Graduate Program in Sustainability Science – Global Leadership Initiative
Graduate School of Frontier Sciences

2018

Master's Thesis

Transition to a Smarter Energy Grid: Insight on Residential Energy Consumer's Intentions to Adopt Demand Side Management and Distributed Energy Resources

Submitted July 20, 2018

Adviser: Associate Professor Onuki Motoharu

Co-Adviser: Assistant Professor Kudo Shogo

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DEMAND SIDE MANAGEMENT AND DISTRIBUTED ENERGY RESOURCES

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ABSTRACT

Growing concerns over climate change, increasing energy demand, security and accessibility of energy supply and the socio-environmental risks following the Fukushima Daiichi nuclear disaster, have heighted the need to upgrade the currently unsustainable electrical infrastructure. As the 21st century progresses, these concerns increasingly applied social and regulatory pressure on the electric power industry to replace the traditional energy distribution paradigm. As such, the electric industry is poised to transform the current, centralized distribution network to one that allows the integration of distributed technologies into the energy infrastructure. This future electricity system is also known as smart grid, allowing the integration of information and communication technologies into the grid, which will enable a bidirectional flow of communication and electrical power between suppliers and end-users that will ultimately transform the passive residential energy consumers into active prosumers.

Moreover, it is believed by a number of researchers that the realization of the full potential of a smart grid is contingent on the residential electricity consumer's acceptance of new technologies and the behavioural changes that innately follow their implementation. As a consequence, this thesis employed a user-centric perspective in an attempt to gain an insight into the perceived and subconscious factors that drive residential electricity consumers, particularly (but not exclusively) those with low income, towards or away from demand side management and distributed energy resources.

A consumer survey from over 200 Japanese households (43 of which are considered as low-income households) was conducted in Kashiwa-no-ha district in Kashiwa City, Japan. This revealed that there is a clear correlation between low-household income and the need to reduce energy related expenditures through energy generation and conservation practices. In contrast, the results indicate that the respondents believe that they do not have enough information or support from the utility company with respect to how they can go about implementing this type of technologies in their household. Additionally, the majority of respondents expressed their fear with respect to the cost of the implementation and maintenance of these technologies.

Further, the comparative analysis conducted by the author demonstrates that the reputation of the utility company that operates within the boundaries of Kashiwa-no-ha is higher among the respondents residing in Kashiwa-no-ha Smart City than those residing in Kashiwa-no-ha districts 1-2-3. Remarkably, the analysis also suggested that both groups

(“traditional” and “smart grid” electricity users) displayed a similar score in the variable associated with the “affinity with technology”.

Lastly, the K-means clustering algorithm and hierarchical cluster analysis provided the author with three heterogenous groups. Segment A included young respondents with low income, Segment B contained middle aged respondents with high income and Segment C was comprised of elderly respondents with average income. The results of the analysis indicate that while Segment A had the highest motivation to adopt new technologies, they also faced the most barriers which prevented them from doing so. In contrast, Segment B displayed an average intention to adopt such technologies but had the least barriers that prevented them from doing so.

DECLARATION

I hereby certify that this thesis is my own manuscript, and the sources of the materials used have been duly acknowledged. I declare that this work has not been submitted to any other institution for the award of any academic degree, diploma or certificate. Any part of this thesis will not be reproduced without accurate acknowledgements.

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Name   Signature

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Date

ACKNOWLEDGEMENT

It is my great pleasure to acknowledge the roles of several individuals and organizations who were instrumental for the completion of my master's research.

First of all, I would like to express my sincerest gratitude to Professor Esteban Miguel, who encouraged me to pursue this project and essentially taught me the art of academia and research. I wholeheartedly enjoyed working in the research environment that was created by Professor Miguel, which could be characterised as one that stimulates and supports original thinking. His stoic patience, understanding, insightful guidance and assistance are greatly appreciated. I would also like to acknowledge the valuable inputs of Professor Shogo Kudo and Professor Onuki Motoharu who contributed significantly in shaping this project through several meetings that aimed at enhancing my knowledge and understanding of quantitative and qualitative data analysis.

I wish to acknowledge the support from the Monbukagakusho scholarship offered by the Japanese Ministry of Education, Culture, Sports, Science, and Technology (MEXT), without which this research would not have been materialized. Additionally, I wish to extend my gratitude to all the faculty members and staff of the Graduate Program in Sustainability Science - Global Leadership Initiative (GPSS-GLI) who each in their own way, guided me towards realizing my research goals.

Further, I extend my gratitude to the Kashiwa-no-ha respondents and all the stakeholders involved in this study for their support and cooperation during the data collection period, and their sincere responses to the household questionnaires that were administered.

Lastly, my deepest appreciation belongs to my family for their patience, support and understanding.

DEDICATION

Although these single, interconnected strings of information have been kindled by myself, they constitute but a mere fraction of the knowledge that has been or will be generated throughout the passage of time. Be that as it may, I wish to publicly share these findings to the interested parties and contribute in my own way to the betterment of humanity.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF TERMINOLOGY: ABBREVIATIONS

DSM	Demand Side Management
DER	Distributed Energy Resources

CHAPTER 1: INTRODUCTION

Over the last two decades, scientific studies have provided ample data to conclude that human activities are, with high certainty, the predominant causes of global warming (Cook et al., 2014). The energy industry, in particular, has become the center of attention as it significantly exacerbates climate change through the combustion of coal, oil and other fossil fuels which power the steam-driven turbines of traditional powers stations (Abdallah & El-shennawy, 2013). Although such inexpensive and readily available energy sources are considered crucial for socio-economic development, the combustion of these fuels is responsible for 40% of human-caused carbon dioxide emissions (United Nations, 2009); which in turn have contributed to the increase of global concentration of carbon dioxide from 360 ppm in 2000 to over 400 ppm in 2018. A recent projection from the 2016 report of the International Energy Agency estimated that by 2030 global energy demand will rise by approximately 50%, which will lead to a 55% increase of the global carbon dioxide emissions related to energy generation and transmission (Administration, 2016).

As the consequences of climate change are starting to be felt, international efforts to achieve sustainable societies are increasing. The ratification of Kyoto protocol, the United Nations Framework Convention on Climate Change and later the Copenhagen Accord and the Paris agreement have resulted in significant commitments by developed and developing countries alike to reduce greenhouse gas emissions (Meyers, Kim, Ward, Statham, & Frei, 2012).

Japan in particular, the third largest economy and one of the world's largest greenhouse gas emitters, has traditionally depended on fossil fuels as a source of energy, despite being practically devoid of fossil fuel resources (Portugal-pereira & Esteban, 2014). Consequently, the Japanese government incrementally introduced a series of regulations and policies that collectively aimed at reducing the national dependency on fossil fuels, which would in turn not only augment the national economy but also help Japan abide by internationally set environmental targets (Tokyo Metropolitan Government, 2007). To realize this goal, the government announced the "Basic Energy Plan" in 2010, which had the share of nuclear power capacity increase to 50% by 2030 (Vivoda & Graetz, 2015). The scope of the aforementioned strategy was meant to diversify Japan's energy portfolio with relatively inexpensive, emission-free base-load energy generation. However, following the Fukushima Daiichi disaster which occurred on March 11, 2011, nuclear energy became the center of attention and was stigmatized as a potentially threatening technology. As such, the Japanese government established the "Energy and Environmental Committee", with the task of evaluating the current and potential environmental footprint of the national electricity infrastructure. Upon considering the conclusion of the review and public opinion, the national government announced a new framework which aimed at completely eliminating the utilization of nuclear energy by 2030 (The Energy and Environmental Council, 2012). The energy demand gap would be met through initiatives that aimed at tripling the penetration of renewable energy sources, increasing the energy efficiency of the energy grid and extending the feed-in-tariff from solar power to other forms of renewables (DeWit, 2014).

It soon became evident that to accommodate such changes it is necessary to enhance the current electrical infrastructure with sophisticated, digital technologies that augment the communication between each stakeholder. Consequently, to build an open market and achieve higher levels of energy reliability and security while lowering greenhouse gas emissions, the concept of smart grid technologies emerged and attracted considerable interest in fields such as economics and electrical engineering (Coll-Mayor, Paget, & Lightner, 2007). Unlike the traditional grid, which is typically unidirectional in nature, a smart grid would enable bi-directional flow of information and electrical power between energy suppliers and end-users, which has the potential to ultimately transform the historically passive residential energy consumers into active prosumers[1] (U.S Department of Energy, n.d.), thus creating a more robust power system through the active participation of all the stakeholders involved in a community in activities pertaining to energy consumption and production.

