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Energy conservation through smart homes in a smart city: A lesson for Singapore households

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ABSTRACT

Energy saving is a hot topic due to the proliferation of climate changes and energy challenges globally. However, people's perception about using smart technology for energy saving is still in the concept stage. This means that people talk about environmental awareness readily, yet in reality, they accept to pay the given energy bill. Due to the availability of electricity and its integral role, modulating consumers' attitudes towards energy savings can be a challenge. Notably, the gap in today's smart technology design in smart homes is the understanding of consumers' behaviour and the integration of this understanding into the smart technology. As part of the Paris Climate change agreement (2015), it is paramount for Singapore to introduce smart technologies targeted to reduce energy consumption. This paper focused on the perception of Singapore households on smart technology and its usage to save energy. Areas of current research include: (1) energy consumption in Singapore households, (2) public programs and policies in energy savings, (3) use of technology in energy savings, and (4) household perception of energy savings in smart homes. Furthermore, three case studies are reviewed in relation to smart homes and smart technology, while discussing the maturity of existing solutions.

1. Introduction

Climate change is a global challenge. The change in the global climate system is directly caused by human activities, which is giving rise to the highest greenhouse gases (GHG) emissions in human history (Pachauri and Meyer, 2014). Studies have shown that GHG have attributed to extreme weather and changes to natural and human systems (Pachauri and Meyer, 2014). These climate changes include floods, droughts, and interrupted food production, which ultimately force people to migrate to safer areas. Extensive exposure to heat waves also affect people's health negatively, and may even spread diseases across multiple territories (Xu, 2015). According to Pachauri and Meyer (2014), electricity and heat production contributed to 25% of the highest proportion of total global GHG emission. This highlights the importance and urgency of sustainable energy consumption to reduce GHG emissions.

In line with the Paris agreement under the United Nations Framework Convention on Climate Change (UNFCCC) in December 2015 (National Climate Change Secretariat, 2016a), Singapore has pledged to reduce 36% of GHG emissions from year 2005 by 2030. Even as a relatively small country, Singapore is also affected by climate change. Statistics show that Singapore's average temperature has risen from 26.6°C to 27.7 °C from year 1972 to 2014, with the rise in annual sea levels at between 1.2 and 1.7 mm from year 1975 to 2009 (National Climate Change Secretariat, 2016b). Besides making international commitment, Singapore has made conscious efforts to change internally to deal with climate change.

Given the global environmental issues, there is a global trend and demand for energy saving and smart technology to increase the efficiency of energy consumption. According to the Energy Market Authority (EMA; 2015), households account for approximately 15% of electricity consumption in Singapore. Under the Energy Conservation Act (2012), the Mandatory Energy Labelling was introduced for registered goods in Singapore. This means that all electrical appliances (refrigerators, air conditioners, etc.) sold in Singapore must be energy labeled.

The role of smart home technologies to increase energy efficiencies in households is becoming increasingly important. A survey has been conducted on the consumers' perception and awareness towards adapting new technologies, as well as the role of these technologies in saving energy. According to Balta-Ozkan et al. (2014), a smart-home is a home equipped with connected devices, appliances and sensors that can communicate with each other, and can be controlled remotely. These functions provide consumers the flexibility of monitoring its electricity consumption and making lifestyle changes to save electricity. Moreover, Balta-Ozkan et al. (2013) noted that a smart home does not

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only provide benefits of efficient energy management, but also provides benefits such as improved lifestyle, security and safety. Smart metering, appliances and home automation devices are some of the many technologies that can be used to change electricity consumption patterns of households (Paetz, 2011).

This article aims to find out the households' behaviors on energy consumptions; it also attempts to identify the benefits and obstacles on the implementation on smart home technologies, and how it should be done for it to be successful. The paper has been organized into six sections: the first section outlines the topic and the structure of the article; the literature review section discusses the household energy consumption in Singapore, public initiatives on energy conservation in Singapore, technology and energy saving household perceptions of smart homes; the subsequent section describes the aims of the study and methods employed; the following section reviews three case-studies on success stories of energy savings in urban households; the penultimate section discusses the survey findings; and the final section presents conclusions and lessons for practice.

2. Literature review

This section reviews the current knowledge base relevant to the discussion.

2.1. Energy consumption in Singapore households

According to the Singapore Energy Statistics (2015a, 2015b), households are significant users of electricity as they account to approximately 15% of total consumption in Singapore. As of 2014, public housing made up roughly 80% of the total housing units in Singapore, while the remaining 20% are private condominiums, apartments, and landed properties (Latest Data: Households and Housing Statistics, 2015). Public housing occupied approximately 60% of overall consumptions while private properties accounted for about 40%. Air-conditioners, water heaters and refrigerators account for around 76% of total energy consumption in a typical household.

This section outlines research projects conducted with an aim to identify a list of factors behind the changes in energy consumption for the residential sector using quantitative models (i.e., index decomposition analysis). Xu and Ang (2013) identified environment control, household appliances and personal devices as three sub-sectors that account for 49%, 45% and 6% of total consumption respectively. Within these three sub-sectors, population growth is the key contributor to increased electricity consumption, followed by the shift towards larger apartments by the households.

Externalities (noise, pollution, etc.) are major factors that have drawn interest in the field of research. As noted by a recent study (see Agarwal et al., 2016), households would most likely not passively tolerate externalities with the hope that they are limited via government regulations, but to mitigate the issue by "purchased comfort" activities such as closing all windows, doors, and switching on air-conditioning. Besides maintaining their desired standard of living, this also acts as a 'self-protection' mechanism from externalities. The 1800 samples taken from Singapore public housing (i.e., Housing and Development Board; HDB) matched with construction sites, proving an approximate increase of 6% in electricity consumption by households (S$ 9770 per annum per HDB block) that were affected by negative externalities, particularly noises generated from construction sites. In addition, the findings revealed that the affected households' electricity consumptions would persist and would not revert back to pre-externalities level, even after the noise pollutions are over.

The studies drew counter-arguments because of some questionable assumptions. For instance, the assumption of similar consumption behaviors by households (Xu and Ang, 2013) might not be realistic and practical. Individuals tend to make decisions that offer sufficient satisfaction, but not optimal utility; they also assume a limitation on their knowledge capacity, and thus practice satisfice and "might exhibit cognitive errors as known as 'bounded rationality' (Simon, 1957). Therefore, the behavioral and psychological aspects are important to take into considerations. Ho (2015) conducted a practice-based study to identify qualitative factors behind energy consumptions to fill in this gap. She emphasized the importance of social science in predicting energy consumption as individuals' practices are characterized by their social and cultural values to accomplish relevant and meaningful activities. She also concluded that energy consumption could be based on socialized rules and ethics that subjectivities should be taken into account. Therefore, households would not follow or practice energy saving programs or methods that do not harmonize with their own social practices.

