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European smart home market development: Public views on technical and economic aspects across the United Kingdom, Germany and Italy

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ABSTRACT

Smart homes will enable the new services and capabilities offered via smart grids and smart cities to be realized by householders. Yet, whilst there is a wealth of research on smart grids' contribution to achieving Europe's ambitious climate change and energy policy goals, smart homes are not studied to the same extent. The aim of this paper is to illustrate differences and similarities in technical and economic drivers and barriers to smart home market development in three European countries characterized by different policy and socio-economic contexts. The research reveals key barriers to the adoption of smart homes such as reliability, data privacy, and costs of smart home technologies across the countries studied. On the other hand, housing stock characteristics, both age of buildings and tenure, reveal deeper cross-country differences in attitudes and perceptions towards these technologies. The research highlights the need for smart home services that go beyond energy consumption and management services. Only when such a holistic approach is adopted, where other applications such as health or security, suited to the householders' needs and making positive contribution to their daily lives, are enabled, will the benefits of smart homes become clear to the consumer.

1. Introduction

The threat of climate change, uncertainties in the price of energy and security of supply concerns necessitate finding new ways of producing, delivering and consuming energy. It is in this regard that smart grids (and smart cities) have gained increasing attention in both the policy and academic communities across Europe and many other industrialized countries. At the domestic level, smart homes might enable new services and capabilities offered via smart grids (and smart cities) to be fully realized by householders such that their needs, requirements and preferences are met in tandem with the grid constraints. Through the ability to control all devices and appliances within a home from a single control unit remotely or manually, smart homes might allow consumers to control and manage their energy use more efficiently whilst increasing their comfort and convenience for a variety of household activities. These activities might vary from space heating (via thermostat settings adjusting automatically to actual weather temperature) to water heating (via providing hot water at a required temperature instantaneously) to lighting (via lights switching off automatically as the occupants leave a room).

Yet, echoing the prospects of social sciences to make as much contribution to the development of a sustainable energy system as technology and natural sciences [1,2], social aspects of smart homes remain largely understudied. An extensive body of literature focuses on technical aspects, including optimal load management strategy [3–5], modelling of user comfort against physical constraints like energy price and power limitations [6], embedding solar and storage energy in smart homes [7], as well as how the demand response might affect wider energy system characteristics [8–10]. Social aspects mostly focus on the effects of user interface on energy demand [11,12], yet the need to incorporate socio-cultural and environmental values alongside intelligent technological systems [13] has not been addressed. An exception is by Jeong et al. [14] whom noted cultural differences for smart home design and operation preferences between Americans and Koreans on issue like smart appliances and their control, environmental connection, physical safety and security. Otherwise, wider socio-cultural aspects have been largely ignored despite identification of a wide range of challenges facing the smart home industry

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over a decade ago. Edwards and Grinter [15] drew attention to interoperability, administration, reliability, systems intelligence and behaviour inference, and security as key issues limiting the growth of smart homes into a mass market. More recent research highlights retrofitting existing homes, interoperability, costs and usability [16] as well as a lack of understanding of user needs and of infrastructure solutions (i.e. technical skills and capacity to install them) as key barriers [17]. While technical factors (i.e. retrofitting existing homes, interoperability, reliability and security) will determine whether and to what degree functionalities and capabilities offered at grid level can be integrated into the householders' lives, economic factors are likely to play a significant role for the actual adoption of these technologies and services. At the intersection of these factors lies the usability; services that smart homes provide to the users (like assisted living, security, remote monitoring, energy management, etc.[1]), enabled by the mix and integration of technologies in the system (sensors, communication platforms, appliances, etc.) and the relevant user interfaces as well as being subject to the socio-cultural context and values. We argue that a more fundamental challenge for the development of the smart home market is the treatment of these different smart home services in *silos* – as distinct sectors, developed by different vendors and studied across disparate disciplines, with poor cross-fertilisation of practices and innovations. This sectoral approach ignores the fact that home is an expression of identity [18] and that a smart home's technology and services should be well integrated into the design, lifestyle and general sense of home [19].