It is in this energy context that an upgrade of the electricity infrastructure through smart grid technologies are projected to take an important role in Japan's future energy policies following the Fukushima Daiichi disaster. Initially, under the guidance of the Ministry of Economy, Trade and Industry of Japan, a total of four large scale smart grid communities were established in Kyoto, Yokohama, Kitakyushu and Toyata City as demonstration projects. The budget allocated for these operations amounted to 126.6 billion yen, of which 65% was derived from public funds and the rest from private investments (D. N. yin Mah, Wu, Ip, & Hills, 2013). In addition to these large demonstrative projects, small-scale smart cities have incrementally sprout up in different regions within Japan, such as those in Tsuru City, Fujisawa Sustainable Smart Town and Toyama City among others. Although all aforementioned large and small scale smart city projects are noteworthy in their own respect, one small project in particular, Kashiwa-no-ha Smart City, has attained international attention over the last couple of years. Kashiwa-no-ha is located in Chiba prefecture 30 km away from the Tokyo Metropolitan area and has approximately 10.000 population. The project, in an attempt

[1] Energy end-users that both consume and generate electricity.

to address three contemporary socio-environmental issues (environmental degradation, super-aging society and economic stagnation) and increase the community's resilience against natural disasters, has designed a platform uniting three major stakeholders; the public sector, the private sector and academia. Through this partnership, this new urban area became the largest "smart" community to earn the platinum ranking under the Leadership in Energy and Environmental Design for Neighbourhood Development (LEED ND) plan rating system, devised by the U.S Green Building Council (Deininger & Yamamoto, 2017). In addition to the measures that are currently being implemented within the boundaries of the smart city project, Mitsui Fudosan, one of the three major shareholders of Kashiwa-no-ha, is planning to significantly invest in distributed energy resources (such as small-scale energy generators and storage devices in order to further reduce CO2 emissions by 60% by 2030). Moreover, to facilitate this transition to a "greener" future, Mitsui Fudosan has installed a number of smart meters within the premises of a number of residential households. Although these remain largely one-dimensional as of 2018 (i.e. they are only able to send, but not receive information), they could be utilized in the near future as a means of facilitating the transformation of these households to ones that both generate and mindfully conserve electricity.

In light of such projected advantages, a number of authors maintain that residential energy consumers have the potential to play a central role in the successful implementation of future smart grid projects (IEA, 2009). On one hand, well-informed, price responsive energy consumers can significantly contribute to energy savings and peak load shifting through the utilization of smart meters and smart, eco-friendly appliances (Nye & Whitmarsh, 2010); technologies that constitute demand side management (DSM)[2]. On the other hand, energy consumers can assume the role of prosumers and increase the penetration of renewable energy through the utilization of distributed energy resources (DER) (D. N. Mah, Marinus, Vleuten, Hills, & Tao, 2012); devices such as small-scale wind-turbines, photovoltaics and energy storage systems. Such is the importance of consumer engagement in smart grid projects that some authors argue that without the involvement of energy consumers, smart grid initiatives risk failing to reach their true potential (Honebein, Cammarano, & Boice, 2011). Hence, the meticulous utilization of sophisticated smart grid technologies such as demand side management and distributed energy resources could in theory grant the opportunity to many households to reduce their energy related expenditures while contributing to the overall socio-environmental

[2] Demand side management is the modification of consumer's demand for energy through various methods.

sustainability of the electricity infrastructure (Energy, n.d.; Eurelectric, 2011; Faruqui, Harris, & Hledik, 2009; Giordano et al., 2013; P., 2010).

Despite such projected advantages, residential consumer intentions to adopt both demand side management and distributed energy resources have not yet received much attention in literature. Amidst the growing body of studies regarding the implementation of smart grids, research efforts related to consumer engagement have focused predominantly on the adoption of specific technologies, rather than consumer's attitude towards energy saving and energy generation as a general concept. For instance, Goto and Ariu (2009), collected data regarding the adoption of two energy generation technologies (photovoltaic; gas based combined heat and power) by the residential sector and identified that usability, energy cost and health are all important aspects that motivate consumers to adopt micro-generation (Goto & Ariu, 2009). Another research conducted by EcoAlign (2011), surveyed a number of households in an attempt to examine residential consumer's perception regarding the different services that become available through the smart grid. The research concluded that although residential consumers believe that smart grids may provide ancillary services to all stakeholders involved in smart grid projects, their concerns regarding "privacy", "security" and "loss of control" constitute significant barriers preventing them from becoming actively engaged in energy related activities (Wimberly, 2011). Chan-Kook Park et al (2014), surveyed a number of energy consumers in three metropolitan areas in South Korea in order to identify which factors influence residential energy consumer's smart grid acceptance. The authors highlight the need to educate consumers regarding the importance of smart grids in order to mitigate the anxiety related to the risks that follow the adoption of smart grid technologies (Park, Kim, & Kim, 2014).

This research thus contributes to the emerging but finite literature regarding the importance of consumer engagement in smart gird projects by addressing three critical issues that were identified as research gaps in the field of smart grid technologies.

First, the author identified that studies regarding the methods of consumer engagement that can be employed to attract residential consumers, especially those with low household income, have remained relatively limited (Schwartz et al., 2017), particularly in the Asian context. As such, the first objective of this paper is dedicated towards delineating the factors that motivate and prevent residential energy consumers from adopting demand side management and distributed energy resources. This is achieved through the empirical testing of a conceptual model of the theory of planned behaviour on a representative group of Japanese households. In contrast to existing studies that focus on residential energy consumers as a whole, this objective aims to better understand the perceptions of lower-than-average income households.

Second, this research puts two distinct groups of residential energy consumers under the microscope. Particularly, it attempts to identify the differences between traditional and smart grid energy users, with respect to their intentions to generate and conserve electricity. The author believes that the information obtained through this objective will allow future researchers to evaluate which drivers / obstacles are of key importance in stimulating the interest of traditional energy consumers in smart grid technologies.

Third, although there is a need to identify and better understand the attitude, needs and values of residential energy consumers (Ellabban & Abu-Rub, 2016), current literature on the field of smart grid technologies does not segregate energy consumers into groups with defined characteristics (such as young people or those with low income). Instead, it targets consumers as a whole, through generalized incentive techniques (Gangale, Mengolini, & Onyeji, 2013). This suggests that the energy providers in charge of the implementation of a smart grid project have no means, as of yet, of systematically addressing the issues that sprout out through consumer feedbacks due to lack of inclusive knowledge with respect to the socio-economic characteristics of their consumers. Consequently, to bridge the gap between consumers and energy providers, the author further divides the target groups into three distinct categories that could arbitrary be categorised as young, middle aged and elderly energy consumers.

The remainder of the paper is structured as follows. Chapter 2 provides an analytical introduction to the conceptual model of the theory planned behaviour that was utilized throughout the extension of this research. Additionally, it develops the hypotheses that, according to the author’s assumption, describe the relationship between the personal motives of the consumers and their actual intention to generate and conserve electricity. Chapter 3 scrutinizes the methodology that was utilized in this study. Chapter 4 delves into the research findings of the empirical analysis, and Chapter 5 provides the lessons learned throughout this thesis and suggests directions for future research. Finally, Chapter 6 concludes.

CHAPTER 2: THEORETICAL DISCUSSION

2.1 Research model and theory of planned behaviour

To understand each household's intentions to change their behaviour in order to accommodate demand side management and distributed energy resources, the author employed the widely used theory of planned behaviour, developed by Azjen and Fischbein (Ajzen & Fishbein, 1977). This principle essentially constitutes an extension of the theory of reasoned action (Fishbein & Ajzen, 1975, 1981), and was designed to overcome the original theory's limitations in dealing with unconscious or non-volitional behaviour (Ajzen, 1991). Ever since its establishment in 1977, it has been refined by several authors (Holbrook & Havlena, 1988) and has been utilized extensively in socio-environmental behavioural studies, including but not limited to research in energy consumption (Jackson, 2005), energy conservation (Barr & Gilg, 2007) and green electricity for domestic purposes (Arkesteijn & Oerlemans, 2005).

The model of planned behaviour that the author propose for this research has been adapted from an earlier version developed by Leenheer et al (Leenheer, de Nooij, & Sheikh, 2011). The main difference between the original and the proposed model is that the latter expands the boundaries of the second hypothesis ("perceived price") of the former. Particularly, the model used in this thesis divides this second hypothesis into two sub-categories, namely "features of electrical supply" and "interest in additional information". Additionally, the author chose to forgo the sixth hypothesis of the former model as power outages in the form of blackouts or brownouts do not constitute issues of concern in the context of Japan.

