A Qualitative Assessment of the Impact of Smart Homes and Environmentally Beneficial Technologies on the UK 2050 Net Zero Carbon Emission Target

Purpose:

There are 29 million homes in the UK, accounting for 14% of the UK's energy consumption. This is given that UK has one of the highest water and energy demands in Europe which needs to be addressed according to the Committee on Climate Change (CCC). Smart homes technology holds a current perception that it is principally used by 'tech-savvy' users with larger budgets. However, smart home technology can be used to control water, heat and energy in the entire house. This paper investigates how smart home technology could be effectively utilised to aid the UK government in meeting climate change targets and to mitigate the environmental impact of a home in use towards reducing carbon emissions.

Research Approach:

Both primary and secondary data were sought to gain insight into the research problem. An epistemological approach to this research is to use interpretivism to analyse data gathered via a semi-structured survey. Two groups of participants were approached: i) professionals who are deemed knowledgeable about smart home development and implementation and ii) users of smart home technology. A variety of open-ended questions were formulated, allowing participants to elaborate by exploring issues and providing detailed qualitative responses based on their experience in this area which were interpreted quantitatively for clearer analysis.

Originality of the research:

This paper bridges a significant gap in the body of knowledge in term of its scope, theoretical validity and practical applicability, by and large, highlighting the impact of using smart home technology on the environment and by providing an insight into how the UK government could utilise smart home technology in order to reduce its carbon emissions, by identifying the potential link between using smart home technology and environmental sustainability in the UK in tackling and mitigating climate change. The findings can be applied to other building types and has the potential to employ aspects of smart home technology in order to manage energy and water usage in other building types including but not limited to larger healthcare, commercial and industrial buildings.

Findings

With fossil fuel reserves depleting, there is an urgency for renewable, low carbon energy sources to reduce the 5 tonnes annual carbon emissions from a UK household. This requires a multi-faceted and a multimethod approach, relying on the involvement of both the general public and the government in order to be effective. By advancing energy grids to make them more efficient and reliable, concomitant necessitates a drastic change in the way of life and philosophy of homeowners when contemplating a reduction of carbon emissions. If both parties are able to do so the UK is more likely to reach its 2050 net-zero carbon goal.

The presence of a smart meter within the household is equally pivotal. It has a positive effect of reducing the amount of carbon emissions and hence more need to be installed.

Research Limitations/Implications:

Further research is needed using a larger study sample to achieve more accurate and acceptable generalisations about any future course of action. Further investigation on the specifics of smart technology within the UK household is also needed to reduce the energy consumption in order to meet net-zero carbon 2050 targets due to failures of legislation.

Keywords:

Smart home, Smart home technology, Smart grid

Background Studies

With nearly 67 million people in the UK, and with an estimated 5 million more in the next 20 years (ONS, 2019) there is an urgent need not only for more housing, but for more environmentally sustainable housing. This is to ensure that the UK reaches its climate change targets of producing zero carbon emissions by 2050 (Gov, 2019). Furthermore, there was a 3% increase of urbanisation in the UK from 2007-2017, with further increase per year (Goddard & Tett, 2019). Despite bringing a wealth of both economic and social benefits, rapid urbanisation proved to be damaging to the environment, often driven by practical imperatives of providing easily buildable housing- using materials that are not most environmentally suited and the least sustainable?

The percentage of the UK covered in woodland is currently 12.9%, which is almost a third of the average coverage of Europe woodlands in its entirety which is currently 38% (IES, 2019). This percentage has been rising since1919 where the percentage of the UK covered in woodland was only 5%, due to World War 2 (IES, 2019). It is most likely to increase in the next few years due to new government legislation.

The construction industry is responsible for 50% of the energy demand, and around 50% of the greenhouse gas emissions with limited research on whole life cycle of the building (Yan et al, 2009; CCC, 2019), there is an urgent need therefore to examine the relationship between the construction industry and its environmental impact in terms of greenhouse gases and air pollution that ultimately create holes in the ozone layer (Rinkesh, 2019). Within the average household, there are a variety of factors that contribute to the rising air pollution within the atmosphere (Rinkesh, 2019). Burning fossil fuels for heating and electricity is one of the largest causes of global warming, with fossil fuels being consumed over three times more than in 1965 (Ritchie and Rosser, 2019). This is largely caused by population growth along with development in technology (Ritchie & Rosser, 2019). Another cause of global warming is indoor air pollution caused by cleaning and painting products, these products then create suspended particulate matter, mainly toxic metal that cause air pollution (Rinkesh, 2019).