By building on rich data from public deliberative workshops in the three selected countries, the aim of this paper is to assess the role and relevance of technical and economic factors on the development of the European smart home market. As a result, our study contributes to addressing gaps in a number of research themes identified in the first issue of this journal. Reflecting on fifteen years of energy scholarship, Sovacool [1] reports that very few studies employ human centred research methods. He further notes a lack of comparative case studies to understand both conceptions of energy services across different cultures as well as the evolution of energy technologies. Rather than conceptions of energy services, our study focuses on understanding perceptions and attitudes to smart home technologies and services across different cultures. On the latter, he asks '*what different social groups may benefit from the use of a particular energy system?*' (p. 25), which has not been addressed in the context of smart home technologies. Our study reveals perceived benefits of these technologies by touching upon different social groups in urban and small town contexts, across different cultures. Sovacool [1] further notes that 64.7% of articles he reviewed has no sponsor which, he argues that, might limit their relevance to real world problems. In this regard, we highlight that our study is funded by industry in an international competition, titled 'Smart Home a New Customer Relationship with Energy'.[2]

More explicitly, our study focuses on the United Kingdom (UK), Germany and Italy that are characterized by distinctive characteristics[3]: Italy is the first European country that rolled out smart meters nationally. Germany has a more decentralized network with lots of renewable energy production taking place at the household level. Of 53 GW installed renewable electricity generation capacity in 2010, only 7% is owned by the four biggest utilities in Germany, whilst the private persons' share is 40% [20]. The UK stands somewhere between the two where a centrally generated, high carbon electricity grid is challenged by a very ambitious emissions reduction target, resulting in the development of a variety of policy schemes including a national roll-out of smart meters by 2019 to initiate demand response. On the other hand, as revealed in a recent Eurobarometer survey, interest in new scientific discoveries and technological developments varies significantly across the UK, Germany and Italy (43%, 32%, 16% respectively, compared to the EU27 average at 30%) [21]. These striking differences open up interesting questions around how perceptions of technical and economic aspects of smart homes vary in these countries, characterized by different levels of acquaintance with innovative technologies and energy systems, and whether they are country-specific or common. Understanding these drivers and barriers in turn can be used to inform debate regarding appropriate European policy in areas such as smart homes and smart grids. Another novelty of the research is its holistic approach to smart home services (avoiding the above-mentioned 'silos' problem), with a view to drawing out conclusions for energy consumption and management services.

The paper is structured as follows: Section 2 reviews the literature regarding the definition of smart homes and key challenges. Section 3 sketches out the national policy contexts as well as relevant socio-economic and demographic characteristics of the three countries. Sections 4 and 5 outline the methodology and results from public deliberative workshops; and Section 6 is devoted to conclusions.

2. Background: smart homes and key challenges

2.1. Smart homes definition

A smart home is a residence equipped with a communications network, linking sensors, domestic appliances, and devices, that can be remotely monitored, accessed or controlled [22] and which provide services that respond to the needs of its inhabitants [23,24]. In principle, the term 'smart home' may refer to any form of residence, for example, a standalone house, an apartment, or a unit in a social housing development. In this definition, sensors are devices used to detect the location of people and objects, or to collect data about states (e.g. temperature, energy usage, open windows). Domestic appliances refer to white goods such as washing machines and refrigerators. Devices can be electronic, for example, phones, televisions, computers, or electric, referring to the more simple toasters, kettles, light bulbs, etc.

The network, connecting and coordinating these various technological features (i.e. sensors, devices, appliances) and information, is central to the concept of the smart home [22,25]. It is the existence of this home network that distinguishes the smart home from a home merely equipped with standalone, highly advanced technological features [26]. In a smart grid enabled environment, a home network will ensure the delivery of smart home services subject to grid constraints in real time, either to ease congestion at local level or to contribute to national balancing, be it managed, accessed and controlled by a single party (e.g. energy company) or third parties managing different services (e.g. heating vs management of electricity demand via demand side response programmes). In a smart city context, a home network will communicate with other sectors like transport or e-health in real time to optimize service delivery.

A smart home network (or more commonly 'home area network', HAN) is made up of two elements: a 'physical' connection

[1] For a list of services please see Balta-Ozkan et al. [58].

