Electronic Devices & Networks Annex
EDNA

Intelligent Efficiency

A Case Study of Barriers and Solutions - Smart Homes

MARCH 2018

connected devices
ALLIANCE

Energy Efficient End-use Equipment
International Energy Agency

4E is the Energy Efficient End-Use Equipment Technology Collaboration Programme, established by the International Energy Agency (IEA) in 2008 to support governments in co-ordinating effective energy efficiency policies. Twelve countries have joined together under the 4E platform to exchange technical and policy information focused on increasing the production and trade in efficient end-use equipment. However 4E is more than a forum for sharing information – it pools resources and expertise on a wide a range of projects designed to meet the policy needs of participating governments. Participants find that is not only an efficient use of available funds, but results in outcomes that are far more comprehensive and authoritative than can be achieved by individual jurisdictions. Current members of 4E are: Australia, Austria, Canada, Denmark, France, Japan, Korea, Netherlands, Switzerland, Sweden, UK and USA. Further information on the 4E Implementing Agreement is available from: **www.iea-4e.org**

Electronic Devices & Networks Annex
EDNA

Network connected devices, including the Internet of Things, are growing rapidly and offer enormous opportunities for improved energy management. At the same time, there is a responsibility to ensure that these devices use a minimal amount of energy to stay connected. 4E's Electronic Devices and Networks Annex (EDNA) works to align government policies in this area and keep participating countries informed as markets for network connected devices develop. Further information on EDNA is available at: **http://edna.iea-4e.org**

connected devices
ALLIANCE

This case study was initiated by the Connected Devices Alliance (CDA) which is a network of more than 350 government and industry participants that have come together to work on the energy efficiency opportunities provided by networked devices. Further information on the CDA is available at: **https://cda.iea-4e.org**

This report is authored by consultant, Vida Rozite. The views, conclusions and recommendations expressed in this report do not necessarily reflect the views of the IEA, 4E, EDNA, the CDA or their members.

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Abbreviations

CDA	Connected Devices Alliance
DR	Demand Response
DSF	Demand Side Flexibility
DSM	Demand Side Management
EC	European Commission
ETSI	European Telecommunication Standards Institute
EU	European Union
EV	Electric vehicle
EVSE	Electric Vehicle Supply Equipment i.e. chargers
EDNA	Electronic Devices and Networks Annex
HAN	Home area network
HEMS	Home Energy Management Systems
HVAC	Heating, Ventilation and Air-Conditioning
ICT	Information and communications technologies
IE	Intelligent Energy Efficiency
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IoT	Internet of Things
IPMVP	International Performance Measurement and Verification Protocol
ISO	International Organisation for Standardization
MEPS	mandatory minimum energy performance standards
S&L	Standards and Labels

Glossary

Automation	Systems that integrate diverse electrical devices and energy- consuming equipment, allowing automatic control in accordance with selected settings or in response to data from sensors.
Demand Response	Intentional modifications to consumption patterns of electricity of end-use customers that are intended to alter the timing, level of instantaneous demand, or the total electricity consumption in response to changes in the price of electricity over time or to incentive payments.
Cloud computing	The practice of using a network of remote servers hosted on the Internet to store, manage and process data, rather than a local server or a personal computer.
Demand response	Demand response or demand-side response refers to the possibility for consumers to adjust their electricity consumption during periods of peak demand, when power supply is scarce or electricity networks are congested, in response to time-based financial incentives. Demand response can consist of interrupting demand for a short duration, or adjusting the intensity of demand for a certain amount of time by reducing or shifting loads, or storing energy. For connected devices, demand response functionality might enable a power utility or aggregator to remotely turn off air-conditioning units in customer homes to avoid peak load issues.
Digitalisation	The application of information communication technologies across the economy, including energy, to achieve desired outcomes such as improved safety, efficiency and productivity.
Electric vehicle	A vehicle whose powertrain includes both a battery (which can be recharged via an external power source) and an electric motor. Charging can be achieved by plugs or by (stationary or dynamic) conductive or inductive power transfer.
Flexibility (in electricity systems)	The capability of an electricity system to respond to upward or downward changes in the supply/demand balance in a cost-effective manner over a timescale ranging from a few minutes to several hours.
Intelligent Efficiency (IE)	The deployment of network-connected ICT technologies to facilitate efficient operation of energy-using equipment, leading to energy savings
Intelligent Efficiency (IE) technologies or solutions	A suite of energy efficiency measures that use information and communications technologies (ICT) such as sensors, networks, and data analytics to save energy.
Internet of Things	System of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.
Learning algorithm	A process or method used to extract patterns from data collection (e.g. from sensors and controls) to identify and adapt appropriate solutions or applications for a device or system.
Open interface	An open interface is a public technical standard for connecting hardware to hardware and software to software.
Plug-and-play	Software or devices that are intended to work perfectly when first used or connected, without reconfiguration or adjustment by the user.

Prosumers	Small-scale, distributed electricity generation which allows consumers to have the choice to buy electricity from a retailer or to produce at least part of it themselves.
Real time	Information available simultaneously with an event, or immediately after collection.
Sensor	A device which detects or measures some type of input from the physical environment (e.g. daylight, temperature, motion or pressure).
Smart charging	A charging strategy for electric vehicles that uses connectivity and other digital technologies to automatically shift battery charging to times when electricity prices are low and/or when overall electricity demand is low.
Smart meter	A meter that records electricity consumption in intervals of an hour or less, and communicates that information at least daily back to the utility for monitoring and billing purposes. This type of advanced metering infrastructure differs from traditional automatic meter reading in that it enables two-way communication between the meter and the central system. Smart meter functionality includes remote reading, two-way communication, support for advanced tariff and payment systems, and remote disablement and enablement of supply.
Standardisation	The process of implementing and developing technical standards based on the consensus of different parties that include industry, interest groups, standards organisations and governments. Standardisation helps maximise compatibility, interoperability, safety and repeatability.
Standby	The energy demand of an appliance or device when it is not actively in use but is ready to be rapidly put into use.

Executive summary

Buildings account for nearly one-third of global total final energy consumption. Forecasts indicate that building energy use, especially electricity use, will grow significantly. Smart homes are a new opportunity to reduce energy use in residential buildings, and studies indicate that smart home technologies could reduce energy use in homes by almost 30%. If a third of all households in the UK were to install and use best available smart home technologies, achieved savings could be more than 3 million tonnes of oil equivalent (Mtoe) per year. Correspondingly, savings in Japan could be in the region of 4 Mtoe per year and in the US more than 23 Mtoe per year could be saved. According to IEA forecasts, smart technologies could between 2017 and 2040 lower energy consumption of residential and commercial buildings globally by as much as 10% leading to cumulative energy savings over the period to 2040 of 5589 Mtoe – equal to more than all the total final energy consumed in non-OECD countries in the year 2015.

In addition to energy savings, smart homes can be an integral part of smart grid development and, through in-home renewables generation and demand response, play an instrumental role in decarbonising the energy sector. The IEA forecasts that by 2040, globally, 1 billion households could actively participate in interconnected electricity systems, providing 185 GW of system flexibility and saving USD 270 billion of investment in new power plants.

However, the uptake of smart home technologies has to date been limited. While growth is projected, there are barriers and gaps in enabling technologies and markets. The key barriers are costs, uncertainty around benefits, privacy concerns, cyber security concerns, and technology risk. Enabling the right market conditions for smart homes to participate in and gain benefits from interconnected electricity systems has yet to occur. The barriers and gaps which are present contribute to a weak value proposition for households to invest in smart homes.

In light of the magnitude of energy benefits that could be gained through smart home technology and interconnection, there is a strong case for policy intervention. This report focuses on the barriers to smart home technology uptake, particularly technologies related to energy management. This is followed by an identification of actions to address these barriers, particularly those that are typically within the mandate of policy makers dealing with policies for energy using appliances, equipment and devices.

This report highlights the role of energy efficiency policy makers in improving the value proposition for smart homes for energy management, by supporting the development of methodologies and studies quantifying benefits, and the provision of accessible information to consumers via labels or other mechanisms.

While the preconditions for large scale implementation of demand response and in-home renewable generation need the interventions of other actors, energy efficiency policy makers could accelerate progress through the development of standards and approaches that ensure that relevant smart home devices are “demand response ready”.

There is a strong case for international cooperation to pool resources, develop approaches and engage in dialogue. The IEA Technology Collaboration Programme on Energy Efficient End-Use Equipment (4E) and its Electronic Devices and Networks Annex, together with the Connected Devices Alliance, are excellent platforms for facilitating this.

Background

"Intelligent efficiency" (IE) is the deployment of network-connected ICT technologies to facilitate efficient operation of energy-using equipment, leading to energy savings. IE typically operates at the system level, rather than at the device level, to optimise the operation of a system of equipment, leading to energy savings.

There is currently a wide range of materials available from a variety of sources that provide information on the potential for Intelligent Efficiency to achieve energy efficiency and other benefits. The Connected Devices Alliance (CDA) Centre of Excellence now hosts 60 publications, 36 of which are in the field of IE. However, even though many see that increased implementation of IE will be beneficial in a general sense - by creating a greater capacity for energy management, IE is still quite intangible for most policy makers and it remains unclear what, if any, response is required in terms of public policy. To address this, the CDA has started to develop case studies, specifically designed to increase understanding amongst policy makers. This case study on smart homes describes scenarios where IE could provide substantial benefits, and addresses questions that are central to the concerns of policy makers:

- *What barriers currently prevent the optimisation of IE that might justify policy intervention?*
- *How can policy overcome these barriers?*

The case study contributes to the work of the CDA to establish the rationale for public policy in this field, and to encourage greater participation by governments in the ongoing work of the CDA. It was commissioned by the *IEA Technology Collaboration Programme on Energy Efficient End-Use Equipment (4E) Electronic Devices and Networks Annex (EDNA) on behalf of the Connected Devices Alliance.*

- *The IEA Technology Collaboration Programme on Energy Efficient End-Use Equipment (4E) was established in 2008 and brings together twelve countries from the Asia-Pacific, Europe and North America to share information and transfer experience in order to support good policy development in the field of energy efficient appliances and equipment. 4E also initiates projects designed to meet the policy needs of participants, enabling better informed policy making.* https://www.iea-4e.org
- *The IEA 4E Electronic Devices and Networks Annex (EDNA) is an annex of 4E which focuses on network connected devices (devices connected to a communications network). EDNA aims to ensure that the next generation of such devices use electricity as efficiently as possible and that opportunities for energy management enabled by connectivity are promoted.* https://edna.iea-4e.org
- *The Connected Devices Alliance (CDA) provides an industry/government umbrella for work on the energy efficiency opportunities provided by networked devices. It was formed in 2015 by participants in the G20 Networked Devices Initiative.* https://cda.iea-4e.org

Introduction

Buildings account for nearly one-third of global total final energy consumption (TFC)[1]. Globally, the energy consumption of the residential sector constitutes 2051 million tonnes of oil equivalent (Mtoe), which is more than a fifth of global TFC (IEA, 2016). Residential energy demand is set to increase - the IEA projects an annual growth of 0.8% in household energy demand to 2040 (IEA, 2016). Buildings-related CO2 emissions have grown by 45% since 1990 and have continued to rise by nearly 1% per year since 2010. Taking into account upstream power generation, buildings are responsible for more than one-quarter of global energy-related carbon dioxide (CO_2) emissions today (IEA, 2017a).

Building electricity demand constitutes more than half of global electricity demand (IEA, 2017d). Electricity demand growth in buildings has been rapid over the last 25 years, accounting for nearly 70% of total growth in global electricity consumption between 1990 and 2014. In some economies, including China and India, electricity demand in buildings grew on average by more than 8% per year over the last decade (IEA, 2017d). Electricity consumption by lighting, appliances and equipment in buildings is currently increasing by 3% on average per year (IEA, 2017a). Electricity use in buildings is set to nearly double from 11 petawatt hours (PWh) in 2014 to around 20 PWh in 2040, requiring large increases in power-generation and network capacity (IEA, 2017d)[2]. Globally, energy expenditures are just below 5% of household disposable income (IEA, 2016).

Significant progress has been made around the world in improving the energy efficiency of building envelopes and of appliances and equipment used in buildings. However, particularly in OECD countries and increasingly in emerging economies, efficiency gains are being offset by increases in the number of electronic appliances used per household. There are still many opportunities for energy efficiency improvements, especially in areas such as whole-home performance and systems (ACEEE, 2017a). An emerging opportunity is intelligent efficiency for homes, i.e. “smart homes”.

The term “smart home” is used to mean different things in different contexts and there is an ambiguity about its meaning. In this report, smart homes mean residences where enhanced monitoring and control functionality has been introduced. Smart homes could significantly contribute to achieving energy savings in the residential sector and could contribute to other energy policy objectives. However, the rapid growth of smart home technologies and systems that has been projected has not materialised - uptake has been limited. For example, currently, only 5% of US households have some form of home energy management system (ACEEE, 2017b).

There are barriers constraining the uptake of smart home devices and systems including consumer awareness, cost, unclear value propositions, immature technology, lack of interoperability, complicated sourcing and installation, operational and usability problems and data privacy and security concerns. Further constraints include regulatory barriers, lack of dynamic electricity pricing and gaps in the wider enabling environment “smart” infrastructure (distributed generation, electric vehicle charging, energy storage solutions), and lack of services that would contribute to a better value proposition. This report focuses primarily on barriers affecting the uptake of smart home devices and systems. However, some of the barriers and gaps related to the wider enabling environment are also covered, as these affect the value proposition and usefulness of smart home devices and systems.