He and Kua (2012) adopted three conceptual pillars as framework to explain social and psychological behaviors related to households' energy usage. Firstly, situational factors consist of households' demographic, accessibility to energy saving services, and the relevant knowledge that they possess. Secondly, different psychological factors towards particular behaviors. Thirdly, households' environmental behavioral choices as a result of their values. They included these factors into their research methodologies and questionnaires, and concluded households adopted energy-saving measures depending on how easily they could implement these procedures, possible monetary savings, and environmental concern.

2.2. Public programs and policies on energy savings in households

In 2007, The Ministry of Trade and Industry Singapore (MTI) developed the National Policy Energy framework with a vision to address the importance of energy security and environmental sustainability while maintaining a balance for continued economic growth and competitiveness. The current emphasis is the strategies and policies that are relevant with the residential sector to improve energy efficiency (National Energy Policy Report, 2007).

Firstly, the framework indicated the commitment of the government to promote competition and innovation in the electricity retail market by privatization of firms, while imposing rules and regulations to safeguard the industry. The aim of liberalization is to increase firm efficiency, which could be due to the improved corporate governance demanded by investors. The retail electricity market divides consumers into contestable and non-contestable categories by threshold of usage intensity. Contestable consumers can choose different electricity packages from different retailers, such as Tuas Power Supply, Senoko Energy Supply, Seraya Energy, and Sembcorp Power. In July 2015, EMA lowered the contestability threshold to 2000kWh monthly (Singapore Power Report, 2015a, 2015b). It should persist to liberalize the market to the small consumers, mainly households, so that they could choose whether they opt to buy electricity from retailers or remain at regulated tariffs from SP Services.

Secondly, as of late 2014, conventional thermal contributed approximately 97.6% (around 80% from natural gas and remaining 17.6% from oil) of the total generating capacity, its dependence on other countries to import natural resources has created significant energy risk (Singapore Power Report, 2015a,2015b). The framework provides new energy options including renewable energy to diversify the energy supply, which could consequently encourage healthy competitions that eventually benefit consumers including households.

Thirdly, there were legislations that align to the goal of improving the energy efficiency. For example, legislations like the Mandatory Energy Labelling Scheme, which was introduced in 2008 to ensure that the two of the most mentioned energy-intensive appliances, air-conditioners and refrigerators, have to be tagged with energy labels that contain an energy efficiency rating. This enables consumers to gauge whether a particular appliance meets their standard for energy efficiency. In July 2015, this scheme was extended to include other appliances, like televisions, clothes-dryers, and light bulbs (About

Table 1
Guidelines and incentive programmes introduced in Singapore.

Year	Program	Background and Purpose
2007	Energy Efficiency Programme Office (E2PO)	Established by National Environmental Agency (NEA) which collaborated with various other relevant agencies like EMA, Economic Development Board (EDB), LTA and BCA to develop an organized a holistic energy efficiency plan for Singapore, known as E^2 Singapore. It covers various sectors of energy users that include, commercial, industrial, transportations, households and others. Its website (http://www.e2singapore.gov.sg/default.aspx) includes posters and tips that are comprehensible enough for general households to understand and apply at home to save energy.
2008	10% energy challenge campaign	NEA launched the 10% energy challenge campaign, which was eligible for all Singapore households. In order to join the lucky draw to win prizes, participants have to prove that they could save at least 10% of electricity between two stated periods by submitting their electricity bills. It encouraged households to adopt simple saving habits and tips. It has been highlighted in NEA's annual report in 2008 (http://www.chasingcleanair.com/cha0sing_clean_air/2008/08/the-10-energy-c.html
2011	Informative TV programme in Mandarin	NEA partnered with Mediacorp to produce a TV programme to remind households of the benefits on energy efficiencies and ease of adopting energy saving habits.
2013–2014	Home Energy Management System (HEMS)	A collaboration between EMA, HDB, EDB, and Panasonic, ten households in Punggol were selected to have HEMS installed in their homes. It allowed them to better manage and control their energy consumptions and costs. It would be a start for government agencies and private companies to work out a solution using latest technologies to achieve the goal of energy efficiency for households. (https://www.nccs.gov.sg/climatechallenge/issue04/green-tech.html)

Mandatory Energy Labelling, 2016).

Minimum Energy Performance Standard is another legislation that was introduced in 2011 to remove models of air-conditioners and refrigerators that fall short of the specified energy performance standard. It has thus seen good progress as consumption data indicated that the top two highest efficiency models of the mentioned appliances were purchased by at least 80% of the households in 2011 (Tightening and Extending Minimum Energy Performance Standards, 2012).

Apart from legislations, there have been guidelines and incentive programs to promote households' energy savings. Table 1 lists a summary on some examples of the relevant offices, policies, and programs that were introduced in Singapore throughout the years.

In contrast to the assumption of traditional economics that people make rational decisions to optimize their utilities, consumers do not always make the best choices due to behavioral patterns. Policymakers have started applying "nudges" that are based on behavioral insights with the aim of helping people to make better choices. In 2012, the Ministry of the Environment and Water Resources (MEWR) formed a unit to research and derive behavioral insights. Since then, it has been working with other relevant government agencies, such as NEA, to utilize behavioral insights for environmental policies. For example, their study showed that people would recycle more, provided that it is convenient. In response, NEA produced recycling boxes for households to separate their general wastes from recyclable materials conveniently (Hartung, 2014).

In addition, Singapore has recently joined with 194 countries in adopting a global agreement (i.e. Paris agreement) to tackle climate changes and environmental concerns. This agreement served as an important milestone for a committed global effort to address and resolve environmental issues. To achieve this global goal, Singapore government would have to continue to pursue various schemes and policies, such as potential implementations of schemes (e.g., car-free zones, car-free Sundays, car-pooling) and incentives (e.g., using public transport). Evidently, households are also encouraged to cooperate and stay committed to energy-preserving behaviors (Chua, 2016).

2.3. Use of technology in energy savings

From late 1940's, the air-conditioner was introduced, and it changed the property space. An American builder, Dick Hughes, claimed that the installation of an air-conditioner in a home is comparable to the electric plug for a refrigerator (Troy, 2012), p. 16. Today, the demand for cooling homes and buildings on a global scale is a billion-dollar industry (Global Industry Analysts, Inc, 2015), where Asia Pacific is the largest and fastest growing market (refer Fig. 1).