[2] http://www.eon.com/en/about-us/innovation/research-initiative/research-topic-2012.html.

[3] Sovacool [1] highlights further research questions on the selection of comparative case studies, whether they should be extreme or unique, representative or typical, static or longitudinal, etc. In our case, while our case studies are significantly different from each other, our selection criterion was dictated by our industry funder's operational base.

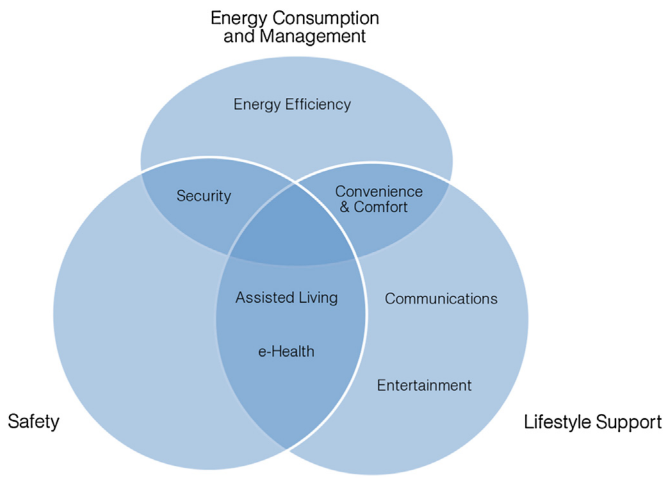

Fig. 1. Types of smart home services.
Source: [63].

linking the components – most often a wired connection or a radio signal (as in the case with 'wireless'); and a shared language by which the various components can communicate with one another and exchange information – a 'communications protocol'. The integration and communication of these different devices, sensors and appliances over a smart home network would potentially improve the quality of life of the householders by offering new *services* that they did not have before (e.g. assisted living) or a much more effective control and management of existing services (e.g. security systems being turned on or off remotely). These services can be grouped into three broad, overarching yet interconnected categories (Fig. 1): energy consumption and management, safety, and lifestyle support.

2.2. Key technical and economic challenges for smart home market development

2.2.1. Retrofitting existing homes

There are three ways of smart home adoption: (i) retrofitting existing homes; (ii) conversion of other properties (e.g. barns, warehouses, etc.) tailored to buyers' requirements; and (iii) purpose-built homes from scratch [22]. Among these, at present, mainly the latter two are used to install smart home technologies [16] as new construction or major renovation offer the ability to optimize high, extensive cabling and intelligent control infrastructure costs with respect to the physical characteristics of a building. This has two implications though. On the one hand, these high installation costs prevent many construction companies from installing them in all but luxury domestic buildings, resulting in many new buildings being constructed without the ability to even accommodate them [16]. On the other hand, these high costs and disruptions to family life, caused by major infrastructure work, create a major challenge for retrofitting existing homes at a wide scale [17].[4] As a result, in countries like the UK where the renewal rate of new builds is very low and a substantial amount of existing homes are estimated to be around in the next 40 years (e.g. 75% of the UK's existing building stock of today will be present in 2050 [27]), retrofitting existing homes seems like the main route for the development of the smart home market.

Furthermore, from a social perspective, homes need to evolve and adapt to changing preferences, demands and needs of householders (e.g. from single to married with children), resulting in smart home technologies being brought into the home in a 'piecemeal' way [15,28]. In this sense, retrofitting is not a one-off process; whilst fitting around the existing structures in a home environment (e.g. physical outline, existing cabling and networking structure etc.), it needs to enable the addition and integration of different devices, appliances, and sensors over time, which might be challenging due to their different design constraints and specifications, which we discuss next.

2.2.2. Interoperability

Interoperability is the ability of equipment, devices, appliances and systems from different vendors to operate together as well as with the existing infrastructures [29]. Different networks and protocols are developed and championed by different manufacturers and suppliers.[5] Interoperability poses a challenge to consumer electronics retailers as to the functionality and therefore the appeal, demand for, and delivery of, smart home services [30,31].