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[1] Includes residential, commercial and public sector buildings
[2] IEA central scenario

There have been isolated attempts by policy makers to take action to remove some barriers and promote the uptake of smart devices and smart homes. However, most countries do not have an explicit vision or policy roadmap that would provide overall direction for policy making in support of energy efficient smart homes. Typically, there are a range of different ministries and government bodies dealing with issues related to smart grids, and the involvement of energy efficiency policy makers is limited. Intelligent Efficiency and smart homes are technically complex areas, which are continuously and rapidly evolving. This report aims to provide guidance for energy efficiency policy makers on what the rationale for energy efficiency policy in this area might be, and what actions could be taken to address barriers.

There is a growing body of literature on smart homes and home energy management systems and the topic has received increased coverage in the past few years. However, this information is typically either highly technical, targets an industry or academic audience, is limited in scope, is specific to a certain region or country or deals with the potential role of policy makers in a superficial or limited manner. As a consequence, an energy efficiency policy maker interested in getting insights on smart homes and their energy efficiency potential, energy system benefits, current and projected market, key barriers and possible policy responses is faced with difficulties in quickly accessing information that could be used as a basis for decision making. This report provides a synthesis of the knowledge, information and results found in reports, scientific and popular articles, and project and programme evaluations.

The report provides a starting point for exploring energy efficiency policy interventions in this area and for initiating dialogue with other government bodies and stakeholders.

Box 1 Definition of key terms

For the purpose of this report, "Intelligent efficiency" (IE) is the deployment of network-connected ICT technologies to facilitate efficient operation of energy-using equipment, leading to energy savings. IE typically operates at the system level, rather than at the device level, to optimise the operation of a system of equipment, leading to energy savings.

For the purpose of this report, **a smart home device** is a device that can connect to a communications network via a hub or central interface (or directly) and can be controlled remotely or set to be controlled automatically based on user preferences and sensor inputs. Following this definition, smart home devices include but are not limited to demand response enabled devices. A connected thermostat that can be controlled via an application on a smartphone is an example of a smart home device. This smart thermostat can be controlled remotely by household members or potentially be controlled by an energy provider in certain circumstances to reduce peak power demand.

A **smart home system** consists of multiple devices that can be controlled via one hub or interface. A smart home system can encompass multiple services or be dedicated to a single service category e.g. smart lighting system or smart security system. **Smart home technologies** encompass smart home devices and systems, and other supporting or enabling technologies.

A smart home is a residence that has a system (composed of a range of smart devices) or several systems that are network connected, and can be controlled remotely or automated. Smart homes can provide a range of services such as enhanced entertainment (e.g. a smart TV, streaming and audio system) and security (e.g. a system of cameras, sensors, controls and locks) and energy efficiency (e.g. a home energy management system).

An **energy smart home device** is a device that is connected and controllable and can enable energy savings or other energy system benefits. Examples of energy smart home devices and systems are smart meters, controls (for heating, ventilation, cooling, lighting, windows, shading), network-connected lighting, home management systems and energy storage systems.

A **home energy management system** (HEMS) comprises smart connected devices that can provide information on, and dynamically adjust, energy use within a home.

Energy provider is a term used to encompass energy utilities and energy retailers.

Smart grids are networks that intelligently monitor and manage the transport of electricity from generation sources to meet the varying electricity demands of end users. In this report, focus is placed exclusively on smart electricity grids. Smart gas systems, smart district heating other smart energy systems are not covered.

A further glossary is provided earlier in this report.

1 What are smart homes?

A smart home is a residence that has a system (composed of a range of smart home devices) or several systems that are network connected and can be controlled remotely or automated. It enables the control and automation of lighting, heating, ventilation, air conditioning, and security, as well as home appliances such as washer/dryers, ovens, refrigerators/freezers and home electronics such as TVs and streaming devices. Smart homes can deliver a range of services and benefits to households:

- Energy management (energy efficiency)
- Demand response (contribute to regulating energy demand)
- Electricity generation, storage and delivery to the grid
- Comfort enhancement
- Security
- Entertainment
- Household management e.g. help with ordering groceries or planning other chores
- Specialised services such as wellness or health management
- Assisted living.

Table 1 Typical smart home technology features

Network connectivity	use networks to send data to and receive data from household members, other devices and other entities such as energy providers
Automation	can be set to turn on, turn down or adjust in response to pre-set settings or learning based on household preferences
Context awareness	can via sensors and other technologies recognise household members and situational contexts
Adaptiveness	can change settings or offerings in response to household members
Interactive	provide alerts and notifications, can be voice controlled
Remote controllability	can be controlled remotely by use of network connection via e.g. a smart phone or tablet
Ability to be personalised	can be tailored to needs and desires
Anticipation	can anticipate desires or needs without conscious meditation

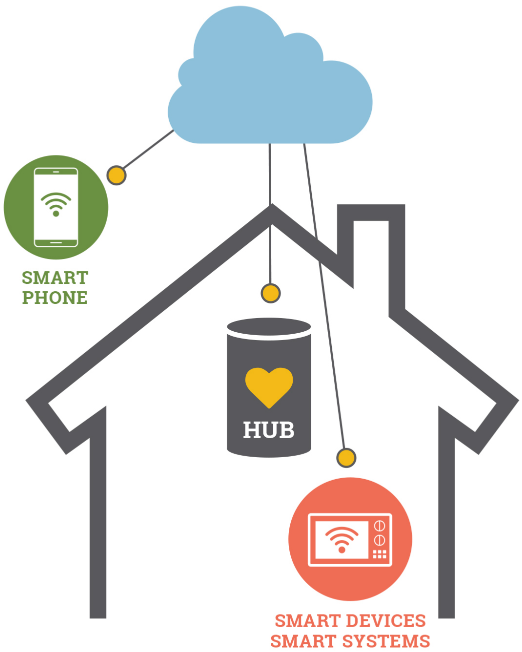
Source: ACEEE (2014)

There is no standard set-up for a smart home. The types of devices and the system or systems within a smart home will vary depending on the needs and desires of the household and can change over time as devices are removed from or added to the system.

Figure 1 Illustration of a smart home

Smart home systems generally consist of sensors and switches connected to a hub (sometimes called a gateway) from which the system is controlled with a user interface via wall-mounted terminal, mobile phone or computer, often via internet cloud services.

Figure 2 Simplified illustration of cloud services for smart homes



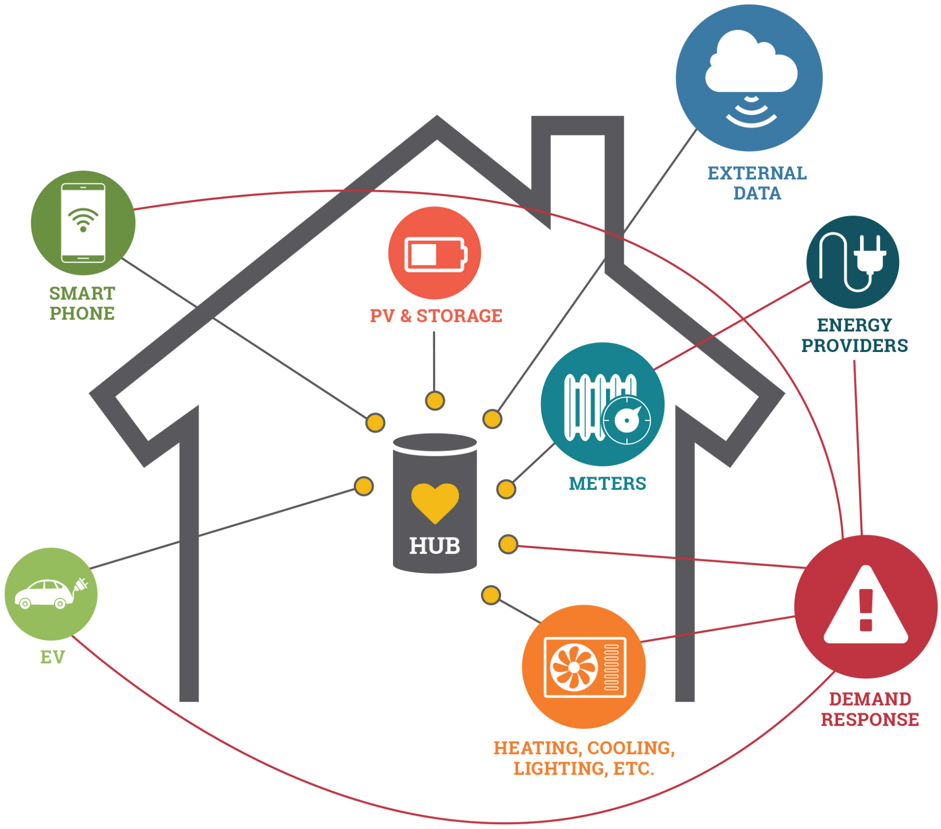
Note: The cloud can provide a range of services including processing power for smart devices and systems, relaying data between devices and storing data.

Currently available smart home energy management technologies include smart thermostats, smart plugs, connected lightbulbs or smart lighting systems, smart appliances, energy-use displays and smart home management systems. In terms of energy management, smart homes offer a range of functions such as near real time[3] energy use information, enhanced feedback on energy use and advanced or automated control (Hargreaves et al., 2015). There are a number of ways smart home technologies can help improve energy efficiency. Technologies can provide households with information about energy consumption to prompt changes in behaviour or can via automation control settings to deliver comfort and convenience in an energy efficient manner. It is possible to set up smart homes without much consideration of the wider energy system. In such a set-up, the smart home receives electricity (and gas) from energy providers and delivers benefits to the household in the form of increased comfort, controllability and some energy savings.

Smart home technologies can be utilised to make smart homes integrated and active participants in the energy system. In this set up, the smart home receives part of its energy requirement from the grid, uses in-home renewable energy generation and energy storage to lower its need for grid electricity and associated costs, and optimises energy consumption by enabling smart appliances to run automatically at appropriate times. Furthermore, the household can sell excess electricity to the grid and provide demand response services to further lower its energy expenses or generate additional household revenue. The latter set-up delivers more benefits to the household in terms of a broader set of energy management options and a better return on investment. It contributes to the energy system by supporting grid stability, reducing the need for additional large-scale generation capacity, and increasing the use of renewable energy.

[3] Near real time refers to data collected and communicated in specific intervals. The duration of intervals varies for different brands and technologies and can range from 15 minutes or more to mere seconds.

Figure 3 Illustration of a smart home as part of the wider energy system



Box 2 Are net zero energy homes smart?

A net or near zero energy home is a highly energy efficient home that produces as much renewable energy on-site as it consumes (on an annual basis). Net zero energy homes have very low energy consumption owing to their design and the materials and technologies used. They are typically well insulated and use a variety of methods to reduce energy demand and have highly efficient equipment and appliances. It is possible to achieve net zero energy using both new construction and retrofitting of existing buildings. Net zero energy homes are typically connected to the electricity grid and purchase electricity from the grid when on-site generation or storage is insufficient. In cases of over-supply, the electricity can be stored or transmitted to the grid. Homes that produce more energy than they use are known as energy-plus buildings.

Smart homes could be net zero energy or even energy-plus homes, but a smart home does not necessarily entail a net zero energy home and vice versa. The definition used in this report does not make "smart" conditional on energy efficiency, consequently, smart homes can be inefficient (net zero energy homes typically have to be very energy efficient). Some of the smart home technologies described in this report (e.g. smart meters and home energy management systems) are integral or beneficial elements of net zero energy homes. Promotion of the uptake of smart home technologies could be a means to achieving net zero energy home deployment policy objectives.

Smart home technologies are evolving. Current trends include integration of voice control, artificial intelligence and machine-to-machine learning. The development and integration of these technologies will make it easier for users to interact with their devices and systems and will enable devices and systems to better adapt to household behaviour, needs and preferences. Of particular interest in terms of energy efficiency are developments in energy awareness. Energy awareness enables energy use data of individual devices to be made available by the devices themselves, which can open up opportunities for new energy efficiency actions, as well as new ways of measuring energy use and developing policies (EDNA, 2016c).

The use of geo-fencing (creating a virtual circular area, or fence, around the home) to address standby energy consumption and other plug loads (i.e. by automatically turning everything off once occupants have left the home) could also have significant impacts on reducing energy use.

2 Technology pathway

To access the full range of energy benefits of smart homes at an individual household level, and on an energy system level, a number of elements are required - from purchase to installation of devices to combining them in a functioning system to connecting this system with the wider electricity system. In turn, there are technological and market changes that need to be made to enable the energy system to interact with smart homes. This is not a linear pathway and steps along the way are affected by whether other elements are in place. Not all elements may be essential, however, the potential energy benefits generally increase as more of these are fulfilled. Table 2 lists the elements that are considered necessary.