The construction of smart buildings involves the selection of appropriate material, that are of the best energy efficient material for construction (e.g., walls, doors, window-frames), as well as the type of dyes used to paint surfaces (Battista et al., 2014). For urban population with high-rises, it is paramount to look into energy efficiency (Cangelli and Fais, 2012) and environmental comfort. This can be achieved by designing the buildings as vertical cities with terraces and green areas.

A Smart City has an interconnected infrastructure that work optimized through communication and data collection from the connected entities. Aligned to this concept, the Smart Nation program in Singapore (Spring Singapore, 2015) consists of various technologies to reduce energy consumption throughout the nation, while monitoring and collecting data from all connected consumers, such as corporate buildings and households (Housing and Development Board, 2014; IDA, 2014). The goal is to achieve an energy efficient nation, whereby proactive and smart planning is used to create a comfortable and secure environment (Housing and Development Board, 2014).

Housing and Development Board (2014) described the technologies considered for Singapore Urban development. Buildings will have access to solar power, water-recycling, low-power lighting (i.e., LED). They will also be fitted with automated Smart fans (Fig. 2) that can be activated when the temperature and humidity reaches a certain threshold. Car parks will have video surveillance systems that will help indicate any available spots. Moreover, Smart lighting in common areas will be capable of detecting human traffic and operate only when necessary, thereby reducing energy usage by up to 40%. Data can also be collected from the lights to analyze traffic together with other sensor data.

HDB (2014) described that homes will be equipped with a digital infrastructure, which will connect homes to the internet and thus give residents access to various services (e.g., healthcare). For instance, elderly alert systems in Fig. 3 help families monitor the elderlies in their homes by using sensors and motion detectors.

A study performed by the HDB and Energy Market Authority Singapore (EMA) showed a reduction of energy consumption by 20% after implementing Home Energy Management System (HEMS) illustrated in Fig. 4. This system will help home owners track their energy consumption and control the appliances via a management system (National Climate Change Secretariat Singapore, 2013).

Fensel and colleagues (2014) presented a study about energy efficiency by using a smart metering system called SESAME. The SESAME solution is integrated directly into the home grid, and permits the system to switch on or off appliances. The system is also able to detect signals from temperature, humidity or other sensors, thus control appliances according to specified configuration. Classification of functions in smart homes have been worked out by Hamernik et al. (2012), where appliances, computer integration, video/audio systems,

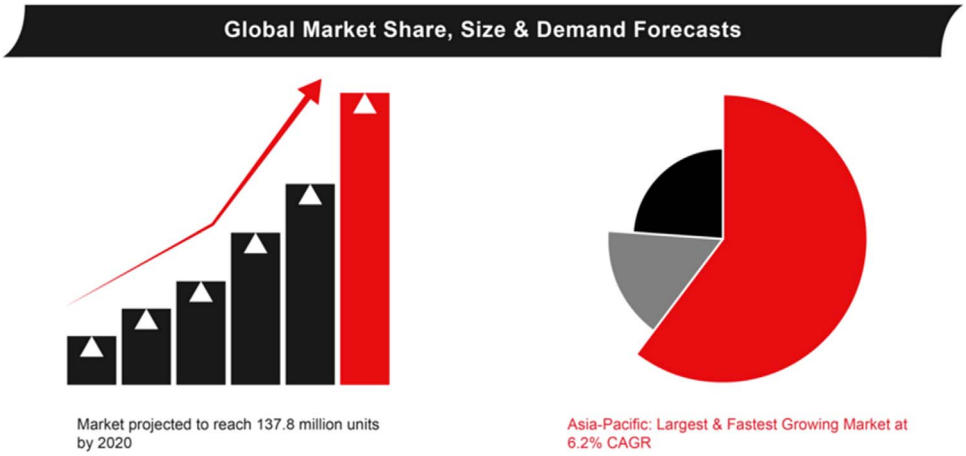

Fig. 1. Global air condition market share (Global Industry Analysts, Inc, 2015).

Fig. 2. Activated by human traffic, temperature and humidity, Smart fans will improve thermal comfort levels for residents. (Source: Housing and Development Board, 2014).

as well as internet availability are evaluated as functions in a smart home. In this study, the functions are outlined in categories dealing from energy monitoring over appliance control and house equipment management to comfort and health functions. With today's evolving technology, where appliances can be connected to the internet, the IoT (Internet of Things) concept is the big step towards developing more integrated solutions for smart homes (Collotta and Pau, 2015).

To sum up, studies on smart technology show the concepts are still in their early phases. Although smart technologies have been used over the years to provide comfort and automation, only recent studies are focused on energy savings. Smart technologies for energy savings will have a full impact when integration of Smart Devices, Smart homes and Smart Grids takes place, which is illustrated by the study by Collotta and Pau (2015), whereby low-powered linked network segments are connected to a central management controller in the household. Moreover, building designs and environmental concepts also influence the energy saving and comfort of living, it is therefore essential to design the ideas and solutions for smart technologies with an under-