“A physical, biological or chemical alteration to the air in the atmosphere can be termed as pollution. It occurs when any harmful gases, dust, smoke enters into the atmosphere and makes it difficult for plants, animals, and humans to survive as the air becomes dirty.” (Rinkesh, 2019)

As shown in Figure1 below, a large amounts of carbon emissions produced by buildings whilst in use stage, with over 82%, it is evident that alternative energy sources must be developed and implemented (BIS, 2019). With the construction industry contributing to 47% of the UK's carbon emissions, there have been a significant increase in the research of reducing greenhouse gas emissions since the implementation of the zero-net carbon legislation (CCC, 2019, 2019 a).

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During construction the average home in the UK emits 50 tonnes of CO2. with an additional 5 tonnes is emitted annually as an average for a lived in home (CITU, 2019). The extent of the problem is quite staggering given the 25 million homes in the UK (BBC, 2019) and the likely increase due to population growth. Suffice to mention that the number of dwellings both started and completed during 2018/2019 were around 42,000- a pattern that has been rising since 2011 (GOV, 2019). As shown in Figure 2, with a single UK home emitting 5 tonnes of carbon emissions per year (CITU, 2019) and with the new homes whilst in use will create an additional 210,000 tonnes of carbon gas.

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A more environmentally sustainable way of building and maintaining the whole life cost of a home is therefore required. Despite a wide range of environmentally friendly materials of low carbon footprint and low embodied energy (EE) were developed, limited renewable technologies being installed using smart operation and management systems post-construction/occupancy phase. For example, only 1 million out of the 25 million homes in the UK obtain their energy from their own solar panels which is 4% (Solar Trade, 2019).

The dichotomy of smart home technology and the environment have received much research attention in terms of the number of papers published. However, many were limited in their scope of linking smart home technology to its environmental benefits over the last 10 years. There is a paucity of information and knowledge gap. Research regarding the interaction between smart homes and environmentally sustainable technology is rather limited. This does indicate a lack of interest and limited scope for development to implement the newly emerging environmentally renewable technologies which are beneficial within a household considering the UK government pledge to stop their contribution to global warming by 2050 (GOV.UK, 2019) based on the implementation of the zero-net carbon legislation (CCC, 2019). This requires new forms of energy and other environmentally beneficial practices which merits further research (GOV.UK, 2019).

Smart Homes and Environmentally Beneficial Technologies

A smart home can be described as an automated home. "A dwelling incorporating a communications network that connects the key electrical appliances and services, and allows them to be remotely controlled, monitored or accessed by the homeowner.". The key rationale is to maximise convenience and ease of use of home appliances during daily activities (Kadam, et al, 2015; Darko, et al, 2018). For example, allowing heating, hot water, or lights to be turned on or off, using an app on a smart phone whilst outside the house (Solaimani, et al, 2013). This technology allows all electronic smart appliance and devices such as remote control or a keypad to access data and services synchronously, integrating home technologies and services through home Wi-Fi network.

Sensors describe the technology which is able to detect movements and locations of objects and people, collecting and displaying data. Finally, appliances and devices define those household technologies which access and control data and services The “smartness” of the system is achieved through connecting devices through what is commonly referred to as the Internet of Things (IoT).

“A smart home is a residence installed with computing and information technology that interacts with the occupants' needs to provide comfort, security, and entertainment through the usage of technology within the home and connection to the world beyond—even the most significant difference between a smart home and a traditional house.” (Georgiev & Schlögl, 2018)

Several benefits of smart homes can be identified from literature including, inter alia, total energy cost reduction, induced comfort management, and improving building security and safety (Kadam, R, et al, 2015; Darko, A., et al, 2018; Georgiev & Schlögl, 2018). Many barriers against the adoption of smart home technology can be envisaged. Cost of installation and affordability were identified as one of the key barriers as with the IT skills required for installing the technology (Zandori, et al, 2020). Lack of market competition had led to disproportionately higher price. Homeowners are sceptical about investing and adopting the technology which is mainly due to lack of awareness and limited technical skills (Georgiev & Schlögl, 2018; Zainordin, et al, 2020). Other key impediments include privacy and security issues, technology availability and the mismatch between functionality offered by smart devices and users' needs were also identified (Darko, et al, 2018; Georgiev & Schlögl, 2018).