Table 2 Smart home technology pathway

Element Required - "What Has to Happen"	Description	Status
Uptake of smart home technologies		
Smart home devices	Smart home devices include appliances and lighting which are network-connected and have the ability to adjust their own energy usage in response to remote commands. They might also report their own energy consumption.	Limited uptake - with forecasts of growing uptake. Developments needed in terms of interoperability and plug and play capabilities.
Sensors and controls	A smart home will require a number of devices to provide information about ambient conditions, user behaviour, etc. Actuators for things such as window shading can also be included in this category.	Limited uptake - with forecasts of growing uptake. Further developments in merging systems and developing integrated solutions are needed, as well as improved battery life for sensors.
Home Energy Management Systems (HEMS)	The HEMS is the interface for all individual appliances and equipment and typically includes some form of visual feedback for the consumer. It may also include a connection to the cloud. It should ideally also record the energy consumption of all end-use devices in the home, enable control of devices and be able to quantify energy savings. To operate (and continue to operate) the HEMS system must be commissioned appropriately (easily and preferably automatically - "plug and play"). It must also be easy to operate.	Limited uptake - with forecasts of growing uptake. Development needed in terms of interoperability and plug and play capabilities.

Element Required - "What Has to Happen"	Description	Status
Development of full interoperability of smart home appliances, sensors and controls with HEMS	For the HEMS to effectively manage energy demand in the home, all appliances, lighting and other devices (including those from different manufacturers) must be able to communicate with each other effectively, and with the HEMS.	Progress is underway but more work is needed to ensure interoperability and to develop solutions that enable already deployed technologies to interact with new devices and systems.[4]
Optimisation and use of HEMS	While some responses may be fully automated, in many cases consumers will need to act on information provided by the HEMS in order to benefit.	Experience indicates that consumers tend to lose interest after a period of time. Technology development is needed to provide automation solutions that suit consumer needs.
Deployment of smart grid elements		
Development of smart grid capability	Energy networks that can intelligently integrate the behaviour and actions of all users connected to them - generators, consumers and those that do both – in order to forecast demand and efficiently deliver sustainable, economic and secure electricity supply.	Progress and investments are underway but more investments are needed as is the further development of standards, methodologies, enabling technologies and regulations.
Installation of smart meters	Smart meters allow the real-time remote monitoring of household energy consumption/demand and enable more accurate demand forecasting. Smart meters can enable advanced demand response and net metering to encourage home energy generation and storage.	Deployment is underway with many countries having ambitious roll-out targets. Some of the already deployed smart meters are not suitable for smart grid development.
Development of full interoperability between smart meters, smart home devices and HEMS	Smart meters provide the interface between the household (HEMS) and the energy provider.	Progress is underway but more work is needed to ensure interoperability and to develop solutions that enable already deployed technologies to interact with new devices and systems.

[4] Currently, machine to machine communication in smart home environments is limited. The majority of existing smart home devices and systems rely upon cloud services in the middle. Efforts are underway to have these services communicating between each other (mainly through translation platforms between protocols), or to build meta services upon existing ones. Further developments that would enable smart home devices and systems to communicate directly with each other could have benefits in terms of functionality of systems and energy savings e.g. by reducing the need for cloud based communication.

Element Required - "What Has to Happen"	Description	Status
Renewable in-home energy generation	In-home generation (e.g. photovoltaic cells or fuel cells) allows consumers to use renewable electricity when available, store excess when not needed or sell excess electricity to the grid. This requires a grid with a two-way communication and transmission capacity and feed-in tariffs.	Deployment is increasing and prices are reducing. Further development is needed in terms of solutions for multi-tenant buildings.
Home energy storage	Energy storage capacity may be provided by batteries or other storage technologies.	New solutions are being developed, deployment is increasing in some segments, prices are reducing. Further development of solutions is needed for multi-tenant buildings and housing areas
Electric vehicle(s)	Electric vehicles can be used as storage for energy generated in-house or from the grid when other demand is low.	Uptake is increasing (but is still marginal), a number of countries have ambitious plans. Requires significant charging infrastructure.
Creation of smart electricity markets		
Establishment of dynamic pricing for energy	Pricing that rewards consumers for reducing demand at times of peak system load or to achieve optimal system balancing.	Limited to a few locations. Enabling conditions need to be established.
Establishment of flexibility markets	Flexibility markets enable other actors such as aggregators to become involved in demand response, providing services to energy providers and added value to consumers.	Limited to a few pilot projects. Further development is needed in terms of enabling technologies and conditions.
Use of smart home enabled demand response		
Demand response ready devices and appliances	Appliances that can be automatically controlled by energy providers.	Limited but uptake is projected to increase.
Establishment of demand response programmes	Energy providers give incentives to consumers to reduce or shift energy use (can also with consumer agreement be done automatically).	Limited to a few locations and a few pilot projects. In general, programmes show positive results.
Households engage in demand response e.g. respond to tariff signals or other incentives	The system for enabling households to engage in the market needs to be simple, user friendly and the rewards need to be sufficiently attractive to maintain consumer interest.	Pilots are starting to provide learning to enable development of systems and mechanisms to effectively engage consumers. More development is needed.

Sources: IEA (2017a), IEA (2017b), IEA (2016c), IEA (2017d), Eurelectric (2017)

2.1 Current smart home technology uptake and forecasts

Smart home technology adoption has been slow to gain traction among consumers (PWC, 2017). However, sales are on the increase. In 2016, eighty million smart home devices were delivered globally – up 64% compared to 2015, 130 million devices were projected to be delivered in 2017 (IHS Markit, 2016)[5]. It is forecast that global shipments of smart home devices will reach 1.4 billion units by 2021 (Ovum, 2017).[6]

In terms of smart major home appliances (washing machines, clothes dryers, dishwashers, refrigerators, room air-conditioners, and large cooking appliances), the global market is expected to grow from around 1 million units sold in 2014 to 223 million units by 2020 i.e. 470 million units deployed between 2015 and 2020. The penetration of these appliances is projected to grow from an estimated 0.2% in 2014 to 31.3% in 2020, with that of smart room air-conditioners reaching 52% and smart washing machines 42% in 2020 (IHS in EC, 2017a).[7]

Europe
In Europe[8], at the end of 2014, an estimated total of 3.3 million smart home systems and devices were in use, up from 1.75 million in the previous year. It is assessed that, around 0.34 million of these systems were whole-home systems whereas 2.93 million were smart home devices. Taking into consideration overlaps (some homes may have more than one system), this corresponds to around 2.7 million smart homes (1.2% of all households in this region) (Berg Insight, 2017). A European[9] survey carried out in 2017, indicates that 13% of households expect to have a smart home within 12 months, compared to 10% in 2016. (Context, 2017). Forecasts indicate that there will be 29.7 million smart homes in Europe by 2019 (Berg Insight, 2017).

In terms of specific technologies - the installed base of smart thermostats in Europe was 2.3 million in 2016 and is expected to reach 13.6 million homes by 2019 and 34.7 million by 2021(Berg Insight, 2017). The penetration of Home Energy management Systems (HEMS) is projected to rise from 2% of homes in 2014 to 40% by 2034 (Waide Strategic Efficiency, 2014).

North America
In the US, in 2015, penetration of smart home devices was almost 19% and rose to almost 25% in 2016. The number of smart home devices in operation was assessed to be 294 million units in 2015 and expected to rise to 1 billion in 2016. Forecasts indicate that by 2021, 69% of US homes will be smart (Ovum, 2017). Around 28% of consumers in Canada currently own smart home devices (Nielsen, 2016) and the share of smart homes is expected to grow to 54% by 2021 (Ovum, 2017).

In terms of specific technologies - US sales of smart thermostats grew from 2 million units in 2013 to 5 million units in 2015 (ACEEE, 2017a). Forecasts indicate that by 2019, there will be 24.6 million homes having smart thermostats in the US and 43.4 million by 2021(Berg Insight, 2017). Currently 5% of US homes have some type of home energy management system (ACEEE, 2017a).

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[5] It should be noted that in the context of sales figures, smart home devices include devices that are not intended for energy management or demand response such as smart TVs.
[6] Definitions of what is a smart home device and what are smart homes vary and are not always explicit in market studies and forecasts, consequently data from different sources is not directly comparable.
[7] This category encompasses appliances that can connect to networks, information on the share of these appliances that is demand response enabled is not available
[8] EU 28 + 2
[9] Based on surveys in UK, France, Germany, Italy, Spain, Sweden, Netherlands, Russia and Turkey

Asia Pacific
It is estimated that there are 3.2 million smart homes in China, expected to grow to 29.5 million by 2021 (Statista, 2017). Forecasts indicate that smart home penetration could reach 48% in South Korea and 41% in Japan by 2021 (Ovum, 2017). Penetration could reach 100% in Japan by 2030 if the governments universal HEMS adoption target is met (METI, 2015). In Australia, in 2016, 29% of households had at least one smart home device, by 2017 it is expected that the number of households with smart home devices will increase to 40%. By 2021, Australian households could have an average of more than 30 internet-connected devices, 14 of which would be smart home devices (Telsyte, 2017).

2.2 Drivers and motivators for smart home technology uptake

Surveys indicate that energy savings are not necessarily a strong motivator for smart device purchases. One 2016 survey in the US lists the top three benefits of device interconnectivity: making life easier (71%); offering convenience (42%); and entertainment (30%) (PlumChoice and Z-Wave Alliance, 2016). This survey showed that while in 2015 energy and resource efficiency was listed as a top motivator, it was replaced by other considerations in 2016. Another US survey found that one four current smart home users (26%) say they bought their first device to either increase overall convenience, improve their quality of life, or help them be more productive. Meanwhile, 10% wanted to make their home safer, and another 10% cited affordability (PWC, 2017). Only 6% of current smart home device users ranked energy savings as a motivator for purchase (PWC, 2017)[10].

2.3 Status and forecast of smart grid capabilities

Smart grids are networks that intelligently monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end users. Smart grids use the two-way flow of electricity and information to optimise generation, transmission, distribution and management of demand. According to the IEA, the widespread deployment of smart grids is crucial to achieving a more secure and sustainable energy future through addressing current concerns with existing electricity systems, such as ageing infrastructure and increasing peak demand. ICT technologies can increase the efficiency of operating the grid, counteract network congestion and can defer or avoid the need to invest in new transmission (IEA, 2016). Furthermore, smart grids are an important element for expanding the use of low-carbon technologies, including electric vehicles and renewables (IEA, 2017b). The extent and rate of smart grid deployment depends on local commercial attractiveness, compatibility with existing technologies, regulatory developments and investment frameworks (IEA, 2017b).

Elements of smart grids include:

- Sensors and ICT that monitor generation, and transmission and distribution lines.
- Sensors and ICT that collect and process data to forecast demand.
- Smart meters that enable the collection of near real-time data.
- Demand response technologies and programmes that enable end-users to support the electricity system by shifting or reducing demand.
- Dynamic tariffs that provide incentives to consumers to participate in demand response.
- Distributed (including in-home) renewables generation.
- Energy storage.
- Electric vehicles.

[10] However, respondents not owning a smart home device awarded significant importance to energy savings as a motivator (53% very impactful, 33% impactful) (PWC, 2017).

Aspects of particular relevance to smart homes include smart meters, demand response and incentives (including enabling market frameworks), in-home renewables, storage and electric vehicles.

Smart meters

The diffusion of advanced metering systems varies around the world. China has more installed smart meters than the rest of the world combined: about 70% of households are already connected to a smart meter, and China is committed to a full coverage in the coming years (IEA, 2016). The share in other regions is lower, but it is increasing fast, with many governments having set a target of reaching full coverage within the next few years. In the European Union, the target date is 2022, but the average share remains low (around 15% today) – although Italy and Sweden have current adoption rates of over 90% (SEDC, 2015). According to the estimations made by the European Commission, 200 million smart meters for electricity will be installed by 2020, representing approximately 72% of all European consumers (EC, 2017a).
The US has an adoption rate of 40% (IEA, 2016).

Demand response

Demand response is a strategy that is used to get electricity consumers to reduce their consumption at times when electricity supply is constrained. Beyond smart meter roll out, technologies and mechanisms are needed to enable demand response. Consumption records, data processing and billing procedures need to be put in place which requires investment in information technology infrastructure. Many smart meters are mostly not able to dynamically identify a particular time, or set certain hours as critical and additional energy management systems have to be developed and integrated (Eurelectric, 2017). The use of demand response targeting the residential sector is still relatively limited, though a number of programmes (notably in the US) exist, residential demand response has been piloted in several countries (e.g. UK, Belgium, the Netherlands), some jurisdictions (e.g. Australia) have started using automated residential demand response (i.e. agreements with customers that the energy provider can automatically adjust devices to manage peak demand).

Box 3 End-uses most suitable for demand response

- Space heating and cooling which can be shifted over a certain number of hours, the extent depending on the thermal insulation of the building – the better the insulation, the longer the period of shift in demand.
- Water heating, most households in cold climates that use electricity to meet their hot water needs are equipped with a storage tank, so water can be warmed a few hours before it is used.
- Large appliances:
  - Cleaning appliances (washing machines, dish washers and dryers) can be run at any me of the day
  - Refrigerators can be turned off for short periods, with no loss of service by taking advantage of their thermal inertia (IEA, 2016).

Electricity market development

For demand response, tariff structures are a tool to improve customer awareness and responsiveness. Dynamic time-based tariffs vary during time of day and seasons to reflect the actual cost of electricity (IEA, 2016). Integrating home energy management systems with dynamic tariffs can facilitate demand management by automating responses to these tariffs. Studies show that peak demand reduction is 60% to 200% greater for dynamic tariffs with automation compared to those without (BPIE, 2017b).

The use of dynamic pricing is still limited. The number of customers on dynamic pricing rates globally is expected to increase from around 3.4 million today to 113.3 million in 2025 (ACEEE, 2017b). In the US, less than 5% of households have access to dynamic tariffs (IEA, 2016).

