energy infrastructures have offered resiliency by allowing neighborhoods to exercise greater control over the production of the energy they consume. As a system, the flexibility and resiliency that embodies the microgrid has to reside across all of its components and functions. Although microgrids integrate various techniques of automation, optimization, pervasive control and computation in its system, but equally important is addressing the human factors. Users, as an undeniable part of microgrid’s operational system, are thus required to act with respect to being resilient and flexible. By making all the information of every grid component accessible to the demand side via energy metering systems and feedback loops, microgrids play an important role in filling the gap of energy illiteracy, increasing users' awareness and understanding about how energy is consumed in their homes and thus helping them to make informed energy consumption decisions.

Research on delivering high quality energy-related information on users' activities and consumption rates signify the effectiveness of such information for inspiring and motivating users to change their behavior towards more energy saving ones but however the issue of making these behavior changes durable and integrated to one’s lifestyle, is still remaining a topic for further investigation. Accordingly this research
attempts to encourage new ways of thinking about users’ engagement in the energy management system of their community based microgrid by combining computational means of feedback delivery with an incentive program which requires users’ self-organized collaboration and participation in the shared-energy community endeavor.
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Chapter 1 | Introduction

1-1. Research Area

1-1-1. The Smart Grid
As we approach the uncertain world in transformation with unpredictable and sudden changes impacting us in shape of uncharted climate change, resource depletion, economic crisis and other events, we face the fact that our designed urban infrastructure, buildings, economics and even ways of living are not resilient enough to tolerate these changes. Resiliency as “the capacity to buffer change” increases the ability to cope with surprise, by adapting or absorbing large shocks without changing in fundamental ways (Folke, et al.).

One of the main dilemmas of the 21st century is the energy crisis which is more incurving in the existing, static electrical power grid areas. The existing grid was designed and engineered to generate electricity by localized power generators built around communities with clear boundaries between its subsystems (generation, transmission and distribution) (Villarreal, Erickson, & Zafar, 2014). The arising issue is embedded in the one-way flow of delivering power from central generators to a large number of users, handling only very stable outputs, without really considering the ever changing demands and fluctuations at the users’ side. This inability has led to serious problems in terms of resiliency and flexibility, by not being sufficient enough to follow up the continuous changes of our dynamic environment and lack of engagement with users (Kang, Park, Oh, Gu Noh, & Park, 2014). Along
these lines, challenges as unprecedented rise in electrical power in the
demand side and outdated investments in the power infrastructure,
coupled with network congestions and atypical power flows across the
distribution network, threatened to overwhelm the system and cause
catastrophic blackouts (Amin & Wollenberg, 2005 - Farhangi, 2010). The
need for resolving the power grid issues attracted a national attention
by an announcement made by the IEEE Power Engineering Society in
the 90’s (Werbos, 2011). In late 20th century and early 21st, the power
industry recognized some mundane needs for upgrading the existing
grid by placing a layer of computation over the infrastructure in order
to solve the problem of lack of resiliency through pervasive control and
monitoring, data management, and communications among its
different components (Folke, et al. - Farhangi, 2010). These basic
ingredients accelerated utilities to deploy technologies as energy
metering and feedback system, simple sensors and communication
networks ascribed at the distribution operator scale and power
operation scale (Werbos, 2011).

The context of these new technologies advanced the outdated
electrical grid to a “smarter” grid capable of substituting energy and
information among its components. The introduced “Smart Grid” is not
known as a replacement of the existing electrical grid but a
complement to it, coexisting with it, and adding to its functionalities and
capacities by deploying a collection of innovative technologies as
sensors, metering and feedback systems (Farhangi, 2010). These
technologies allow the fully integrated networking and
communications of all generation, transmission and distribution
subsystems and thus support the needs of its stakeholders by efficient
exchange of data, services and transactions (Farhangi, 2010).

1-1-2. Microgrids
Smart grids could be viewed as an ad-hoc integration of small groups
of interconnected loads and distributed command-and-control energy
resources (Villareal, Erickson, & Zafar, 2014). In this view, loads are
known as any device or mechanical system at the users’ end that
require electricity for operation and are controlled via customer’s
demand. Distributed energy resources (DERs) refer to decentralized
energy generators which are typically constituted of renewable energy
resources (including but not limited to solar panels, wind turbines, fuel
cells, biomass and etc.) and distributed energy storage systems (DESS)
which are unique to each microgrid costumed by specific spatial and
climatic constraints, utility regulations and incentives, and customer’s
demand (Sherman, 2012). These small blocks of DERs delivering energy
to a network of users in a spatially defined area with clearly outlined
electrical boundaries, are known as microgrids (Figure 1).
Figure 1- Illustrations representing the grids. From left to right: Conventional Grid, Smart Grid (which is basically the conventional grid with a layer of computation), Microgrid (divisions of the smart grid with clear electrical boundaries).

While energy production is typically a regional enterprise with the majority of energy produced far from the main areas of demand, microgrids, as local community-scale energy infrastructures, allow neighborhoods to exercise greater control over energy production by generating energy close to the point of its consumption. Moreover, microgrids technically support the integration of renewable energy resources, enabling the development of low-carbon energy technologies, improving energy reliability and security, and consequently lowering energy costs due to reducing energy loss (Sherman, 2012). Equally important is addressing human factors. By making all the information of every grid component accessible to the demand side, microgrids play an important role in helping the end-user to make informed energy consumption decisions. Microgrid’s two-way communications technology, set at ease the optimal decision making relative to the market, so as to reduce the consumption rate during the most expensive peak hours (Ipakchi & Albuyeh, 2009 - Kang, Park, Oh, Gw Noh, & Park, 2014).

Microgrids are not necessarily owned or run by a utility company, they can be built and operated by a community neighborhood, university, hospital or any other entity that has legal authority over power infrastructure. As microgrids provide value to energy consumers, energy utilities and communities at large, these stakeholders benefit in different ways from the shared energy infrastructure.

**Benefits and Values of Microgrids**

The IEEE Power Engineering Society calls the benefits of microgrids as being economic, environmental-friendly, resilient and reliable, automated and controllable (Paglia, 2011).

Economic Value: Utica College and St. Luke’s Hospital and Nursing Home in Burstone, New York have cut their utility consumption costs by
15%-20% according to Sherman (Sherman, 2012). This economic value is due to microgrid’s unique feature in supplying energy by generating it close to the point of consumption which results in reducing distribution and transmission energy loss and as a consequence, financially benefits cities towards a larger economic development and consumers by saving money on energy consumption.

Resiliency and Reliability: Microgrids simultaneously utilize a variety of energy resources (mostly renewables), providing security, reliability and resiliency under unexpected environmental conditions of resource depletion (e.g. earthquake, hurricane, etc.) or a rise on energy expenses. On the other hand, if the consumption rate of a microgrid community is higher than its harvesting rate, the infrastructure could retreat its “island” mode and reconnect to the smart grid, or other microgrids for further supplementations.

![Figure 2: From left to right, microgrids could operate in island mode, or for further supplementations they could connect to other microgrids or to the larger smart grid.](image)

In Sendai, Japan, a university zone got upgraded to a microgrid between 2005 and 2008. Thus in 2011 after the earthquake and tsunami which were followed by a service loss, the engine generators of the microgrid supplied the teaching hospital of Tohuku Fukushima University, with both power and heat while other sectors had a two day blackout (Paglia, 2011 - Hatzargeorgiou, Asano, Iravani, & Marnay, 2007).

The state of Connecticut recently passed a legislation for allowing the establishment of a microgrid to support distributed energy generation for critical situations. After the two back-to-back storms in August and October 2011 which resulted in power outage for almost nine days, improving the emergency preparedness of the state became one of the main problems to solve in the state of Connecticut. The severe problems caused serious disruptions in the electric generation and transmission infrastructure causing high energy costs and congestion issues, and also a growing negative perception among residents about the reliability of the state’s electricity grid and disappointment with the actions of the two main utilities of Connecticut (Sherman, 2012).
Environmental: While uncertainties of intermittent renewable resources has challenging effects on the conventional grid, the microgrid energy management system can effectively control the unstable qualities of renewable generator outputs through the coordination of battery storage technologies and demand (Villarreal, Erickson, & Zafar, 2014). The deployment of a wide variety of renewable energy resources will remarkably decrease the use of fossil fuels and lead the cities towards cleaner technologies. Almost every microgrid’s demonstration project has benefited from equipping renewable technologies. A project at Fort Collins, CO belonging to Colorado State University features a 4 megawatt microgrid powered by PV solar, fuel cells and micro turbines. Another microgrid demonstration project created at the Santa Rita Jail in Alameda County, CA is also featuring PV solar, wind and fuel cell energy sources and large-scale battery storage (Marnay, 2010).