By identifying the benefits and drawback of a smart home can enhance the existing knowledge and may trigger a further understanding of the concept itself. An attempt will be made to review and explore in greater detail the current smart home technology and assess their impacts and challenges on homeowner in reducing the amount of greenhouse gas emissions.

Smart Homes and Smart Grids

There are multiple apparent trends which can be identified from literature with a prominent theme of reducing the amount of carbon emissions. These revolved around the idea of a smart power grid and smart energy based on digitisation and automation of energy management processes. A smart power grid can be defined as a more sustainable upgrade on the pre-existing electricity power grid which ranges from faster electrical transmissions to higher reliability. A smart power grid also offers more efficient electricity delivery at a lower cost for the end user (Carlucci, et al, 2016; Pandya, 2019).

“The electric power grid, known as the most complex and most substantial machine on the globe, is an interconnected energy infrastructure made up of power generation, transmission, and distribution. As technology transforms the electric grid, the rapidly emerging microgrids, intelligent sensors, 2-way communication, digitization, and automation of energy management processes have laid the foundation to not only smart grids but also smart energy.” (Pandya, 2019)

There is a growing recognition that the development of the smart grid within the home will create significant change in terms of cost and electricity consumed by home appliances under the notion of demand side management (DSM)- This is an energy management technique that allows users to change their energy usage and consumption pattern (EIRGRID Group, 2019). The key emphasis is how the optimal energy performance can be achieved for user based on the type of appliance and the time it was used (Khan & Javaid, 2018).

Clearly DSM is of paramount importance to the efficiency of smart power grids, as the feedback information allows for the reduction in carbon emissions and cost minimisation to end users whilst improving the sustainability of the grid (Khan, et al, 2018). A priority-induced DSM based on loading shift techniques was advocated by Khan, et al (2018) to move the consumption of varying appliances from peak to off-peak hours and to further reduce the 'Peak to Average Ratio' (PAR) and the cost and amount of electricity for the user (Khan, et al, 2018).

Home energy management is a device used to monitor the electrical usage of appliances within home (Ullah et al, 2015). By using energy efficient optimization model, electricity can be scheduled for optimised use using Binary Particle Swarm Optimisation (BPSO) (Ullah et al, 2015). However, further research undertaken by Khan et al (2019) found that the improved reliability and efficiency of the system can result in a larger PAR. According to a published paper entitled 'Energy Sufficient Scheduling of Smart Homes', there is an increasing demand for energy in residential, commercial, and other sectors that the traditional energy grid is unable to cope with (Khan, et al, 2019). Given its more advanced technological solutions, the smart power grid must be put into greater practice in order to attain the energy demands of the public, as opposed to the current traditional grid which is unable to sustain public demands (Khan et al, 2019).

Faisal et al, (2020) focused on DSM and a smart grids domain rather than household. The emphasis was largely on reducing the total cost for the end user based on PAR. The key rational is to reduce the waiting time for the user and consequently the amount of energy being used leading to carbon emissions reduction. Despite providing a springboard like scenario for further research, the paper is limited in exploring the ways in which PAR will be environmentally beneficial where the emphasis was on saving money for the end-user and reducing the amount of energy required during peak times.

As demonstrated above, the majority of research conducted on smart homes was focused on smart grids and home energy management and usage based on the appliances of a multiple households, that have been looked at individually utilising DSM which provides effective measures that guide homeowners to optimise appliances power usage towards improving efficiency and optimise resource allocation. When smart communities are considered, price tariffs for smart grids users can be more accurately calculated, and energy consumption may be decreased (Awais, et al, 2018; Zhu, 2019). Equally there is a likely reduction in PAR, greater than in single homes which can also be influenced by the energy needs of the individual community (Awais, et al, 2018).