A strategy for realising a larger share of demand response potential is to enable consumers to participate in the market via aggregate service providers. Aggregators combine the flexibility from multiple customers to provide balancing services to the grid by adjusting power demand and/or shifting loads at short notice. The aggregated load-reduction can be sold to the markets or energy provider (IEA, 2016). Aggregators can play an important role as intermediaries between customer groups and the electricity market, and can take charge of managing the process, with the consent of customers (BPIE, 2017b).

In-home renewables generation, energy storage, electric vehicles

In a smart home context, rooftop photovoltaic solar (PV) is the most prevalent form of in-home renewable energy generation. The unit cost of small-scale PV has dropped by a factor of four since 2008 (IEA, 2017d). From 2008 to mid-2016, residential PV electricity system prices fell by over 80 % in most competitive markets (JRC, 2016). In 2016, photovoltaic capacity increased by at least 75 GW, with a 50% growth year-on-year of new installations. The cumulative installed capacity reached at least 302 GW by the end of the year, sufficient to supply 1.8 percent of the world's total electricity consumption (IEA, 2016). The theoretical potential of rooftop PV is huge. For example, in the US the theoretical potential of rooftop (all types of buildings) PV is in the region 1.1 TW of electrical power and 1432 TWh of annual energy generation (NREL, 2016).

Energy storage can enable consumers to more effectively utilise their in-home renewables. The unit cost for battery storage has fallen by 85% since 2008 (IEA, 2017d). Estimates indicate, that the global market for residential energy storage systems could experience growth in the region of 3 to 10 GWh in 2020 and 6 to 15 GWh in 2025 (EC, 2017a).

With rapid electric vehicle adoption around the world, power grids are facing a new problem, as they were not designed to support this new type of uncontrolled load, which can cause power quality issues (IEA, 2017c). Smart homes can help energy providers manage charging by making sure that charging does not add to peak load stress on the grid. Smart homes equipped with renewables can use electric vehicles as storage for renewable electricity (e.g. by automating charging when renewable energy generation is high). EVs can also be used as storage enabling the home to draw power from the vehicle when renewables do not cover the home´s energy demand. The energy stored in vehicle batteries could also (for compensation) be returned to the power grid at times of increased energy demand.

The number of electric cars on the roads globally rose to 2 million in 2016. It is estimated that between 9 and 20 million electric cars could be deployed by 2020, and between 40 and 70 million by 2025. In Norway, electric cars had a 29% market share last year, followed by the Netherlands with 6.4%, and Sweden with 3.4%. Globally, electric cars make up only 0.2% of the total fleet (IEA, 2017c).

3 Energy savings potential and other energy system benefits

Smart homes can enable significant energy savings and contribute to wider energy system benefits. Smart energy management can provide users with information about real-time device-level consumption, and via sensors and automation provide comfort and energy savings as well as a variety of alerts, prompts or energy savings suggestions. Advanced set-ups with learning and energy savings algorithms can adapt to user needs and patterns and provide services such as lighting, cooling or heating when needed, while automatically making adjustments to save energy when possible. When combined with home-generated renewables and energy storage or electric vehicles, smart homes can provide households with additional benefits in terms of saving grid-purchased energy. When smart homes are connected to the energy system they can provide value in terms of management of peak demand, better supply and demand balance, and related benefits (IBE, 2012; IEA, 2017).

3.1 Residential energy efficiency benefits

To date, only a limited number of field studies and other types of assessment have sought to quantify the benefits of smart homes. In terms of energy savings achieved, the results from field studies vary. These variations are largely due to differences in the set-up of smart homes, i.e. which technologies are used and how they interact and the level of automation used, differences in external conditions e.g. climate zone and differences in how efficient the home was to begin with. The methodologies used in field studies and other types of studies vary. Some studies also indicate a lack of persistence in regard to some of the savings (e.g. van Dam, 2013). Lack of persistence is typical for set-ups that require users to take an active role in managing energy use - automated systems do not suffer from this problem.

The net energy savings of a smart home will depend on a range of factors:

- **The smart home devices** – how much electricity they use in different power modes and the intervals at which they power down.
- **The smart home system(s)** – the influence of controlling devices in terms of turning on or off other devices, making them operate more or less efficiently.
- **The level of automation and the premises behind automation** – whether energy efficiency is a priority and there are robust algorithms to ensure energy efficiency in different situations or whether automation is based on user preferences with no or marginal consideration of energy efficiency.
- **User behaviour** – whether the user looks at energy monitoring information, whether the user uses this information to change settings or change behaviour.

A single device with energy saving capabilities can already provide some savings opportunities, while a management system can provide greater savings by coordinating lighting, shading, ventilation and heating or cooling. Since several technologies address the same energy end-use (e.g., connected thermostats and smart zoning both affect heating ventilation and cooling (HVAC) energy consumption), the combined savings potential is less than their sum but additional savings and benefits can be achieved by intelligently coordinating technologies.

Table 3 Energy savings benefits of smart home technologies

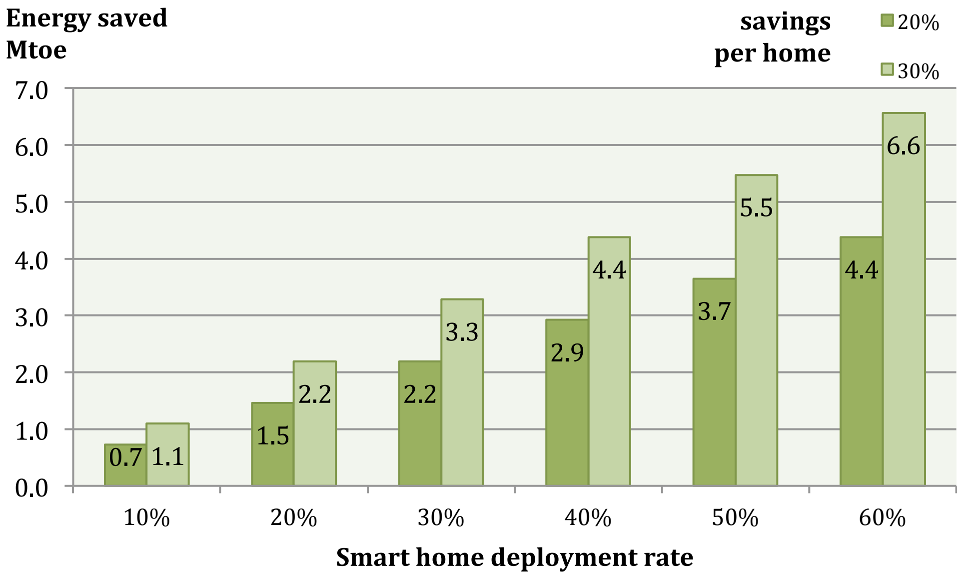
Technology	Benefit	Energy savings range
Smart thermostat	Heating and cooling can be switched on and off remotely and the temperature adjusted up and down	5-10% for heating (Fraunhofer, 2016) 8-16% for cooling (Fraunhofer, 2016) 2-16% electricity (NEEP, 2015) 5-22% gas (NEEP, 2015)
Smart zoning	Allows individual rooms or zones to be heated or cooled to a specific temperature, at a specific time of day	10% for heating or cooling (Fraunhofer, 2016)
Smart window control	Controls the amount of light let through and can block heat or cold	11-20% of heating or cooling (Fraunhofer, 2016)
Occupancy based lighting	Sensors monitor room occupancy and turn on lighting when needed and turn it off when rooms are empty	30-41% of lighting energy use (Fraunhofer, 2016)
Smart lighting	Lighting that can be controlled remotely, automated, reacts to occupancy	1-10%[11] of whole home energy use (NEEP, 2015)
Smart plugs	Turn an unconnected product into a connected one, enabling customers to receive some of the functionalities offered by smart appliances with existing, traditional appliances at a much lower cost	1-4.6% of whole home energy use (NEEP, 2015)
Home energy monitoring system	Provides energy consumers with **information** about how they use energy in the home and/or prompts to modify consumption.	4-7% of whole home energy use (PG&E, 2015)
Energy portal	A type of home energy monitoring system that is linked to a web-based platform which provides information on energy use and suggestions on how to improve efficiency.	5.7% - 7.4% electricity (NEEP, 2015) 5.7% - 13% gas (NEEP, 2015)
Home energy monitoring system (display) plus dynamic pricing	Provides energy consumers with **information** about how they use energy in the home and/or prompts to modify consumption connected to a demand response programme that gives incentive via electricity tariffs to reduce energy use.	8-22% electricity (NEEP, 2015) 8-22% gas (NEEP, 2015)
Home energy management system	Provides the household (or third parties) the ability to **control** energy- consuming processes in the home, either remotely via a smart phone or web service or based on a set of rules, which can be scheduled or optimised based on user behaviour.	7.8%[12] of whole home energy use (van Dam, 2013) 20% of whole home energy use (Bhati et al., 2017)
Smart home	Combination of smart home technologies that provide measurement, monitoring, information displays, management, control, automation, zoning, occupancy systems, etc.	27% of whole home energy use (BPIE, 2017a)

Smart home enabled energy savings could be in the region of 20-30% of household energy use. As technologies are optimised, developed and linked with the implementation of further energy efficiency opportunities in homes the energy savings potential could increase. As an illustration, the potential energy savings in the UK could be more than 3 Mtoe per year with a smart home penetration share of 30%. Correspondingly, savings in Japan could be in the region of 2.6-3.9 Mtoe

[11] The lower end of the range shows savings in cases where the home already has efficient lighting and the higher end shows savings in cases where the smart lighting replaces inefficient lighting products
[12] Study shows savings reducing over time

per year. Energy savings in the US could be around 15.7 – 23.5 Mtoe per year and could grow in excess of 30 Mtoe with 40% deployment.

Figure 4 Potential energy savings in the UK from energy efficient smart home deployment



Source: Own calculations based on IEA energy balance data.

The IEA forecasts that smart technologies could between 2017 and 2040 lower energy consumption of the buildings sector globally by as much as 10% leading to cumulative energy savings over the period to 2040 of 65 PWh (or 5589 Mtoe) – equal to more than all the total final energy consumed in non-OECD countries in 2015 (IEA, 2017d).

3.2 Benefits in terms of collecting and analyzing data

Smart home energy management devices and systems provide new opportunities for evaluation, measurement and verification. This would enable identification of energy savings or demand response opportunities, monitoring and programme evaluation at a vastly lower cost than traditional methods.

Short interval data can be used as a tool to evaluate savings from installed measures with greater accuracy and to evaluate savings delivered through energy efficiency or demand response programmes. Analysis of these data can also help identify and fix programme issues mid-cycle (Lamoureaux and Reeves, 2016). Such data could also be used perform remote audits to identify opportunities for energy efficiency and demand response. Such audits can identify potential for individual homes, as well as customized estimates of the energy savings potential and payback period of retrofits (Fraunhofer, 2016). Post-retrofit data could be used to confirm that the retrofit had been successfully completed and provide remote evaluation, measurement and verification (EM&V) of actual energy savings and demand reduction (Fraunhofer, 2016).

Smart home data could also be used by policy makers to get information that would help design more effective energy efficiency programmes such as data on the actual energy use of appliances, household behaviours, and other factors that impact on energy consumption.

3.3 Energy system benefits

Smart homes can provide a wide range of benefits to energy providers and electricity system operation. Benefits include:

- Access to data that enables better forecasting of demand to help better plan and prepare to meet demand more efficiently.
- More sophisticated device-level demand response and help shift loads from peak to off-peak times with more efficient generation or renewable generation sources.
- Reduction of the need to install additional generation via demand response.
- Prevention of supply interruptions via demand response.
- Reduction of grid congestion via demand response thereby decreasing line losses and contributing to improved efficiency.
- Facilitating the use and integration of in-home or other distributed renewables generation.
- Helping energy providers manage impact on demand by electric vehicles by making sure that charging does not add to peak load stress on the grid.
- Providing balancing services by shifting operation and adapting energy consumption to short term positive or negative discrepancies between forecasted and real generation by intermittent renewable energy sources (IBE, 2012; EC, 2017a).

3.3.1 Quantification of benefits to energy systems

There are a number of smart home demand response programmes and pilots that have been carried out that provide some indication of the potential benefits. However, the magnitude and value of these benefits depend on the size of the grid, energy mix, options for peak demand management, the number of smart homes and the extent to which smart homes participate in demand response. Benefits increase with increased involvement of smart homes in the energy system. Programmes indicate that even a relatively low penetration and involvement of smart homes can provide value.

According to the IEA, in all regions, most of the current and future technical potential of demand response at lower overall cost (upfront and opportunity costs) lies in the buildings sector, especially in space and water heating and cooling. Assessments indicate that, provided that all enabling conditions are in place, demand response could be applied to almost a fifth of annual electricity demand in the EU and the US (IEA, 2016c). Globally, about 3600 TWh of current electricity consumption is technically available for demand response, and it is expected to double by 2040 to around 6400 TWh, or almost 20% of electricity consumption worldwide (IEA, 2017d). The IEA forecasts that by 2040, globally, 1 billion households could actively participate in interconnected electricity systems providing 185GW of system flexibility saving USD 270 billion of investment in new power plants (IEA, 2017d).