Automation and Control: By using advanced metering technologies, automated control systems, information and communication software, multiple DERs and loads are controlled by both the supply and demand side. On the supply side, these technologies allow a central operator to optimize the use of each of the DERs according to variety of environmental, financial and humanistic factors. On the customer’s side, the aggregation of advanced energy metering systems and feedback loops inform the users of their consumption rate and expenses, and accordingly help them acquire greater control over their energy-related consumption patterns (Sherman, 2012).

Within the context of these technologies and capabilities, microgrids offer resiliency in multiple ways (Farhangi, 2010):

• A microgrid is a “self-healing” system. It predicts looming failures and takes corrective action to avoid or mitigate system problems.

• By being flexible, microgrid’s have the ability to operate in different modes: while connected to the smart grid and/or disconnected from the smart grid in an autonomous condition named “the island” mode. They could also connect to each other and create a collection of networked microgrids by the existing transmissions lines and distribution systems in order to back up each other in certain situations.

• The microgrid uses information technologies to continually optimize the use of its capital assets while minimizing operational and maintenance costs.

• It empowers consumers to interact with the energy management system by making the grid visible to them through metering systems. In this sense, users could adjust their energy use based on different conditions and reduce their energy costs.
1-2. What's Wrong?

As mentioned earlier, the embedded resilience and flexibility in the operation of microgrids has led to a substantial quality in tolerating the constant changes emerging in the electricity network area. The flexibility and resiliency that embodies the microgrid has to reside across all components and functions of the system (Farhangi, 2010). Microgrids integrate various techniques of automation, optimization, pervasive control and computation in its system, but equally important is addressing the human factors. Users, as an undeniable part of microgrid’s operational system, are thus required to act with respect to being resilient and flexible. Microgrids offer resiliency at the users’ end in the format of energy management by deploying advanced energy metering systems and feedback loops, giving users the ability to control their consumption pattern by making informed consumption decisions based on the energy pricing rates throughout the day.

Energy feedback technologies are based on the hypothesis that most people lack awareness and understanding about how their everyday behavior affects the environment and therefore limits the consumer’s capacity to decide on taking conservation actions (Froehlich, Findlater, & Landay, 2010 - Lutzenhiser, 1993). Research on delivering high quality energy-related information on users’ activities and consumption rates signify the effectiveness of such information for inspiring and motivating users to change their behavior towards more energy saving ones (Yu, Fung, Haghighat, Yoshino, & Morofsky, 2011) but however the issue of making these behavior changes durable and integrated to one’s lifestyle, is still remaining a topic for further investigation. Researchers’ analysis on human behavior in this context have shown that although displaying energy consumption information via visualizations is necessary and valuable in increasing awareness and helping consumers control their consumption, but is not enough in making long-lasting changes in behavior as it fails to account for broader psychological, social and cultural patterns of household energy use (Hargreaves, Nye, & Burgess, 2010).

As an example, an extensive qualitative field study done by Hargreaves and his fellow researchers in the UK have grounded this fact by studying how householders interact with feedback systems from different types of smart energy metering systems. The early assumption was that increasing feedback will increase awareness in household members and thus result in a change in behavior. After analyzing behavior and interviewing with the participants, their observations show that almost all participants and family members got excited about the devices in the first place and started to change their energy behavior towards conservation by adjusting their consumption based on the timing of the day and peak hours. People got obsessed with their gadgets and
monitoring devices when they first got it but after some time they just got used to it and their usage just fell off to almost nothing (Hargreaves, Nye, & Burgess, 2010).

A growing body of literature suggests that combining feedback delivery on consumption patterns with other strategies such as goal setting, incentive programs, economic penalties, etc., is a more effective way of nudging users towards more responsible energy consumption habits. (Costanzo, Archer, Aronson, & Pettigrew, 1986 - Fischer, 2008 - Froehlich, Findlater, & Landay, 2010 - Hargreaves, Nye, & Burgess, 2010). These studies have emphasized the complexities of human behavior and highlighted a body of environmental psychology literature offering techniques and inspiration on behavior change strategies to guide and/or complement persuasive energy feedback technologies (Lutzenhiser, 1993 - Hargreaves, Nye, & Burgess, 2010).

Building upon the reviewed literature, this paper recommends a shift in focus more on the community’s energy use rather than individual energy consumers as the key unit of analysis. The focus is not on directly educating users about their energy consumption, but rather on fostering cooperative and energy-saving dynamics by coupling energy feedback technologies and an incentive program which requires users’ self-organized collaboration and participation in sharing energy within their community’s microgrid.

Numerous studies have been looking at the effects of feedback delivery via different devices and interfaces on energy consumption to efficiently reduce a household’s energy use, but however, comparably little study has been done on effective interfaces. The interface system described in this research is proposed as a way to increase the possibility of a community microgrid to be energy responsive through its users. In this system the visualization of energy use through feedback devices, an aesthetically appealing method for inducing behavior change, is combined with game-like built-in incentives to motivate long term behavior modification. The system seeks to foster collaboration and participation among users, advancing a new view on energy consumption as a community endeavor. The “game” can provide targeted incentives for users of a microgrid to alter their consumption patterns and shape the use of shared-energy resources, resulting in new patterns of energy responsive collaboration and participation in the microgrid, linking resiliency to a community’s collective intelligence.
Chapter 2 | Background

In this section I’ll discuss why the mere use of energy monitoring systems and feedback technologies in microgrids are not enough in nudging the users towards greener habits. In this regard, I will study the effects of the 1970’s energy crisis on exposing the importance of conservation behavior as a discursive artifact seeking to “nudge” human behaviors towards energy saving ones. For nudging users towards changing behavior, it’s essential to understand the complexity of human behavior and the social-psychological aspects of conservation. Having this in mind, I’ll then explain various methods of promoting energy conservation and its evolution through time, ranging from providing mass information to users via pamphlets to nowadays smart metering feedback technologies which are highly used in the demand side energy management in microgrids. While in microgrids smart meters are deployed to encourage users to adopt conservation habits, researchers have observed that the effectiveness of these devices decays with time and use. Studying the reasoning behind this issue, I’ll discuss Froehlich’s research on the two disciplines involved in designing feedback technologies (Human-Computer Interaction (HCI) and Environmental Psychology) and how their miscommunication in research has led to this malfunction. For further notice, since there are multiple forms and manifestations of energy, I would like to clarify that the one discussed in my thesis is electricity.
2-1. Social-Psychological Aspects of Energy Conservation

Studying human’s social behavior in energy analysis has attracted great importance since the 1970’s energy crises were energy production and conservation became major public policy issues in the United States (Lutzenhiser, 1993). The Arab oil embargo in 1973 and the Iranian revolution in 1979 forced the US government to develop new energy resources and/or conserve domestic energy use. Researchers clearly state that although considerable effort was put on energy production and conservation technologies in that time, users’ conservation behaviors and actions played an even more critical role in sustaining the economic growth (Coltrane, Archer, & Aronson, 1986).

Figure 4 – These two image from the 1970’s show the scarcity of energy resources in United States (in this case in gas stations have ran out of gasoline).
Source: http://chiefwritingwolf.com/2012/03/page/22/

Figure 3 – A cartoon about the 1973 oil embargo by Gib Crockett from the old Washington Star. This is an image of an oil sheikh from the Middle East holding America’s energy needs hostage. Source: http://www.capitolreportnewmexico.com/2014/04/
The significance of conservation behavior grounded the fact that individual human behavior and social process should not be underestimated as it extensively “amplifies and dampens” the effects of technological innovations and energy efficiency improvements of buildings (Costanzo, Archer, Aronson, & Pettigrew, 1986 - Lutzenhiser, 1993 - Masoso & Grobler, 2009 - Froehlich, Findlater, & Landay, 2010 - Kim & Gerow, 2013). Lee Schipper, an international environmentalist, sharply calls attention to the social-psychological aspect of conservation with a sense of irony: “Those of us who call ourselves energy analysts have made a mistake...we have analyzed energy. We should’ve analyzed human behavior...” (Cherfas, 1991).