Smart Homes and Smart Meters

The key rationale for installing smart meters in the UK is primarily focused on optimising energy consumption towards reducing carbon emissions. As of March 2019, only around 13.19 million smart meters had been installed into homes within the UK, a 4.2% increase from December 2018 (GOV.UK, 2019). Based on Figure 3 there are a round 8 million domestic smart meters operated by large energy suppliers on smart mode as at 31 March 2019 However, the government has previous stated that it is committed to offering all households a smart meter by the end of 2020 which could lead to a tangible decrease in energy consumption, as consumers can see in real-time how much energy they can consume and therefore how much money they have spent (GOV.UK, 2019).

India have implemented a similar policy which see 130 million smart meters installed, this will be mandatory for those whose consumption is 500 units or more as of December 2017 (Power Technology, 2018). The European Union had similar initiatives to supply 80% of households with smart meters by 2020. Key challenges were observed in France and the UK where consumers were sceptic about access and storage of their personal information (Buchanan, et al, 2016; Faure & Schleich, 2018). Energy consumption was reduced by 15% in France compared with 5% reduction in Austria. This shows that smart meters reduce energy consumption albeit to varying extent not only saving the consumer money, but also reduces the amount of carbon emissions for the household concomitant with similar reduction in peak loads, which could supplement smart grids loads (Faure, 2018)

Germany has made it compulsory for all new or fully renovated buildings to have a smart meter installed (Belta-Ozkan, et al, 2014). Whilst intertwining smart home technology into newer homes is fairly simple and straight forward there appear to be resistance within older building as many consumers cannot envisage smart home technology within their older property; or simply believe that it could not be incorporated.

Smart Thermostats:

The idea of using of smart thermostats centres around controlling the heating in homes by allowing user to control the temperature of each individual room using phone app (Black, 2018). In so doing inform the customer how much energy has been used to heat home which enable them to see in real-time how much money is being spent on heating. Homeowners reported a 23% decrease on heating costs. If less energy is being used then less carbon emissions are being emitted (Black, 2018). In addition, smart thermostats can learn when a house is occupied or even just the heating patterns of the consumers, as a result the smart thermostats can reduce energy consumption during peak load, further reducing carbon emissions (Outrider post, 2020).

Clearly there is major gap in the body of knowledge and a paucity of information to assess the effectiveness of these interventions for both homeowners and government bodies with the majority of research investigating smart grids and PAR.

A holistic approach based on shared knowledge and practice on smart homes and how their widespread utilisation can aid meeting global climate targets is therefore needed.

An attempt will be made to address why smart homes technology has not been more thoroughly incorporated to aid the government's climate change targets and to establish why a knowledge gap exists. A theoretical framework is established based on qualitative secondary data.

Methodology

Following from the review of literature and the analysis of secondary data, a theoretical framework is established based on the research aims and objectives of this study. The purpose of this research is to ascertain public perceptions about smart home and environmentally beneficial technologies.

The authors argue that a qualitative method is more appropriate than quantitative method as it examines events that are often ordinary and representative of individuals, groups, and society daily life. By and large, the qualitative approach is concerned with opinion, views, experience and perspectives regarding issues related to objects, and circumstances (Amaratunga, et al, 2002).

Qualitative research is regarded to be “subjective in nature” (Naoum, 2012). This indicates that qualitative research is based on the opinion, experience, and insight of persons educated in the field of research, whereas quantitative research examines phenomena that can be quantified and observed in some form through the identification of a set of variables. The authors argue that epistemological approach using interpretivism is most suited to analyse data research. Interpretivism allows the researcher to develop theories based on the data collected, unlike other forms of data analysing methods.

However, despite allowing a wide spread of data to be collected, it can be subject to confirmation bias- which is where the results interpreted from the data are swayed depending on the pre-existing beliefs of the researcher (Ryan, 2018). Another disadvantage of interpretivism is that the conclusions drawn from the data, are based solely on the data collected, which can cause narrow insights into the topic. In order to reduce this risk, this study argue that a semi-structured interview of a wide range of participants is needed. This method implies that additional information and data can be added by participants, with a wide ranging views on the research topic.