The volume of controllable load by smart appliances in the EU is estimated to be at least 60 GW, of which 40 GW is assessed to be economically viable. The shift of this load from peak times to other periods could reduce peak-generation in the EU by 10% (Bertoldi and Serrenho, 2017).
Ongoing programmes, pilot and research projects confirm that smart home enabled peak reductions can be significant, for example:

- 20% of electricity customers in California participate in demand-side programmes, contributing 5% of total peak demand savings (IEA, 2016c).
- In Japan, four pilot projects implemented between 2011 and 2015 have shown peak reduction levels of 10% to 20% by relying on a combination of technologies such as HEMS, as well as time-of-use (TOU) or critical-peak pricing (CPP) (Bloomberg, 2016).

- In Sweden, the peak reduction potential of dishwashing and laundry is between 150 MW to 300 MW and remains the same throughout the year. Expressed as a percentage, the peak load in Sweden could be reduced by 1.1 – 2.3 %. (Puranik, 2014).
- In Germany, the project eTelligence used a time of use tariff with two price levels (price spread of 0,26€/kWh) in combination with bonus (0€/kWh) and malus events (1,2€/kWh) that were based on the availability of renewable energy (announced day-ahead). Electricity savings up to 20% in case of malus events and additional electricity consumption up to 30% during bonus events were observed (EC, 2017a).
- The German project MoMa project tested a real-time pricing tariff with daily price updates (price spread of 0,075€/kWh). The project showed that, on average, a doubling in price resulted a reduction of demand of around 10% (EC, 2017a).

The value of demand response varies but is considerable, for example, in the US, 100 hours of peak demand comprise 10-20% of annual electricity costs (ERC, 2013). There are also potential climate benefits of peak demand reduction as it can enable the retirement of older generation facilities that are kept in operation to cover peak demand. For example, in the US, shutting down 10% of the plants that are necessary only because of peak conditions could prevent 100 million to 200 million metric tons of greenhouse gases annually (NDRC, 2016).

There are currently no studies that quantify the potential contribution of smart homes to avoidance of supply interruption. However, the cost of blackouts to energy providers and to economies is considerable. Studies indicate that countries tend to lose 1 to 2 per cent of GDP growth potential due to blackouts, over-investment in backup electricity generators, and inefficient use of resources (United Nations Development Programme 2010). In the US, grid failure costs approximately USD 150 billion a year (US Department of Energy, 2014).

4 Energy costs of smart homes

As with all electrical appliances and electronic devices, smart home technologies require energy throughout their life-cycle, from materials extraction and manufacturing to use and disposal. All network connected technologies also contribute to the energy demand of networks, servers, data centres and other ICT infrastructure.

Studies show that network connected devices, including smart home technologies, will be responsible for a growing share of residential energy use. For example, the IEA assesses that 50% of household electricity demand for appliances by 2040 is expected to come from connected devices (IEA, 2017d).[13] The reasons for this are several:

- Conventional devices will be replaced by connected devices.
- Connected devices generally need to be on or at higher power modes for extended periods of time to maintain connectivity, increasing their energy consumption.
- Connected devices offer new functions and services which may lead to intensified use and increased energy demand.

A key issue of concern is the standby energy consumption of smart home devices. To function, smart home technologies need to be on or at higher power modes for extended periods of time to maintain connectivity. Consequently, network connectivity is causing additional energy demand. In 2014, the IEA forecast that, if left unchecked, the energy demand of network connected devices in homes and offices could grow from 616 TWh/year in 2013 to 1140 TWh/year by 2025 (IEA, 2014). Since this forecast, policies and programmes to reduce network standby power energy consumption have been put in place in several jurisdictions (e.g. EU, US and South Korea).

Recent studies indicate that the power required for network standby has reduced significantly in many products. A study focusing on compliance to EC regulations on networked standby measured a games console drawing 0.2 watts (W) and a video games console drawing 0.3 W in network standby, while a 2010 model games console required 10 W (EDNA, 2017b; IEA, 2014). The study also showed variations in terms of network standby for similar products, for example, one wireless Bluetooth speaker requiring 0.9 W while another required 5.2 W – indicating that there is further scope for reducing network standby in some product categories (EDNA, 2017b).

There is currently no comprehensive study on the standby power requirements and energy consumption of smart home technologies. Considering the potentially large quantity of smart home devices per smart home, network standby could amount to a considerable energy demand per home and cumulatively. There is a risk that increased deployment of smart homes will offset part of the energy savings that smart home technologies can enable. The following examples indicate an order of magnitude:

- **Smart lighting** - standby power ranges from 0.15 W to over 2.71 W, potentially consuming as much as 25 kilowatt hours (kWh) per light fixture or bulb (IEA 4E, 2016).
- **Home automation technologies** - globally currently use in the region of 12 TWh while in standby and could increase to 36 TWh by 2025 (EDNA, 2016b).
- **Networked audio products** - global annual energy consumption in the lowest responsive power mode could be almost 11 TWh in 2018 (EDNA, 2016a).

[13] IEA central scenario

- **Smart appliances** (excluding lighting) - could be set to globally use 7 TWh annually by 2025 (EDNA, 2016b).
- **Smart devices** (excluding televisions and computers) - the standby power energy consumption of mains-connected smart devices is projected to grow to 46 TWh by 2025, with 36 TWh coming from home automation (IEA, 2017d).
- **Energy storage** – may have a high stand-by consumption due to the controllers, power electronics and internet connection. There is a large spread in standby requirements: 5 to 80 W (average is 30 ±20 W) (EC, 2017a).

Smart homes also drive energy consumption by providing new services (e.g., pre-heating homes or running automated security routines) or by intensifying existing services (e.g., audio visual entertainment). There are currently no studies on the energy implications of new services or new patterns of usage.

5 Barriers to implementation

There are a number of barriers hindering the uptake of smart home devices and systems. Most studies list barriers such as: lack of awareness or interest, costs, uncertainty around benefits, privacy concerns, cyber security concerns, and technology risk (e.g. GfK, 2016, Houzz, 2016, PWC, 2017).

In the context of enabling a conducive environment, there are also a range of barriers and gaps including: slow roll out of smart meters, smart meters that are not compatible with other smart technologies, absence of dynamic energy pricing, high share of electricity cost being fixed costs, high price of technologies for distributed renewable energy generation, lack of feed-in tariffs, high price of electric vehicles and lack of charging infrastructure.

5.1 Barriers to implementation pathway

If smart homes are to be integral players in smart energy systems, there are a range of hurdles that need to be overcome. As mentioned earlier, the trajectory to energy-saving smart homes is not linear - parts of the implementation need other parts to be in place. For example, the business case for consumers to invest in smart technologies is improved if they can benefit from demand response opportunities. This however requires smart meters and demand response programmes to be in place. Table 4 lists the known barriers to energy-saving smart homes.

Table 4 Barriers to the implementation pathway of smart homes

Element required/ What has to happen:	Barriers that affect this:
Uptake of smart home technologies	
Installation of smart home devices (e.g. smart lighting, smart thermostats)	Cost of devices, low consumer awareness, lack of interest, benefits are unclear to consumers, long replacement cycles, mistrust of technology, cyber security concerns, data privacy concerns, lack of trust in energy providers (for demand response enabled devices)
Installation of sensors and controls	Costs, complexity, lack of interoperability
Installation of home energy management system (HEMS)	Cost of the system, cost of services, unclear what the benefits are and if they will be achieved, cyber security concerns, data privacy concerns, lack of trust in providers, lack of incentives (lack dynamic pricing, lack of demand response programmes, low energy prices in some jurisdictions)
Development of full interoperability of smart home devices, sensors and controls with HEMS	Lack of standards and communication protocols that enable devices from different manufacturers to interact, might require external assistance to set up the systems, use of technologies from different manufacturers may lead to problems getting technical support
Commissioning and operation	Cost of services, lack of service provider expertise in or interest in how to optimise for energy efficiency, low quality of services, insufficient product support services
Optimisation and use of HEMS	Complexity, lack of interoperability, lack of user-friendly interface, sometimes need to use separate displays and controls
Establishment of smart grid elements	
Development of smart energy grid capability	Requires large investments in ICT and other enabling technologies, regulations need to be changed, new regulations may be needed, new forms of cooperation need to be established
Installation of smart meters	Customer opposition (privacy issues, cost issues), technical issues, part of the smart meters rolled out are not suitable for demand response and additional technologies need to be installed, and requires energy provider to be capable of financing the installation

Development of full interoperability between smart meters, smart home devices and HEMS	Lack of standards that enable devices from different brands to interact, some smart meters are not compatible with home energy management systems
Establishment of demand response programmes	Absence of enabling technology e.g. load control devices. Lack of standardised methodologies, regulatory barriers (e.g. to enable energy savings to be part of capacity market)
Establishment of dynamic pricing for energy	Absence of enabling technology e.g. many smart meters need to be equipped with additional systems, regulations may need to be changed
Establishment of flexibility markets	Framework conditions to enable new market participants to participate in the market need to be established
Householder engage in demand response e.g. respond to tariff signals, etc.	Complexity of design and functionality, fall away in consumer interest if benefits are not apparent or if it is too time consuming or complicated, lack of confidence in the organisation that is permitted to control smart home devices, energy price structure may constrain benefits to households from shifting consumption/making energy savings
Installation of in-home renewable energy generation	Upfront cost, technology risk, lack of feed-in tariffs, uncertainty about tariff structure and incentives, lack of space, need to get agreement from building owners, need to reach agreements with all households of multi-tenant houses
Installation of home energy storage	Upfront cost, lack of space, need to get agreement from building owners, need to reach agreements with all households of multi-tenant houses
Purchase of electric vehicle(s)	Cost, technology risk, lack of charging infrastructure, rate of turnover of stock, limited driving range per charge

Sources: NEEP, 2015; PG&E (2015); PWC (2017); IEA (2016c); IEA (2017a); IEA (2017b); IEA (2017d); Eurelectric (2017).

5.2 Barriers To the uptake of smart home technologies

A relatively large number of consumer surveys have been carried out to understand reasons for why consumers are not purchasing smart home technologies. Results vary but most list the following key barriers (e.g. PWC, 2017):

- High costs and unclear benefits
- Privacy, trust and cyber security
- Complexity and technology risk

5.2.1 High Costs and unclear benefits

Smart home devices cost more than traditional devices, for example, in the US an average price for a smart thermostat is in the region of USD 250, whereas a traditional, basic programmable thermostat costs USD 25. In addition to the cost of devices, there are often installation costs and in some cases service costs. There is currently a lack of solutions such as bundling with other services or leasing that could help consumers reduce the upfront cost of the investment. Non-monetary costs can also act as a deterrent, for example, time and effort associated to searching for a contractor or missing work to be at home during installation. Another aspect deterring purchase of smart technologies is that most homes are fully equipped with functioning conventional devices and consumers are faced with the decision whether to discard functioning non-connected devices and purchase a smart device or wait until the conventional device stops working.

A key barrier constraining consumer interest in smart home devices and systems is a lack of clarity about the energy benefits. A very limited number of field studies about the impacts of smart homes have been carried out. Consequently, there is a lack of independently verified empirical data on savings impacts (Fraunhofer, 2016). While manufacturers provide some quantifications of savings, measurement methodologies are typically not harmonised across the industry and vary by manufacturer (CDA, 2016).

Energy costs are not a significant expense for many households and saving energy may not be a sufficiently compelling argument alone for investing in smart home devices and systems. Benefits (e.g. energy cost savings) may not outweigh the investment costs and other barriers. For example, a typical US household spends 8-14% of their income on energy. Heating and cooling costs are approximately 3-5% of gross annual income (Zhao et al., 2016). A smart thermostat that is claimed to save 23% of heating and cooling energy would provide the household with savings in the region of 0.7 – 1.15% i.e. corresponding to USD 39 – 64 (compared to US median household income USD 55,775). With an average price of USD 250 this gives a payback period of 4 – 6 years, which might be considered long in light of how long the smart thermostat will actually work before needing to be replaced or how long people stay in the same home.

Dynamic pricing could enhance the benefits (cost savings or other incentives) of using a home energy management system – however, this requires demand response programmes and tools to enable consumers to participate in the market. The value of other benefits of smart home technologies (increased comfort, security, control) could contribute to a more compelling case for investing, however, there is a lack of information about how smart home energy management can help contribute to the attainment of these benefits.

Early adopters of smart home technologies have socio-demographic characteristics which are similar to those of information communication and technologies more generally (Wilson et al., 2017). There is a risk that smart home technologies reinforce the digital divide associated with information communication technologies further into homes.

Impact: Without clear and reliable information about the energy benefits of smart home technologies, the case for consumers to invest in order to make energy savings remains weak. The investment costs for technologies are still relatively high considering the monetary value of potential energy savings.

5.2.2 Privacy, trust and Cyber security

Privacy and trust-related issues have in some cases delayed or halted smart-meter rollouts (AlAbdulkarim and Lukszo, 2011; Hoenkamp et al., 2011). Similar issues may arise with data collected by smart home technologies (Cavoukian et al., 2010; Balta-Ozkan et al., 2013b). Once devices are connected to the internet, information about how and when devices are used is communicated online and often stored in cloud servers. This data can reveal personal identities, behaviours, location and health and could be accessed and utilised by non-authorised parties (e.g. burglars, identity thieves). Recent large data breeches have left many consumers wondering how safe their private information is in the cloud (NEEP, 2015).
Many consumers have concerns about how much of their information is being transmitted electronically, and who is receiving it (NEEP, 2015).

Beyond unauthorised access, some consumers are in principle not comfortable with having others (energy providers, internet providers, service providers) having access to their data.
Lack of trust in energy providers represents key barrier in adopting demand response enabled appliances (NEEP, 2015).