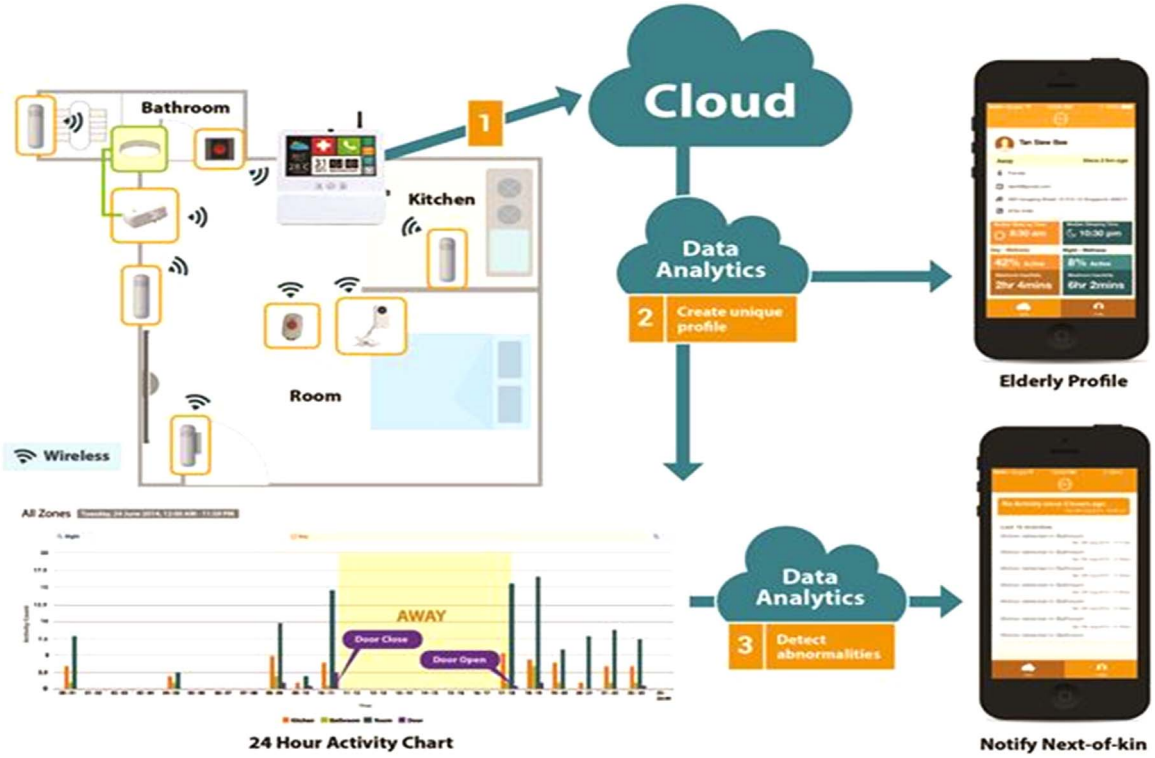

Fig. 3. The Smart Elderly Alert System learns the living pattern of the elderly at home, and enables timely alerts to their caregiver (HDB, 2014).

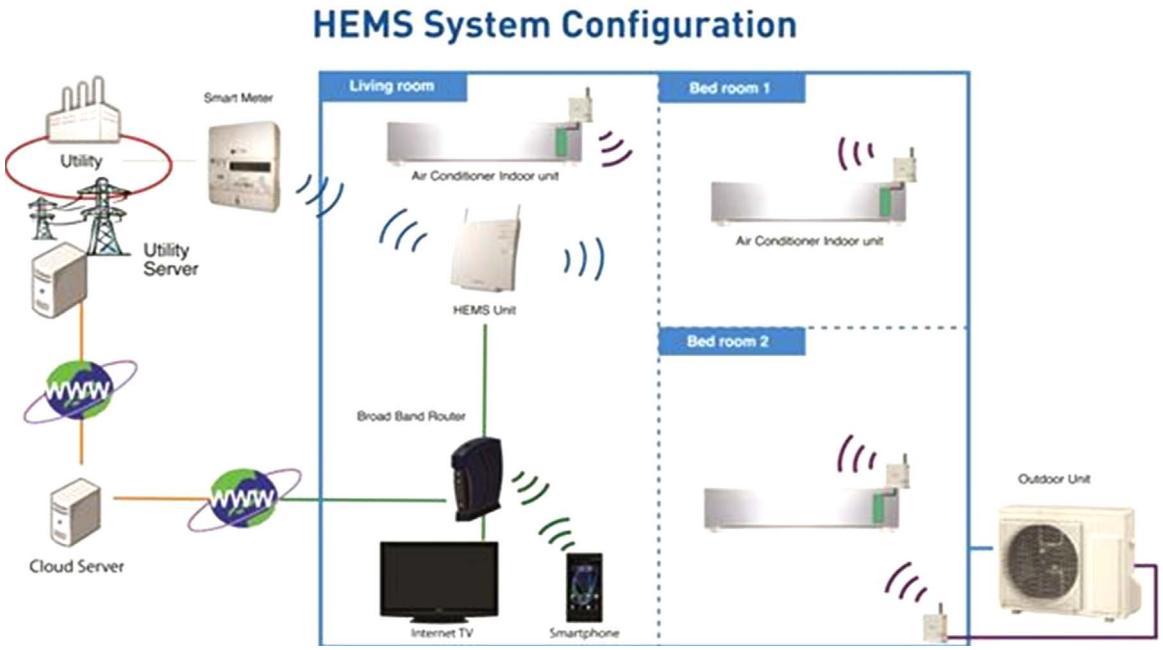

Fig. 4. This system allows residents to track and manage their energy consumption, and control their home appliances through this management system. (HDB, 2014).

standing of living environment. This includes human behaviors, technology devices with automation, as well as artificial intelligence. Moreover, IoT modules that integrates the appliances via a Smart controller and a Smart Grid can improve the user experience by giving a seamless perception of the technology usage.

2.4. Household perception of energy savings in smart homes

Smart homes, being integrated into a Smart Grid eco-system in terms of households' energy consumption and management, has become the next big thing and is generally believed that consumers are able to decrease energy consumption (Makovich, 2011). Thus, it is of high importance to find out the true perception of households on energy saving through smart homes.

Paetz et al. (2011) conducted a study to understand consumer perceptions and reactions to energy saving through smart home technologies and concepts (smart meter, variable tariffs, smart devices, home automation, etc.) and found out positive reactions to living in a smart home environment that could help reduce energy consumption and cut energy costs. Although there were more advantages than disadvantages of living in a smart home environment, people found it difficult to change their lifestyles in order to save money. Moreover, findings from a recent survey conducted by Iwata et al. (2015) has also shown that saving money through reducing energy was one of the benefits that households could see immediately. However, the same survey emphasized that people in Tokyo tended to overestimate perceived monetary benefits of energy saving activities. In other words, people in different countries might perceive energy saving benefits differently. For example, Attari and colleagues (2011) have shown that people in the United States have underestimated monetary benefits of energy saving activities.

In addition, a study done by Murtagh et al. (2014) has highlighted that households could be categorized as monitor enthusiasts, aspiring energy savers, and energy non-engaged. The majority of households in this study gave several reasons of why they were adopting in-home displays and the primary reason was about being an eco-friendly household to save the environment. According to the study, money saving was the main motivation to the monitor enthusiasts. Saving energy is saving money to these households and these two concepts are used interchangeably. However, Makovich (2011) argued that even though electricity bills may go down due to smart grid and home technologies in the long run, there would be many other factors that would increase the electricity prices and energy consumptions. The second group of households, the aspiring energy savers, are mostly concerned about how much energy they are using and how much energy they can save which highlights their environmental concerns. Urban and Scasny (2012) have also agreed that households with higher environmental concerns tend to take more actions to save energy and deploy smart home technologies. Besides, households within different age groups tend to behave differently towards saving energy. For example, older age-groups are more concerned about the environment, and are more willing to take additional steps to save energy by implementing energy measuring tools and devices in their houses (Urban and Scasny, 2012). However, due to the recent increase in energy price and global cost of living, this influences the aspiring energy savers' behavior to not only save energy, but to save money too (Murtagh et al., 2014). Lastly, the energy non-engaged households do not bother saving energy neither from monetary nor environmental perspectives. One of the important factors for being the energy non-engaged household is households' income level (Murtagh et al., 2014). According to Urban and Scasny (2012), wealthy households are not very concerned about environmental issues, but they are more likely to invest into smart home devices. Besides, Murtagh et al. (2014) commented that although in-home displays can change behavior of households to save energy, most of them have been active in energy saving actions before usage of any devices.