The semi-structured survey consists of open-ended and perceptual questions, allows the participant to provide more detailed qualitative data which can be interpreted quantitatively to achieve clearer analysis. The target participants of this research include both individuals who are either deemed knowledgeable about smart home technology and its development and implementation and those who are the key users of smart home technology.

Opportunity sampling was adopted in determining the study sample. Surveys and questionnaires have the beneficial ability to provide researchers with desired qualitative or quantitative data, along with allowing respondents to provide the level of detail as deemed comfortable. Despite this, surveys can have a low response rate, and therefore an incentive may be required to improve response rate. Additionally, the type of response from surveys are greatly dependent on the wording of the questions. Plain and non-emotive language was used in formulating the questions to improve quality and reduce the risk of misinterpretation attributed to technical terminologies and jargons.

The questionnaire was formulated based on intrinsic recognition of the key issues raised during theoretical analysis of smart homes and smart grids technology where common recurring themes and areas of concerns were highlighted. Participants were initially encouraged to share their own experience with smart homes and write down their own comments and observation, based on open-ended exploratory questions. Written statement were collated and then analysed for meaning based on qualitative code analysis method (Mayring, 2000; Schreier, 2014). Statements were then merged into core concepts and subsequently agglomerated and assigned to 6 key code categories which were identified from literature. These encompass conceptual, practical/operational, cost, energy efficiency, usefulness and utility, and safety and security issues as shown in Table 1.

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Several guiding criteria were identified prior to formulating the questionnaire. These were based on the recurring interrelated themes and issues raised in literature encompassing i) ease of use and ease of integrating the technology and efficacy; ii) operational and technical challenges involved; iii) understanding of smart home technology, iv) implementation of the technology and monitoring its effectiveness in use and v) energy and cost reduction. The questionnaire is formulated based on 5 key overarching open-ended questions based on the following indicators:

Ease of use and ease of integrating smart home technology in a pre-existing home.

Challenges posed when integrating smart home technology.

Perception of smart energy grid vs smart home technology.

Changes required to implement and monitor technology to aid the UK government meeting its 2050 net zero carbon goals.

Perception about technology used in reducing the average UK house's energy consumption?

A pilot study was conducted to assess the questions in terms of structure, format, clarity and legibility of the questions to avoid any emotive and technical jargons and to address any anomalies and gaps. The questionnaire was administered to two groups which include: i) academic colleagues and researchers in the faculty who are familiar with smart sensors and renewable technologies as representative of energy suppliers and smart homes professionals, and ii) final year students representing homeowners. Based on the feedback and the comments raised, the questionnaire was further refined and embellished prior to final launch.

Ethical processes were followed to ensure both confidentiality and anonymity are met and to ensure no subject comes to harm as a result of this research. Participants were fully briefed on the intentions and guiding policies of the research prior to providing informed consent which included respect for the anonymity of the subjects. Equally all data collected was anonymous to ensure full compliance with Data Protection Act 2018. No data sharing is permitted during or after this research, to further protect the subject's data. Additionally, all data collected was destroyed, adhering to the university Ethical Code and Data Protection Guidelines.

Several operational difficulties were experienced due to the Covid-19 lockdown which led to lower response rate which stood 23%. Only 24 questionnaires were completed out of a total 104 sent as shown in Table 2. The target sample was representative of energy suppliers, smart homes professionals and companies, and homeowners- the ultimate beneficiaries of the technology.

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The majority of questionnaires were sent to homeowners to obtain their views and perspectives. This is given that the aim of this research is to determine why smart home technology has not been further developed and implemented within UK homes, therefore the answer mainly lies with homeowners who are in control of how smart technology is implemented within their own homes. This approach allowed range of information from individuals who have different experiences with smart home technology to be obtained.

Energy suppliers were also questioned in order to gain further insight into some of the operational complexities involved in installing smart home technologies within the UK household.

Many who initially agreed to take part were unable to complete the questionnaire due to various reasons and circumstances. This resulted in limited data input as reflected in the findings.

The questionnaire was conducted through email. This greatly reduced researcher bias by using blind questionnaires to eliminate the researcher and participants communicating. When no response was obtained, alternative approach based on virtual conversational interviews was adopted. The data was collected from mid-February 2020, until the end of April 2020, totalling around 75 days of collecting data. This allowed enough data to be gleaned and to gain a comprehensive understanding of the responses and to further analyse the data and create a well-informed set of guidelines.