After the mid 1980’s while studies on the relation between users’ attitudes and conservation responses expanded, researchers explored a wide range of attitudinal foundations for conservation action and inactions considering complexities of human’s characteristics and positioning (Costanzo, Archer, Aronson, & Pettigrew, 1986 - Lutzenhiser, 1993 - Owens & Drifill, 2008). Attempts to promote conservation are necessarily based on implicit theories of persuasion, attitude change, and the decision-making process of individual energy users (Costanzo, Archer, Aronson, & Pettigrew, 1986). Based on the theory of Reasoned Action by Fishbein and Ajzen in 1975, human behaviors, attitudes, beliefs and intentions are the result of a dynamic balance between individual’s decision-making and social environmental forces (Fishbein & Ajzen, 1975). On the other hand, related literature demonstrate the fact that most conservation behaviors are due to the dominant conceptions of comfort and convenience (Costanzo, Archer, Aronson, & Pettigrew, 1986 - Farhar & Fitzpatrick, 1989 - Lutzenhiser, 1993). In this sense, while variety of personalities are shaped in different social and cultural backgrounds, people perceive household’s notions of comfort...
and coziness in various ways (Hargreaves, Nye, & Burgess, 2010). Aune perfectly illustrates how differently inhabitants express and experience these emotions mostly through heating and lighting. Her analysis of interviews and observations, assert that we cannot explain private energy use without understanding the diverse meanings of homes. While it’s clear that occupants ought to adjust their behavior to a good balance between energy savings and their own acceptable definition of comfortable life, it is essential to communicate with people’s image of home when trying to change their energy consumption patterns (Aune, 2007).

2-1-1. Strategies of Promoting Conservation Behavior

Mass Information and Human Behavior
Parallel to social-psychological aspects of energy conservation, Coltrane et al identified a number of effective parameters for planners and policymakers to consider while promoting conservation behavior, including giving consumers vivid and personal information (Coltrane, Archer, & Aronson, 1986). Bringing information to consumers is widely used to carry about pro-environmental behavior change. These information are used to increase awareness in the cost and energy efficiency of appliances, propose practical suggestions to users on energy saving strategies, and inform them about other users’ effort in the procedure of employing more efficient behaviors (Staats, Harland, & Wilke, 2004).

Applications of information delivery spans from providing formal written information such as labeling appliances about their energy consumption rates and costs (fig. 6) (Froehlich, Findlater, & Landay, 2010) till more “humanized” means such as face-to-face interactions, interventions, energy campaigns, social diffusions, community role models, home auditing and others (Fig. 7) (Coltrane, Archer, & Aronson, 1986 - Staats, Harland, & Wilke, 2004).

A review on the literature of these strategies gives us some advantageous suggestions on how to increase the quality and effectiveness of information provided. For instance, researchers suggest that informations are more effective when they contain a threat of loss rather than a promise of gain (Tversky & Kahneman, 1974). Another
important factor is the credibility of the source which the information is derived from. For example, a study has found that energy conservation pamphlets distributed by a state regulatory are more trustworthy for users than identical pamphlets believed to be distributed by the area’s electric utility company (Costanzo, Archer, Aronson, & Pettigrew, 1986).

Eventually after practicing these interactive, face-to-face strategies on groups of people, researchers started evaluating behavior change; but results still implied that the application of these strategies usually targeted a limited number of behaviors and had difficulties in achieving a durable change (Dwyer, Leeming, Cobern, Porter, & Jackson, 1993 - Al-Mumin, Khattab, & Sridhar, 2003 - Hargreaves, Nye, & Burgess, 2010). These findings demonstrate the fact that understanding why people engage in pro-environmental behavior is a complex task rooted in many disciplines including but not limited to education, sociology, psychology, and philosophy.

Lutzenhiser refers to this type of mass information which is provided prior to an act as the “antecedent strategy” and he argues that it is generally less effective than “consequent strategy” which is giving direct feedback information after an action has been performed (Lutzenhiser, 1993). However, although mass information is an important tool for creating awareness, for reasons discussed later in the section, they should not be the only component of an influential strategy.

Feedback Delivery through Time
Providing feedback on energy use has attracted tremendous attention as its techniques have proved to have positive effects on triggering conservation behavior (Froehlich, Findlater, & Landay, 2010). Although providing feedback serves as a good technique for initiating behavior change, later household analyses demonstrate its lack of success in merging the affected changes into one’s lifestyle. It’s worth noting that despite the problem of durability of changed behavior, no studies have
actually undermined the role of feedback delivery in the process of provoking conservation behavior in users.

Feeding consumers with feedback on energy engages three basic methods according to Costanzo et al.: 1- Installing devices that monitor energy use and give feedback as a digital visual record or display (e.g. dollars per day), 2- providing consumers with daily or weekly readings of electric or gas meters, 3- and presenting detailed information on monthly bills (Costanzo, Archer, Aronson, & Pettigrew, 1986). Utility bills are among the earliest and simplest methods of transmitting feedback, but they ordinarily provide information about the number of energy units consumed and the total amount due with no information on how much various energy loads are costing to operate (Farhar & Fitzpatrick, 1989). In early days with receiving utility bills as frequent as one every each month, even if consumers attempted to conserve energy, they had little or no feedback on how well they did in a breakdown.

With an increase in energy conservation concerns and parallel advances in human-computer interaction (HCI) technologies and ubiquitous computing, and also the availability of cheap sensors and wi-fi networks, feedback delivery developed in a more computerized way in the shape of energy metering systems. HCI approaches feedback technologies through sensory devices, information visualization, and novel interfaces and interactions. These technologies automatically sense human activities and then feed the related information back through computerized means such as ambient displays and online visualizations (Froehlich, Findlater, & Landay, 2010).

Fischer conducted an extensive literature review on publications from 1987 onward exploring the effects of feedback (specified solely to meters, displays and utility bills) on energy consumption and consumer’s reactions towards it. Based on the reviewed projects she explored different reasons for feedback delivery in different contexts. Her findings show that almost 90% of the projects were aiming to stimulate energy conservation behavior, while the rest were merely focused on raising consumer’s consciousness. Moreover, projects using computerized methods for delivering feedback have reported to be more effective in provoking conservation behavior than earlier mentioned traditional methods. Their effectiveness rely on some specific features such as interactivity, providing multiple feedback options (comparisons, energy saving tips and etc.), appliance detailed breakdown of energy use, comparison between different uses at different time of the day among others (Fischer, 2008).
Figure 8 - Two different energy metering systems in terms of display. The right one shows the kWh of energy consumption and the one on the left shows the cost information per day and per hour.
Source: http://www.nabllab.com/testing-calibration-services.html

Figure 9 - Example of a utility (here electricity) bill. The information indicates details of energy consumption, consumption summary, details of charges, total charge, payment and billing information, customer services and etc.
The newest generation of energy measurement systems often referred to as “smart meters”, are uniquely designed to provide real-time data on energy usage in buildings. One of the main uses of smart meters is for managing energy consumption at the demand side of microgrids. Houses within a microgrid are equipped with smart metering systems which incorporate a communication network that connects the key electrical appliances and services and allows them to be remotely controlled, monitored and accessed in terms of energy usage (Blumendorf, 2013).

![Figure 10 - An example of a user interactive smart metering system providing real-time data on energy consumption](http://michellekaufmann.com/2010/03/smart-dashboard/)

The purpose behind the concept of interacting and connected appliances, besides offering automation and control, is to nudge users towards conservation behaviors (Froehlich, Findlater, & Landay, 2010 - Werbos, 2011). However, later studies examining the durability of the resulted behavior change report no evidence of metering systems and feedback technologies having a more long-term effect than utility bills or one-time reports (Farhar & Fitzpatrick, 1989). Interviews with groups of people which have been using different variations of these technologies for a reasonable amount of time in their homes report that these displays provoked a great interest when first acquired but after some time users got used to it and their usage just fell off to almost nothing (Hargreaves, Nye, & Burgess, 2010).

