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**Fostering Household Energy Saving Behavior and Socialization of Smart Grid
Technologies:**

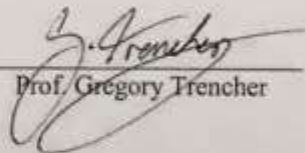
Outcomes of a Utility Smart Grid Program

Josephine Munene

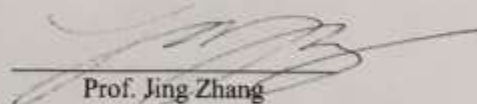
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Submitted to the faculty of Clark University, Worcester,
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Graduate School of Management

And accepted on the recommendation of



Prof. Gregory Trencher



Prof. Jing Zhang

Abstract

Smart metering and feedback technologies are designed to foster changes in demand side behavior. But the question, *Do smart grids and smart technologies actually change behavior and promote more sustainable energy use?* is yet to be answered—notably at the scale of a city. This study examines the way by which residential customers adopted and engaged with smart grid technologies, and the resulting changes in behavior from both these and pricing incentives from the utility. Data was obtained by analyzing a random sample of 240 respondents to three questionnaires (total n=1,303) implemented by a private sector consulting firm over summer in 2015 in Worcester, Massachusetts, USA where National Grid, is piloting a two-year smart grid project. Findings demonstrate that by creating a peak pricing scheme and diffusing household smart technologies, the program was able to foster an overall, modest reduction in energy consumption through energy saving behaviors.

Key words: Smart-metering, demand side, energy consumption, behavior, socialization of technologies, smart grid, smart technologies

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DEDICATION

I give praise to my heavenly father for seeing me through this achievement. I would like to dedicate this paper to my family; my dad James Munene; my mum Nancy Njoroge; my sisters Elizabeth Munene and Beth Munene; my brothers Daniel Munene, Obadiah Munene and Peter Munene; my brother in-law Gerald Kariuki; my nephews Gabriel Mwangi and Raziel Ngatunyi; my niece Beulah Wanjiru and my friend Stephen Ngondi.

Without your love and support, my life would be meaningless.

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1.0 Introduction

In December 2007, U.S. Congress passed and the President approved Title XIII of the Energy Independence and Security Act (EISA) of 2007. The primary aim of EISA was to increase the use of advanced technology so as to improve the reliability, security and efficiency of the electric grid (U.S. Congress, 2007; Graab, 2010). As a result of this federal legislative and funding support such as the American Recovery and Reinvestment Act and EISA, the U.S. electric grid in many states and cities is undergoing significant transformations and upgrades in pursuit of transition to a smart grid (Chopra, 2011).

There exist several definitions of a smart grid. This paper adopts Sioshansi's definition that describes smart grid as "a combination of enabling technologies, hardware, software, or practices that collectively make the delivery infrastructure or the grid more reliable, more versatile, more secure, more accommodating, more resilient, and ultimately more useful to consumers" (Sioshansi, 2011). In the same way that smart phones and the Internet were transformational technologies, smart grids have the potential of reshaping economies and societies (Mah, 2014). A key feature of smart grids is the utilization of technology to allow communication and exchange of information between utility and customers (Feng, 2015). In addition to offering promise of increased responsiveness by grid operators, reduced blackouts and line losses, the communicative capacity of smart grids promise greater

insight for consumers about their own energy use and its costs (Alliance Commission on National Energy Efficiency Policy, 2013).

Though the foremost objective of EISA was to authorize federal agencies to improve the electricity's reliability through technological modernization, Congress did not expect for smart grid upgrades to solely address the reliability of power distribution. Rather, Congress envisioned for smart grids to provide a solution to the nation's growing energy concerns (Graab, 2010). It was envisioned that smart grid systems could benefit both consumers and utilities, particularly regarding energy conservation and reduction of GHG emissions (Simchak, 2011). To achieve this, reductions in peak demand are crucial. Reduced peak demands allows utilities to deliver "cleaner" electricity to customers, since demand for "dirty" back-up sources is reduced. Reducing peak demand, however, requires behavioral shifts in energy consumers. This in turn requires smart grid programs that foster engaged customers and energy conservation during peak times (Baldissin, 2015). Although grid-linked technologies differ broadly, they generally offer the potential of reducing energy usage through efficiency and/or restriction in addition to altering use to off-peak periods hours (Sintov, 2015).

Smart grids and associated technologies are under testing in residential and commercial settings in various cities worldwide. Since they are currently enjoying massive government and private sector investment (Mah, 2014; Reinprecht, 2016), government and utility

expectations are accordingly high. They are shaped on assumptions that smart grid technologies can change consumer behavior and reduce demand side energy consumption (Khan, 2016). Yet, empirical evidence for this currently lacks. As a result, the question, *Do smart grids and smart technologies actually change behavior and promote more sustainable energy use?* is yet to be answered—notably at the scale of a city.

Some scholars have examined smart grid initiatives to influence user behavior. The consumer is recognized as an essential component of the smart grid paradigm (Bouhafs, 2014; Vasirani, 2013; Baldissin, 2015). He is envisioned to have an active role in the problem of balancing demand with supply. Smart grid features enable active participation by consumers. The positioning of intelligent and communication technologies in domestic environments has resulted in smarter homes enabling households to play a more active role in energy management (Vasirani, 2013). Research has shown that the chief motivator for participants to adopt smart grid technologies is financial rather than environmental reasons (Goulden, 2014; Horst, 2011; Khadgi, 2015). These customers' actions are guided by increasing energy knowledge, computer savviness and being environmentally conscious alongside regulatory state changes (Gharavi, 2011). This study builds on this literature, breaking new ground by examining how consumers respond to the call to save energy in smart grid programs. The study is focused on whether or not consumers are incentivized by real time pricing structures and if they use smart grid technologies to make decisions surrounding energy saving.