For demand response purposes, energy providers may enter into agreements with consumers that they can remotely shut down or reduce the energy draw of their smart home devices if needed for the electricity system. Consumers have concerns that this will have a negative impact on comfort or services (e.g. food spoiling in the fridge or clothes getting ruined in the washing machine) if energy providers make changes in how devices operate at inappropriate times.

Recent large scale hacking operations that have been intensely covered in media are bound to intensify concerns related to hacking and having non-authorised persons accessing data or controlling their home devices for malicious purposes. Because of their limited computing capacity most smart home technologies have not been designed with proper protection capabilities so are susceptible to hacking attacks. In the case devices have advanced protection, consumers may not understand how to use the security settings to protect themselves.

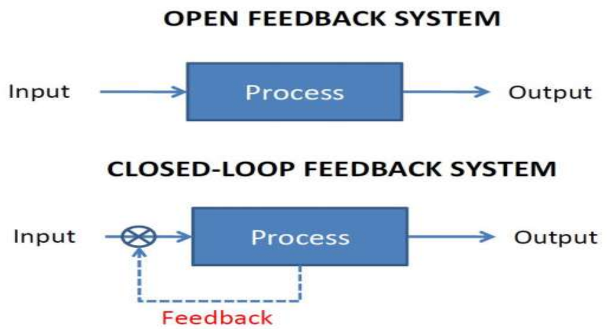
Impact: Without proper feedback loops, fail safes, and network security, the potential for unwanted use, access and interaction can be off-putting for consumers and potentially dangerous (NEEP, 2015).

5.2.3 Complexity and technology risk

Connecting devices and systems makes them complex and more difficult to manage than conventional products. Increased complexity adds to risks of things going wrong. There is a greater risk for error-proneness of smart home technologies because of additional technical components. Smart home devices utilise new technologies, making them susceptible to problems. A survey in the US in 2016 found that 28% of smart home device owners reported experiencing problems with their devices or systems. In 2017, that number increased to 34% of consumers having issues. The top problems reported were connectivity and device performance issues (Martin, 2017).

Box 4 Smart home automation – open vs closed loop systems

Understanding how automation works can help identify the causes for some of the problems with smart home technologies. In general, there are two types of control systems, namely, open loop control systems and closed loop control systems. In closed loop control systems, the output is sensed and given as feedback along with input to the system. Meanwhile, in open loop systems, the input is given to the system that generates output but the output is not sensed or fed back.



Source: Shetab (2017)

For example, a smart thermostat with a closed loop control system would use input (readings from sensors on indoor and outdoor temperature, occupancy and other parameters) to make a change (e.g. adjust temperature up or down) and then collect information on the result (i.e. new readings from sensors) and then make additional adjustments if required.

Compared to closed loop control systems, open loop control systems are simpler in their layout, cheaper, more stable and easier to construct. Not all smart home technologies use closed loop control and, consequently, may not provide the service level that users may wish for.

Homeowners are also increasingly sceptical of wireless internet and cable providers and their ability to reliably deliver service (NEEP, 2015). This contributes to concerns that smart home technologies may stop working in the case of service interruptions. For example, a smart lighting system could stop working when WiFi is down. Further concerns are how these technologies will perform in case of accidents such as fire or flooding.

Glitches in software updates can lead to devices or the system malfunctioning. For example, in August 2017, a software update from a well-known TV brand led to thousands of newly purchased smart TV sets in the UK to stop working for several days. The need for software updates also leads to concerns that smart appliances software updates could change settings (e.g. different default standby mode, higher wash temperature, brighter screen, etc.) (EC, 2017a).

At the centre of many barriers constraining smart home uptake is the lack of interoperability. There are currently many networks, standards and types of devices that create interoperability problems and confusion for consumers needing to set up and control multiple devices. There are efforts underway to establish communication protocols that can enable all smart devices to communicate with each other. Some companies and organisations have formed alliances to promote interoperability among solutions (PG&E, 2015). However, many manufacturers are still using proprietary technology i.e. their smart home devices will only communicate with devices from the same brand.

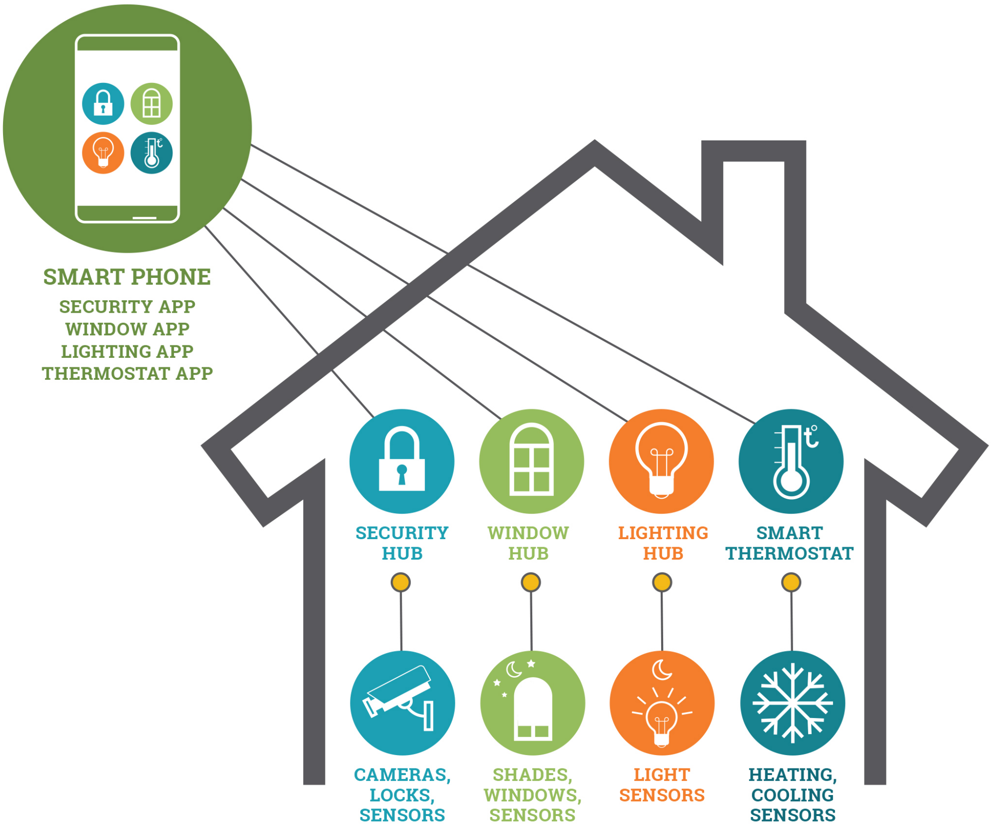
Why is interoperability crucial?

Interoperability is necessary to allow householders to switch systems, strategies, suppliers and individual appliances irrespective of their previous purchases and contracts. To enable demand response, interoperability is needed to ensure that smart home technology hardware and software designs can communicate with smart meters or via other channels with energy providers. This would enable smart home technology control algorithms to respond to supply constraints by shifting time-flexible domestic loads.

Promoting the use of open source communication protocols (as opposed to proprietary solutions) enables other actors to develop solutions that can ensure communication between devices from different manufacturers. Use of open source also enables other parties to develop solutions e.g. additional software to help users analyse their data and identify energy savings opportunities.

For consumers, lack of interoperability poses a risk for vendor lock-in, as well as inability to access full benefits both in terms of controllability and energy savings. Even where the same communication protocol is used for different products, the user may still have to use different software applications (apps) to control each product (IEA 4E, 2016). In some cases, consumers may have to deal with multiple systems and interfaces, for example, smart meter display, lighting control display, heating and cooling control display, window system display etc.). This not only negatively affects user experiences with smart home technologies but might result in fatigue and lead to users not making efforts to monitor and manage energy use.

Figure 5 Illustration of a smart home with multiple smart systems



Smart home technologies are evolving, new product versions are being developed and marketed and many new actors are launching new products onto the market. This leads to a situation where solutions are relatively quickly replaced by new solutions. As a consequence, consumers may prefer to wait until the market is more mature before making a commitment to smart home technologies. Some of the manufacturers of smart home technologies are also new market entrants, which in combination with an immature market can lead to a risk of companies going out of business. If a manufacturer goes out of business, then a consumer can face the risk having parts of or the entire smart home system becoming obsolete. It is also unclear what the lifespans of different smart home technologies are. There is a risk that developments in information and communication technologies could render smart home technologies obsolete quicker than conventional non-connected counterparts.

Setting up a smart home system is complicated and may require expert assistance. The quality of such services has an impact on system performance. Poor quality service can act as a barrier for further uptake or deter potential consumers.

Impact: The lack of standardisation to ensure compatibility and enable consumers to easily choose and swap technologies without impacting their interoperability causes problems for consumers (BPIE, 2017b). Problems with smart home technologies receive a lot of attention particularly in online news and social media. Negative publicity can act as a strong deterrent for households to invest in smart homes. Often smart home development occurs incrementally rather than at the whole home level at once, if the user experiences problems this may deter the purchase of further smart home technologies.

5.3 Establishment of smart grid elements and markets

The full energy benefits of smart homes can only be accessed if smart homes are an integrated part of a wider smart grid. While elements of the smart grid are still being deployed, there is no fully operational smart grid in place. There are currently gaps in technologies, methodologies, infrastructure, as well as in mechanisms that would enable and incentivise households to participate in a smart grid. There are numerous barriers constraining the development and deployment of smart grid elements.

Rollout of smart meters and compatibility
Most developed countries are in the process of implementing a rollout program for smart meters. Some consumers are choosing to 'opt-out' due to cost or privacy concerns, with the result that they forgo the potential benefits. There is considerable diversity in the capabilities of these meters and their communication technologies, which may limit their capacity to be used for demand response programmes and their capacity to communicate with other smart home technologies. There is also currently a lack of standardised communication protocols allowing interoperability.

Demand response programmes, dynamic pricing and getting households to engage in demand response
A key barrier to establishing demand response programmes is the absence of enabling technology (metering equipment and related information communication infrastructure) and processes. Many countries lack standardised measurement and baseline methodologies, or have methodologies which are designed for generators and do not accurately measure consumption changes. Without proper methodologies, consumers cannot receive payment for the demand response services they deliver (SEDC, 2015).

Another barrier is lack of incentives such as lower energy bills due to dynamic pricing. Dynamic pricing refers to retail electricity prices that pass through at least part of the wholesale price volatilities to the end user. Dynamic pricing can include time-of-use pricing, critical peak pricing and real-time pricing (RTP) or time of use pricing. Dynamic pricing is to date used only in very few jurisdictions[14]. Even in jurisdictions where there are time of use tariffs, they may not provide consumers with sufficient incentive to subscribe to dynamic pricing and to modify behaviour. To get consumers interested in dynamic pricing they need to be well informed and schemes need to be designed in an easy-to-use way to make savings achievable. Without information about their level of exposure to price volatility, i.e. knowing that when electricity prices increase, they may potentially face significant increases in their bills during certain months. For example, in the case of real time pricing with a direct exposition to spot prices, customers need to be aware that they could on one day pay more for their electricity than for the rest of year (Eurelectric, 2017).

Consumers may find dynamic prices and responding to them too complex, resulting in response fatigue and only very limited behavioural changes (Eurelectric, 2017). There is a lack of automated solutions that would enable consumers to more easily engage in the market and adjust their consumption. For example, the results of the AlpEnergy project in Germany, indicate that in the case of systems requiring households to keep track of tariffs and modify behaviour accordingly (i.e. not automated systems), complexity can limit consumer engagement. The project trialled two time of use tariffs - a simpler static type with 2 time blocks and an annual price update, and a more dynamic

[14] For example, in the European Union, spot based pricing exists for residential consumers only in the Nordic, Estonian and Spanish electricity markets

tariff with 5 time blocks and a price update every 36 hours. Results showed an average load shift of 2% for the more static tariff and an average load shift of only 1% for the more dynamic tariff (EC, 2017a)

Even with dynamic pricing in place, insufficient or even no savings can occur, due to weak price signals (Eurelectric, 2017). There are several reasons why this could occur:

- Prices in the wholesale market may not be high and volatile enough.
- The energy component represents only part of electricity bills. For example, in the EU the energy component is only a third of the bill, the remaining 2/3 of the bill are regulated charges, including network costs and taxes and levies (Eurelectric, 2017).
- Lack of incentives to shift to e.g. electric heating (that would enable them to participate to a larger extent in demand response programmes) (Eurelectric, 2017).

Purchase of in-home renewable energy generation, energy storage and electric vehicles
Distributed in-home renewable energy generation, home energy storage and electric vehicles are seeing an increase in uptake but this is still relatively limited. Barriers constrain consumer interest and further solutions are needed to enable the optimal usage of these resources for the benefit of consumers and the energy system.

Cost and technology risk are key barriers affecting in-home renewables, home energy storage and electric vehicles. Both in-home renewables and storage require space and may require permits from authorities and energy providers and permission from building owners. Obtaining permission to install and operate an energy storage device can be a complicated, expensive, and uncertain process (NREL, 2016). A decisive barrier to in-home generation is lack of feed-in tariffs or insecurity over the longevity of feed-in tariffs. Electric vehicle uptake is constrained by lack of charging infrastructure, rate of turnover of stock, limited driving range per charge

To support large scale deployment of distributed renewable energy generation, changes are needed in electricity systems, especially in the areas related to balancing, reliability, flexibility, resilience or environmental constraints which require re-optimising transmission and distribution networks (ETP Smart Grids, 2016).