### 2-2. Current Approach

Over the past fifty years, studying environmental discourses in human-computer interaction (HCI) has been a popular subject for research as well as studies on motivations for environmentally positive behavior.
within the field of environmental psychology (Goodman, 2009). In this sense, the potential of feedback technologies in promoting durable behavior change has been approached differently by researchers. Some have approached it as a technological deficiency and some from the psychological point of view.

Environmental psychologists argue that data can persuade people but it doesn’t inspire them to act. This means in the context of provoking conservation behavior and nudging users towards greener habits, giving feedback on consumption behavior is not enough in promoting durable behavior change and is more effective when it is combined with other strategies like goal settings, incentive programs, economic penalties and etc. (Costanzo, Archer, Aronson, & Pettigrew, 1986 - Fischer, 2008 - Froehlich, Findlater, & Landay, 2010 - Hargreaves, Nye, & Burgess, 2010)

On the other hand, HCI researchers describe that users believe that these computerized devices are making life more complex and frustrating rather than easier and more relaxing and they are wary of the aesthetics, financial, and cognitive challenges that come with new technologies. Studies in this category strongly recommend that the exploited technologies should not undermine people in their own home, and they need to be designed in a way to require human effort in ways to keep life mentally and physically challenging (Davidoff, Kyung Lee, Yiu, Zimmerman, & Dey, 2006). Requiring users to adapt to technology is very likely to fail quickly (Blumendorf, 2013)

One of the best references on the design of feedback delivery technologies or smart meters is a research conducted by Froehlich et al. The uniqueness of this research is that the authors look at the design of feedback technologies as the intersection of the two fields of environmental psychology and human-computer interaction (HCI). After reviewing 139 related literature in HCI and 82 in environmental psychology, the authors identified that less than half of the HCI papers referred back to psychology literature and almost no study in environmental psychology referenced HCI. Findings resulted in this paper demonstrate two distinct approaches addressing the design and evaluation of feedback technologies which in consequence represent a profound gap between HCI and environmental psychology. Froehlich et al finds this divergence as the main reasoning behind the failure of feedback technologies in promoting long-lasting behavior change. While the primary motivation of designing feedback technologies in both disciplines is to nudge users towards energy conservation behaviors, studies in environmental psychology have largely focused on the effects of feedback intervention itself while HCI focuses on iterations of feedback designs and the production of the artifact with an emphasis on understandability, usability and aesthetics
(Froehlich, Findlater, & Landay, 2010). In order to resolve the issue of behavior change in metering systems and feedback technologies, the authors strongly suggest that the two disciplines of HCI and environmental psychology learn from each other; feedback researchers and practitioners in HCI base their designs on the fundamental principles of behavior studies across the life span explored by environmental psychologists, and then apply their unique methodologies and approaches found in HCI to advance the design of feedback technologies. When designing eco-feedback technology it is important to consider not just which motivation techniques to employ but what behaviors, in particular, a design is hoping to motivate (Froehlich, Findlater, & Landay, 2010).
Chapter 3 | Hypothesis

As mentioned earlier, one of the main features of microgrids is to provide resiliency and flexibility under unexpected conditions and tolerate constant changes emerging in the electricity network area. Having this in mind, microgrids constitute of different components and functions (in both the supply and demand side) and as a system in order to operate with resiliency, Hassan Farhangi argues that this feature has to reside across all of its components (Farhangi, 2010). Microgrids attempt to offer resiliency at the users’ end, as an undeniable component of the system, by the mere display of their energy consumption feedback information, while researchers’ investigations have not credited its success in promoting resilient ways of living. It is assumed that displaying energy feedback information will result in increasing users’ knowledge on consumption which consequently leads to managing energy usage by adopting long lasting conservation behaviors, but studies have observed a nonlinear process of adopting greener habits while feedback delivery alone is not going to make people change their consumption behaviors. In this regard, studies have emphasized on considering the complexities of human behavior by centering attention on environmental psychology literature for techniques and inspiration on pro-environmental behaviors and behavior change strategies in addition to involving persuasive technological interventions as energy feedback technologies (Lutzenhiser, 1993 - Hargreaves, Nye, & Burgess, 2010). While tremendous studies have addressed this issue in different ways, researchers suggest that feedback delivery on consumption pattern is

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1 For more information see the section on “Benefits and Values of Microgrids”
more effective when it is combined with other strategies such as goal setting, incentive programs, economic penalties and etc. while considering the intricacies of human behavior (Costanzo, Archer, Aronson, & Pettigrew, 1986) (Fischer, 2008) (Froehlich, Findlater, & Landay, 2010) (Hargreaves, Nye, & Burgess, 2010).

But adding to this strategy, I’m hypothesizing that if in a microgrid as a community-based shared-energy infrastructure, energy feedback information is combined with a successful incentive program requiring the users’ self-organized collaboration and participation derived from themselves, then they will get engaged in the energy management system of their microgrid and this will result in more efficient, resilient and sustainable life styles making sustainable living acceptable and desirable for users.
3-1. Precedents

3-1-1. Residential Microgrid of Am Steinweg in Stutensee, Germany

One of the first pilot projects on microgrids with renewable energy in a residential area was carried out in the neighborhood of Am Steinweg in Stutensee in Germany. This test system is built to test the work carried under the DISPOWER project since the beginning of 2005 (Lidula & Rajapakse, 2011). The objectives of this test is to validate the DISPOWER approach for integrating distributed energy generation with a large share of renewable energies into electricity grids (Jiménez, 2007). The total 101 apartments and 400 inhabitants which are linked to this microgrid operate on combined heat and power (CHP), different PV installations, storage batteries and a bi-directional inverter (Lidula & Rajapakse, 2011).

The storage element prevents the over-voltage that would result when the energy produced by the PV installation is more than the instantaneous demand and allows the peak shaving to be achieved. During periods of high demand, the batteries deliver part of the power, reducing the amount drawn from the net. Sometimes, it is also possible to match the local demand perfectly with the local production, so that no power runs through the transformer, and thus the microgrid works independent of the grid, in the island mode. Storage is important in grids with a significant proportion of renewable energy sources, considering the variable power output of these sources. Without storage, it is a nearly impossible task to ensure that the local demand can be fulfilled at any one time by the local generation (Erge, et al., 2005).

An energy management system regulates the energy current in the network so that the microgrid is used as efficiently as possible. This can lead to a reduction of the maintenance costs and an increase of the lifespan of the CHP as well as the pursuit of the lowest possible electricity price for consumers (Erge, et al., 2005). This project has also addressed the social integration of inhabitants of the neighborhood by reconciling their energy use with the local energy generation (Jiménez, 2007). An example of this is the “Washing with the Sun” initiative. Residents received a text message if the PV installations produced too much energy, in which they were informed in what period the solar panels generated a lot. If they adjusted their peak consumption (including washing machines, hence the name of the initiative) with these periods of optimal photovoltaic production in mind, they received a financial bonus. This initiative has been observed to be a success, considering the great response from the residents in following the guide of the financial incentive (Erge, et al., 2005).
3-2. Method

In this research I’m going to explore the idea of combining incentives, participation and feedback delivery by proposing the concept of sharing energy among users of a microgrid. Thus I propose a small-scale community micro grid in which an adequate number of proximate interconnected houses with diverse intense energy users, explicitly share energy with each other, in order to balance the local energy harvesting and demand in the micro grid.

As my methodology I’m taking several steps to investigate and enrich this concept. The concept consists of two main parts: the strategy and the sharing system.

The Strategy: After conceptually defining the energy exchange system, I’m outlining its operational principles and fundamentals which would act as the basis of the strategy. By fleshing out the hypothesized strategy (incentives, feedback delivery and participation), according to previous studies I’m explaining the main characteristics of an effective feedback delivery interface in terms of content and methods of display. In addition, I’m laying out the features that makes an incentive program successful in a sense that motivates users’ participation and collaboration in a shared-energy community endeavor. Having discussed the details of the proposed strategy I’m introducing a prototype of an interactive interface with the above mentioned features.

The System: In this part under the title of “How it Works” I’m explaining the system’s architecture (size of the system, how energy is being supplied, its different components etc.), and then discuss the system’s operational regulations as a policy framework to nudge users towards conservation behavior by participating in a community-based energy-sharing system.