Another study done in Germany by Torsten and Paukert (2013) found that households willing to pay for smart meters were not due to energy saving and as a form of long term investment. Instead, they perceived that energy data from smart meters is kept confidential and used for specific purposes only, so there is no risk related to privacy violation. Moreover, the same study also suggested that initiatives, such as deploying smart meters in households to monitor energy consumption should not primarily emphasize on energy saving, as households are not able to visualize or imagine it easily. Instead, households could benefit from using smart meters when they are given a chance to change their household activities in energy consumption and to utilize more efficient electrical devices (Torsten and Paukert, 2013).

To sum up, various studies have shown that households' primary

perception of energy saving through smart home is about cutting electricity cost. These findings have been consistent in households across different countries. However, it is worth mentioning that there are people who are concerned about environmental issues and taking additional steps to save energy.

3. Methods and aims

There is a global trend and demand for smart technology to reduce energy consumption. According to Pachauri and Meyer (2014), electricity and heat production contributed to 25% of the highest proportion of total global GHG emission. This highlights the importance and urgency of sustainable energy consumption in order to reduce the emissions of GHG. Although the Singapore government has been promoting a lot of policies and programs about energy saving, there has been very few empirical studies on energy saving conducted in Singapore households. Many overseas studies have shown that households are very positive to the idea of saving energy through smart homes and are willing to invest in new technologies. However, those findings cannot be generalized to Singapore's context, as culture, infrastructure, eco-system, support from government and other factors might be different in Singapore. Therefore, there is a critical need to understand energy saving in Singapore households through smart homes.

The current research will explore the perception of households on energy saving and give fair understanding about the acceptance of smart technologies in Singapore households. The research aims to achieve the following:

A1: To evaluate success stories on saving energy in urban households through smart homes
A2: To explore Singapore household perceptions on saving energy through smart homes

A1 covers the research of three case studies that have implemented smart homes to save energy in urban cities. These success stories will provide better insights on how smart homes and how smart technologies can be used to save energy. The case studies have been selected based on their research with smart home technology and related energy savings. Moreover, they aligned with this papers sections covering policies, smart homes and consumer's perception of energy savings.

A2 covers an online survey conducted to receive insights on energy consumption in Singapore households by looking at the effectiveness of government policies to save energy, usage of smart technologies in households, and households' perception about energy saving through smart homes Two hundred households were randomly selected for the study. A total of 131 valid responses were received via mail showing a 66% response rate. The questionnaire comprised of closed ended questions categorised under four sections: energy consumption in Singapore; public policy on energy saving in Singapore; use of technology in energy saving and household perceptions of energy saving..

Since Singapore is one of the most developed countries in the world and its government is actively promoting policies and programs to save energy, it is predicted that Singapore households will have a positive perception towards energy saving and will see benefits of using smart technologies. This will directly address some of the environmental issues and reduce households' electricity bills.

Case studies: Global success stories of energy savings in urban households.

Case 1:Chinese consumer attitudes towards energy saving: The case of household electrical appliances in Chongqing.

Key words: Government Policies, Energy efficiency, energy savings

Ma et al. (2013) conducted a case-study which explored 246 consumer's attitudes towards energy savings through a questionnaire over a one-year period from 2009 to 2010. The survey was conducted in Chongqing, China and was conducted via face-to-face surveys due to previous experience of no or low feedback.

Energy consumption in China has doubled from 2000 to 2008. Moreover, usage of appliances in urban households (e.g., air conditioners) has increased 30–100%. To tackle this issue, the Chinese government has introduced policies to raise energy efficiency in China by improving power plant equipment and labelling appliances, which means that electrical appliances must be manufactured to consume electricity below a certain threshold. As a result, this has a positive impact by helping households to save money. One potential downside is that some households may spend the money they save to purchase other energy consuming products. Apart from labeling appliances, the Chinese government also banned sales of inefficient air conditioners, and offered buy-back schemes of energy inefficient equipment as well as applied discounts on various energy-efficient appliances.

Consumers can be provided with as many energy efficient products as there are on the market, yet the big issue is the awareness around energy savings. They must also be educated on how to reduce energy not by purchasing new products, but by changing their behaviors and habits when using these appliances. This is the biggest challenge faced by the government as the energy policies and energy consumption issues on a national plan may seemed too complex for consumers.

The findings are based on a survey of questionnaires covering knowledge, awareness, and behavior patterns around saving energy. Results show a high level of knowledge among the respondents that energy is a challenge, but less knowledge about saving energy at home. Knowledge about government policies was clearer among the younger respondents and those with higher education level. Moreover, the results show a good level of awareness around energy pricing. This was matched up against the knowledge of which appliances consumed the most energy, and rightfully, the respondents consistently ranked air-conditioners and refrigerators highest, whereas light bulbs and fans at the lowest. The study concluded that the willingness to save energy is high among the citizens, given that their comfort of living are not affected. It also show that general information about government policies and awareness about energy savings could be provided in a more informative manner with better results to build energy-saving behaviors among the citizens.

In conclusion, the study showed that there was a general awareness about energy savings and government policies, though little understanding about energy savings. Nevertheless, participants were willing to save energy, yet they lacked the proper guidance and awareness about proper energy saving behavior.

Case 2: Consumers' Perspective on Full-Scale Adoption of Smart Meters: A Case Study in Västerås, Sweden.

Keywords: Smart meters, energy saving, electricity consumption

This recent case study (Vassileva and Campillo, 2016) described a full-scale implementation of smart meters integrated with a smart grid in Västerås, Sweden. A survey was conducted to evaluate the consumer's perspective and feedbacks in regards to energy savings and information given to the consumers around pricing and other information. Over the years, appliances have become more energy-efficient, but consumers tend to have more energy-consuming appliances than before, which results in a higher combined energy consumption.