This study attempts to fill the research gap identified above by examining customer behavioral responses to a smart grid pilot program (Smart Energy Solutions [SES]) by National Grid (the utility), implemented in Worcester with a population of 181,045 (City of Worcester, 2016) in Massachusetts, USA. The overall objective was to determine how residential customers adopted and engaged with smart grid technologies, and the resulting changes in behavior from both these and pricing incentives from the utility. A defining feature of the program was a triple strategy to influencing demand side energy consumption behavior. This involved provision of; 1) Free smart in-home technologies such as, smart plug control devices and smart thermostats; 2) Real-time energy consumption feedback via digital picture frames and Internet portals and; 3) Real-time pricing plans which are electricity prices directly connected to cost of electricity production. In particular, this study focuses on the influence of access to in-home smart technologies on participating high and low-income households. Data was obtained by analyzing a random sample of 240 responses to three surveys (total n=1,303) implemented by a private consulting firm on behalf of National Grid over summer in 2015. This data was used to answer the following research questions:

- To what extent did (some) people adopt and engage with energy feedback technologies in the home?

- How did customers change their energy use activities in response to the pricing structure incentives and interaction with in-home technologies? To what extent is the change vary between high-income and low-income households?
- Has the program been able to reduce energy demand from participant households?

Findings show that customers adopted and engaged with energy feedback technologies such as WorcesterSmart web portal and digital picture frames. Findings also show that both high-income and low-income households used the information to change their behavior towards energy saving activities. They embraced activities such as avoiding usage of energy intensive household appliances, and discussing energy conservation issues with family. Findings also reveal that real time pricing influenced consumers to reduce demand of electricity. This was through the shifting of energy activities from peak event hours when the rate was expensive to off peak hours when electricity price was affordable.

2.0 Theoretical perspectives

2.1 Socialization of technology

Customers in smart grid programs are connected by a relatively complex system and subsystems that integrates a bi-directional flow of information along with electricity (Fan, 2010; Hossain, 2012). From a structural perspective, a smart grid has three principal layers. The first is the physical power layer for transmission and distribution of electricity. The second is composed of the data transport and control layer for communication and control. The third is the application layer for applications and services (Hossain, 2012). The first two layers of smart grid technology are beyond the scope of this paper. The main focus of this paper is on the application layer, which is utilized on the demand side of the grid (Zipperer, 2013).

Smart grid technologies intended for home or businesses include smart meters (Uribe-Pérez, 2016); home energy devices (Sioshansi, 2011), which are connected to the home area network (HAN), and smart appliances. In particular, smart grid in-home technology and appliances include:

- *Smart metering systems* - Uribe-Perez et al (2016) describe smart metering system as a system of diverse infrastructure consisting of; a meter; data gathering device; communication used for data flow; centralized management and control center.

- *Smart thermostat* - A temperature controlling and on/off device for controlling the home's heating, ventilation, and air-conditioning (HVAC) system. Smart thermostats are digital, with an installed memory so that the user can program setting preferences.
- *In-home display* - Commonly called a "digital picture frame". This electronic graphical display device renders visible energy consumption amounts and costs to the customer. The information is updated in real time, based on the data received from the smart meter.
- *Online web portal* - A specially designed website that serves as the central contact point for accessing information related to home energy consumption. Web portals contain personalized information on energy use and categorized content in comparison with other houses. They also contain energy management and bill comparison software with the aim of empowering consumers to actively control their energy usage and costs (U.S. DOE, 2016; Zipperer, 2013).
- *Smart appliances* – Devices that are connected to electronic appliances at the power socket. They are linked wirelessly to smart electric meters to assist the customer in shifting electricity use to off-peak hours. For instance, smart dishwashers have the ability to postpone the washing cycle until the time of off-peak electricity rates, thereby saving the customer money (U.S. DOE, 2016).
- *Smart Plug* – A 3-prong outlet that allows customers to plug appliances into and can be controlled via the Home Area Network or broadband Internet connection

More than being simple technological devices for enhancing the functioning of the electricity grid, the above devices can have a direct influence on the behavior and lives of energy consumers (Sioshansi, 2011). Smart technologies can influence users and energy consumption in two ways. First, a prerequisite of the smart grid is that conventional analogue electricity meters at each home, farm, factory or office be substituted by far more advanced meters that incorporate communications and data-processing capabilities. This smart meter could be linked to a display screen in the customer's kitchen or office. The customer could then be informed of an upcoming change in the price of electricity and could then choose to schedule electricity-using activities at a time when price will be low (Levinson, 2010). Such information can also be conveyed to users via digital picture frames or online web portals that are accessible from smart phones, tablets and personal computers. Second, smart technologies can also control when energy is consumed, either with the settings pre-selected by the consumer (e.g. smart thermostats) or by automatic overrides made by the devices themselves (e.g. smart appliances) (Baldissin, 2014). Smart technologies thus interact with humans, and visa-versa, to become integrated into a social network of human activity.

“Socialization”, in standard sociology and psychology, is the process by which individuals identify their position and become entrenched parts of collectives such as, for instance, a family, class or society (Skjølsvold, 2015). Socialization is an involving lengthy process

where individuals learn ideologies that are important through interactions with social institutions (Templin, 2014). It is important to note that technologies too can assist humans in identifying themselves as part of a wider network—the ultimate examples being the Internet, social media and smart phones. As new technologies are introduced, using them results in the evolution of new form of social interaction. In the same vein, socialization can also occur through smart grid technologies, such as those described above. As new technologies have been introduced, people have created new uses for them, which in turn cause new forms of social interaction to evolve (Walker, 2015). In particular, human behavior with regards to energy consumption could be influenced by such technologies. This can happen as humans begin to interact with in-home technologies to monitor their energy consumption, adjust daily behavior in response to feedback provided from such devices (Gottwalt, 2011). In parallel, the users identify themselves as energy users in a larger, interconnected system.