After describing the strategy and the system, I’m exploring the users’ behavior in interaction with the interface and as a part of a shared-energy community by graphically illustrating three user experience scenarios.
Chapter 4 | The Energy Exchange System

As outlined in the background section, although observations indicate that providing feedback on consumption actions are capable of slightly stimulating conservation behavior, the durability of these changes is still a matter of question. That is because these information provisions are neutral through meters since they only display information, and they acquire meaning after going through each household’s interpretive and discursive lens, point of view and cultural practices (Hargreaves, Nye, & Burgess, 2010). After information is being processed by each individual, it brings in the ability of persuading people and solving the gap of “energy illiteracy”, but it doesn’t inspire them for adopting long-lasting behavior change. In this regard, studies have emphasized on considering the complexities of human behavior by centering attention on environmental psychology literature for techniques and inspiration on pro-environmental behaviors and behavior change strategies (Froehlich, Findlater, & Landay, 2010). While many studies have addressed this issue in different ways, common among all of them is that structuring an effective strategy for adopting durable behavior change requires the coupling of energy feedback delivery to an incentive program while considering the complexities of human behavior (Lutzenhiser, 1993 - Hargreaves, Nye, & Burgess, 2010).

Building upon the reviewed literature, in order to address the hypothesis this research recommends a shift in focus more on the community’s energy use rather than individual energy consumers as the key unit of analysis. Toward this end, a conceptual prototype of an energy exchange system – a collaborative energy sharing network for small-
scale community microgrids - with a diversity of intense energy users, structured on a collaborative incentive program with interactive and comprehensive energy feedback information is proposed as a possible solution. This concept points to a strategy where the focus is not directly on educating users about their energy consumption, but rather on fostering cooperative and energy-saving dynamics by coupling energy feedback technologies and an incentive program which requires users’ self-organized collaboration and participation in sharing energy within their community’s microgrid.

In this joint cooperative model, since the proposed community is home to multiple, diverse and relatively intense energy users with various consumption behaviors with common resources of energy, according to Sherman, sharing of energy is the most economical methodology for lowering the consumption rate in the community and thus reducing the energy costs among households (Sherman, 2012). Moreover, sharing is used for socially challenging and connecting the users in terms of cooperation for developing energy efficiency in their community. Also sharing allows the energy infrastructure itself to better engage and interact with users other than by methods like pure display of energy information. This interaction offers wider energy management opportunities in the scale of their own house and their joint community.

As a result of this energy exchange system, it’s expected that new patterns of energy responsive collaboration and participation result in the community microgrid from the users’ themselves, suggesting resiliency in form of participants’ collective intelligence.

4-1. System Principles

The proposed conceptual model of an energy exchange system operates based upon a set of principles and fundamentals, illustrating energy consumption and energy efficiency as a more social and collective process rather than individual:

1- Users more or less consciously choose their activities and consumption patterns and thus are the main influence and last instance for any decisions. Founded upon this presumption, the energy sharing mechanism operates based on the users’ tacit knowledge. That is, users perceive the payoffs proposed by sharing, and they themselves chose and decide to borrow or lend energy to their similarly situated others in the community based on the energy information provided by feedback technologies.

2- HCI and feedback technologies in this system are being used merely for information and communication facilitation and therefore the focus will be on the users of the community as the smartest component of the system rather than any so-called smart technological device.
3- In this sharing system, I’m not aiming at reducing the users’ quality of life. While each individual has its own image of home, coziness and comfort (Aune, 2007), it’s not effective nor laudable to aim at reducing their life quality, health and safety in the design of our strategies. That is because users automatically adjust their behavior to a good balance between conserving energy and their own acceptable quality of life (Ouyang & Hokao, 2009). As I believe Aune is the best reference in this case, I directly quote from her that “High energy costs, new energy-efficient technologies, information campaigns and other instruments implemented to reduce private energy consumption should probably not challenge ‘the home as haven’’ mentality, but rather try to address it” (Aune, 2007).

4- In this proposal I’m not aiming to change the users’ behaviors, but I’m actually benefiting from the different consumption patterns of different users and the dynamism of their behavioral attributes, as a potential for constructing an energy exchange mechanism.

5- The system per se is not a recommender system; in other words it doesn’t dictate the users what to do. Instead it aims at helping users perceive their personal and group benefits to make better consumption decisions. So its operation fully depends on the users based on people’s perception of the feedback information displayed on the interface they will understand the payoffs of taking conservation actions.

6- This strategy looks at energy consumption as social and collective process rather than individual. Hargreaves et al recommend that future researchers to focus more on the household energy use rather than individual energy consumers as the key unit of analysis. The authors point to a strategy which the focus is not on actually educating users about their energy consumption, but fostering a “cooperative and energy-saving household dynamics” (Hargreaves, Nye, & Burgess, 2010).

4-2. System Overview

This section discusses how the proposed conceptual prototype of the energy exchange system operates, and introduces an interface structured upon an incentive program that motivates users’ participation.

**Conceptual Prototype:** The proposed system is based on a small-scale community microgrid constituted of a moderate number of interconnected houses with a diverse set of energy users\(^2\). It is

\(^2\) Larger communities might get out of control since the number of users overriding the system increases, on the other hand smaller communities reduces the diversification of the users which increases the probability for everyone to act respectively to the system and lead to its collapse.
introduced as a method to address the assumptions and principles laid out in the previous section. The variegation of users in the community plays an important role in driving the system since it intensifies the possibility of exchanges to take place.

![Image](Figure 13 - The conceptual prototype of a model of 6 interconnected houses in the community)

**Energy Supply:** For this proposal community energy is supplied by a common source of renewable energy such as solar, wind power or fuel cells. As a small-scale microgrid the intent is to reach a level of independency on fossil fuels, in which the community’s need for energy is mostly provided by renewables. This is because dependence on clean energies is a challenging task since the amount of renewable energy harvested normally doesn’t match the amount of energy consumed at homes (Zhu, et al., 2013). While sharing energy will keep the supply and demand rate balanced in a microgrid community, it also serves as an efficient strategy addressing this challenge.

While operating on renewables, there are some critical times in which the community requires supplementary energy for operation. These cases are also solved because of the microgrid’s ability to reconnect to the larger smart grid for a backup.

**Operation:** In this conceptual prototype the operation of the energy exchange mechanism results from a pro-environmental strategy combining energy feedback technologies with an incentive structure promoting user’s participation and collaboration for saving energy in the community. As a computational strategy, the energy exchange system has two layers: One is the layer of computation and algorithms which technically drives the system, handles communication among different households’ energy profiles and is responsible for the energy transactions. The other layer, which is particularly discussed in this
research, is a simplified translation of the computation layer into an interactive user-friendly interface.

The interface graphically translates only some parts of the technical layer which is required for users to perceive in order to make more energy efficient decisions. Some information given to users include each household’s debit and credit account, the whole community’s credit account, financial rewards and penalties, current state of energy efficiency of their home, the energy consumed by main electrical appliances, and specific customized suggestions given to users for improving their consumption pattern.

4-3. The Incentive-Structured Interface

The interface system described in this section is proposed as a way to increase the possibility of a community microgrid to be energy responsive through its users. In this system the visualization of energy use through feedback devices, as an aesthetically appealing method for inducing behavior change, is combined with game-like built in incentives to motivate long term behavior modification by requiring users’ self-organized collaboration and participation in a community-based endeavor. These “games” can provide targeted incentives for users of a microgrid to alter their consumption pattern and shape the use of shared-energy resources.

The interface used in this strategy is a communicative web-service device serving as a medium between the user, the community and the
grid, accessed from anywhere in the house and outside and presented in many manifestations: through tablets, phones, website profiles and home dashboards.

Figure 13 - The interface in this strategy is a communicative web-service device serving as a medium between the user, the community and the grid.

Figure 154 - The interface comes in many platforms and manifestations: through tablets, phones, website profiles and home dashboards.
The interface graphically displays three different, but related sets of data on the household’s personal energy information for instance the debit and credit-energy accounts in the “YOURS” tab (these energy accounts will be discussed later), the community’s general energy information such as the community-energy account in the “OUR” tab, and recommended energy conservation suggestions and tips customized based on the household’s overall consumption pattern in the “TIPS” tab. The information displayed in these tabs help users perceive their personal and group benefits of making more efficient energy consumption decisions and understand the payoffs of taking conservation actions.