The number of smart meters installed worldwide is expected to be around 90–130 million units. The advantage of smart meters is their ability to collect consumption data, which is easily accessed via a website or a mobile app. This will give the consumer an upfront overview of their consumption patterns, to which they can take action, such as reducing usage of appliances. The research also revealed some gaps in consumers' interactions with smart meters, as can be seen with consumers' feedbacks and preferences on how the smart meters should be improved in the future. Another advantage of the smart meters is the dynamic electricity usages based on tariffs which permit consumers to be guided on peak hour usage and choice of energy suppliers. This is

typical in areas where energy providers are privatized and multiple suppliers exist within a country (e.g., from renewable energy sources, power-plants). The survey was conducted online, which was considered to get the best feedback from the participants as they felt they had greater privacy. Questions included perceptions from consumers on smart meters and energy savings, but also covered their expectations of using smart meters, and if they find energy saving important. The survey is distinct between genders, age groups, and whether the consumers receive the energy bill by paper or electronic format. Findings show that consumers would have to learn how the usage of their appliances affect energy consumption, and therefore, learn to change their behavior patterns to use the appliances more efficiently. Higher energy efficiency was also indicated among consumers with smart meters over time.

To sum up, this case study evaluated the energy consumers in a city with smart meters, and show that smart meters can provide detailed energy consumption information and possibility for consumers to choose between pricing plans. However, it was also revealed that in reality this has not been achieved yet, furthermore the higher level of energy savings through knowledge of smart meters and electricity price offerings has not been reached. Results show that there was not enough information provided by the smart meter data, thus consumers would not be able to understand or take action based on the data provided. This highlighted that consumers need to be better informed and educated in understanding appliance energy consumption. Concomitantly, energy providers must also provide adequate information around the energy consumption data.

Case 3: Case Study of Smart Meter and In-home Display for Residential Behavior Change in Shanghai, China.

Keywords: Smart meters, energy savings behavior

A case study conducted by Xu and colleagues (2015) has covered one of the national issues, which is the high energy consumption levels in Shanghai, one of the most densely populated urban cities in China. Energy saving behaviors in households were investigated through in-home displays and smart meters. The study claimed that one of the main contributors to high carbon emission is the building sector in China and there is a huge demand to reduce energy consumption in those buildings. Since households are part of the buildings, the case study has explored energy consumptions behavior of households through implementation of smart meters and in-home displays.

In this case study, smart meters and in-home displays were installed in two newly-built apartment buildings. A total of 131 households participated in this study (76 without in-home display devices, 55 with the devices). There were additional sensors and devices installed to assist data gathering from smart meters and in-home displays. Data from smart meters were shown on in-home displays and transferred to back-end system via the internet. Raw energy data, statistical data, and background information data were stored in dedicated databases, so researchers could work on the respective data separately.

Findings from this study has been categorized to in-home display checking frequency, electricity energy saving, standby power saving, and on- and off-peak power consumptions. The study revealed that households with in-home displays tend to check their devices frequently at the beginning and end of month. Xu et al. (2015) claimed that this finding might be due to economic habits of households as they would usually receive bills (e.g., energy consumption, credit card) during that period. Moreover, findings have shown that households with in-home displays saved more energy than those without the devices. In other words, electricity consumption for single household without in-home displays were 9.1% higher than those who used in-home displays in their houses. In addition, there was another improvement in energy savings in terms of standby power. Households with in-home displays tended to reduce standby power by 12.9%, which indeed changed behavior of households in energy saving through smart meters and in-home displays. Lastly, due to smart meter and in-home displays, households' energy consumption was smoothly distributed across 24 h. However, demand for power was much higher between 7pm and 11 pm for households without in-home displays.

In conclusion, this case study was successful as it showed that households' behavior towards saving energy positively changed due to installation of smart home technologies. This study is relevant to Singapore's context as it was conducted in a similar densely populated urban city.

4. Survey findings and discussion

In the survey, 50% of the responses from households' have monthly energy bills ranging from SGD$100 to 200. While, 53% of the respondents believed that the price of their energy bill is "about right", 31% believed that it is "too high" and 9% believed it is "far too high".

Respondents also indicated their awareness of which household appliances consume the most energy. Air-conditioners, washing-machines, and water heaters have scores that ranged from medium to high (in terms of energy consumption), with air-conditioners scoring the highest among all choices. It should be noted that Singapore is situated on the equator and experiences a hot and humid climate for most of the year. As a result, air conditioners may be used throughout the year. In addition, respondents mostly agreed on the fact that using energy efficient appliances would help them to save energy. This finding is consistent to Case Study 1, whereby households also recognized the particular appliances that consume most energy.

With regards to the perceptions on using smart home meters, in-home displays, and relevant smart home devices, respondents indicated that they were less convinced that the technology was capable of helping them to save energy, in comparison to using energy efficient appliances directly. This might be due to the fact that the respondents have not 'visualized' the actual effect on the devices and technologies before. As in Case Study 3, households became more aware of their energy usage and saved their consumption when they had in-home smart meters and devices installed, as they allowed them to easily control their energy consumption patterns and behaviors to save energy.

The respondents had a general idea of energy efficiency, yet their consumption patterns and behaviors could not be amended easily. As mentioned in the literature review, various social and cultural values of various households could derive different behaviors.

Next, respondents mostly agreed that the reduction of energy consumption could be encouraged by educating the public on environmental issues. Therefore, educating individuals earlier on would result in successful knowledge on environmental issues as well as linking it to how it could affect their lives, thereby resulting in appropriate energy consumption. As we could also observe in the Chongqing case study, lack of proper education and guidance could have a negative impact on households' energy savings visions.

Government legislation on available market products is another aspect that survey respondents tend to accept and agree on its effectiveness. The ideas behind the legislations of Mandatory Energy Labelling Scheme and Minimum Energy Performance Standard do not only apply to Singapore's context. As observed in Case Study 1, the Chinese government have these policies implemented to raise energy efficiencies in households too.

The daily usage of internet services (e.g., world-wide-web, email) has become a necessity in developed urban cities such as Singapore. As per the respondents, it is the most effective communication tool for the government to convey the message of energy saving and efficiency to the general public. Survey findings reveal that the internet is more efficient than the traditional media such as television, radio, or newspaper. Evidently, information on strategies, implementations, and policies should definitely be facilitated by various internet technologies.