The model proposed focuses predominantly on the assumption that the energy-related behaviour of residential consumers is driven by their attitudes (i.e. reputation of energy provider), subjective norms (i.e. environmental awareness) and perceived control (i.e. affinity with technology). These three independent variables are believed to positively or negatively influence a given household's intention to generate and / or conserve electricity, which in turn, could lead to a change of consumer behaviour. Though this model is based on the assumption that the intentions and behaviour are strongly related to one another, it is important to note that other external factors could also influence a household's energy-related behaviour. These external factors consist of the availability and accessibility of smart grid technologies, governmental subsidies, regulations related to the management of a building / neighbourhood, etc.

With that said, throughout the extension of this paper the author chose to focus explicitly on describing the relationship between the three independent variable groups and the household's intentions to generate and conserve electricity. The process of transformation of consumer's intentions to actual behaviour over a certain period of time and through the influence of external factors is deemed to be outside the scope of this study for a number of reasons. First, there are very few residential communities that have been known to collectively generate power and systematically conserve their electricity consumption in a timely and coherent manner over a significant period of time (Williams, 2010). As such, a behavioural study of any given residential community would only shine light on early adopters of smart grid technologies, which are arguably not representative of the population as a whole. Furthermore, although external, supply-side factors are today considered as highly influential with respect to their role in engaging energy consumers in energy generation and conservation activities (Scarpa & Willis, 2010), the roll-out of smart grid technologies is projected to empower residential consumers, thus diminishing the monopolistic authority of large utility companies over energy provision (Parag & Sovacool, 2016). As such, this thesis will follow the assumption that the only limitations that residential energy consumers face towards producing and conserving electricity are limited to the extension of their very own intentions.

The following chapter will scrutinize the six hypotheses that, according to the assumption stated earlier, influence a given household's intentions to generate power and conserve electricity through distributed energy resources and demand side management, respectively. These hypotheses are derived from the theory of planned behaviour, which is illustrated in **Figure 1** below.

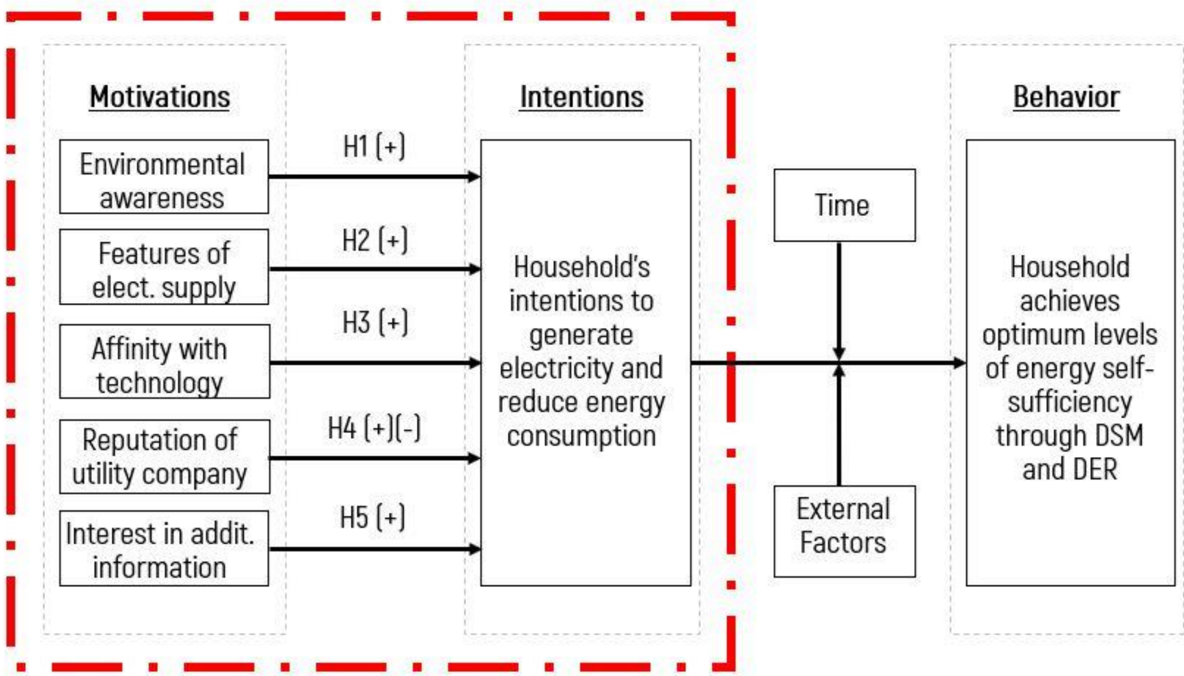

Figure 1: Theory of planned behaviour, adapted from Leenheer et al *(Leenheer et al., 2011)*

2.2 Hypotheses

Hypothesis 1: Environmental awareness positively influences a given household's intention to conserve electricity and generate power.

In the past, a number of authors had made the case that our society's environmental problems stem predominantly from the values, attitudes and overall beliefs that underlie the structure of our civilization (Disch, 1970). For instance, the rapid industrial growth that occurred during the twentieth century was marked by a laissez-faire type of economic development, which focused on the continuous expansion of production and consumption and laid strong faith in science and technology. This devotion towards uncompromised financial growth and prosperity laid the foundation for the environmental degradation that citizens of the world today have come to find deeply unsettling. On the other side of the spectrum, previous studies have conversely indicated that there is a strong correlation between environmental awareness and activities related to environmental activism (Stern, Dietz, Abel, Guagnano, & Kalof, 1999). Particularly, some authors maintain that the extent to which households are concerned about the environment influences their decision to conserve electricity and utilize "greener" forms of energy (Poortinga, Steg, & Vlek, 2004). Thus, the first hypothesis conceptualizes this positive attitude of environmental awareness as a collection of values that unconsciously motivate residents to conserve electricity and generate their own power, potentially through demand side management and distributed energy technologies respectively.

Hypothesis 2: Certain features of electricity supply positively influence a household's attitude towards energy conservation and micro-generation.

Financial factors are considered as remarkably influential with respect to their role in driving residential consumers towards or away from energy-related technologies and utility companies (Sauter & Watson, 2007). When grid-purchased electricity is considered as relatively expensive and / or it's price is expected to increase, end-consumers (particularly those with low household income) might attempt to attempt to reduce their energy-related expenditures by searching for alternative forms of electricity. Traditionally, residential consumers would be directed towards a cheaper energy supplier, though advances in technology could also allow them to either reduce their energy consumption through sophisticated technologies such as smart meters, or even generate electricity at their own premise, as prosumers. Moreover, in addition to these aforementioned financial factors, studies reveal that other, non-economic factors constitute significant barriers and motivations for the uptake of smart grid technologies (Faiers, Cook, & Neame, 2007). Consumers decision to adopt a "green" attitude towards energy generation and consumption is affected by a range of factors such as potential social and environmental risks, inadequate information or bounded rationality (Chesshire, 2003). As such, for the second hypothesis the author argues that a number of potential features of electrical supply, such as lack of opportunities to choose between energy sources / suppliers and the impact of the energy supplier on the community, influence a household's intention to adopt demand side management and distributed energy resources.

Hypothesis 3: Affinity with technology positively influences a household's intention to conserve electricity and generate power.

Prior to the final selection of a product or a service, consumers inevitably undergo a series of information processing (a.k.a. perceptual selectivity) wherein they are called to evaluate a portion of the stimuli to which they are exposed (Solomon, Bamossy, Askegaard, & Hogg, 2007). According to a number of authors, when these segmented stimuli are processed, they are unconsciously amalgamated into three district categories; individual, technological and implementational (Mahbob, Wan Sulaiman, Wan Mahmud, Mustaffa, & Abdullah, 2012). These arbitrarily refer to the characteristics and the ability of an innovative idea to meet the requirements of an individual on a personal and societal level. Of greatest interest for present purposes, however, is the second category, which asserts that a higher knowledge and expertise alongside a positive perception with respect to the usage of a technology are likely to strengthen the intention of an individual to accept new technologies (Schaper & Pervan, 2007). In the same vein, for the third hypothesis the author maintains that there is a direct, positive correlation between the ability of an individual to process technical information and the rate of which the same individual adopts innovative technologies.