For adolescents, “socialization agents” such as parents, peer groups, social media, TV commercials (Shim, 1996; Ryan, 2000) have been seen to influence the teens’ decision making and styles. In the same way, influential players are imagined to play a significant role in the socialization of smart grids and this paper refers to them as “socialization agents”. In the manner that parents, peer groups or media have a great influence on an adolescent’s experiences, these socialization agents affect the ability to orient or socialize in-home smart grid technologies. Smart grid programs are visualized to have the

fundamental socialization agents comprising of “the smart user”, the utility, marketing companies and the government (Gungor, 2012; Harter, 2010; Farhangi, 2010).

Socialization agents are crucial factors in fostering the socialization of energy feedback technology and in-home smart devices, which can lead to increased awareness of energy consumption habits, and potentially, reductions in energy consumption.

2.2 How socialization occurs

According to psychological research, socialization occurs in phases. These include; (1) Recruiting learners; (2) Defining norms of the learning environment and anticipate learners’ adjustment; (3) Use of a mix of tactics by socialization agents to socialize learners; and (4) Assessment of key outcomes in accord with goals (Sanders, 1983; Field 2011).

Regarding the first, the vital player in the concept of socialization of technology is the “smart user” on the demand side—the individual who actively engages with the technology to make “smart” decisions or behave “smartly” (Chesi, 2013, Goulden, 2014). This is the “learner” that is recruited in the first phase of socialization. Smart grid technology such as digital picture frames, thermostats and web portals provide electricity monitoring that stimulates curiosity and awareness, thus providing potential to initiate savings because of increased attention towards energy consumption (Geelen, 2013). The extent to which in-home smart devices are socialized is influenced to a large degree by the

level of curiosity and active engagement of the user towards the technology, yet socialization can also be sensitive to electricity pricing. Consumers pay attention to when electricity rates are high and respond accordingly by making changes to their energy usage for instance, they re-organize their day-to-day energy usage routine with the aim of reducing their electric bills (Bouhafs, 2014).

As an important socialization agent, utilities are vital in implementing the second phase of socialization, since they define the learning environment and anticipate the learner's response, thereby making necessary adjustments. Utilities (companies) may play a crucial role. These include designing real time pricing plans to influence the energy consumption patterns of the user, educating users about benefits of energy conservation, and additionally, diffusing smart in-home technologies to connect these with the customer (Barbose, 2004; Gungor, 2012).

The third socialization phase, which involves providing a mix of instruments to facilitate socialization, is carried out by the designers of in-home technology. The global market for smart grid technologies has been experiencing a steady growth (Brown 2011; Newswire, 2014). Companies developing devices perform the significant duty of designing technology devices that are comfortable and convenient for customers (Gungor, 2012, Siano, 2014). This enhances consumer adoption of smart grid technology.

The fourth and final phase of socialization is mainly focused on key outcomes assessing to what extent technologies have been adopted. A significant social agent that facilitates this is the government. Regulators by passing laws such EISA, they mandated utilities to modernize the grid with the intentions of reducing GHGs. The utility and the marketing companies thus depend on the government to create policies to encourage societal diffusion of smart technologies and in addition provide funds for R&D (Cavoukian, 2010; Faruqi, 2010). Assessment is done periodically to gauge the adoption of these technologies. This is crucial in evaluating and identifying weaknesses or constraints in the development of smart grid (Sun, 2011). These socialization agents should work in some level of collaboration to increase socialization of technology at the home.

2.3 Peak demand and pricing

Consumers' use of power is generally propelled by convenience. This results in "coincident demand", which is energy demand required by a given class of consumers. This then results in electric load peaks (Khadgi, 2015; Skjølsvold, 2015). The consequence of this is periods of peak demand, where electricity consumption is highest. From a utility perspective, coincident demand creates challenges for upholding adequate and continuous power supply in peak periods such as, during summer time, when air condition systems are mostly utilized constantly (Simchak, 2011; Wang, 2016). To cope with peak periods, in many countries utilities are often forced to bring online dirtier forms of electricity generation such as older coal fired-power plants, or purchase more expensive electricity

from neighboring countries. In turn, electricity consumption during peak times has a higher carbon intensity than off peak power. To navigate peak load challenges, utilities use load forecasting to assist the planning and operation of power systems (Khan, 2016). Load forecasting offers the ability of utilities to predict the performance of the grid and their customers thereby establishing appropriate models for energy production (Uribe-Pérez, 2016).

Flexibility in electricity consumption is known as demand response (Zhang, 2015).

Demand response is the ability of consumers to change their energy usage due to influence from electricity pricing. Utilities use demand side management to boost power system stability. This is done by shifting high demand to periods of low demand (Davito, 2010; Khan, 2016). Fostering demand response in the goal of shaving the height of peak loads can also increase the utility's capacity to absorb electricity from intermittent renewable sources (Clarke, 2007; Enkvist, 2007). This is in addition to reducing the above mentioned need to bring online other forms of more carbon intensive electricity generation, thus reducing GHG emissions.

As mentioned earlier, in addition to smart technologies, real time pricing plans from utilities also harbor potential to change user behavior—and this type of pricing is an essential component of the smart grid paradigm. Given that costs are incurred by the utility in generating, transmitting and distributing electricity, costs are recovered by charging

customers a set tariff for each kilowatt-hour (kWh) of usage (Khan, 2016). Typically, the most common approach used for pricing electricity is a flat rate tariff. The introduction of distributed generation in the grid system has made it complex for old tariff methods to comply with smart grid requirements (Sioshansi, 2011). Electricity pricing systems should therefore be designed such that electricity rates reflect challenges, increase reliability and recover cost (Chitkara, 2016). Proposed dynamic pricing schemes for smart grid programs could be time-based rates or/and demand charge rates. Information on demand charge electricity rates can be found in the Chitkara et al report (2016). This paper focuses on time-based electricity rates.

Time-based rates are basically electricity rates that differ depending on the time of day.