On the other hand, respondents in general were either not familiar or did not pay enough attention on relevant government policies. The

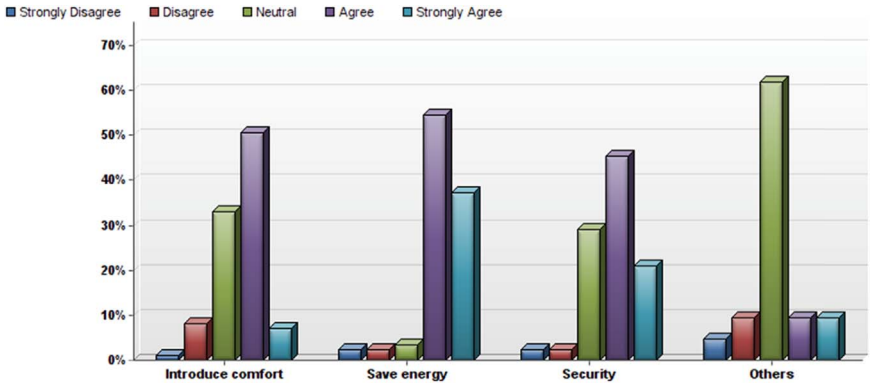

Fig. 5. Motivations to adopt technology at home.

Energy Efficiency Programme office provides a holistic energy efficiency plan across all sectors, which also include households. The office has a dedicated website that provides information and tips to households on easy-to-follow procedures for consumers. Nevertheless, it seemed that the respondents were not aware of this. The descriptive statistics indicated the Mandatory Energy Labelling Scheme draws the most familiarity as compared to other policies, and it maybe because whenever households are choosing which appliances to purchase, they could see the corresponding labels on each of the appliance. This legislation does not only exist in Singapore, but also in other major cities, like Chongqing that was mentioned in the case study.

There have been many other suggestions for the government. Some respondents advocate a movement to impose additional taxes as penalty for households that consume energy over a specified threshold. The more widely accepted option for the respondents is to explore renewable energy. In fact, the Singapore government has already started to explore renewable energy.

In conclusion, with the pledge of the government to the Paris agreement, its vision to tackle global warming and other climate issues are evident. As a result, they would further contemplate strategies and policies across all sectors including households to achieve its vision. Energy saving and efficiency certainly is one big aspect that they would research and tackle. They would continue to build on the existing National Policy Energy Framework. Smart home technologies could play a crucial role to have an impact on households' behaviors in energy consumptions, and to be taken into considerations by the government while they contemplate the relevant strategies and policies.

In regards to the usage of technology in energy savings, responses from the survey indicated that smart technology in appliances could help saving electricity. This highlighted the awareness about energy savings, and the purchase decision may often reveal the consumer's plan for long term energy savings.

Likewise, the understanding of smart home is generally a term that is understood by participants to be a "home" where smart technology is installed. This technology can range from smart appliances (e.g., air conditioner with temperature sensors) to possible uplink using internet of things (IoT) to an online management system. This includes smart meters that integrates the home grid to the energy providers, who possess an intelligent management service that can provide a behavior-based feedback to the smart meters to regulate energy usage efficiently.

Smart motion sensors, temperature and humidity sensors, as well as cameras and smart locks make up part of the household's smart security. Participants also illustrated their understanding of smart technology and smart home by highlighting smart motion sensors, smart meters, air-conditioners, and temperature/humidity sensor as part of a smart home.

In Singapore, 9 out of 10 households are connected to the internet (Lee Hsien Loong, 2014). Singapore is striving to build a Smart Nation, where citizens will be able to benefit from smart technology and improve their lifestyles in several areas, from energy and environment savings to personal comfort and security.

Participants in the current survey were selected on the condition that they are currently residing in Singapore. Therefore, there is a reason for the participants to respond to this survey because of a desire for a better environment and living standard, including personal comfort and security.

The majority of the participants would invest in smart technology to save energy in their household. Smart technology and smart home devices will eventually be interconnected with health-sector platforms as well as to power plants and other utility providers. Such integration will host the risk of privacy and confidentiality over personal data (e.g., patient records in hospitals). Therefore, there is a big concern about security on smart technology (Popescul and Radu, 2016), and how to manage security risks to secure the privacy of personal data (Bugeja et al. 2016). This is considered a critical risk, as a hacker could take control over the smart home controller or appliances, like surveillance cameras. In the survey, this security risk was reflected from the concern of the participant.

The survey also shows a focus on energy savings using smart technology, followed by an increase of security. (Note that security is part of comfort and safety in the home.) This is where surveillance comes in, in the forms of cameras and motion detectors. In the survey, energy savings and comfort are voted more favorably, followed by security as the least important among the three options.

The Smart Nation program initially focuses on Singapore as a whole, which includes infrastructure, healthcare, and urban city complex. As described by HDB (2014), the technology introduced will improve the environment for citizens, while building more secured living conditions. This relates to the survey (see Fig. 5) whereby some of the responses focused on security and comfort with smart technology. Housing and Development Board (2014) also introduces HEMS, which has the same features as a smart meter solution, and thus integrates house appliances to an online system. A similar study was also conducted by Fensel et al. (2014), which demonstrated the use of smart meters and the control of appliances. In the Sweden case study by Vassileva and Campillo (2016), it was highlighted that the consumers must take action on the smart meter to improve the energy savings further. This was not reflected in this study. Although participants in the survey are willing to purchase or make use of smart meters, their behavior patterns are likely to repeat in Singapore, as experienced with the study in Sweden. This might be an indication that the maturity level of the smart technology is not at an optimal stage for smart home users to adapt to smart technology. In the survey, the participants are willing to invest in smart technology to improve their comfort and save energy. However, according to Vassileva and Campillo (2016), the consumers must actively engage with the smart meters in order to get improved energy savings. People will want to save energy and increase comfort of living, but the additional behavior pattern to actively follow-up on the smart meters or devices may not result in a successful deployment of smart technology and homes. In

regards to security concerns, the case study by Vassileva and Campillo (2016) also gets the consumers' attention as they perceive that the smart meters could possibly give indication of household behavior models which could be intercepted by burglars. In the survey, participants indicated concerns about privacy and personal data as appliances could be connected via the internet to health sector or other public services. According to Collotta and Pau (2015), the design of smart meters and devices must account for a certain level of security, which can protect the communication stream between the appliances and the connected servers.

To sum up, smart technology and smart homes are well-received by consumers. Seemingly, the main motivation for the consumers is to save energy, as well as increase their comfort in their homes. Based on the case study findings by Vassileva and Campillo (2016) on the Swedish homes with smart meters and the study with energy efficient appliances in Chongqing by Ma et al. (2013), there is a pattern on users' perception of energy supply and savings. This indicates that consumers are taking electricity for granted, and will most likely not adjust their behavior patterns to actively monitor or engage with a smart meter to reduce energy consumption. Researchers' conclusion on smart home and smart technology is, that the usage and perception of how smart technology design is still at an early stage. In order to provide consumers with an efficient energy-saving solution, smart home and smart technologies must work seamlessly with the occupants of the households. This means that the technology must be built on artificial intelligence in order to detect behavior models and usage patterns, and hereby adjust the energy usage accordingly. This method will permit the smart technology or home to notify occupants on the best timings to use certain appliances, or indicate billing limits and other thresholds.