Hypothesis 4: A negative socio-environmental reputation of energy utility companies positively influences a household's intention to conserve electricity and generate power, and vice versa.

Corporate social responsibility (CSR) has emerged in recent years as a concept that promotes self-regulation amongst private entities aiming at bridging the gap between a given company's attempt to maximize its shareholder's value and decrease the environmental footprint related to the company's activities. Arguably, one of the dominant reasons that drive private entities towards socio-environmental sustainability is CSR's increasing influence on consumer behavior (Sen, Bhattacharya, & Korschun, 2006). In addition to the provision of high quality products at a reasonable price, well informed and educated consumers expect organizations to contribute to the welfare of the community and society as a whole through environmental (e.g. reduction of CO_2 emissions) and social (e.g. creation of jobs) activism (Marin, Ruiz, & Rubio, 2009). This increasing demand for corporations with high socio-environmental concern means that, in contrast to the past, energy utility companies now need to act in an economic, philanthropic, ethical and environmentally responsible way if they are to remain competitive and operational (Maignan, 2001). On a sequential perspective, the author follows the assumption that residential consumers who perceive the actions of an energy utility as irresponsible towards the environment or the society as a whole will start searching for alternative methods of meeting their energy demand. Under such circumstances, the reduction in energy consumption alongside the generation of electricity could become two financially accessible options for environmentally concerned energy consumers. On the other side of the spectrum, if the reputation of a given energy utility company is high, then that could prevent end-users from adopting a behavior that reduces their environmental footprint as energy consumers. To derive a conclusion regarding the relationship between consumer behavior and the reputation of the energy utility, the author drew the hypothesis that the reputation of the energy utility positively or negatively influences a household's intention to adopt demand side management and distributed energy resources.

Hypothesis 5: The interest in additional energy-related information positively influences a household's attitude towards energy conservation and micro-generation.

Consumers' intrinsic psychology is considered by a number of authors as an underpinning factor which significantly influences their daily habitual activities (Brodie, Ilic, Juric, & Hollebeek, 2013). As such, alongside the external factors that were aforementioned throughout the introduction of the second hypothesis, consumers' own beliefs and perceived needs play an important role in driving the consumer towards the use of sophisticated smart grid technologies (Geelen, Reinders, & Keyson, 2013). Furthermore, given that the concept of a Smart Grid is centered around the idea that it empowers consumers in a way that allows them to have greater information and control over their energy consumption and production (Chandler, 2008), the author makes the following deduction: consumers who find interest in attaining additional information about their community's energy consumption (e.g. the exact source used for the production of their electricity) and production (e.g. the electricity production rate of other prosumers) would be highly positive towards the adoption of smart grid technologies. Therefore, although an interest in additional information does not by itself constitute a drive towards the adoption of new technologies, it could be used as a catalyst to provoke behavioral change. Consequently, for the fifth hypothesis the author maintains that interest in additional energy-related information positively influences the intention of residential consumers to adopt micro-generation and energy conservation behavior.

CHAPTER 3: METHODOLOGY

3.1 Household surveys and data collection

To bring light to the research gaps that were mentioned in the introduction, the author conducted a questionnaire survey within the boundaries of Kashiwa-no-ha. To start with, in order to ensure the validity and reliability of the methodology, the author chose to conduct a preliminary test-survey amongst 20 households. The pilot survey that was carried out aimed at testing the clarity of the questions, allowing the author to identify possible mistakes in the translation. Following the test-survey, slight modifications were made. Once the author was satisfied with the questionnaire, the real survey questionnaire was distributed. Although the questionnaire was initially designed in English, it was translated to Japanese prior to distribution, to avoid any implications that may have arisen due to misinterpretation.

The communities included in the survey were Kashiwa-no-ha Smart City and Kashiwa-no-ha districts 1-2-3, which are comprised of smart-grid users and traditional energy users, respectively. The questionnaire survey was conducted for 16 days, from 1st to 16th of September 2017, using a representative sample of 650 residential electricity consumers; 325 traditional energy users and 325 smart grid users. **Figure 2** below illustrates the location of these two distinct communities.

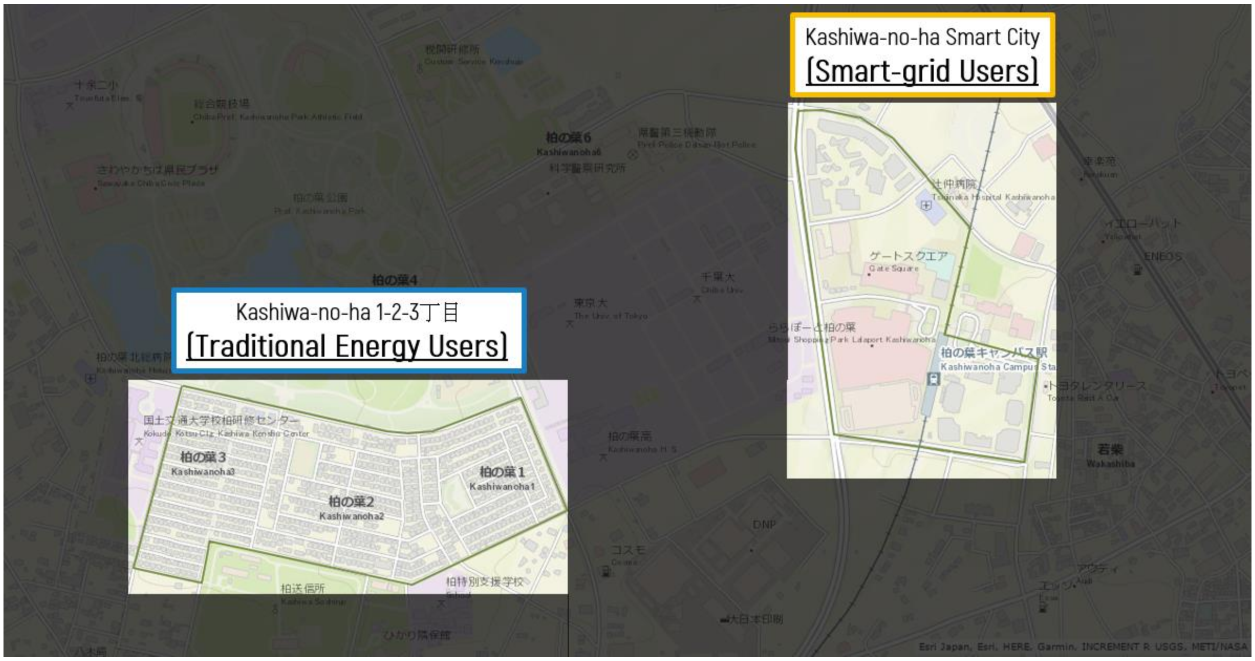

Figure 2: A Map of Kashiwa-no-ha illustrating the locations were the questionnaire survey was conducted.

Through a method of random sampling, the author estimated that the sampling error was approximately ± 6.7 with a confidence level of 95%. This essentially indicates that our results are within ± 6.7 points away from the real answer for the population as a whole, 95 times out of a 100[3]. To increase the consistency and accuracy of the answers, the author advised each household to allocate the task of filling out the questionnaire to the "household head" or, ideally, to the person who is responsible for the household's energy related decisions. Following the completion of the questionnaire, each household was instructed to mail it to the premises of the University of Tokyo, using the pre-paid stamp that was included inside the folder that contained the questionnaire.

3.2 Data analysis method

Initially, respondents were asked to report their perspectives on a number of issues including their concerns about the environment, intention to generate power and conserve electricity, interest in additional energy-related information /

[3] The population of the two representative communities within Kashiwa-no-ha is estimated at around 5,625 (Municipality of Kashiwa City, 2015, 2018). To determine the required sample size, we utilized the approach developed by Rea et al (Rea & Parker, 1997) in 1997; $n = \left[\frac{Za/_2\,\sigma}{E}\right]^2$ where n is the sample size, $Za/_2$ is the critical value, σ is the population's standard deviation and E is the acceptable sampling error.

services and affinity with technology, as delineated by the model of the theory of planned behaviour outlined earlier in this thesis. In addition to the above questions, which were directly connected to our five hypotheses, the questionnaire obtained information relevant to the household's demographic characteristics, such as the age, gender, occupation and education level of the respondent, as well as the average monthly income of the household in question.