There are four main types of time-based electricity rates:

- *Real Time Pricing (RTP)* – Offers variable prices at relatively short intervals, for example, hourly or daily. This pricing scheme approximately reflects the exact actual costs incurred by the utility in generation, distribution and supply of electricity. This pricing could be hourly charged or done a day ahead.
- *Time of Use (ToU)* –Offers a variety of prices at peak time and off-peak time. Off-peak time has relatively lower rate than peak time. Both prices at peak and off-peak are predetermined.
- *Critical Peak Pricing (CPP)* –An adjusted form of ToU that focuses on a specific period of the year when energy demand is high in comparison to the other peak

time in the year. CPP is only declared a day ahead of the CPP, and only occurs in a limited number of days in a year.

- *Critical Peak (CP)* – Also known as Peak Time Rebate (PTR), customers are provided with credit, or rebate, for reducing their energy usage during peak hours (Chitkara, 2016; Khan, 2016)

Time based electricity rates involves assigning appropriate energy and demand related costs to the actual time they are incurred. Of the options outlined above, real time pricing is a major goal for utility smart grid programs (Navigant Consulting, Inc., 2016). This is because by shifting demand and generation towards periods of low-demand, utilities experience both economic and environmental benefits. Pricing is one of the most commonly utilized approaches that could be considered non-technological. Pricing plans play a vital complementary role to smart technologies by economically incentivizing behavioral change in electricity users (Samadi, 2010).

3.0 Methods and overview of case study

3.1 Smart energy solutions program (SES)

Massachusetts, the study site for this paper, has an established history of energy efficiency programs in the electric utility sector (Hurley, 2008). The 2008 Green Communities Act enabled utilities to proceed even further, asserting: “Electric and natural gas resource needs shall first be met through all available energy efficiency and demand reduction resources

that are cost effective or less expensive than supply” (Commonwealth of Massachusetts Acts of 2008). The Act mandated that each investor-owned electric utility conduct a smart grid pilot with the overall objective of reducing active participants’ peak and average loads by at least 5%. Accordingly, National Grid¹, a utility company, launched a pilot smart grid project called Smart Energy Solutions Program (SES). The program cost \$44 million. This was recovered through increased electricity charges to all National Grid customers throughout the entire northeastern USA grid network (Moulton, 2015)

The SES program pilot is ongoing from January 2015 to December 2016. National Grid installed 15,000 smart meters² on the homes and business of the customers who are residents in Worcester, Massachusetts. These customers were chosen when National Grid flagged their homes across 11 electric power supply feeders in the city. SES program customers were given the opportunity to choose from several home energy management devices and technologies at no additional cost (National Grid, 2016). These included:

- WorcesterSmart portal that shows personalized electric information to the customer
- Digital picture frame

¹ National Grid is an international electricity transmission, distribution and gas distribution Company based in the UK and northeastern US. As an energy distribution company, National Grid does not produce electricity or gas but connects consumers to energy sources through its networks. It is the largest distributor of natural gas and electricity in the northeastern US, serving more than 3 million customers in New York, Massachusetts and Rhode Island.

² At the onset of SES program, 15,000 smart meters were deployed. But at the time this research was conducted, some customers had opted out; others shifted to different electricity suppliers or moved, reducing the number of participating customers to 10,849.

- Smart thermostat
- Plug control devices

Customers were also enrolled in two different pricing plans. The default plan was *Smart Rewards Pricing*. This combines Time of Use and Critical Peak Pricing structures to offer daytime electricity rates lower than the basic service rate (for a customer not in SES) for 335 days per year. This plan has Time of Use kind of smart pricing that offers a variety of prices at peak time (8:00 am to 8:00 pm) and off-peak time (8:00 pm to 8:00 am and weekend). On the remaining days each year (i.e. up to 30 days or 175 hours, called *Conservation Days*) electricity rates would increase significantly during specifically designated hours known as “peak events”. The peak event rate is about five times the regular rate. Peak events typically happen during summer months, when electricity is in high demand and supply is constrained. During these Conservation Days, customers are encouraged to take action to conserve energy and reduce their electricity costs during those designated hours. National Grid notifies customers through telephone messages and email the day before so they can plan accordingly.

Customers were however given the alternative choice of opting for the Conservation Day Rebate plan. This is modeled using the Peak Time Rebate structure. It offers customers the opportunity to stay at the basic service rate as non-participating customers in the SES program and earn a rebate when they reduce their energy usage below what they normally

use during peak events. Customers receive a credit the following month for any energy they saved during the previous month's peak events on the Conservation Days. This plan does not include the Time of Use (ToU) electricity rates for the 335 days of the year the Smart Rewards Pricing plan offers. For more information on the different pricing plans see Chitkara (2016) and National Grid (2016).

3.2 Data collection

This study draws upon survey data collected over June to September 2015, by a private consulting firm to evaluate preliminary outcomes of the utility's SES program. In addition, firsthand knowledge from the author (from employment at the utility) in implementing the program is incorporated into findings.

The consulting firm used a stratified sampling technique to select the survey respondents. As shown in *Table 1*, the entire SES customer population (10,849 households as at September 2015) was stratified into different segments, then random samples were taken from each strata. This was done in accordance with the household's enrollment in differing technology plans. The consulting firm surveyed a total sample of 1,301 sampled customers across a total of three surveys while retaining the distribution of the population

subscriptions. Questionnaire results were organized into high-income³ and low-income⁴ respondents.