Finally, survey results show that 67 Singapore households either agree or strongly agree that "smart home" concept is associated with energy efficiency. Moreover, these households also perceived "convenience" as one of the important aspects of a smart home. Survey findings have highlighted that close to 52% of households are concerned about environmental issues, which was their main reason to save energy. On the other hand, close to 44% of respondents have associated energy saving with reduction of electricity bills.

Besides, 83% of respondents have shown interest to know how much energy is consumed by each and every device in their households. Additional findings have shown that the households' interest for knowing the energy consumption for every device is to save energy (60% of respondents) and save money (30% of respondents) by reducing energy consumption. The radar chart in Fig. 6 revealed that general attitudes of the households towards energy saving have been positive as survey has shown that close to 90% of respondents have either agreed or strongly agreed that people in the world (including the respondents themselves) should adjust their behaviors to address energy challenges. In addition, solar power and energy from waste as sources of energy were two favorite choices by the respondents, while negative interest was reflected in regards to using nuclear power.

IThe findings on the perception of households about energy saving through smart homes were consistent with other studies (e.g., Paetz et al., 2011, Iwata et al., 2015) where households are positive towards using smart technologies to save energy and reside in more energy-efficient and secured houses. Some questions have been designed to identify households' motivation to save energy, and subsequently, used for a comparison with the discussed literature review and case studies. Consistent with Murtagh et al. (2014), we noted that households in the survey fell under one of the three categories (i.e., monitor enthusiasts, aspiring energy savers, energy non-engaged). The majority of the households were categorized as aspiring energy savers, followed by monitor enthusiasts, whereas only one household was categorized as energy non-engaged. This may be an indication that Singaporeans are more concerned about environmental issues, and may see energy saving as one of the actions to address environmental challenges.

Urban and Scasny (2012) have claimed that people who are more concerned about environmental issues take additional steps to save energy through the use of smart technologies. The results were consistent with their findings, as the majority of the households in the present survey who are concerned about the environment were willing to know the energy consumption for devices/appliances. However, it is noteworthy that some of these households were willing to know energy consumption of their appliances because they wanted to save money by reducing electricity bills. Consistent with most of the studies (e.g., Paetz et al., 2011, Iwata et al., 2015, Urban and Scasny, 2012, Murtagh et al., 2014) which noted that people are willing to invest in smart home technologies to save money, the findings have also indicated that monetary factor is one of the primary reasons to save energy. According to Murtagh et al. (2014), income level of households might be one of reasons why some of the households are categorized as energy non-engaged. High-income households tend to use the latest smart technologies not to save energy and cut costs, but to keep up with the trend. Moreover, Urban and Scasny (2012) have claimed that older people are more concerned about environmental issues, which could explain why they are more willing to take part in energy saving. However, the survey results have not confirmed the findings by Urban and Scasny (2012) as responses in the present

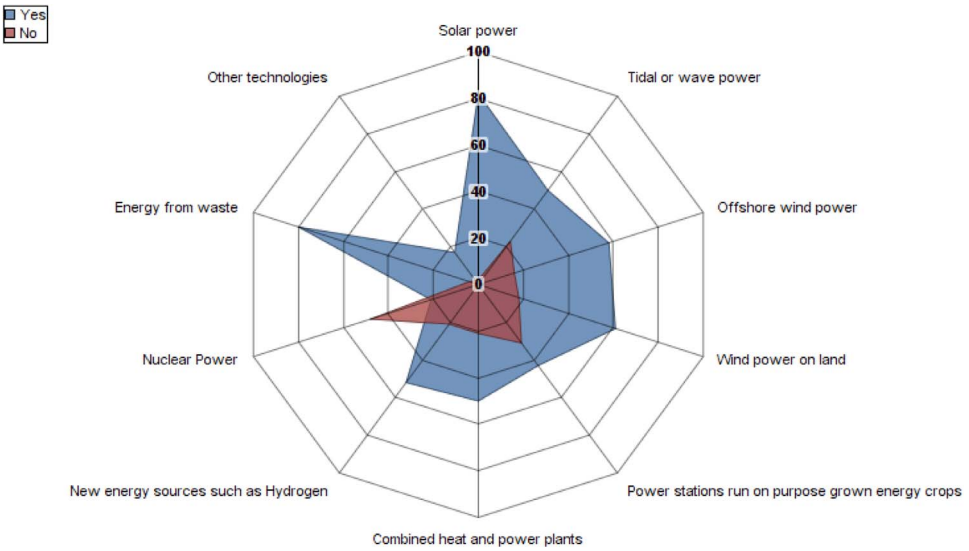

Fig. 6. Perception of new technologies supplying energy by 2020.

survey were evenly distributed across all age groups.

In summary, the findings are very much aligned with other studies in terms of household perceptions on saving energy through smart homes. Households (in particular, aspiring energy savers and monitor enthusiasts) in Singapore have shown concerns on environmental issues, and are willing to invest in smart home technologies to address them.

5. Conclusion and policy implications

Most people perceive electricity as a normal commodity which is readily available. Smart technology and smart homes will require the consumers to take action in order to control appliances and to save energy. Findings from the case studies show that the behavioral patterns of consumers may not change just to save energy. Even though an individual claimed to be concerned about the environment and energy-saving, it is evident that comfort and security play a bigger role in people's life. The present research showed a gap on the maturity and design of the technology as it does not take people's behaviors and perceptions as part of the smart home design functionality. Therefore, smart home technologies would not be efficient if it is not designed with artificial intelligence modules that allow the technology to seamlessly interact with consumers. Also, to achieve a successful smart home solution in Singapore, smart technology must be integrated into public services and utility sectors, such as smart grids and health sectors. For example, smart meters should detect behavioral patterns and proactively take action, so that consumers no longer have to actively turn on light if needed. Likewise, notifications through mobile gadgets or house consoles can provide advice for the best time to turn on certain appliances (e.g., washing machines). Lastly, the findings in this research showed that the maturity of the smart meters are still at its early phase, but projects like Singapore Smart Nation might be one of the leading projects to improve the technology and smart homes in the near future.

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