Recent literature highlights two ways in which the sought-after consistency and coherence within smart home systems might be achieved: (i) the adoption of universal standards for communications protocols for smart home devices; or (ii) the development of a 'gateway' – a central node that connects and acts as an interpreter between the different smart home devices and their protocols. The former involves a set of specifications to which new smart home technologies would have to be developed to ensure interoperability, resulting in the development of communications protocols such as Universal Plug and Play (UPnP), the Building Automation and Control Network (BACnet) and the Digital Living Network Alliance (DLNA) [17]. A gateway, on the other hand, would connect and act as an interpreter between the different smart home devices or sub-networks; e.g. by connecting multiple home computers and peripheral devices (e.g. printers) to one another and to the Internet [32] as well as by communicating between smart meters and other devices connected to a home network.

2.2.3. Reliability

In an integrated smart home, interconnected technologies with different tolerances for technical errors pose a concern (e.g. control of a boiler via a home computer and insignificant malfunctions in the latter causing potentially dangerous malfunctions in the former). Combining two or more different products introduces room for complications; while certain services in the home, such as security, or the sounding of a fire alarm upon detection of a fire are more crucial than others. In their design, smart home systems must aim to be robust and dependable in this respect [33]. However, in addition to avoiding malfunctioning, smart home services and technologies also need to accurately interpret the householder's desired outcome and needs (e.g. security alarm going off as a cat walks in to the house).

2.2.4. Privacy and security

In order to tailor its systems to best support the inhabitant's lifestyle, a smart home may collect information about them, such as: their movement, energy use and bills, purchases or even music preferences. The industry faces the challenge of ensuring that personal data is adequately safeguarded. Similarly, with the possibility of the remote control of security services (opening the garage door,

[4] Among others, retrofitting challenges for energy efficiency are discussed by Dowson et al. [64] and Pelenur and Cruickshank [65].

[5] An article published on the front page of the Financial Times on 25/02/2013 presents the current state of industrial alliances in the 'battle over standards for wireless power'.

or turning lights or heating on or off using a mobile phone), efforts will also be needed to ensure that control of the network's sensitive systems cannot easily be compromised.

2.2.5. Costs

The costs associated with the purchase of smart appliances, monitors, devices, etc., along with installation and cabling costs imply that smart home systems are potentially only available to the more wealthy sections of society. Focusing on energy consumption and management services, high costs of demand response technologies (e.g. a programmable refrigerator) and difficult user interfaces are highlighted as key barriers in the literature [34]. However, Holroyd et al. [16] argue that people are willing to spend money on technology as is evident in the success of the iPhone, a more expensive product than its competitors. He argues that by taking a modular approach to each aspect of the device, ensuring that each feature of the phone was not only up-to-date but also that it did not confuse the user, the iPhone differentiated itself. If a similar approach is followed by smart home designers, then costs should not deter the development of the smart home market.

Despite this optimistic view, benefits of energy consumption and management services are hindered further due to the inconspicuous nature of energy [35]. The fact that people do not consume energy per se but instead combine it with other goods to produce services, e.g. combining electricity and a shower to provide hygiene, affects the evaluation of the costs and benefits of smart home technology or services. As a result, as evidenced in behavioural economics, individuals who do not put enough value on the future will be less likely to invest in technologies with a high initial cost as they do not take future benefits (in terms of, e.g., potential savings in the energy bill) into account.

2.2.6. Usability

Holroyd et al. [16] define usability across two dimensions: having a clear benefit and an intuitive/user-friendly interface. The operational and management needs of a smart home cannot be fully dealt with by a third party developer or service provider as they may not fully grasp or anticipate the specifics of a particular individual's needs or how they interact with certain devices [15]. This highlights the need for smart home services and technologies to be outwardly intuitive and easy to use. In particular, '*rather than needing to be managed by an external expert, control and use of smart home systems should be intelligible to the user who will be interacting with them*' [19,36]. On the other hand, this intuitive interface needs to offer a clear benefit or a 'killer feature': '*This recent success of the Apple iPhone, with the killer mobile Internet browsing feature, shows how having an intuitive user interface alongside a killer feature can create a product people want and are willing to pay money for.*' ([16], p. 58)

3. National background: energy policy and socio-economic characteristics

This section outlines the national energy policy background as well as key socio-economic characteristics, including housing stock, which are likely to significantly affect the pace of development of the smart home market as well as its final form in the UK, Germany and Italy.