There were eligibility requirements for certain technology packages, see *Table 1*. For example, in order to be eligible for the Level 2 package with a digital picture frame, customers had to have a high-speed broadband Internet connection. To be eligible for Level 3 with a smart thermostat, customers had to have central air conditioning. To be eligible for Level 4 with a smart thermostat and a smart plug and/or load control device, customers had to have central air conditioning and a broadband high-speed Internet connection.

| Level/Technology package | Types of technology | Requirements | Share of population |
|---------------------------------|---|---|----------------------------|
| Level 1 | Smart meter + WorcesterSmart web portal | None | 92% |
| Level 2 | Level 1 + digital picture frame + mobile app | High-speed broadband Internet connection | 5% |
| Level 3 | Level 1 + smart thermostat | Central air conditioning | 1% |
| Level 4 | Level 1 + Level 2 + Level 3+ load control devices | Central air conditioning and a broadband high-speed Internet connection | 2% |

Table 1: Levels of technology packages⁵

³ High-income – Customers on R1 rate (basic residential rate), with income greater than \$100,000 based on demographic data

⁴ Low-income - Customers on R2 rate (reduced rate) where they are given a 25% discount on their entire bill

⁵ Source: Navigant Consulting (2016)

3.3 Data analysis

The principle data used specifically for this paper consists of an analysis of questionnaire responses from a randomly selected sample of 240 respondents from the above-described population of 1,301 SES participants. As shown in **Table 2**, this sample comprises of three smaller samples of 80 responses, each extracted equally from the three survey administration periods in the original survey (i.e. early, mid- and late- summer in 2015). The objective of this research is to study how in-home technology is influencing differing income household responses to calls to save energy. Accordingly, selection of the sample was done in each questionnaire administration period by ensuring an equal representation of high-income and low-income respondents. Random sampling was achieved by utilizing the random sampling tool in MS Excel.

| | Survey 1: Early summer 2015 | Survey 2: Mid-Summer 2015 | Survey 3: Late summer 2015 | Total |
|--|--|--|---|--------------|
| Total population (n) | 525 | 270 | 506 | 1301 |
| Low-income respondents sampled | 40 | 40 | 40 | 120 |
| High-income respondents sampled | 40 | 40 | 40 | 120 |
| Total sampled respondents | 80 | 80 | 80 | 240 |

Table 2: Overview of sample created for conducting data analysis

4.0 Findings

4.1 Integration of different technologies

Data analysis was done to determine the extent to which users adopted and engaged with energy feedback technologies in the home. Descriptive statistics of this data can be found at the appendix under *Table 3* and *Table 4*. As shown in *Figure 1*, it was found that across the three surveys, the WorcesterSmart web portal was the most commonly integrated form of technology. This was incorporated by 78% of high-income and 57% low-income respondents. The WorcesterSmart web portal provides the customer access to electricity usage information via a desktop computer or mobile device. This portal offers personalized online graphical electric usage information, comparisons to friends and neighbors, and the opportunity to take part in a reward system to win prizes for conserving electricity. Smart plug controls (allowing customers to remotely adjust any appliance plugged into them such as a window unit air conditioner) experienced an extremely low adoption rate in both income groups. As an overall trend, when comparing high-income to low-income households, findings show that the latter lagged behind in integrating all the four sets of in-home technology provided by the utility. This most probably reflects financially related obstacles such as lack of access to high-speed internet (required for picture frames) or central air-conditioning (required for thermostats). This means that adoption of smart technologies in low-income households, and use for guiding decisions and energy management, was significantly lower, relative to high-income households.

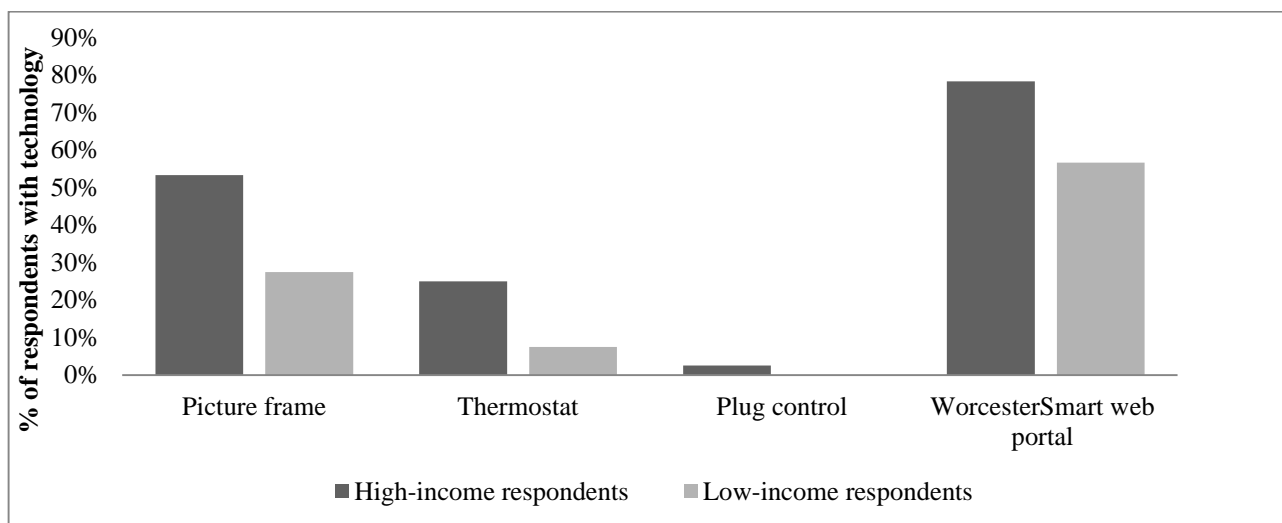


Figure 1: Types of in-home technology integrated by SES customers

4.2 Actions taken by SES customers on Conservation Days

Data analysis was also done to determine the ways in which customers from high-income and low-income households were changing their energy use activities in response to the call to save energy during Conservation Days.

Descriptive statistics of data on number of respondents that took action can be found at the appendix under *Table 5* and *Table 6*. As shown in *Figure 2*, findings revealed that SES program, through the real time pricing structures, was highly successful in triggering behavioral responses and energy saving actions during Conservation Days. In fact, the proportion of respondents who did not take action was limited to 5% in high-income and 11% in low-income. The most common action across both high-income and low-income households was “avoided use of certain appliances during peak event hours”. This was

practiced by 52% of high-income and 50% of low-income respondents. A possible explanation is that customers tried to reduce the high bills that could result from running appliances during the peak event hours. Changing the temperature setting on air conditioner (both single and central) was done by 22% of high-income compared to less than half of this percentage (8%) for the low-income respondents. This can likely be explained by the probable absence of central air conditioners in low-income homes.