The aforementioned issues were presented to the respondents in the form of pre-formulated statements, on which they were called to denote to what extent they agreed or support them. With the exception of the demographic items, all constructs were presented through a 5-point Likert scale[4]. Although Likert-type scale is often used interchangeably with numerical rating scale, the author chose the former psychometric 5-point scale for two reasons. Firstly, the constructs of the present research measure sensitive elements that are prone to observational error, such as intentions and behaviour, and thus multi-item scales (such as that provided by Likert scales) present higher reliability than single-item scales (Cooper & Schindler, 2008). Secondly, the author opted for 5-point instead of the commonly utilized 7-point Likert scale because, as Matell and Jacoby point out (Matell & Jacoby, 1971), fewer options provide higher outcome reliability when an author attempts to survey a target group which is untrained and potentially disinterested in a given subject. The product of this thesis which displays the exact formulation of the constructs, can be found in **Table 10**, located in the Appendix.

Furthermore, in order to test the internal consistency of the variables at hand, the author calculated Cronbach's α for each multi-item construct. Following Tavakol et al's suggestion, the author assumed that the acceptable value of alpha ranges from 0.70 to 0.90 (Tavakol & Dennick, 2011). That is predominantly because a low value of alpha indicates a poor interrelatedness between items, while a high value may suggest potential redundancies. Following the statistical analysis, the author decided to remove a small number of items from the scales, to increase the overall reliability of the results. Although the construct related to environmental awareness was measured through five items, respondents were instructed to choose only one of them, as such it could not be measured for internal consistency. The second construct, which measured the features of electrical supply which end-users could be interested in, was comprised of six items and had an initial Cronbach alpha score of 0.65. Upon closer examination, however, the author identified that forgoing the second item "Electricity tariffs should encourage energy saving", could grant a higher score of 0.69.

[4] 1=Very important, 2=Important, 3=Neutral, 4=Of little importance, 5=Unimportant

As such, although it is indeed slightly lower than 0.70, the author assumed that it is highly reliable and continued with the scale as it was. The third construct, which attempted to understand the end-user's affinity with the technology, was formed out of five items and offered a Cronbach alpha score of 0.83. For measuring the fourth construct, related to the reputation of the electricity company, the author utilized five items. Although the initial Cronbach's alpha score was 0.53, the author increased it to 0.89 by dropping the fifth item "My electricity supplier's activities are centred only around activities related to direct generation of profit" from the list. The fifth construct, which examined the interest of the respondents in additional energy-related information / services, was measured through three items. The score was deemed acceptable as it was estimated at 0.72.

Finally, in addition to the aforementioned five constructs, the author included four questions pertaining directly to the understanding of the factors that motivate and prevent residential electricity consumers from adopting demand side management and distributed energy resources. These served as dependent variables and facilitated the understanding of the perceived and unconscious factors that drive a consumer towards or away from smart grid technologies. The intention to generate power is measured through five items, and has a Cronbach's alpha of 6.99, which was deemed as acceptable. The intention to conserve electricity was measured through four items and had Cronbach's alpha of 0.77. For the factors that prevent residential consumers from generation their power, six items were utilized, which identified a Cronbach's alpha score of 0.76. On the other hand, for the factors that prevent consumers from conserving electricity, the author also utilized six items, and calculated a Cronbach's alpha score of 0.70.

CHAPTER 4: RESULTS

4.1 Demographic information

The response rate of the questionnaire survey was estimated at 32%, or 207 responses out of the 650 questionnaires that were delivered (100 and 107 responses for the first and second group, respectively). The analysis on the first group (i.e. smart grid users) indicates that over 70% of the respondents were male of varying age groups ranging, from relatively young (20 – 39 years old – 28%) to middle aged (40 – 59 years old – 35%) and elderly (60+ – 35%). Approximately three-fourths of the respondents had acquired a bachelor's degree or equivalent and were employed full-time (71%). Their median monthly household income ranged predominantly from average (47%) to high (37%)[5]. On the other hand, although the respondents of the second group (traditional energy users) were also predominantly male (77%), the data show that approximately three-fourths (71%) of the people answering the questionnaire could be considered as elderly citizens. Though their education status resembled that of the first group, 54% of the respondents had already retired or were taking part in a part-time activity (42%) and had a median monthly household income ranging from low (35%) to average (46%). For more information look at **Table 1** below.

[5] The statistical data related to the average monthly income of Japanese households were divided into three distinct categories based on the data released by the Ministry of International Affairs and Communications of Japan (Ministry of Internal Affairs and Communications, 2007). In particular, they were divided into: Low-Income Households (0 – 249.999¥), Average-Income Households (250.000 – 549.999¥) and High-Income Households (550.000¥ or more).

Table 1: Demographic characteristics of the two case studies.

	Smart Grid Users		Traditional Grid Users	
Demographics	**Frequency N**	**Valid Percent (%)**	**Frequency N**	**Valid Percent (%)**
Gender				
Male	74	74.7	82	77.4
Female	25	25.3	24	22.6
Age				
20 - 39	28	28.6	15	14.2
40 - 59	35	35.7	20	18.9
60+	35	35.7	71	67
Education				
Secondary education	8	8.1	24	22.6
First stage of tertiary education	75	75.8	73	68.9
Second stage of tertiary education	16	16.2	9	8.5
Occupation				
Employed	66	66.7	41	39
Unemployed	6	6.1	20	19
Student	5	5.1	1	1
Retired	16	16.2	34	32.4
Housewife	6	6.1	9	8.6
Income (JPY)				
0 - 249.000	12	14.6	31	35.2
250.000 - 549.999	39	47.6	41	46.6
550.000+	31	37.8	16	18.2

Note that the above table presents only the "Valid Percentage" of the responses, meaning that all missing data were excluded from the calculations.

Moreover, although the aforementioned demographic analysis divided respondents into essentially two heterogeneous groups, the distinction between the two was only utilized for the second research objective, which aims to explore the response differences between residential electricity users that do and do not use smart grid technologies. The following three sections that are presented below, namely the univariate, bivariate and multivariate analysis, are dedicated towards the statistical analysis of the first objective, and as such aggregate the above two groups into one, which is characterised by one prevalent variable; low household income.

4.2 Univariate analysis

Although the scale was comprised of five response units (value 1 being the highest and value 5 being the lowest), the variables that were measured throughout this analysis displayed noticeable response variation. The environmental awareness of the households could be characterised as relatively high, as most respondents stated that they believe in climate change and do indeed support actions that aim towards increasing the penetration of renewables and the reduction of energy consumption. Furthermore, the reports indicate that even though the households are interested in both power generation and energy conservation, they face several challenges that prevent them from adopting technologies that would allow them to do so. **Table 2** below displays the descriptive statistical analysis of the dependent and independent variables for all low-income households (N=43 or 20.77% of all respondents).

Table 2: Descriptive statistics: Min-max values, means and standard deviations of study variables.

Variables	Minimum	Maximum	Mean	Std. Deviation
Dependent				
Intention to generate power	1	3.2	2.32	0.50
Intention to conserve electricity	1	3	2.01	0.49
Factors that prevent the generation of power	1	5	2.75	0.75
Factors that prevent the conservation of electricity	1	5	2.72	0.63
Independent				
Environmental awareness	1	3	1.92	0.53
Desired features of electrical supply	1	3.3	2.08	0.53
Reputation of electric utility	1.6	4.6	2.89	0.58
Desired information from electric utility	1	3	1.98	0.55
Affinity with technology	1	5	3.17	0.95

4.3 Bivariate analysis

In order to further investigate the factors that low-income households perceive as potentially inhibiting or motivating with respect to their influence on the intention to adopt smart grid technologies, the results of a one-way ANOVA analysis were inspected (see **Table 3**). To rid the reader from the presentation of unnecessary information, the four sub-dimensions below display only the items within the dependent constructs that exhibited noticeable difference between the three condition means (Sig. value is less than .05). The results of the ANOVA analysis suggest that "reduction of energy related expenditures" constitutes a factor that motivates low-income residential consumers to both conserve electricity and generate their own power. Particularly, the significance of this item is estimated at [$F(6.9, 72) = 7.9$, $p = .000$] and [$F(15, 104) = 11.9$, $p = .000$], respectively. Furthermore, "additional actions might bring further costs" and "insufficient information or support" are two factors that prevent low-income residential consumers from adopting energy conservation behaviour / technologies and micro-generation devices. Further, the items "additional actions might bring further costs" and "insufficient information or support" that represent the two factors that prevent consumers from conserving electricity are significant at $p<.01$ level for the three conditions [$F(56, 138) = 33.7$, $p = .000$] and [$F(74, 155) = 38.6$, $p = .000$] respectively. The same items are significant at [$F(44, 154) = 23.5$, $p = .000$] and [$F(37, 177) = 16.9$, $p = .000$] respectively as factors that prevent residential consumers from generating their own power.