3.1. National energy policy background

3.1.1. United Kingdom

The UK Government has a legally binding target to reduce its carbon emissions by 80% from 1990 levels in 2050 [37]. The European directive 2009/28/EC requires the UK to meet 15% of all energy consumption from renewable energy sources by 2020 [38]. In order to meet these targets, various policy scenarios highlight electrification of heat and transport [39–41]. In addition to these broader energy system drivers towards a low carbon energy system, the most relevant policy initiative for the UK smart home market is the smart meter roll-out plan by facilitating communication across different technologies within homes as well as the exchange of data between the householder and the grid (via an energy company or a third party provider) so that new smart home services can be developed.

The UK smart meter roll-out is an on-going process on a voluntary basis for consumers who are taking part in schemes set up by utilities wishing to initiate installation early. Since the initiation of large-scale trials in 2007, a total of 229,067 (127,331 electricity and 101,736 gas) smart meters have been installed in domestic properties by the end of June 2013 [42]. With an accelerating schedule of installation from 2014, it is planned that 53 million gas and electricity meters will be installed at 30 million domestic and smaller non-domestic properties by 2019.

3.1.2. Germany

Germany made a policy decision to focus on a sustainable long-term energy supply and adopted its strategy, the Energy Concept, in 2010. The strategy establishes the principles of a long-term and integrated pathway looking towards 2050 with renewable energy as its cornerstone. The German Government is seeking for Germany to become one of the world's most energy-efficient and environmentally friendly countries, while maintaining economic prosperity and affordable energy prices. In addition, the Government is also seeking to phase out nuclear power in Germany by 2022 as part of the *Energiewende*, or the second Energy Package, which followed the Fukushima nuclear accident [43].

Energy efficiency is a key element of the Energy Package, and Germany set targets to reduce primary energy consumption by 20% by 2020 and 50% by 2050 compared to 2008 [43]. Several German policies and initiatives underscore the commitment to improving energy efficiency and smarter consumption. The Energiewirtschaftsgesetzt prescribes the installation of smart meters in all new or fully renovated buildings. In addition, the Energy Saving Act (EnEG), in particular through the Energy Saving Ordinance of 2007, allows the Federal government inter alia to establish requirements on the functioning of a building for insulation, ventilation and heating. Beyond concerns of energy efficiency, as information and communication technology (ICT) is central to the concept of smart homes, the Federal Office for Information Security (BSI) is currently developing a policy for a privacy protection profile for smart meters.

3.1.3. Italy

Italy adopted the new National Energy Strategy ("Strategia Energetica Nazionale", SEN) on March 8, 2013. SEN highlights energy efficiency, the sustainable development of renewable energy sources and the deployment of smart grids for electricity distribution as priorities[6] for a low-carbon growth path whilst ensuring security of supply from a medium (2020) to long-term (2050) perspective.

Italian residential and tertiary buildings went through significant energy efficiency improvements (including installation of high efficiency boilers, solar panels, retrofitting and thermal insulation

[6] For additional information and the full text of the document, see http://www.sviluppoeconomico.gov.it.

of buildings, etc.) over the period 1990–2010,[7] enabled via various policy instruments and tax allowances.

Italy was the first European country where smart meters for electricity were deployed on a massive scale, in the first half of the 2000s. Digital smart meters have been compulsory for all electricity providers since 2006 (Regulatory Order No. 292/06). The Italian regulatory authority (AEEG) established minimum functional requirements and introduced incentives for the adoption of advanced metering features related to the quality of supply.[8] The regulator's intervention was required after the choice by ENEL (Ente Nazionale per l'Energia eLettrica) – the main electricity provider in the national market – of replacing around 32 million standalone electricity meters with communicating solid-state meters networked via a hybrid wireless/ANSI 709 power line (Telegestore project, 2001–2006, €2106 million).[9] More recently, ENEL has also envisioned a path (through a set of projects) to move from the roll-out of smart meters to a demand response market platform.