Throughout the period of conducting questionnaires, there was a minimal amount of engagement from larger companies and local council, who were also sent the questionnaire. This can be attributed to lack of interest which may not be their top priority in the build up to Covid-19 lockdown.

Findings

The key aim of this paper is to investigate how smart home technology can be effectively used to mitigate the environmental impact of a home in use in towards reducing carbon emission and to determine the key factors which militate against their integration in the design and construction of new and pre-existing UK homes.

Ease of integrating smart home technology in a pre-existing home.

When participants where asked about ease of integrating smart home technology more than 50% home owners indicated that it is simple and straight forward process which indicate wide variations amongst homeowners' experience IT and technical skills for installing the technology. This is compared with 80% smart sensors professionals indicated ease of use of technology. Discrepancies can be attributed to the level of savviness i.e. having prior practical experiences in installing the technology. Smart home technology can appear simple with only an internet connection required. However, past studies show that 22% of users return smart home technology due to a fault that cannot be rectified, while other users reported undergoing an 8-step process in order to rectify the issue (Castenson, 2019). Whilst integrating smart home technology was perceived to be simple, most participants indicated that more government incentives is needed to make smart home technology more affordable and much cheaper to be integrated into the existing housing stock. Providing incentives and changing public perception should be a key priority in any future government intervention.

The findings reject the claims by Georgiev & Schlögl (2018) regarding integrating smart homes technology in a pre-existing home of being highly complex and expensive to install apart from homeowners' perception regarding value for money and trustworthiness of the technology.

Challenges posed when integrating smart home technology

One of the key findings is the general public lack of trust and acceptability of having smart home technology within the house. When participants were asked about the biggest challenge of integrating smart home technology 40% indicated security challenge as the main concern, with many felt unsure of how to effectively protect themselves against hackers. No response from smart home installers was made regarding this indicator.

This can be attributed to how smart home devices are connected and networked increasing its vulnerability to hackers. Every piece from light bulbs to smart meters, are connected and therefore, it would simply take a hacker to change on piece of technology before the whole house has been hacked (Hu, 2018). Hacking into a piece of smart home technology creates a variety of security issues. This is particularly true if the hacker is able to access the homes Wi-Fi (Hu, 2018). The findings support the claims by Darko, et al (2018) regarding privacy and security issues. It also confirm Georgiev and Schlögl (2018) observations about trust and acceptability of technology which appears to be a key barrier of its full adoption. Suffice to mention the increase in the number of worldwide sale of smart homes technology devices from £ 814.8 million in 2019 to £1396 million in 2023 (Petrock, 2019). There is a need for more user-friendly tutorials produced by smart homes companies on how to effectively protect homes from hackers to encourage more people to buy the technology and therefore reducing the carbon emissions of these homes.

Maintaining internet connection and cost of doing so were also identified by 42% of the homeowners as another key challenge when integrating smart home technology. Operability of smart devices requires a reliable connection to the internet as highlighted by Bouckley (2019) and further supporting his claim that a good and reliable internet connection is paramount to the adoption of the technology. As a general rule for smart devices is that for every 10 devices within the household, 5 megabytes (Mb) is required- for cameras it is an extra 5 Mb (Schmind, 2019). In order to get internet connection to support smart home devices, along with the daily internet requirements, some users could be paying between £35-£40 for having a high speed fibre-optic broadband (BT, 2021; TalkTalk, 2021): Apart from the cost of installation of the smart home technology, this may be too costly for some homeowners.

Perception of smart energy grid and smart home technology

All participants agreed that smart grids would be beneficial in reducing the carbon footprint of UK homes. This was consistently the case amongst homeowners with 20% of participants stated that it would likely be more accepted than smart home technology whereas equal emphasis was given by smart homes installers since this is part of their own business. Smart home technology was perceived to be more expensive and daunting particularly for elderly users who are not familiar with using the technology due to the gradual decline of cognitive abilities and memory triggered by the ageing process including deteriorating of visual, hearing and fine/gross motor coordination. This militates against effective use of smart devices and effective implementation due to lack of understanding of the technology and lack of appreciation of its efficacy and utility. The longer-term real system implementation/integration of smart devices particularly in existing residential care homes remains to be seen.