6 Policy rationale

Smart home technologies present a new challenge for energy efficiency policy makers. The technologies are more complex and intangible than conventional home appliances because they are part of networked systems. Technology development is rapid with many new products entering the market every year. Their benefits in terms of energy savings and their own energy use depend on a higher number of factors than conventional non-connected devices.

Smart homes interface with smart grids, with distributed renewable energy generation, energy storage and electric vehicles. Smart home technologies are also an area of innovation and potential economic growth in terms of enterprise development and employment creation. In consequence, energy efficiency policy makers are faced with an evolving situation that intersects with areas where policies are already in place or are being developed. Energy efficiency policy making in this area requires developing approaches enabling cooperation and synergies between policy areas that may not typically have worked together in the past, such as energy efficient product policy, building regulations, telecommunications, and energy supply and distribution.

6.1 Benefits of action

There is a strong case for policy action. A proactive approach could accelerate the development and deployment of smart home technologies that are optimised for energy savings and demand response. Benefits include:

- Significant energy savings could be made, contributing to a range of policy objectives (e.g. energy security, climate change mitigation)
- Significant energy system benefits (e.g. peak management, more efficient supply, support integration of renewables)
- Opportunity to influence the development of devices and systems towards achieving greater energy savings.

6.1.1 Possible risks of action

There are risks associated with a proactive policy approach at this stage of technology and market development. These could for instance include:

- Backlash if technologies do not meet expectations in terms of energy savings
- Backlash if some of the issues with smart home technologies are not fixed e.g. home security breaches, spread of personal information, cyber-attacks or hacking causing damages to households
- Making a push for demand response when the market conditions are not in place could make households disenchanted and uninterested in future offerings
- Rapid technological change could make preparatory policy efforts obsolete as technologies evolve and the products considered become something else (e.g. smart lighting gateways could potentially evolve into whole home management systems).

Further drawbacks include the need for significant resources in terms of time and effort to source and commission information about smart home technologies, and the resources required to engage with relevant actors.

6.2 A case for delaying action?

Considering the complexity of the topic and the resource requirements for policy making and the potential risks, one option is to delay policy making to a point where the market and technology situation is deemed to be more stable. Benefits of delayed policy making include:

- With time the market will mature and it may be easier to understand which technologies to focus on.
- Other countries may have already put policies in place and adaptation/replication could be explored.

In the absence of active energy efficiency policy making, technology and market developments will take place and other policies will be planned and implemented. Even without energy efficiency policies, some smart home energy efficiency savings would be achieved, but without a focus on the development, uptake and optimisation of energy management systems, it would be a relatively low reduction and a larger share of the savings could be offset by energy intensification.

However, there are risks with delaying action including:

- Missed residential energy efficiency opportunities.
- Households do not achieve significant energy savings and become disenchanted with smart home enabled energy efficiency.
- Missed opportunities to promote the development of energy efficient and energy efficiency enabling technologies.
- Technologies will develop without consideration to energy efficiency and limit future energy efficiency opportunities.
- Energy efficiency is not a core consideration in smart grid development and that technological lock-in prevent accessing energy efficiency opportunities.

Increasing uptake of smart home technologies will happen. Based upon trends and the forecasts by market research companies, connectivity will be a common function in most appliances sold from 2020 onwards (HIS Markit, 2016). However, this tendency does not necessarily mean that these appliances will be interoperable, support energy efficiency or will provide demand response functionality. Some surveys indicate that consumers are more interested in smart entertainment, comfort and security than smart energy management (e.g PWC, 2017). There is a risk that the energy efficiency opportunities that could be enabled by smart home technologies will not be attained, products enabling energy efficiency will not be developed due to perceived low consumer interest. Service providers installing smart home technologies and systems would not consider energy efficiency in terms of default settings and advice to users. There would be a smart home driven intensification of demand due to more connected devices and lack of focus on energy management.

Actors working on smart grid development will continue with their projected course of action. This could potentially lead to wide-scale deployment of smart meters that are not compatible with other smart energy saving home technologies, leading to lost savings opportunities or situations where households have multiple smart systems for energy monitoring and management and lose interest to engage in them due to complexity and interoperability issues. Or this could also lead to a situation where households have more devices than necessary for energy management that draw energy to provide the same services.

Demand response programmes could be developed without necessarily taking into consideration opportunities for energy efficiency and overall energy savings. The net impact on energy consumption depends on how the programmes are designed i.e. if they also provide assistance or incentives to reduce overall consumption.

7 Possible policy actions

Realising the energy benefits of smart homes requires a portfolio of policies and measures. Energy efficiency policymakers can play an important role in addressing some of the barriers and supporting the energy management potential of smart homes. The combination of measures that could be considered will depend on country specific circumstances such as policy priorities, mandates for policy making, the market for smart home technologies and the energy system.

Some of the actions required are not in the mandate of energy efficiency policy makers, such as ensuring safeguards against potential cyber-attacks and developing electricity markets that incentivise demand response. This section of the report focuses on the types of actions that are typically in the mandate of energy efficiency policy makers dealing with policies for energy using appliances, equipment and devices. Some of the actions that could be required but are not within the scope of energy efficiency policy makers are covered as they are relevant to boosting the uptake of smart homes, and there may be opportunities to develop policy solutions jointly with other policy actors.

The key barriers for smart home uptake identified in this case study are:

- High costs and unclear benefits
- Privacy, trust and cyber security
- Complexity and technology risk

Other barriers discussed in the case study include:

- Lack of smart grid capabilities and electricity market conditions that would enable smart homes to become and integrated part of smart grid and effectively contribute to the attainment of energy system benefits.

7.1 Vision and engagement

A starting point for energy efficiency policy actions in this area could be to develop a vision or roadmap for smart home energy efficiency. This could help clarify policy objectives, communicate the rationale for policy making and provide something against which to track progress.

Engaging with other actors to stimulate efforts towards increasing energy efficiency should be a priority. There are a number of organisations or actors that could be relevant to consider in this context, including:

- Policy makers in other areas (smart grids, energy systems, renewables, climate change mitigation, building regulations, etc.)
- Energy providers (including regulators)
- Standardisation organisations
- Smart technology manufacturers

Other actors could also have roles to play such as insurance companies (provide incentives), housing companies (procurement of technologies, technical assistance to households), energy service companies (provision of financing solutions), municipalities (facilitate access for low income or social housing households to smart home technologies to e.g. counteract fuel poverty and digital divide) and academia (technology research, modelling, impact assessments, field studies).

Box 5 Mapping of existing standards and ongoing standardisation initiatives

Standardisation initiatives

Technical standards play an important part in energy efficiency policy making. In terms of smart homes, technical standards can support the development of test procedures and methodologies for laboratory and field measurements. Technical standards can also be instrumental in developing solutions to privacy and cyber security issues. Technical standards lie at the core of interoperability and are an essential part of developing smart grid capabilities and can even play a role in ensuring the development of effective market mechanisms.

A key recommendation of this report is to engage in standardisation processes to ensure that energy efficiency is a priority and that solutions that promote energy efficiency are developed. The standardisation landscape in regard to smart homes is complex. There are numerous organisations working on national, regional and international levels that are developing standards that are relevant to smart homes, including communications protocols. A mapping of relevant initiatives could provide a good starting point for determining where it makes sense to focus effort. Concerted efforts, e.g. under the auspices of EDNA, would make sense from a resource efficiency perspective as well as in light of the value of the development and uptake of international standards. A starting point could be consultation with national standardisation bodies that partake in international standardisation efforts. Businesses participating in the Connected Devices Alliance (CDA) could be a valuable source of information regarding international standardisation processes and work conducted by industry alliances or groups. An overview of IoT protocols can be found on: www.postscapes.com/internet-of-things-protocols

For a mapping exercise, it would be relevant to include at least the following organisations and initiatives:

International standardisation organisations/bodies
International Telecommunications Union (ITU), the International Organisation for Standardization (ISO), the International Electrotechnical Commission (IEC), The Institute of Electrical and Electronics Engineers Standards Association (IEEE), Internet Engineering Task Force (IETF).
Regional
CEN, CENELEC and ETSI (Europe), Asia Pacific Economic Cooperation.
Alliances, consortiums, initiatives
oneM2M, OpenStand, Thread Group, Open Connectivity Foundation, Z-Wave Alliance, Zigbee Alliance, OASIS.

7.2 High costs and unclear benefits

Lower up-front costs

There are a number of policy measures that could be used to stimulate market development, reduce upfront costs and help finance investments in smart home technologies. Examples include procurement of energy saving smart home technologies (for example for social housing) or provision of subsidies or grants for the purchase of energy saving smart home technologies. This has been done, for example, in Ontario in 2017, where the government agency Green Ontario Fund launched a programme providing free smart thermostats together with free energy reviews to 100,000 households (Green Ontario Fund, 2017) and Japan has been providing a subsidy for HEMS since 2001 (IEA PAMS, 2017). Other options include supporting financing schemes e.g. “pay as you save” for smart home technologies and the development of reliable and user-friendly payback period calculators. Some efforts are already underway to develop suitable financial mechanisms. For example, the Rocky Mountain Institute in the US, has explored how the use of residential property assessed clean energy (R-PACE) could be used to promote the uptake of net zero energy homes (RMI, 2017).

Improve the value proposition

The perception of high costs and unwillingness to pay upfront costs is closely linked to perceived benefits. There are a number of measures that could be taken to improve the business case for smart home technologies. The value proposition for smart home enabled energy efficiency could be improved by linking energy savings to other benefits, however this requires that they are available and communicated to consumers. The business case could be further improved by developing mechanisms to fairly share energy system-wide cost-savings with households that enable the achievement of these benefits i.e. households that participate in demand response programmes.

Develop standards and methodologies to measure benefits

Uncertainty around benefits could be addressed by the development of test standards and field measurement methodologies and the development of suitable evaluation, measurement and verification protocols. Efforts are already underway, for example, the European Union standard prEN 15232 establishes methods for estimating the impact of automation, control and management on energy performance and energy use in buildings (EDNA, 2017a). The China Smart Home Industry Alliance plans to establish a set of smart home system regulations which will be linked to a verification platform to test and verify smart home technologies. This will contribute to enabling the replacement of products (due to same technical specification) and to standardisation of the smart home technology value chain (CSHIA, 2017). ENERGY STAR® has also developed energy measurement protocols for smart thermostats.

Conduct research on benefits

Common methodologies and standards could then be used to commission and publish reliable and comparable studies on benefits (energy savings, cost savings, other benefits, energy system benefits) of smart home technologies and smart homes. Policy makers could help develop a stronger case for energy efficiency by compiling and providing information on how energy efficiency enabling technologies can contribute to other benefits such as increased comfort, better indoor air quality and enhanced home security. Such work could build on work done by the IEA secretariat and the IEA Demand-Side Management Technology Collaboration Programme on multiple benefits.

Conduct research on energy consumption

Research on the energy consumption of smart home technologies (particularly on energy management related technologies) would help convey reliable information on the net energy benefits of smart homes. Demonstration and in situ research programmes could further contribute to reliable quantifications of benefits. As the attainment of part of the energy and cost savings benefits can be constrained by sub-optimal installation and configuration, information on best practices could be collected to develop guidance for manufacturers, consumers and installers.

Explore opportunities to access and use smart home energy data

Energy efficiency policy makers, could investigate opportunities for how to gain access to granular data from smart homes (via HEMS or from energy providers via smart meters) that could be used to track energy efficiency progress and inform future policy making. This would require an exploration of tools and expertise needed analyse big data sets to get insights into device level energy efficiency improvements, behavioural impacts and other aspects that can help inform policy making and be used to evaluate the impact of future policy measures. The use of big energy data requires finding solutions for the following:

- Collection, storage and management of big energy data
- Methods for how to analyse and mine big energy data
- How to use big energy data to support more effective and efficient decision making
- Prevention of risks and adequate privacy protection (Zhou et al., 2016).

Develop labels to inform consumers
Uncertainty could also be addressed by developing labels or certifications that can serve both as a seal of approval, and as a mechanism to recognise features and benefits (EDNA, 2017a). An information label could provide a foundation on which to build a minimum energy performance requirement at a later date, providing consistency to manufacturers and clarity to consumers. For example, in the US, products that satisfy the energy efficiency, connectivity, and demand response criteria set by EPA, can be certified as ENERGY STAR® connected products, a label that conveys to consumers a product's reliability and superior performance. The EPA label helps create consumer confidence in connected devices (EDNA, 2017a). In Germany, there is a smart grid ready label available for heat pumps and a searchable database of products that that the label. The label has been developed by the German heat pump industry association (BWP, 2017). Smart functionalities can be included as requirement for certain label classes. For instance, the South Korean regulation for air conditioners and multi heat pump systems require that, to get the energy label 'grade 1', the indoor units of air conditioners of 4-10kW and the indoor units of multi heat pump systems of 1-30kW in size must include smart functions i.e. display power consumption using a smartphone, tablet or computer application, and the ability for the user to control the mode, temperature, air volume, and other functions using the application

Figure 6 German heat pump industry association Smart Grid Ready label

Source: BWP (2017)

Promote energy efficiency and energy savings
Smart home technology manufacturers will prioritise energy efficiency if there is a clear demand. As this report indicates, consumer demand for energy saving and energy efficient smart home technologies could be waning, and there could be a case for policy makers to promote the development of energy efficient solutions. This could be done via regulation but could also be achieved through engagement and dialogue.