Generally, examining the households by economic status, high-income customers who had better access to in-home technology, as seen in section 4.1, took more actions to conserve energy compared to low-income households, who had more limited access to in-home smart grid technologies. This is surprising, since it could be assumed that low-income households would have a higher economic incentive to save electricity. If assuming conversely a lower financial incentive for energy saving in high-income households (due to higher incomes), the larger adoption of smart technologies (shown in *Figure 1*) appears to have been a major determinant. Energy saving behaviors and socialization rates were thus higher, overall, in high-income households due to larger access to and interaction with smart technologies.

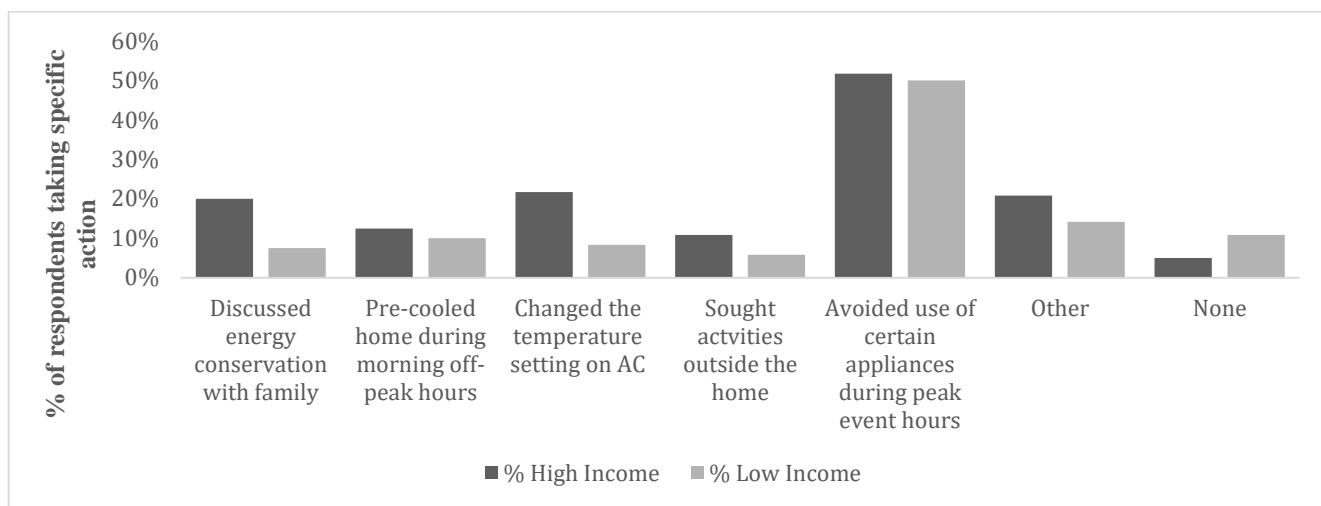


Figure 2: Actions taken by SES customers to conserve energy during Conservation Days

4.3 Energy savings achieved

Lastly, energy savings for customers participating in the SES program was examined. Data was obtained from an interim evaluation report from the consulting firm (Navigant Consulting, 2016) in February 2016 to evaluate the first year (2015) results for all SES program customers. The most important findings are as follows.

Overall, it was found that by participating in SES program customers did conserve energy. The total of these energy savings equates to a 2,300 MWh reduction for calendar year 2015 for the 10,849 participating households. This translates to 17 kWh a month per customer on average reduction. In addition, not only did SES customers save energy, they also experienced dollar savings. However, it was found that the two differing pricing plans achieved different results. The most effective pricing structure was the Smart Rewards Pricing that combines Time of Use and Critical Peak Pricing. Respondents participating in

this plan achieved an average bill saving of \$109 for the first year period of SES. Customers in the Conservation Day Rebate plan, modeled using the Peak Time Rebate structure also achieved financial savings, although relatively less. Time of Use and Critical Peak Pricing structures appear to motivate energy consumption reductions (in both high and low-income households) more successfully.

5.0 Discussion

The analysis of this research showed smart grid customers adopted and are assumed to have engaged with in-home technologies in the context of large-scale smart grid experiment. Findings show that across the three surveys, the WorcesterSmart web portal, followed by digital picture frames, were the most commonly integrated form of technology. The provision of real time feedback on energy consumption seems to have contributed to the adoption of smart grid technology by the user. They have modified energy consumption behavior (also guided by pricing incentives) and possibly realized their place in the broader context of the entire energy distribution system. This technology-enabled adoption and use seems to be influenced by the smart user's curiosity regarding the novelty of the feedback data and devices, and a willingness to use them to guide decisions about electricity use to reduce monthly expenditures. It was also possibly influenced by some level of competition with neighbors, since users can see their performance on the portal. However, the opportunities for socialization of technology and

fostering demand side behavioral changes appear to hinge on the level of technological support provided.

It was also found that lower rates of engagement with technology (observed in low-income households) seemingly correspond with lower rates of energy saving actions (also observed in low-income households). This can be mostly explained by the lack of any obstacles in acquiring the freely provided technologies to customers with high-speed internet (for digital picture frames) or central air-conditioning (for smart thermostats). These actions included avoiding usage of energy intensive household appliances, discussing energy conservation issues with family, pre-cooling homes in off-peak hours, adjusting air-conditioning temperatures, and vacating households and/or avoiding activities inside the home. This willingness to make behavioral changes could be attributed to the postulation that these high-income households readily utilized the technology to make informed decisions about saving energy. The higher participation in energy saving activities is also mostly likely the natural result of a higher exposure to additional reminders that the high-income received from their in-home technology devices such as the digital picture frame and the WorcesterSmart web portal. Such reminders were messages from the utility that provided electricity usage information, real time pricing, which are vital in guiding more informed decisions about energy usage. As demonstrated in this case, utilities, as socialization agents, have an important role to influence demand side energy consumption behavior through three key strategies. The first strategy is the provision of

smart in-home technologies such as smart plug control devices and smart thermostats. Second, is a provision of energy consumption feedback via a digital picture frame and Internet portal. The third key strategy is real-time pricing plans.