3.2. Housing stock characteristics

This section outlines housing stock characteristics (both types of buildings and tenure) of the UK, Germany and Italy in a comparative context.

Housing stock characteristics could affect the development of the smart home market in different ways. Firstly, the physical outline and size of a home (flats vs terraced homes) determines how that space is used to carry out certain daily activities/routines, what types of appliances can be fitted etc. Secondly, the strength and coverage of communication signals might affect the actual operation of different functions in a home environment. In particular, the propagation of communication signals in the home is subject to both free space path loss (reduction of signal strength with distance) and barrier losses (e.g. loss of signal strength as it propagates through walls) [44]. Finally, other physical characteristics of the buildings, such as building (e.g. stone vs timber) or insulation (e.g. foil-backed plasterboard) materials, whether it is a shared building (i.e. flats) or a single family home, its height, etc., could exacerbate propagation of signals further. On the other hand, installation and use of technologies and appliances are found to differ between renters and owner-occupiers, highlighting the importance of tenure [45].

As can be easily observed from Fig. 2, the majority of the German and Italian populations live in apartments or flats, whereas most of the UK population live in semi-detached houses.

The age of the residential building stock in each country is likely to affect the type of intervention that might be implemented in the building. This is a critical issue in a country like Italy, with plenty of old and ancient buildings and historic centres to preserve[10] (Fig. 3). Moreover, as discussed in Section 2, there are important differences between building a smart home ex novo and enhancing or retrofitting existing homes with new technology and smart home appliances.

In terms of tenure of the housing stock, while more than two-thirds of homes are owned (either with an on-going mortgage/loan or outright) in the UK and Italy (70% compared to 72%, respectively), almost half of housing stock is rented in Germany (47%) (Fig. 4).

[7] See http://www.odyssee-indicators.org/publications/country_profiles_PDF/ita.pdf.

[8] See http://www.autorita.energia.it/allegati/docs/06/292-06allengnew.pdf.

[9] See http://www.enel.com/en-GB/innovation/smart_grids/smart_metering/telegestore/.

[10] *Source*: CRESME – ENEA, "Analysis of the socio-economic impact of the 55% tax allowances for energetic requalification of the existing real estate", 2010.

Table 1
List of cities indicating the origin of public deliberative workshop participants.

	Population	Location
UK		
London	8 million	Capital city, in the South East of England
Bridgend	40,000	22 miles west of Cardiff, the Welsh capital
Germany		
Berlin	3.5 million	Capital city and one of 16 states
Brandenburg	2.5 million[a]	A federal state surrounding Berlin with many geographically dispersed small towns
Italy		
Rome	2.8 million	Capital city, in the centre of Italy
Gubbio	33,000	40 km from Perugia, Umbria region in the Centre-North of Italy

[a] Population for the entire state.

4. Methodology

As smart homes are new technologies with which the householders are generally not very familiar, it was not deemed possible to get informed feedback from the public on their perceptions of and concerns about smart homes in a limited time of a conventional focus group. Instead, public deliberative workshops were organized, offering a more interactive setting where information via different means (videos, presentations, drawings) was provided to the public and their feedback and reflections were explored in detailed and structured discussions. This workshop format also enabled the recruitment of a diverse range of people (up to 30) who could interact together and be addressed as a whole during the presentations but could also be split into smaller groups for more detailed discussions.

4.1. Locations and participants

A total of six workshops (two per country) were conducted over two different days in the UK, Germany and Italy. In each country, one workshop included participants from large cities and another one from smaller cities (fewer than 50,000 inhabitants,[11] following [46]). In the UK and Italy, the workshops took place in the origin cities of the participants whilst in Germany the participants attended at the partner institute's offices (see Table 1 for the origin of participants). Each workshop was carried out with 24–30 participants and lasted 4–4.5 h (including breaks).