Energy efficiency policy makers could for instance, in cooperation with smart home device and system manufacturers and other relevant parties (e.g. IT service providers, energy provider associations, component and software developers) develop guiding principles (e.g. modelled on the CDA Voluntary Guiding Principles for Energy Efficient Connected Devices) for energy efficient smart homes. Lessons learned on such an approach could be, for instance, drawn from the United Kingdom where the Department of Energy and Climate Change (DECC) was integral to an industry-wide effort to set design and operating standards, and offer in-home displays as an integral part of the smart meter installation process (DECC, 2014; DECC, 2015).

Further measures could include investigating future opportunities for energy savings and other energy system benefits in dialogue with smart home device and system manufacturers and other relevant parties (e.g. IT service providers, energy provider associations, component and software developers). Measures could be taken to incentivise manufacturers to include energy efficient features in products. For example, several US ENERGY STAR specifications for appliances (clothes washers, clothes dryers, dishwashers, refrigerators and freezers, room air conditioners, and pool pumps) have content on energy awareness and energy reporting (EDNA, 2016c).

Energy efficiency policy makers could also develop programmes for training and qualifications in the construction and electronics installation sector to ensure quality and that energy management opportunities are enabled and communicated to households. Efforts in this area are already underway in some jurisdictions. For example, China Smart Home Industry Alliance (CSHIA) launched the "smart home systems engineer" training in 2012. Students receive a "smart home systems engineer "certificate issued jointly by the Ministry of Industry and the smart home industry alliance, and record in the Ministry of Education and Examination Center (CSHIA, 2017).

Curtail energy intensification

An aspect of promoting energy savings is ensuring that the parasitic energy consumption of smart home technologies and smart homes (e.g. due to network communications function) is kept at a minimum. Smart homes can also lead to an increase in energy consumption (posing a risk of energy intensification) though increased use of technologies (e.g. to turn on air conditioning or other services before you get home), increased number of devices and increased energy consumption of devices (due to being on higher levels of power for longer periods of time).

To address the risk of energy intensification, there is a need for methodologies to measure the energy demand of smart home technologies and to commission research to measure how much energy is used in actual conditions. In terms of home energy management systems, research could be commissioned to understand what is actually needed to manage home energy and to check whether equivalent results can be achieved with fewer devices (Wilson et al., 2017). A further measure in this area could be to develop guidelines for energy optimisation to steer industry to include design features in smart home technologies that mitigate the potential for energy intensification (Wilson et al., 2017). Other measures could be to enter into dialogue with smart home device and system manufacturers about how future products could be developed to maximise savings and minimise own energy demand. Energy efficiency policy makers could also demand that manufacturers ensure energy efficient settings as a default and provide information to consumers about which settings are most energy efficient and impact on savings if settings are changed. Guidelines for users could be developed outlining the energy cost of the use of different types of services and settings. Policy makers could also commission research on the extent to which energy-management algorithms can automate certain functions to avoid risks of energy intensification (Wilson et al., 2017).

Finally, policy makers could consider initiating preparatory studies or consultations on the feasibility and value of minimum energy performance requirements for smart home devices and system. For example, the European Commission Regulation (EU 801/2013) places minimum energy performance requirements limiting network standby of network-connected devices.

7.3 Privacy, trust and cyber security

Privacy and cyber security concerns are not limited to smart home technologies but are an issue relevant to all things connected to networks. While it makes sense to address these issues at an overarching level by developing solutions for all "Internet of Things" applications, efforts focusing on smart homes could also be initiated or promoted. This could include the development of guidelines on smart home data collection, use and privacy protection. For example, the European Union Agency for Network and Information Security (ENISA) has issued a report on good practices and recommendations on security and resilience of smart home environments (ENISA, 2015).

Efforts could also be made to require that manufacturers, service providers and energy providers develop and clearly communicate privacy policies that clarify what information is being collected; who owns the information; who has a right to see it; who has a right to use it; and, where information sharing is anticipated, to whom, for what purpose and under what conditions. Minimum requirements on security and data encryption could be included in specifications, standards or voluntary agreements.

International, regional and national standardisation organisations are working on issues related to cyber security for IoT applications. For example, the European Telecommunication Standards Institute (ETSI) is working closely with relevant stakeholders to develop standards for horizontal and cross-domain applicability, as well as for the security of infrastructures, devices, services and protocols and security tools and techniques (ETSI, 2017). Work on security is also underway, for instance, within the International Organisation for Standardization, the International Electrotechnical Commission and the International Telecommunication Union. Energy efficiency policy makers could support the development of privacy and security solutions for smart home technologies through mapping existing initiatives, identifying gaps and opportunities and engaging with relevant actors to ensure that solutions for smart home technologies are covered.

7.4 Complexity and technology risks

The development and adoption of technical standards lies at the heart addressing complexity and technology risks. The development of international test standards can play an important role in the provision of transparent and comparable information and help alleviate risk perceptions. These could, for instance, also include life-time and fatigue tests to help address concerns about the durability of smart home technologies.

Efforts are underway on national, regional, international and private sector levels to address the issue of interoperability. Energy efficiency policy makers could stimulate progress in this area by mapping existing standards and standard projects and their status and coverage and identify gaps and opportunities. Some mapping has already been conducted that could be used as a basis, for example, an overview of existing standards has been published as part of the Ecodesign Preparatory Study on Smart Appliances performed for the European Commission (EC, 2017a). Energy efficiency policy makers could form, lead or support collaborative efforts to develop (preferably international) technical standards, open source software platforms and common communication protocols for networks and devices. A number of smart home related technical standards such as Green Button and Green Button Connect, OpenADR, BACnet and many ISO and IEC standards have benefitted from the leadership and participation of government agencies over extended periods of time (EDNA, 2017a).

The use of proprietary protocols can constrain interoperability. Energy efficiency policy makers can require or encourage the use of common standards and open source protocols.

In some jurisdictions, policy makers can play an active role in ensuring interoperability, for example, in Japan, the Ministry of Economy Trade and Industry (METI) approves communication protocols to be used between smart meters and HEMS controllers (Japan Industry News, 2016). Voluntary approaches to encourage interoperability can also be effective. For example, the US Environmental Protection Agency's ENERGY STAR connected thermostat programme, has taken measures to promote interoperability and support demand response. In this initiative, manufacturers are encouraged to include common interfaces in their products and ensure the ability to respond to demand response signals from energy providers (EDNA, 2017a). Information labels could also be used to encourage the use of open source protocols. For example, the US ENERGY STAR has developed requirements for connected products in ENERGY STAR product specifications where compliant products must use open standards based communications (except for remote controllability) (Kaplan, 2016).

Further actions to address risks or risk perceptions could include developing quality control standards and mechanisms and ensuring rights or recourse for installations. Initiating demonstration and pilot projects and providing transparent information about issues, solutions and results could also help mitigate risks.

7.5 Lack of smart grid capabilities and enabling market

The full range of benefits for households, for the energy system and for society in terms of e.g. carbon dioxide emission reductions can only be accessed in a situation where a smart home is connected to a smart grid and where market conditions encourage on-site renewables, storage, electric vehicles and participation in demand response programmes. This means that progress in terms of smart grid elements and market developments are a key aspect to accelerating the uptake of smart homes (and attainment of associated energy savings).

This is an area where energy efficiency policy makers dealing with product policy are typically not active. However, there are opportunities to via dialogue and engagement explore possible ways to contribute to developments.

Smart meter roll out
In terms of smart meters, policy guidelines or requirements could be developed to ensure smart home technology hardware and software designs are compatible with smart meter-enabled communications from energy providers. Smart meter roll out schemes could be used to promote the uptake of energy saving technologies such as smart thermostats or home energy management systems or at least with information about smart home enabled possibilities.

Link demand response and energy efficiency
In terms of demand response, energy efficiency policy makers could explore how synergies between smart home enabled demand response and energy efficiency can be maximised. Demand response and energy efficiency can be complementary, with energy efficiency reducing both energy use and peak demand, while demand response provides additional peak demand reductions. By combining the revenue stream of demand response with the energy savings provided by energy efficiency, households could get better financial outcomes than would be possible with either approach alone. Both demand response and energy savings require the measurement and verification of savings. There could be opportunities to share the underlying data structure. Furthermore, the availability of almost real-time energy consumption data creates a platform from which further energy savings opportunities may be discovered (US EPA, 2010).

Develop standardised approaches for demand response enabled devices
Measures could be taken to develop standards for connectivity and controllability and mandate or provide other incentives for making devices "demand response ready" (which should encompass "smart home ready" or vice versa) and for households to purchase such devices. For example, Australia has been working for 12 years on a suit of standards to enable demand response. Increasingly products such as air conditioners, water heaters, pool pump controllers and electric vehicle supply equipment are sold with a built-in standardised interface, which will allow them to connect to a communications system and participate in demand response schemes. Any AS/NZS 4755 compliant appliance can work with any other compliant device (Utility Magazine, 2017). In 2016, Standards Australia published a standard relating to the demand response of energy storage systems. It supports the development of the storage market, opening up rewards for storage owners and manufacturers who introduce complying products (Standards Australia, 2016). ENERGY STAR®

specifications for a wide range of equipment also contain optional requirements for device energy reporting and smart grid controllability. The European Commission´s Ecodesign Preparatory Study on Smart Appliances (Lot 33) is analysing the technical, economic, market and societal aspects that are relevant for a broad market introduction of smart appliances that could support demand response.

Improve the value proposition of demand response

The business case for households to engage in demand response needs to be developed, which includes mechanisms to share the benefits from demand response with households. Studies on demand response costs and benefits including costs and benefits for households could be a useful step in developing a business case for smart home enabled demand response. Further steps could include the development of standardised processes for information exchange, transfer of energy and financial settlement including fair mechanisms to share benefits. Other actions to improve the attractiveness of demand response for households could include lowering the fixed component of electricity price e.g. by financing policy support cost through alternative means such as tax credits or spreading costs over other fuels (Eurelectric, 2017).

Other ways of engaging households in demand response is by offering subsidies or other incentives. For instance, Energex (a subsidiary of Energy Queensland Limited, a State government-owned corporation in Australia) that builds, operates and maintains the electricity distribution network offers rewards for demand response. Consumers are offered a rebate on the cost of an air conditioner if it is compliant with a demand response platform and activated at installation. The demand response is automated i.e. shifted to lower performance mode when the network is under stress (Energex, 2017). Similarly, in the US, Austin Energy and CPS Energy offer consumers a free thermostat or a thermostat rebate in exchange for demand response control of the air-conditioning (EC, 2017a).

Promote in-home renewables, in-home energy storage and EVs

There are a number of actions that could be taken to promote the uptake of renewables, energy storage and EVs as part of a smart home. Solutions (technical and administrative) are still needed in terms of renewables and storage for multi-tenant buildings. A significant barrier to uptake can be overly complex permitting processes. Feed in tariffs and security in terms of the longevity of tariffs are also important factors. Subsidies can be an effective tool to promote uptake. For instance, in Germany, a subsidy scheme for residential energy storage (up to 30% of initial investment is subsidised), makes a home battery system attractive. Estimates predict that by 2018, the German market will have stabilized with on average 100,000 units per year. By 2020, a total of 500,000 units are expected to be installed in Germany (EC, 2017a). A greater interconnection between energy efficiency and home solar (or other renewable) policies and programmes would be beneficial. For example, the Canadian Government of Alberta agency Energy Efficiency Alberta designs and delivers programmes related to energy efficiency, energy conservation and the development of micro-generation and small scale energy systems (Energy Efficiency Alberta, 2017). The uptake of EVs can be promoted by purchase incentives such as use and circulation incentives, waivers on access restrictions. Promoting the development and use of uniform and non-proprietary communications messaging protocols between EVs and smart homes is an important step in ensuring that EVs can be used as energy storage and that smart charging solutions can be implemented.

8. Conclusions and recommendations

Smart homes can provide significant energy savings for households as well as benefits for the energy system. Currently, the uptake of smart home technologies is still limited. There are a number of barriers constraining uptake that need to be addressed.

There is a case for energy efficiency policy makers to be active in this area. Delayed action could result in the loss of energy savings opportunities, especially if the solutions developed and deployed do not take into consideration energy efficiency.

At a minimum, energy efficiency policy makers should take action to source sufficient knowledge of developments in the areas of Intelligent Efficiency, Internet of Things, smart homes and smart grids. This is needed to assess energy implications and to be able to quickly deploy policies so as not to forgo energy efficiency opportunities. In this context, there are two key courses of action – commissioning research and entering into dialogue with other relevant actors.

Energy efficiency policy makers can also play an important role in improving the value proposition for smart homes, by supporting the development of methodologies and studies quantifying benefits and the provision of accessible information to consumers via labels or other mechanisms.

The value proposition for smart home energy management could be improved if it is linked to demand response programmes. However, smart home demand response is still at an early stage of development and a range of gaps and barriers need to be addressed to enable households to actively participate in electricity markets and to reap the benefits of participation. In this context, policy makers could consider the development of standards and approaches that ensure that relevant devices are “demand response ready” as well as “smart home ready” (these should ideally be the same thing). Experiences from Australia, the US and the current European Ecodesign preparatory study could provide valuable guidance on how to proceed in this area.

There is a strong case for international cooperation to pool resources, develop approaches and engage in a high-level dialogue. EDNA and the CDA are excellent platforms for ensuring this.

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