The “YOURS” Tab: as shown in figure 15 this tab represents household’s personal energy information and includes several graphics: 1- the two explicit energy accounts of the energy exchange system, the debit-energy account and the credit-energy account, are displayed as two inner circles with an arrow which displays the user’s current energy consumption status (more information on the energy accounts will be discussed later in the section) 2- the energy bar on the right shows the current overall energy efficiency status of the house 3- the plans of the house display how efficiently energy is being consumed in different locations and spots of the house.

![Figure 16 - The “YOURS” tab of the interface in an iPad](image-url)
For increasing the effectiveness of feedback delivery, researchers have suggested to display information in a graphical format rather than referencing them in numbers due to the long-lasting effect that visual media has on the users' understanding and perception. Another effective method for drawing users' attention on their energy consumption is to provide users with cost information on consumption rather than the kWh of the used energy, as monetary data is more motivating for users (Fischer, 2008). In this sense, for the users' better and faster understanding of their consumed energy the visual representation of two circles have been chosen. As the user consumes energy, a larger radial part of the circle fades away with an arrow showing the related cost information on consumption based on the system's own currency which will be explained further in the section. Moreover, the energy bar on the right in addition to plans help users to better understand the overall energy efficiency of their house.

**The “OURS” Tab:** with the features outlined below and the information provided, this tab attempts to abstractly incentivize communal collaboration and participation among the users for saving and sharing energy in the community. The general information displayed here are related to the community’s energy efficiency status and the household’s stance and contribution to it. The energy ribbon at the right of this tab displays the overall energy efficiency of the community.

![Figure 17 - The "OURS" tab of the interface in an iPad.](image)

Comparison: As a reason for taking energy saving actions, comparing has showed to be effective particularly when it is combined with
feedback about performance (Froehlich, Findlater, & Landay, 2010). In this order, the interface is featured with a visual evaluation of each household’s current and past energy behavior in addition to graphically displaying the user’s stance in the overall community’s energy consumption.

On the left there’s a visual display of the community-energy account (yellow gradient circle) and the users’ consumption of the shared resource (the blue arc). When users of the community use from the community-energy account, the yellow gradient moves toward completing the circle into a bold yellow color. Moreover, by tapping on the circle appears information on the users’ ranking in energy efficiency among other users of the community. Also, a graph is provided comparing users’ energy performance in the last five months.

![Image of the interface](image)

Figure 18 - Information on the user’s ranking among other users of the community in addition to a graph comparing users performance in the last five months. This information appears after tapping on the circle displaying the community-energy account.

The effectiveness of self and else comparison shows that when users receive energy conservation information from their friends and acquaintances they automatically start to compare it with their own consumption behavior and energy usage. However, studies show mixed results observed from the effectiveness of social comparisons in the realm of environmental psychology. Although earlier studies in the 80’s and 90’s have shown that interpersonal comparison affects users’ behaviors (Costanzo, Archer, Aronson, & Pettigrew, 1986 - Harrigan,
the 21st century literature demonstrates that while people are often interested in social comparison, it does not necessarily have an impact on their behavior (Froehlich, Findlater, & Landay, 2010); however, it’s valuable to have it in mind as an approach for enhancing the effectiveness of a deployed pro-environmental strategy (Lutzenhiser, 1993). Another notable study about comparison shows that people are more influenced by the threat of loss than promise of gain. Thus, comparisons would be even more effective when the emphasis goes on considering current losses that result from failing to adopt energy-conserving habits in comparison with other members of the community (Yates, 1982 - Costanzo, Archer, Aronson, & Pettigrew, 1986 - Kahneman & Tversky, 1979; Tversky & Kahneman, 1974).

Rewards and Penalties: Rewards and penalties are consequence motivation techniques coming after a behavior. Research into the effects of rewards have found that people respond to rewards even if they are nominal in nature (e.g., an acknowledgement of positive behavior) and that the reward should be linked as closely with the target behavior as possible. Previous research in persuasive health technology has shown that even providing an asterisk after the completion of a behavior is enough to elicit a positive response. Eco-feedback designs may not be able to offer financial incentives, but most certainly can rely on game-like reward elements (e.g., points, levels, etc.) to promote behaviors (Froehlich, Findlater, & Landay, 2010).

One of the main drivers that makes offering rewards a strong motive for users is that they become thrilled to set goals for themselves, either mentally or physically, to reach those rewards. When a goal is set, especially when the goal is to win a reward, a sense of commitment, a promise to behave in a specific way to attain that goal will thrive in the user. A person that expresses commitment increases the probability that s/he will pursue that behavior (Froehlich, Findlater, & Landay, 2010).

In the incentive structure of this strategy, I have set monetary rewards for those users which have better energy-saving performance, and monetary penalties for inefficient users. Details and information on the rewards and goal setting is found as part of the interface’s design and functionality. In addition to the monetary incentive, there’s an ethical incentive shown as part of the interface in shape of leaves. By being an

Figure 19 - Ethical incentives and monetary incentives shown in the "OURS" tab
efficient user all the leaves will be displayed in green. On the other hand by starting being inefficient, the leaves start to lose their color.\(^3\)

### 4-4. How It Works

This section first provides a brief definition of the terms used in the context of this energy exchange system and then describes how it works:

- **Monthly standard fee**: a monthly fee good for getting access to both the physical microgrid infrastructure and to the energy exchange system.
- **Annual insurance fee**: an annual insurance fee for critical conditions that require the microgrid to connect to the larger smart grid.
- **Energy-tokens (eT)**: the system's suggested currency which is based on price of electricity and average per capita.
- **Debit-energy tokens (Debit-tokens)**: represents the first and main share of energy that each household receives in form of energy tokens based on price of electricity and average per capita energy use. The amount of debit-tokens assigned to each household is upon the number of family members.
- **Debit-token account**: a virtual account holding the debit-energy tokens which could be accessed and monitored by the interface.
- **Credit-energy tokens (Credit-tokens)**: represents a trading mechanism for obtaining additional energy-tokens, in which case the household gets charged by energy-tokens.
- **Credit-token account**: a virtual account holding the credit-energy tokens which could be accessed and monitored by the interface.
- **Community-energy tokens (Community-tokens)**: a system for sharing energy-tokens were individual households may either sell extra energy-tokens at the end of the month or purchase energy-tokens if all debit and credit-tokens are used.

The power of the community is supplied by a common source of renewable energy leading to the resource being shared among community users. In this energy exchange system there are three set of energy (in form of energy-tokens) given to users under different

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\(^3\) In this strategy or system, being an efficient user means to only use energy up to the limit of your energy-debit account in a month. If the users’ energy consumption exceeds the debit limit, than starting using from the energy-credit account translates to being an inefficient user. In this chapter while talking about efficient and inefficient users, the above explained situations are being meant.
conditions as in this order: debit-energy tokens, credit-energy tokens and community-energy tokens.

At the beginning of each month every household receives two constant share of debit-energy tokens and credit-energy tokens which can be accessed and viewed through the “YOURS” tab of the interface at the same time. The household’s monthly energy usage is tracked using debit-energy tokens at the first place which leads to several scenarios that might occur in a household:

- If a household stays in its limited share of debit-energy tokens within a month, they’re being considered as efficient users in this system. As in this case, by the end of the month efficient users will receive monetary rewards because of staying in their limits of debit-energy account.

- If a household uses energy less than their monthly share of debit-tokens, at the end of the month they are able to sell the extra energy-tokens to the system and receive actual money in their bank account.

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4 First a user uses energy from the debit-energy account. If finished before the end of the month, s/he could get access to extra energy from the credit-energy account. After using all debit and credit the user gets access to additional energy from the community-energy account.
• If a household uses all its debit-energy tokens prior to the end of the month, a buffer zone, the credit-token account, is provided to allow household’s continual access to necessary energy. By using all the debit-energy tokens, users start using from their shared amount of monthly credit-energy tokens\(^5\) by paying its specific trade off: due to the end of the next month the user should give back the excess energy used from the credit-energy account to the system in form of energy-tokens. For the user to provide the system with energy-tokens, s/he has to save eT from the debit-tokens earned in the following month. A situation similar to the one explained above will happen which by saving energy, at the end of the month the user has extra eT to give back to the community (but this time not to sell it to the community, but to pay for his excess energy use in the previous month). If a user couldn’t manage to save energy-tokens from the debit-energy share in the following month, an additional option has been considered. In this case the user would actually pay money for the extra energy s/he used noting that the rate is higher than the price of eT in that month\(^6\).