Table 3: Analysis of variance (ANOVA) between low-household income and dependent variables.

Variables		Sum of squares	Df	Mean square	F	Sig.
Intention to conserve electricity						
Reduction of energy related expenditures	Between Groups	6.984	2	3.492	7.970	.000
	Within Groups	72.296	165	.438		
	Total	79.280	167			
Intention to generate power						
Reduction of energy related expenditures	Between Groups	15.298	2	7.649	11.981	.000
	Within Groups	104.702	164	.638		
	Total	120.000	166			
Factors that prevent the conservation of electricity						
Additional actions might bring further cost	Between Groups	56.848	2	28.424	33.773	.000
	Within Groups	138.026	164	.842		
	Total	194.874	166			
Insufficient information or support	Between Groups	74.054	2	37.027	38.694	.000
	Within Groups	155.976	163	.957		
	Total	230.030	165			
Factors that prevent the generation of power						
Additional actions might bring further cost	Between Groups	44.493	2	22.246	23.504	.000
	Within Groups	154.279	163	.946		
	Total	198.771	165			
Insufficient information or support	Between Groups	37.355	2	18.678	16.961	.000
	Within Groups	177.297	161	1.101		
	Total	214.652	163			

Following the identification of the factors which motivate and prevent low-income residential electricity consumers from adopting smart grid technologies, the author examined the statistically significant correlation between dependent and all hypothesized independent variables. The empirical analysis of the results indicates that in incongruity with the model and in contrast to previous studies (which focused exclusively on residential electricity consumers of all income (Leenheer et al., 2011)), three out of our five hypotheses do not significantly influence the intention of low-income households to adopt technologies pertaining to the generation and conservation of electricity (see **Table 4**). Indeed, the author identified that environmental awareness, affinity with technology of the end-consumers and the reputation of the utility company do not in fact correlate significantly with the factors that motivate or prevent consumers from adopting such technologies. However, as per the model's projection, the desire for certain features of electrical supply and an interest in additional energy-related information present a strong relationship with the dependent variables ($p < .00$).

Moreover, to scrutinize the relationship between the dependent and independent variables further, the author continued examining the data through a multivariate analysis that inspects all variables concurrently. The Variation Inflation Factor (VIF) amongst all of our independent variables was estimated at ($VIF < 3$), and thus conclude that multi-collinearity should not be an issue of concern.

Table 4: Pearson's correlation coefficient amongst dependent and independent variables.

Variables	Abbreviation	INTGENP	INTCONS	PREVGENP	PREVCONS	ENVAW	DERFEAELES	REPELEUT	DERINFELEU	AFFTEC
Dependent										
Intention to generate power	INTGENP		.000	.000	.019	.215	.006	.320	.001	.434
Intention to conserve electricity	INTCONS	.000		.000	.000	.530	.220	.651	.000	.840
Factors that prevent the generation of power	PREVGENP	.000	.000		.000	.159	.020	.641	.024	.586
Factors that prevent the conservation of electricity	PREVCONS	.019	.000	.000		.550	.047	.316	.001	.483
Independent										
Environmental awareness	ENVAW	.215	.053	.159	.550		.878	.641	.917	.122
Desired features of electrical supply	DERFEAELES	.006	.220	.020	.047	.878		.415	.191	.220
Reputation of electric utility	REPELEUT	.920	.651	.641	.916	.641	.415		.493	.748
Desired information from electric utility	DERINFELEU	.001	.000	.024	.001	.917	.191	.493		.452
Affinity with technology	AFFTEC	.494	.840	.586	.483	.122	.220	.748	.452	

4.4 Multivariate analysis

Table 5 summarizes the results of the multivariate regression analysis between the four dependent variables, the demographic characteristics of the participants and the two statistically significant independent variables. The dependent variables include "intention to generate power", "intention to conserve electricity", "factors that prevent the generation of power" and "factors that prevent the conservation of electricity". The variables directly associated with the initial hypotheses have been limited down to only two, namely the "desired features of electricity supply" and "desired information from electric utility". Further, the demographic characteristics included in the analysis are comprised of the gender, age, education level and occupation of the respondents.

Table 5: Results of the multivariate regression analysis[6].

Variables	**Intention to generate power**			**Intention to conserve electricity**			**Factors that prevent the generation of power**			**Factors that prevent the conservation of electricity**		
	B	**Beta**	**t**	**B**	**Beta**	**t**	**B**	**Beta**	**t**	**B**	**Beta**	**t**
Desired features of electrical supply	.248	.271	1.905*	-.025	-.030	-.196	.293	.249	1.369*	.210	.229	1.308
Desired information from electric utility	.418	.457	3.540**	.554	.651	4.782**	.382	.329	2.013*	.429	.476	3.029**
Gender	.093	.088	.655	-.020	-.021	-.145	.172	.128	.754	.164	.157	.964
Age	-.001	-.001	-.006	.035	.073	.725	.076	.112	.460	.014	.026	.112
Education	.193	.176	1.304	.288	.273	1.914	.251	.180	1.047	.208	.192	1.161
Occupation	.364	.463	2.412*	.111	.154	.752	.236	.235	.977	.087	.111	.481
Model's R^2	.577			.532			.347			.397		

"B" stands for unstandardized coefficient.
"Beta" stands for standardized coefficient.
*Significant at .05 level.
**Significant at .01 level.

The multivariate regression analysis conducted by the authors was divided into four parts, each one centred around one dependent variable. The first model centred around the "intention to generate power" and was significant at

[6] "B" stands for unstandardized coefficient whereas "Beta" stands for standardized coefficient.

($F=6.35$; $p \leq .001$) with R^2 of .577 whereas the second based on the "intention to conserve electricity" was significant at ($F=5.11$; $p \leq .001$) with R^2 of .532. The third model was significant at ($F=3.4$; $p \leq .05$) with R^2 of .347 and the fourth was significant at ($F=2.96$; $p \leq .05$) with R^2 of .397.

Following this analysis, the author identified that the desire for certain features of electrical supply have a positive influence on the household's intention to generate power by both motivating respondents and facilitating the process of overcoming their obstacles ($B=.248$; $t=1.905$) with $p < .05$ and ($B=.293$; $t=1.369$) with $p < .05$ respectively (confirming H2). The desire for additional information from the electric utility was found to have a positive influence on all dependent variables, thus confirming H5. Specifically, the analysis indicates that H5 was significant at ($B=.418$; $t=3.540$) with $p < .001$, ($B=.554$; $t=4.782$) with $p < .001$, ($B=.382$, $t=2.013$) with $p < .05$ and ($B=.429$; $t=3.029$) with $p < .001$ for the first, second, third and fourth dependent variables respectively. Moreover, as described in the previous section, environmental awareness, affinity with technology and the reputation of the utility company do not relate significantly to the dependent variables, and as such H1, H3 and H4 were rejected. Likewise, the author confirmed that although the occupation (full-time employment) of the respondents has a positive influence on the intention of the households to generate their own power ($B=.364$; $t=2.412$) with $p < .05$, all other demographic characteristics displayed no signs of positive or negative effect on the decision of the respondents to adopt smart grid technologies.

The next step is dedicated towards detecting and evaluating the relationship amongst the items listed under our dependent and statistically significant hypothesized independent constructs (**Table 6**).

Table 6: Relationship amongst the items under the dependent and independent variables.

Variables	Intention to generate power			Intention to conserve electricity			Factors that prevent the generation of power			Factors that prevent the conservation of electricity		
	B	**Beta**	**t**	**B**	**Beta**	**t**	**B**	**Beta**	**t**	**B**	**Beta**	**t**
Desired features of electrical supply												
Opportunities to choose between different energy suppliers	.276	.330	2.587*									
Opportunities to choose between different energy sources	.293	.409	2.736*									
Low electricity tariff							.228	.341	2.194*			
Desired information from electric utility												
Electricity consumption and generation of other users	.270	.477	3.197**	.238	.440	3.011**	.319	.412	2.482*	.242	.391	2.588*

*Significant at .05 level.
**Significant at .01 level.