Based on this finding, utilities, government and companies that design smart grid technology could collaborate as important socialization agents. They could encourage customers to participate in energy saving behavior by increasing access to smart grid in-home technology that don't require, for instance, central air-conditioners or access to high-speed internet. Thus, smart grid programs implemented in the future should consider affordable access of smart grid in-home technology to all households when designing smart grid programs. For socialization of smart grid technology to be successful, the smart user should be assisted through the four phases of socialization mentioned earlier. For instance, upon recruitment of the customer into the smart grid program, socialization agents could collaboratively facilitate arrangements with householders to obtain the requirements needed for the in-home technologies like digital picture frames. This could be achieved by partnering with internet providers to provide a discount on high-speed internet access based on participation in the smart grid in-home technology program. Additionally, utilities could focus on early adopters, learn from, and involve them as advocates for technology adoption and socialization to other customers.

Findings suggest that convenience and usability is critical to successful engagement with smart grid technologies and fostering of energy reducing behaviors. Research from the consulting firm revealed that customers in Level 2 saved the highest amounts of energy. Since the picture frame is a defining feature of this package, this suggests that the picture frame was the most influential device in fostering energy saving behavior. These picture frames can be placed in the kitchen, living room or wherever customers prefer. The convenience by which communication from the utility reaches the customer through onscreen messages is an important feature of this device. This could be considered easier to use compared to the smart thermostat, load control devices and WorcesterSmart portal. For these, a customer has to undertake an extra step of logging into a device to monitor energy usage. Utilities should therefore consider the convenience afforded by devices like digital picture frames, relative to other technologies, to encourage energy saving behavior. Most consumers do not have or wish to create time to think about energy. Others do not like the inconvenience associated with the obligation of logging onto an online system to view energy use data (Goulden, 2014; Simchak, 2011). Generally, energy users are individuals prioritizing comfort and interested in simplicity (Skjølsvold, 2015). This is a key take away for successful socialization of technology. Utilities and marketing companies should aim for maximum levels of simplicity and convenience for smart devices to successfully engage customers.

SES customers saved energy and therefore also money by participating in the program. This ranged from an average of \$20 rebates for the Conservation Day Rebate plan (devised using Peak Time Rebate [PTR] pricing structure) customers to an average of \$109 for Smart Rewards Pricing (designed using a combination of Time of Use [ToU] and Critical Peak Pricing [CPP] pricing structures) customers. This could be attributed to the actions taken to conserve energy during Conservation Days and probably some form of shifting energy demanding activities to periods when the electricity rates were low. It is postulated that the most important savings occurred through interaction with technology. The total of these energy savings equates to a 2,300 MWh reduction for calendar year 2015 for 10,849 participating households. This translates to 17 kWh a month per customer on average reduction. Although this could appear as an insignificant achievement, this reduction was only by residential customers and does not factor in commercial clientele. The utility was impressed with this reduction since it was not expecting massive energy efficiency savings with the pilot and its main focus was on shifting peak demand. The utility's goal through the entire SES program was a 5% reduction in energy and demand savings. This has been achieved and continues to be exceeded with the program in session.

Although participants in the program experienced energy savings, there is a foreseen possibility of future rebound effects, also known as the "Jevons paradox". This states that energy efficiency gains result in an overall increased use of resources rather than reducing energy consumption (Sorrell, 2009). For instance, 11% of high-income and 6% of low-

income respondents chose to seek activities outside home during peak event hours. Though these customers avoided staying in the house in an effort to save energy, the alternative actions taken might also have resulted in the consumption of other forms of energy such as gas while driving to seek for alternative ways to spend their day and also other energy expenditures. Projecting this situation on a large scale, smart grid programs might end up saving energy in the indoor household setting but increasing use of energy and other expenditures outside the household unit. It could be worth considering the influence of environmentally meaningful behaviors that would accompany the technological influences to enable the successful achievement of the goal of saving energy holistically. For instance, utilities could organize low-energy use community events during peak event hours that participating customers would be invited. At the very least, utilities could seek to educate customers on the importance of ensuring that environmental benefits accrued from electricity usage reductions were not offset by energy consumption elsewhere.

Socialization of technology, as mentioned before, depends on the collaboration of social agents amongst which customers play a key role. By providing the technologies, the utility empowers the customer to take charge of their energy consumption; however, as findings show that the adoption of technology should be carefully taken into account. The smart grid technologies (i.e. the smart meter, WorcesterSmart web portal, in-home display, smart thermostat and plug control) were provided for free to the customer in the pilot. If the SES program were to be expanded, this provision of free in-home technologies to a larger set of

customers might not be feasible. In such a situation, the utility would most likely be forced to cost-share the expenditure of acquiring the technology with the customer. Whether customers will be willing to burden a share of acquiring technology is yet to be seen, and would be an interesting topic for a future study. When designing smart grid programs, utilities should consider the suggestion to test the willingness of customers to adopt and copay for the in-home technology, as this study suggests that customers would financially benefit from installing such devices.

6.0 Conclusions

The main objective of this research was to examine customer behavioral responses to a smart grid pilot program (Smart Energy Solutions [SES]) by National Grid (the utility), implemented in Worcester, Massachusetts, USA. This research set out to fill a gap where consumers' response to the call to save energy in smart grid programs was examined. The study set out to determine if consumers are incentivized by real time pricing structures and use smart grid technologies to make decisions surrounding energy use reduction. Through the conceptual lens of "socialization of technology", this research determined how customers adopted and engaged with smart grid technologies, and the resulting changes in behavior from both these and pricing incentives from the utility. Customers across high-

income and low-income households and their interaction with the freely provided technology were studied.