While explained the conditions which debit and credit-energy tokens are being used, a situation might occur that a household’s consumption goes beyond the limits of the second share of energy (credit-energy token) in a month, leaving the user in need of extra energy-tokens. In this case a shared community-token account can be borrowed against, providing household’s access to additional energy-

\(^5\) The share of credit-tokens is less than the share of debit-tokens. That is because if a household uses all its credit-tokens, s/he has to return it in form of eT by the end of the following month by saving energy on debit-tokens of the next share. So the amount of the credit share has to be in a reasonable relation to the share of debit so the user won’t get to the situation of giving up a huge amount of the following debit-energy tokens. Moreover, that’s the main reasoning why the option of paying for the extra used energy has also been considered.

\(^6\) In this case, users have both options of giving back energy-tokens and actual money to the system as the tradeoff of obtaining additional energy-tokens. In order to be in line with the system’s goals for nudging users towards saving more energy, it has been considered that the rate of charge for paying back money be higher than paying back by energy-tokens.
tokens. By using energy-tokens from this shared account, the user owes the community both energy-tokens and actual money due to the end of the following month. In order to prevent users from continuously depending on the credit and community energy accounts for purchasing extra energy, the energy price follows an ascending pattern.

Figure 25 - The household has used all its debit and credit-tokens

Figure 24 - This image shows the community-energy account at the "OURS" tab. The yellow gradient circle shows the neighbor's usage of this account and the blue radial of the circle shows the specific user's consumption of this account. In the left image both the user and the community have used less eT from the community-account than the right image.

A summary of comparing debit-energy account, credit-energy account and community-energy account is discussed in figure 26.
### Figure 26-A summarized comparison of debit, credit and community energy accounts

<table>
<thead>
<tr>
<th>ACCOUNT TYPE</th>
<th>CHARGE OF USE</th>
<th>DUE</th>
<th>RATE OF CHARGE</th>
<th>AMOUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEBIT-ENERGY ACCOUNT</td>
<td></td>
<td></td>
<td></td>
<td>Limited (to number of users)</td>
</tr>
<tr>
<td>CREDIT-ENERGY ACCOUNT</td>
<td>eT or $</td>
<td>End of the next month</td>
<td>1eT=$</td>
<td>Limited (to number of users and less than debit)</td>
</tr>
<tr>
<td>COMMUNITY-ENERGY ACCOUNT</td>
<td>eT and $$</td>
<td>End of the next month</td>
<td>1eT=$$$ (with an ascending pattern)</td>
<td>Unlimited</td>
</tr>
</tbody>
</table>

**4-5. Conclusion**

In a community home to a diverse number of households with different energy consumption patterns, at the end of the month there are always users which have been efficient\(^7\) and users which have been more or less inefficient\(^8\) in terms of energy consumption. This means every month there are always some users selling their extra energy-tokens to the community, some buying the energy-tokens, some staying in the limits of their debit-energy share and receiving monetary rewards and some crossing the lines of efficiency (as defined in the system) and paying back money to the system. By this conceptual prototype and the introduced framework it is expected that energy and money transactions constantly occur in the scale of the community and become the main driver of the energy exchange system. In this scenario the system will be host to users’ participation in this community endeavor.

In the background study of this research, it was observed that it’s not laudable to focus directly and particularly on changing user’s lifestyle and energy behavior because users automatically adjust their behavior to a good balance between conserving energy and their own acceptable quality of life (Ouyang & Hokao, 2009). Thus by combining several incentives which are mostly financial-based, this system

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\(^7\) Their consumption have not exceeded their share of debit-tokens

\(^8\) Their consumption reached to the point of using from their credit-tokens or from the community-tokens
attempts to provoke the users’ sense of responsibility towards their own finance, and by this indirectly intrigue them to act more energy responsive.

In this system the visualization of energy use through feedback devices, as an aesthetically appealing method for inducing behavior change, is combined with game-like built in incentives to motivate long term behavior modification by requiring users’ self-organized collaboration and participation in a community-based endeavor.

As a result of this energy exchange system, it’s expected that energy efficiency shift its meaning from individual energy users to a larger scale of community. And at the last but not least, by shifting the focus more on fostering a cooperative energy saving household dynamics rather than focusing on changing each individual’s energy behavior, it’s expected that new patterns of energy responsive collaboration and participation result in the community microgrid from the users’ themselves, suggesting resiliency in form of participants’ collective intelligence.
4-6. **Scenarios**

The scenarios introduced here attempt to show how users interact with the interface and clarify its impact on users’ everyday life.

4-6-1. **Scenario Number One**

As a small town, Clementon is host to around a thousand of households. By being a small town, the government has passed a legislation to advance its electricity infrastructure with new communication technologies so it could operate independent from the larger grid as a small-scale community microgrid. An interesting feature about Clementon which distinguishes it from other microgrids, is that all the houses are equipped with a community-dashboard for participating in an energy sharing network.

Gabi and Carlos are a newlywed just moved into a small house in Clementon. While signing the lease they realized that the policies described in the contract includes some community-based regulations. They understood that the utilities is neither included in the rent nor is being paid monthly as other normal houses. All they knew was that they are given the right to use a limited share of energy each month and they have to try not to exceed that amount. If they don’t exceed they’ll be rewarded money at the end of the month, and if they do exceed they are being penalized under special circumstances. They also understood that from now on, an energy-dashboard which contains all their energy information would be their best friend.

Gabi and Carlos both work outside the house. In the mornings and evenings which they’re at home they usually spend time together in the kitchen and the living room. Their energy-dashboard is also located on the wall between the kitchen and the living room so they could always see it. Since November that they moved to this house, they were using electricity as they normally did and not really interacted with all the layers of the dashboard except the “ours” tab which had the information on their energy accounts (energy-debit and energy-credit). While in the past two months money rewards would be depositing to their account at the end of the month, according to the contract, they assumed that their energy consumption is just on track, and well it was a good deal for them to get money for using energy well.

It’s the first day of January and the first day of the new year. The dashboard has deducted 60 dollars annual insurance fee for the grid, and also renewed their energy account. They’ve been given 50 tokens (as the right of using up to 50 tokens of energy) in their energy-debit account, and 25 tokens on their energy-credit account.
Gabo and Carlos decide to go on a vacation on the last week of their holidays. After a week when they come back, a warning sign on the dashboard attracts their attention. They get closer and they see this sentence: “10 tokens is a lot for a week...”!! They realize something has been going wrong since based on their previous experience they’d never use 10 tokens of energy for a week! At the most they’d use half of it. What was happening? They weren’t even home!

The dashboard guides them to check the “Tips” tab for further information on the problem and ... THE HEATING SYSTEM!!

The dashboard tells them that heating was on for all the entire week while they were gone and the temperature was set to 78 degrees! It also suggests them to reduce the temperature when they’re not at home and increase it whenever they are. This could also be done by scheduling the thermostat which is incorporated in the dashboard. Or they could modify the temperature manually and also remotely by the application on their cellphones and tablets. In this case even if they forget to reduce the temperature when they get out of the house, they could easily do it remotely by their phones.

Getting to know the use of the “Tips” tab and the cellphone application was a great undertaking for Gabi and Carlos. Since they didn’t want to lose any money at this month or any energy tokens for the next month, they tried to recoup the recent 10 tokens loss by following the guides of the dashboard for the month which they later understood it got more and more customized to their living pattern, as if it was learning and remembering their actions and softly nudging it towards more energy saving ones!
Once there was a small town named Clementon. This small town was host to around a thousand of households. Clementon is a small scale community microgrid and thus is being equipped with new communications technologies and the electricity is provided by renewables.

Gabi & Carlos are a newly wed just moved in a small house in Clementon.

Their energy dashboard is installed wherever in the house they are the most. 

In the mornings and evenings when they come back from work they spend most of their time in the kitchen and in the living room.