The results show the desire for information relevant to the electricity consumption and generation of other users have significant impact amongst all dependent variables. The effect is estimated at (B=.270; t=3.197) with $p < .001$, (B=.238; t=3.011) $p < .001$, (B=.319; t=2.482) $p < .05$ and (B=.242; t=2.588) $p < .05$ for the first, second, third and fourth variables respectively. Further, the desire for additional opportunities to choose between different energy suppliers and energy sources influence the intention of consumers to generate their own power with a significance of (B=.276; t=2.587) $p < .05$ and (B=.293; t=2.736) $p < .05$, respectively. Lastly, the author identified that the price of electricity constitutes a direct inhibiting factor that prevents consumers from generating their own power. The significance of the last item is estimated was estimated at (B=.228; t=2.194) $p < .05$.

4.5 Comparative analysis

Prior to the analysis, the author firmly believed that the electricity consumers of each case study would display disparate signs of behaviour and beliefs. For instance, it was assumed that the electricity consumers who utilized smart grid technologies on a regular basis would have a higher affinity with technology and potentially higher environmental awareness than those that had never used them. However, in contrast to the initial assumption, the only statistically significant difference amongst the two groups was limited to the reputation of the utility company (Look at **Table 7**). Particularly, the Mann-Whitney test indicated that the utility company had a higher rapport with the smart grid users of the community and a lower rapport with the traditional energy users ($U=3870.5$; $Z= 3.10$) with $p < .05$. Note that although the demographic characteristics of the two groups display signs of a significant difference, this could be interpreted as case specific, and can be attributed to the chronological order of construction and general establishment of the two communities. Kashiwa-no-ha Districts 1-2-3 were established a number of years before the commencement of the project that brought forth Kashiwa-no-ha Smart City and as such the demographic status of the residents in these two areas are very different.

Table 7: The results of the non-parametric Mann-Whitney analysis.

	INTGENP	**INTCONS**	**PREVGENP**	**PREVCONS**	**ENVAW**	**DERFEALES**	**REPELEUT**	**DERINFELEU**	**AFFTEC**	**Gender**	**Age**	**Education**	**Occupation**	**Income**
Mann-Whitney U	4929.500	4915.500	5078.000	5032.500	4261.500	5032.000	3870.500	4771.000	4232.500	5110.000	3552.500	4236.500	3612.000	2541.500
Z	-.520	-.679	-.050	-.282	-.494	-.395	-3.102	-.324	-2.194	-.437	-4.275	-3.028	-4.266	-3.590
Asymp. Sig. (2-tailed)	.603	.497	.960	.778	.621	.693	.002	.746	.028	.662	.000	.002	.000	.000

4.1 Household segmentation

The concept of smart grids is projected to play a relevant role in limiting CO_2 emissions and addressing electricity over-consumption within the distribution network. Along with the implementation of sophisticated metering and other related technologies, the organizations in charge of the distribution system have devised a plan to motivate residential consumers to incrementally transform from passive to proactive actors of the electricity infrastructure by generating power and consuming electricity in a thoughtful manner. Though there are a number of benefits to be gained from the engagement of end-users, a given community's sensitivity to social changes is highly contingent on the aggregated socio-demographic characteristics of the households that it encompasses. As such, the next objective aims at providing insights to utility operators and policy makers regarding the perspective of Japanese households with respect to energy generation and conservation. The electricity consumers of the two case studies were aggregated and classified according to their socio-economic class (e.g. age, income etc.) The analysis was conducted using K-means clustering algorithm with a predefined number of clusters. A closer inspection of the results of the cluster analysis led the authors to believe that three clusters provided the highest coefficient value. To validate the results, the authors also run a hierarchical cluster analysis using Ward's method. Much like the results of the first analysis, the second test suggested that three clusters provide optimal results.

Table 8 below, describes the socio-economic profile of the three clusters. Though the respondents on all three clusters were predominantly male, Group A represents the highest concentration of female participants (34.1%). In contrast to the respondents within segments B and C, which indicated that they are residing in their own house (94.5% and 98% respectively), more than one third of Group A's respondents specified that they are living as tenants. Looking closer to the age distribution of the respondents, it is possible to notice that while segment A contains predominantly younger respondents aged 20 – 39 (70.7%), segment C contains mostly elderly citizens which are 60 years old or older (76.5%). Segment B lies somewhere in the middle of the spectrum, containing both middle aged (38.2%) and elderly respondents (54.5%). Further, Group A had the lowest income amongst the three groups (41.5%), while Group B had the highest (47.3%).

Table 8: Socio-economic profile of the segmented groups.

Demographic	Group A (%)	Group B (%)	Group C (%)
Male	65.9	92.7	74.5
House owner	56.1	94.5	98
Age			
20 – 39	70.7	7.3	0
40 – 59	29.3	38.2	23.5
60+	0	54.5	76.5
Income			
0 - 249k	41.5	3.6	23.5
250k - 549k	41.5	49.1	56.9
550k+	17.1	47.3	19.6

The final step of our analysis is dedicated towards determining the relationship between the three segmented households and the dependent and independent variables. The authors have identified that there is a significant variation amongst the answers of the three groups (**Table 9**). The analysis indicates that respondents within segment A (which contains the youngest population) have the highest motivation to generate power (2.07) and conserve electricity (1.82), thought they also face significant barriers that prevent them from doing so (2.52 and 2.6 respectively). Further, though segments B and C display the same attitude towards power generation and conservation (2.56; 2.13 and 2.54; 2.09 respectively), segment B faces the least barriers with respect to the adoption of new behaviour and technologies. Group C unveiled that they generally do not believe that their electric utility is operating in a socio-environmentally friendly way (with a score of 2.91 on the reputation of the utility company) and they have the lowest understanding of smart grid technologies amongst all groups (4.02). In contrast, Group B had the highest understanding of smart grid technologies (2.5), though the authors believe that this score is still relatively low, given that a score of 3 represented “I am not certain” to the question “are you familiar with the following technologies…”.

Table 9: Relationship between the segmented households and all dependent and independent variables.

	Households	INTGENP	INTCONS	PREVGENP	PREVCONS	ENVAW	DERFEAELES	REPELEUT	DERINFELEU	AFFTEC
Group A	41	2.07	1.82	2.52	2.6	2.02	2	2.5	1.79	3.34
Group B	55	2.56	2.13	3.43	3.48	1.87	2.17	2.54	1.94	2.5
Group C	51	2.54	2.09	3	2.93	2.22	2.18	2.91	2.05	4.02

*The above values are measured on a scale from 1 to 5, with the latter being the lowest. The results from the "PREVGENP" and "PREVCONS" constitute notable exceptions, because the values have been reversed (e.g. a low "PREVGENP" score indicates that the respondent has faced many challenges with respect to power generation).

CHAPTER 5: DISCUSSION

Throughout this thesis, the author maintains that the realization of the full potential of a smart grid is contingent on the residential consumer's acceptance of new technologies and the behavioural changes that innately follow their implementation. As a consequence, a user-centric perspective was employed by the author in an attempt to gain insight into the perceived and subconscious factors that drive residential electricity consumers, particularly those with low income, towards or away from DSM and DER.

5.1 Factors that prevent or motivate low-income consumers from adopting DSM and DER

Empirical data from over 200 Japanese households (43 of which are considered as having low-household income) reveal that the potential reduction of electricity-related expenditures constitutes the strongest driver that could lead low-income households towards the adoption of electricity conservation and generation practices. On the other side of the spectrum, a significant number of residential consumers expressed their concern regarding the up-front cost associated with the enablement of these technologies. This fear is only exacerbated by the lack of momentum of the utility company towards educating these consumers regarding the steps they have to undergo in order to transform from passive electricity consumers into active prosumers. As such, the lack of information and support from the utility company, and the fear of balancing the costs and benefits of the associated technologies, are deemed by the author as the two factors that prevent consumers from transitioning to smart grid users.

Further, the multivariate analysis in section 4.4 indicates that in incongruity with the model, three out of our five hypotheses do not significantly influence the intention of low-income households to adopt technologies pertaining to the generation and conservation of electricity. Indeed, this thesis has identified that in contrast to previous studies (Leenheer et al., 2011), environmental awareness, affinity with technology and the reputation of the utility company do not constitute factors that motivate or prevent low-income consumers from adopting such technologies. However, the desire for certain features of electrical supply and an interest in additional energy-related information present the strongest motivators that drive consumers towards smart grid technologies. Particularly, the results show that the opportunity to choose between different energy sources and suppliers could lead consumers towards generating their own electricity. This is interpreted by the author as an attempt by residential consumers to align their own actions and behaviour with those of the electric utility's. For example, customers may be more likely to support environmentally-friendly measures such as residential electricity generation when they are aware that their electric utility is taking measures towards enhancing the socio-environmental sustainability of the society as a whole. Furthermore, the provision of information regarding the energy consumption and generation of other users has been identified as another factor that could not only motivate low-income consumers to adopt smart grid technologies but also facilitate their attempt to overcome their obstacles. The provision of such information could enable households within a community to "compete" with their neighbours, with the ultimate goal of achieving maximum energy generation and minimum energy consumption.