“There is a level of reluctance for individuals to adopt smart home technology and this would unite the approach. A smart grid would also have the ability to more effectively distribute energy from renewable sources and redirect excess energy reducing waste.” (Anonymous participant, 2020)

However, one participant did note that although a smart grid would reduce carbon emissions, it would not solely be enough to help the UK reach the 2050 net-zero goal supporting the CCC (2019) claim that stopping global warming would be achievable with not only known technologies, but also with a change in the way people live their life. Reducing carbon emissions requires a multi-modal effort, however it is widely believed that in order to efficiently tackle climate change, the UK's aging and insufficient electricity grid, must be updated (Power Technology, 2018).

When compared to China as one of the global leaders in the developments of smart grids one can see the environmental benefits of the grids where $4.3 billion was invested into implementing smart grids around the country which led to 15% increase in the amount of non-fossil energy consumption (Chen, 2018). By the same token, greater research emphasis on renewable energy sources and development in the efficiency levels of wind and photovoltaic technologies had led to more energy created and an overall reduction of cost for this type of energy in China (Chen, 2018).

"A number of governments are increasingly viewing smart grid technology as a strategic infrastructural investment that will enable their long-term economic prosperity and help them to achieve their carbon emission reduction targets." (Power Technology, 2018)

The findings clearly demonstrate that such an investment is a worthwhile. The benefits of incorporating smart grids not only increase the amount of energy being produced, but also reduce the price of electricity for homeowners.

Changes required to aid the UK government meeting its 2050 net zero carbon goals

Only around one fifth (21%) of the participants agreed that updated thinking of the average homeowner was required to help the government attain its 2050 goal compared with 63% of smart homes installers. Without homeowners getting on board with smart home technology, it will be near impossible to reach the goal due to the vast amount of carbon produced by UK homes on a daily basis.

One participant argued that incentives were the best way to help persuading homeowners of smart home technology and used the example of Germany where shop owners were instructed to charge customers an additional cost on all products that came with recyclable packaging- like bottles. Once the product has been consumed, the customer can return the packaging to a recycling point and claim back the money. This is an initiative which could be put in place in the UK with regards to saving energy. For example: setting energy consumption goal, depending on the household conditions, and for every kilowatt that the household exceeding their goal, there will be and incremental increase in the price of electricity. This type of incentive would be aided by smart meters as consumers could see exactly how much energy is being used.

Perception about technology used in reducing the average UK house's energy consumption

When homeowners where asked about the single piece of technology which they would recommend to significantly reducing the average UK house's energy consumption some interesting array of responses were gleaned. Around 64% of home owners indicated that smart meters would be the most popular types of smart home technology in comparison to only 21% who pointed to smart thermostat and timers as a piece of technology that could significantly reduce energy consumption.

When smart homes installers were questioned 88% indicated smart meters will be the key to energy saving. A few suggested installing renewable energy technologies such as solar photo-voltaic panel systems, passive infra-red detectors (PIR) and energy efficient bulbs to reduce home energy consumption. The findings demonstrate a wider views and perceptual difference in scale of priority between the two groups. This is partially supports Faisal, et al (2020) and Faure & Schleich (2018) claims regarding energy consumption- a reduction in peak loads results in less waiting time for the user which implies a reduction in energy consumption towards a decrease in carbon emissions.

"People need incentives to reduce their energy consumption and waste, as not everyone can afford the technology, and most are too lazy to use other techniques." (Anonymous Participant, 2020)

Conclusions

The aim of this research is to establish whether smart homes technology can efficiently and significantly reduce the greenhouse gas emissions within the average UK lived in home, and how government legislation can be used to best utilise these technologies. This paper has investigated a range of aspects related to smart homes technology which was narrowed down to the most influential aspects which hinder its full implementation within UK households, and hence hindering the UK's 2050 net-zero carbon goal.