Since they've just moved in, they're kind of unfamiliar with the whole community-based energy sharing system that they signed the lease for. Last month they normally used electricity as they always did and they even got rewarded money at the end of the month. However they really didn't understand the use of the dashboard.

It's the first day of the new year and the system has deducted sixty dollars for insurance fee. Also since it's the first day of the month the system has given them their monthly share of token energy usage.

For the new year's holidays (Jan) and Carlos decided to go on a small trip nearby for a week.

Figure 27- Scenario 1-1
Figure 28 - Scenario 1.2

After they had the problem, their chauffeur and driver decided to turn down their heating system. They sped the chauffeur to use their share of tokens wisely and consistently.

From January 31st, they knew the chauffeur and driver had to use their chauffeur and chauffeur to be efficient. Also, they promised to be more than before.

TEN

BUT WHY???
4-6-2. Scenario Number Two
Mike and Suzie have been living in Clementon for several years. They’ve been more or less concerned energy users but with up and down in their consumption pattern. Sometimes they ended up being efficient users at the end of the month and sometimes inefficient and obligated to penalty. However they always tried to pay attention to their dashboard and follow its lead in being more conservative in energy consumption.

Just a few years ago, after Mike and Suzie had their first child, little John, they’ve been consuming energy a bit more than before even though their share of energy increased. On the other hand as little John grew up it seemed that he’s not that much of an efficient user. There are two things that excites John: The fridge and the dashboard!

Whenever in the afternoons Suzie takes a nap, little John directly goes to the fridge, leaves it open and plays in it for hours. When he realizes that his mother is awake he suddenly shuts the door and pretends nothing has happened. Until one day Suzie suddenly wakes up and from the red sign on the plan drawing of their house in the interface, realizes that something in the kitchen is tremendously consuming energy. When she enters the kitchen she finds out the source of energy waste: her son playing in the fridge.

Rather than punishing little John, Suzie realizes that she has to teach him not to play in the fridge. As a smart idea, she takes advantage from his interest in the dashboard. The dashboard provides some sort of an ethical incentive for promoting conservation behavior in addition to financial ones, by abstractly displaying how the users’ consumption affects the environment: the featured leaves lose their color when the user steps into inefficiency, that is by starting to use their credit account.

Suzie explains little john in simple words that how leaving the fridge open for a long time would destroy the flowers and the trees as it is displayed in the interface. Her simple explanation affects little John’s sensibility in a way that from that day on he even reminds his parents not to destroy the environment.
Mike & Suzie have been living in Clementon for a few years. Just a few years ago their child, little John was born. Mike and Suzie always tried to be efficient users for years. After John’s birth they’ve been using a bit of their credit store as well.

Two things interests little John the most the fridge and the dashboard.

But it seems their new family member is not as an efficient user as his parents are ...

Every day when Suzie takes a nap, little John goes to the fridge, opens it and plays in it for a few hours. When he realizes Suzie is awake he immediately closes the fridge. Until one day Suzie suddenly wakes up and sees the warning on the dashboard.

Every day when Suzie takes a nap, little John goes to the fridge, opens it and plays in it for a few hours. When he realizes Suzie is awake he immediately closes the fridge. Until one day Suzie suddenly wakes up and sees the warning on the dashboard.

I don’t wanna punish him but how should I teach him not to play in the fridge! All the food will get poisoned and energy will just go to waste.

While dashboard teaches John a lot, Suzie decided to simply teach little John that how his playing in the fridge destroys the flowers on the dashboard and in reality.

Little John’s child mind got pretty impressed how his destroying the flowers. Surprisingly he never played in the fridge again and the energy consumption pattern of the family went back to normal.

Figure 29- Scenario 2-1
4-6-3. Scenario Number Three
Julie, Maria and Nina are roommates living in a three bedroom house in Clementon. As teenagers they really have not cared about saving energy or being more efficient from the time they started to be part of this shared energy community. Their inefficient behavior spans from leaving the lights on when not needed and leaving their electrical appliances plugged in when not used, till turning the washing machine on at peak hours and opening the window when heating is on.

In their few months of residence in the community, their energy consumption always exceeded their credit share resulting in both energy and monetary penalties. At the end of each month, the system would send the girls notifications on their cellphones and devices about their efficiency status and the amount of money being charged. Then the system would withdraw the penalized amount from their bank accounts in addition to reducing their share of debit-tokens for the upcoming month.

The first few months that the girls got charged for using energy more than their credit share, the amount wasn’t that much for them to care. It started with 10 dollars each. But while months passed this amount exceeded until December which they got penalized for 120 dollars each! This amount seemed a lot for the girls and was beyond their ability to afford due to their inefficient behavior. They thought to themselves that if this pattern continues they have to spend a lot of money on their utilities which seemed not reasonable. January first was the time that Julie, Maria and Nina started really considering their consumption pattern and attempted to follow the lead of the dashboard on giving energy saving suggestions. As a process of becoming efficient users, it took a while for the girls to limit their usage to their debit share, but the important thing was starting to take action.
Julie, Maria & Nina are roommates in a house in Clementon. As teenagers they really don't care about saving energy and well...they're not efficient users at all.

Their lights are on all day long. They use their washing machine whenever they want, not considering peak hours...when the heating system is on, whenever they get warm they just open the window...even they don't unplug their electrical appliances when not using them...energy is always wasted in their house.

Every month they receive various messages from the dashboard warning them but they never cared even they've been penalized a few times.

They saw the warnings on their cellphones and tablets, and when they found out that a great amount has been deducted they came to the conclusion that they have to start taking action.

But this time the amount that they've been penalized has increased! Now they have to give one hundred and twenty dollars each for the previous month.

It's the first day of the month and the girls have been given they're taken share of energy.

After the huge penalty the girls are always checking their dashboard and energy account. Their best friend is now the "Tips" tab, and before turning on any high-consuming appliance they first check if it's a good timing for it to run or not. Also whenever they see a red circle on a part of the house they investigate for the problem, and immediately go for it. Now the girls could hope for not being charged this month.

Figure 30- Scenario 3-1
While talking about community and collaboration in my research, I'm not trying to define a well-functioning, resilient, energy-efficient, and ideal community for people try to live up to. Rather I'm encouraging a shift in our ways of thinking about how users could have a say in the resiliency of their societies and communities.

Environmental studies and energy related issues are vast disciplines per se and combining them with human behavior opens up even more immense questions. Apparently this research is not going to put an end to all energy crisis, but its attempt is to narrow down the problem to the role of human behavior in constructing resiliency in local energy infrastructures. While being aware of the larger context this research falls into, I'm specifying my studies to the issue of adopting energy conservation behavior in the context of an energy exchange mechanism by means of users' participation and collaboration.

This research introduces only a conceptual prototype of a small-scale community microgrid and attempts to describe its expected functionalities. The next step for this project is to actually evaluate it by means of testing and experimenting it on an actual pilot study or virtually by running a simulation.

The multidisciplinary feature of this research opens up opportunities for further studying it in different ways and in context of various fields ranging from architecture, HCI, computer science and power engineering to system thinking, environmental psychology, sociology, urban and regional planning, policy making, business and etc.
System thinking requires looking at things across its boarders and in a larger context. Looking at this thesis from a larger point of view arises many fascinating questions mainly on how small scale microgrid communities work in connection with each other and in connection with other microgrids. So in a scenario at a point people see their benefit in going out from their community microgrid and have their energy-related activities in another community or in another microgrid. For example users might find buying food from a restaurant less expensive than preparing food at home and paying for its energy. In this case some behaviors, not necessarily positive will happen that affects the microgrid’s economy at large. A valuable next step would be to study the governmental need for imposing different taxation strategies and policies to regulate the economy at large towards participatory forms of democracy and self-organization deriving from the citizens themselves.

Sharing of energy is a challenge from a sociological perspective, since users may resist to act collaboratively in this community endeavor. Thus further research might address creating new organizational structures, policies and incentive that allows for the involvement of multiples users in developing the system.

From computer science and power engineering viewpoint designing the next step as Froehlich suggested would be for HCl researchers to design the feedback technologies with regard to environmental psychology. On the other hand as a conclusion derived from my studies I’d like to add that in the design of these devices it’s important to address simplicity. While these devices become easy and simple for everyone to operate with, it’s probable that their usage go beyond being only a gadget.
References