5.2 Differences between traditional and smart grid electricity consumers

The results of the comparative analysis displayed in section 4.5 reveal that the only statistically significant difference amongst the traditional and smart grid electricity consumers was limited to the reputation of the utility company. Particularly, the test indicated that the utility company had a higher rapport with the smart grid users of the community and a lower rapport with the traditional energy users. Despite such evidence, the author would like to emphasize that this finding could likely be case specific. The residential electricity consumers that reside within Kashiwa-no-ha Smart City could likely feel privileged, given that their community enjoys exclusive benefits derived from the implementation of smart meters, in-home displays and a supervisory control and data acquisition system. These aggregated investments towards energy sustainability may have potentially led the residents of the area to believe that their energy supplier is actively engaged in environmentally-friendly practices. These findings could differ in case studies where such investments are targeting a wider audience, nation-wide. As such, future research should attempt to assess the generalizability of the findings presented in this section to other populations, predominantly to ones that showcase similar socio-political features.

On a side note, it is important to notice that the affinity with technology amongst the two groups was remarkably very similar. This indicates that although the residential consumers in Kashiwa-no-ha had smart grid technologies installed in their households, they were not particularly familiar with the way they operate. As such, the author believes that these households need to go through a follow-up training program, which could facilitate their understanding on not only how to use these technologies, but also the benefits that they derive from them.

5.3 The perspective of three distinct consumer groups on DSM and DER

The cluster analysis in section 4.6 concluded that the respondents in Kashiwa-no-ha could be categorised into three heterogenous groups. Arbitrary, the results indicate that segment A contains the youngest population with the lowest income amongst the three groups. These respondents have the highest motivation to generate power and conserve electricity, but they also face the most barriers that prevent them from doing so. Segment B contained middle-aged respondents with high average household income. Though the results indicated that these respondents were less motivated to adopt such technologies compared to those in Segment A, they faced the least barriers that could prevent them from realizing their intention. These findings align particularly well with the paper by Rogers, (1995), which maintains that a younger population is more receptive to the adoption of innovative ideas than an older one. As such, the author firmly believes that the electric utility should place extra emphasis on developing a variety of measures that aim towards engaging the needs of these two heterogeneous groups. Particularly, monetary incentives and other forms of financial compensations could be highly effective in facilitating young customers to overcome the challenges they are facing with respect to the adoption of new technologies such as electricity generation devices. On the other hand, education schemes should be developed to target older consumers, in an attempt to enhance their knowledge regarding innovative technologies and their role in supplementing the socio-environmentally sustainability of society as a whole. The structure of these educational programs, in the author's opinion, should be fully transparent and aim towards simplifying the potential risks, costs and benefits of the technologies associated with the smart grid. Following this perspective, it would be of particular interest for researchers to assess which communication tools and methods policy-makers and utility operations could utilize to effectively transmit this type of information to the residential electricity consumers.

CHAPTER 6: CONCLUSION

The electricity infrastructure of the 21st century is experiencing a renaissance, driven by the attempt of electric utilities and policy makers to address numerous contemporary challenges, such as generation diversification and the reduction of the overall carbon footprint of the electricity industry. In the debate towards overcoming such socio-environmental challenges, a number of smart grid technologies have come to the surface. Within the distribution network, the technologies that are incorporated within distributed energy resources and demand side management have attracted significant attention, as tools that can potentially engage the interest of one of the most dubious actors involved within a smart grid; the residential consumer. Throughout this thesis, the author maintains that the adoption of these technologies by the residential electricity consumers is essential if the utility operators are to exploit the full potential of a smart grid system.

Thus, to facilitate the attempt of utility operators and policy makers to understand the factors that influence residential electricity consumers to adopt demand side management and distributed energy resources, this thesis employed a user-centric approach, which aimed at answering three gaps in the literature.

First, the author attempted to understand the factors that motivate and prevent low-income residential consumers from adopting the aforementioned technologies. The aggregated results of the bivariate and multivariate analysis indicate the following: The potential reduction of energy-related expenditures, the provision of information regarding the energy consumption and generation of other consumers and the ability to choose between different energy sources and suppliers could motivate low-income electricity consumers to adopt DSM and DER. On the other hand, lack of information and support from the utility company, and the cost associated with the installment and operation of these technologies prevent this type of consumers from transitioning from traditional to “smart grid” consumers.

The second research objective attempted to identify the differences between traditional and smart grid energy users, with respect to their intentions to generate and conserve electricity. Although the results of this objective indicated that the reputation of the utility company differs amongst the two study cases, this could likely be case specific, and limited to Kashiwa-no-ha and other similarly structured residential communities. As such further research is needed on other populations, predominantly on some that showcase similar socio-political features in order to validate this finding.

Finally, the third objectives aimed at bridging the gap between consumers and energy providers, by scrutinizing three distinct residential consumer target groups. Given that all three groups represented different socio-demographic respondents, it is in this author's opinion that different measures should be implemented for each one. Particularly, the author believes that financial incentives and monetary compensations could be effective when targeting respondents within Segment A, while education schemes and training programs might be more useful on respondents from Segment B.

To the authors knowledge, this research represents the first study that has carried out a social experiment in the form of a questionnaire survey in Kashiwa-no-ha, focusing specifically on DSM and DER at the residential level. The aforementioned research findings of this paper supplement the growing but limited body of literature regarding the two aforementioned smart grid technologies by highlighting the factors that drive residential electricity consumers towards or away from power generation and energy conservation. Finally, although the results of this research are context specific (Kashiwa-no-ha / smart city), the author firmly believes that the findings can be generalized and utilized in other compact cities such as Tokyo, Beijing or New York, as they share common attributes such as high energy consumption, an urban design characterized by a mixture of modern and traditional residential buildings, alongside the need to accommodate for an increasing population density.

APPENDIX

Table 10: The list of items and constructs that were scrutinized throughout this thesis.

Constructs	Items
Dependent	
Intention to generate electricity	I want to be independent of the energy grid I want to minimize my environmental footprint I want to diversify the energy mix of my local grid I want to reduce my energy related expenditures Other…
Intention to conserve electricity	I want to minimize my environmental footprint I want to reduce my energy related expenditures I want to reduce my dependency on electrical appliances Other…
Barriers preventing the generation of electricity	I believe that my privacy might be at stake I believe that any additional action might bring forth unwanted costs I believe that electricity tariff is currently not expensive I believe that any additional action might bring forth inconvenience I believe that my actions cannot stop climate change I believe that I do not have sufficient information or support Other…
Barriers preventing the conservation of electricity	I believe that any additional action might bring forth unwanted costs I believe that my privacy might be at stake I believe that electricity tariff is currently not expensive I believe that I do not have sufficient information or support I believe that my actions cannot stop climate change I believe that any additional action might bring forth inconvenience Other…

Independent	
Environmental awareness	I participate in and support actions that aim towards enhancing the environmental sustainability of my society
	I am sometimes interested in actions that aim towards enhancing the environmental sustainability of my society
	I am not certain if environmental sustainability is important
	I am not interested in actions that aim towards enhancing the environmental sustainability of my society
	I believe that the concept of environmental sustainability is exaggerated and such I do not worry about it
Features of electricity supply	Positive impacts on the community (e.g. job creation)
	Opportunities to choose between different energy suppliers
	Positive impacts on the environment
	Opportunities to choose between different energy sources (e.g. coal, nuclear, renewables etc.)
	Other…
Affinity with technology	Smart appliances
	Demand response services
	Energy information displays
	Smart meters
	Renewable energy generation schemes (e.g. feed-in tariff or net metering)
Reputation of the utility company	My electricity supplier provides affordable electricity
	My electricity supplier is committed to energy efficiency
	My electricity supplier is committed to utilizing green energy sources (e.g. renewable sources such as wind, solar)
	My electricity supplier is only interested in making profit -R-
	My electricity supplier is an active member of my community
Interest in additional information	My monthly electricity consumption and / or generation of the past year(s)
	The source and percentage from which my electricity comes from (e.g. 70% coal, 30% solar etc.)
	The average monthly electricity consumption and generation of other users within my community

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