The paper provided further explanation of the key impediments against smart homes technology adoption and integration by homeowners and proposed ways to overcome and address them more effectively. The findings, to certain extent, bridge a major gap in the existing body of knowledge of smart homes technology in such a poorly understood research area, providing further explanations and understanding to the limitations and key interrelated operational, technical, financial and societal impediments against their full implementation. Key area of concerns include ease of use, challenges posed when integrating the technology in existing homes, perception of smart energy grid vs smart home technology and changes required to implement and monitor technology to aid the UK government meeting its 2050 net zero carbon goals.

With fossil fuel reserves depleting and rising demands for energy, there is an urgency for using renewable and low carbon energy sources that reduces the 5 tonnes of carbon emitted annually by existing homes. Despite a plethora of research on the development and implementation of smart grid in order to reduce energy consumption, it is evident that further research is needed on the specifics of integrating smart grid with smart homes technology within the average UK household to further reduce the energy consumption which is hindered by government legislation

Suffice to mention that the UK will fail to reach their net-zero carbon 2050 targets, if government legislation fails to address the need to reduce the energy consumption of the average lived in UK household.

The paper proposes a set of guidelines to reduce carbon emissions of the average UK home, these guidelines are formulated from the information attained from both primary and secondary data which is consistent with statements provided by UK homeowners.

The first guide would be to provide most of the UK with efficient smart grid technology integrated into the existing network. This should be part of a holistic multi-facetted government-led strategy which should include financial incentives and subsidies to make it more affordable to homeowners to embrace environmentally efficient smart homes technology. Greater harmonisation and standardisation of operating platforms is needed to ensure great compatibility and interoperability of smart appliances and devices supported by reliable broadband connectivity and robust home Wi-Fi network. Such multi-pronged approach can significantly reduce carbon emissions by withholding electricity, reducing peak-loads and minimising energy wasted or lost due to faulty existing lines.

Secondly and most importantly, homeowners need to be educated on smart home technology in order to have a different outlook on the technology- with 50% of participants stating that incentives and education were required to ensure more people welcomed smart home technology into their homes, it is evident that the UK government need to do more and introduce education and incentives for UK homeowners to ally homeowners' concerns about security and safety of smart technology. Perhaps homeowners need proper training on how to effectively and diligently protect their home and devices from hackers in order to make homeowners feel safe. Other incentives mainly subsidies, for people to help them invest in the technology and internet connection so that they can use the technology to its full potential.

Thirdly, it is evident that the presence of a smart meter within the household has a significant impact on reducing the amount of energy used in the household, effectively reducing the amount of carbon emissions each house emits. It is vital that more houses are installed with smart meters, so that more people can manage their energy in a real time. It is particularly important to ensure these meters are compatible in occasions when homeowner switch to different energy. A free smart meter initiative by energy suppliers is therefore needed to increase uptake. The findings clearly demonstrate that reducing the nation carbon consumption require a multifaceted approach in order to minimise the emissions of the average UK home which significantly aid the UK government into reaching its 2050 net-zero carbon goals. Further research is needed to explore other interventions to achieve government targets.

Research Practical Applications

Several practical applications can be envisaged to empower built environment professionals, home builders, smart sensors professionals and energy suppliers, homeowners, and government to incorporate the latest thinking regarding smart sensors technology and smart grids.

For smart homes manufacturers and suppliers more emphasis should be placed to enhance compatibility and interoperability of appliances and devices using different platform and creating more user's friendly manuals supported by step-by-step visual to support homeowners in the light of the wealth of knowledge base generated over the past few years.

For homeowners more emphasis should be placed on creating online knowledge management platform easily accessible which provide and virtual support and technical advice to home owners to deal with any operational and technical issues or IT glitches.

Developing technical design online platform for built environment professionals on incorporating smart sensors and environmentally beneficial technology during early design and construction stages towards achieving low to zero carbon homes. This will equally be beneficial to home builders who need to work synergistically and appreciate the practical implications of smart sensors technology

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Q1) In your experience, how easy is it to integrate smart home technology in a pre-existing home?

Q2) What is the biggest challenge when integrating smart home technology?

Q3) Do you feel the government implementing a 'smart energy grid' would be more beneficial to reducing the energy consumption of UK homes, than the smart technology within the household?

Q4) What single piece of technology would you recommend for significantly reducing an average UK house's energy consumption?

Q5) What changes do you feel are required to UK homes, to aid the UK government in reaching it's 2050 net zero carbon goals?