Findings reveal that smart grid in-home technology can indeed be socialized. Collaboration is called upon of all the socialization agents—utilities, governments and marketing companies—to provide affordable in-home devices to the customer to promote successful intensification of socialization. Findings also showed that the majority of low-income households were not able to socialize with technologies, and use them to guide their decisions and energy management. This resulted in a lower number of energy saving behaviors despite a pricing incentive to save energy. Utilities ought to ensure that there are no major limitations inhibiting some customers from acquisition of smart grid technologies. The research also showed the difference in energy consumption with the introduction of SES across participating households. It was found that the real time pricing encourages the consumers to take action towards saving energy where customers are able to shift demand to when the rate is cheap.

Thus, influenced by the motivation to save money, and guided by technology, consumers in other smart grid utility experiments could be brought to align their activities appropriately in response to calls for energy conservation from power utilities. In effect, smart grid in-home technology provides information of energy use in the house and

influences the user to take actions to reduce energy consumption and for that reason save money in their electric bills.

7.0 Appendix: Tables with numeric figures for the graphs presented

| | Survey 1-NG 15337 7/9/2015 | | | Survey 2 - NG 15337B 7/29/2015 | | | Survey 3 - NG 15337C 9/28/2015 | | | Total High Income | Total Low Income |
|---------------------------|----------------------------|------------|-----|--------------------------------|------------|-----|--------------------------------|------------|-----|-------------------|------------------|
| | High Income | Low Income | Sum | High Income | Low Income | Sum | High Income | Low Income | Sum | | |
| Picture Frame | 19 | 14 | 33 | 22 | 10 | 32 | 23 | 9 | 32 | 64 | 33 |
| Thermostat | 6 | 6 | 12 | 11 | 0 | 11 | 13 | 3 | 16 | 30 | 9 |
| Plug Control | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 3 | 0 |
| My National Grid Account | 25 | 25 | 50 | 36 | 22 | 58 | 33 | 21 | 54 | 94 | 68 |
| Total Sampled Respondents | 40 | 40 | 80 | 40 | 40 | 80 | 40 | 40 | 80 | 120 | 120 |

Table 3 Number of High income and low income respondents that integrated technology:

| Technology | Average No. of high-income respondents that integrated in-home technology | Average No. of low-income respondents that integrated in-home technology | Average Total | High-income respondents | Low-income respondents | Average Total |
|---------------------------|---|--|---------------|-------------------------|------------------------|---------------|
| Picture frame | 21 | 11 | 32.33 | 53% | 28% | 40% |
| Thermostat | 10 | 3 | 13.00 | 25% | 8% | 16% |
| Plug control | 1 | - | 1.00 | 3% | 0% | 1% |
| WorcesterSmart web portal | 31 | 23 | 54.00 | 78% | 57% | 68% |
| Total sampled respondents | 40 | 40 | 80.00 | 100% | 100% | 100% |

Table 4: Average number of respondents that integrated technology across the three surveys

| | Survey 1-NG 15337 7/9/2015 | | Survey 2 - NG 15337B 7/29/2015 | | Survey 3 - NG 15337C 9/28/2015 | |
|--|-----------------------------------|----------------------------------|--------------------------------|-------------------------|--------------------------------|----------------------------|
| | High Income - Beginning of summer | Low Income - Beginning of summer | High Income - Mid summer | Low Income - Mid summer | High Income - End of summer | Low Income - End of summer |
| | Total | Total | Total | Total | Total | Total |
| Kind of Action Taken to reduce Electricity Use during Conservation Day | | | | | | |
| Discussed Energy Conservation with family | 4 | 3 | 7 | 12 | 3 | 15 |
| Pre-Cooled Home during morning off-peak hours | 2 | 3 | 5 | 5 | 8 | 11 |
| Changed the Temperature setting on Air Conditioning system to a warmer setting during peak hours | 4 | 3 | 7 | 13 | 9 | 16 |
| Sought Activities outside the home | 1 | 1 | 2 | 7 | 5 | 9 |
| Avoided use of certain appliances during peak event hours | 10 | 16 | 26 | 24 | 28 | 44 |
| Other | 12 | 5 | 17 | 11 | 2 | 21 |
| None | 4 | 6 | 10 | 1 | 1 | 4 |
| Unsure/Don't Know | 0 | 0 | 0 | 0 | 0 | 0 |
| Refused | 0 | 0 | 0 | 0 | 0 | 0 |
| Total Sampled Respondents | 40 | 40 | 80 | 40 | 40 | 80 |

Table 5: Kind of actions taken to conserve energy by high income and low income respondents

| | Average High Income respondents | Average Low Income respondents | Average Number of respondents per survey | Total High | Total Low | Grand Total | % High Income | % Low Income |
|---|---------------------------------|--------------------------------|--|------------|------------|-------------|---------------|--------------|
| Kind of Action Taken to reduce Electricity Use during Conservation Day | | | | | | | | |
| Discussed energy conservation with family | 8 | 3 | 11 | 24 | 9 | 33 | 20% | 8% |
| Pre-cooled home during morning off-peak hours | 5 | 4 | 9 | 15 | 12 | 27 | 13% | 10% |
| Changed the temperature setting on AC | 9 | 3 | 12 | 26 | 10 | 36 | 22% | 8% |
| Sought activities outside the home | 4 | 2 | 7 | 13 | 7 | 20 | 11% | 6% |
| Avoided use of certain appliances during peak event hours | 21 | 20 | 41 | 62 | 60 | 122 | 52% | 50% |
| Other | 8 | 6 | 14 | 25 | 17 | 42 | 21% | 14% |
| None | 2 | 4 | 6 | 6 | 13 | 19 | 5% | 11% |
| Unsure/Don't Know | - | - | - | 0 | 0 | 0 | 0% | 0% |
| Refused | - | - | - | 0 | 0 | 0 | 0% | 0% |
| Total Sampled Respondents | 40 | 40 | 80 | 120 | 120 | 240 | 100% | 100% |

Table 6: Average number of respondents that took action across the 3 surveys

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