In addition to these geographic differences, groups were further subdivided into smaller groups based on age, which was used as a proxy for life stage. These groups were subsequently called pre-family (under 30 without children[12]), family (30–50, potentially with children) and post-family (50+ with no children, or no children living at home). Whilst we aimed to have an equal number of participants from each life stage at any workshop, due to last minute dropouts, each sub-group included around 7–10[13] participants at the end. Each of these sub-groups further had a mix of participants differing by gender, tenure (owner vs renter), property type (house vs flat) and income (high vs low).[14] The aim was to

[11] We have adopted the OECD definition of small vs large city distinction as a proxy for urban vs non-urban areas.

[12] In Italy, the age limit for the pre-family participants was raised to 40 to account for the fact that a relevant share of single Italian adults leave their parents' home relatively late (aged over 30 or more).

[13] One sub-group in Italy included 13 participants.

[14] Educational qualification and job are used as a proxy instead of income variable in Italy.

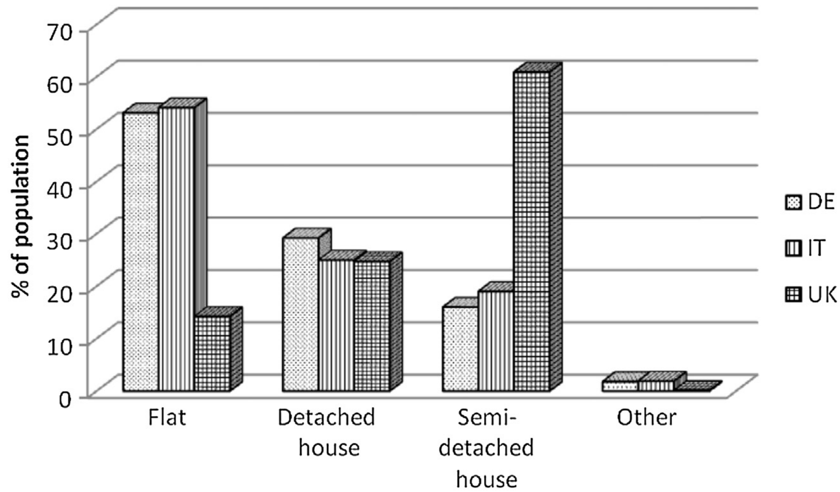

Fig. 2. Distribution of population by dwelling type (%) (Germany, Italy, and UK; year 2009).
Source: http://epp.eurostat.ec.europa.eu/statistics_explained/images/5/5c/Housing_statistics_YB2012.xls.

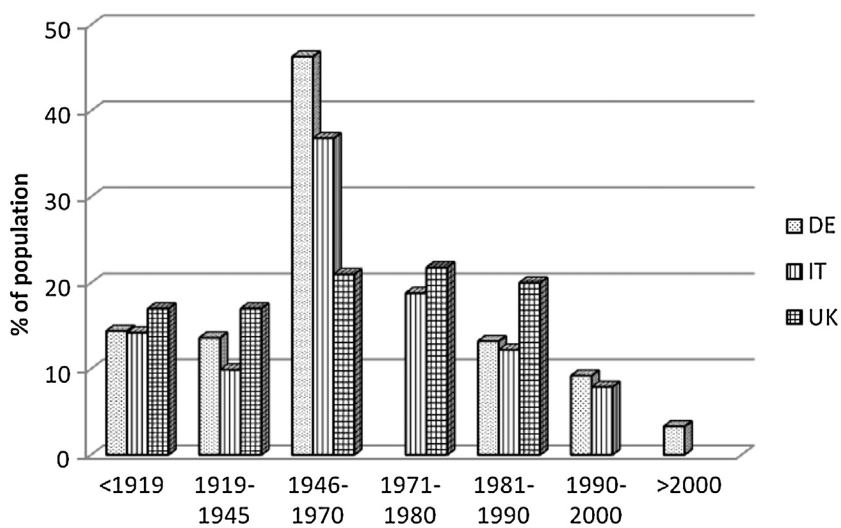

Fig. 3. Age distribution of housing stock (UK,[15] Germany,[16] Italy[17]; different years).
Source: Housing Statistics in the European Union 2010, OTB Research Institute for the Built Environment, Delft University of Technology, edited by K. Dol and M. Haffner.

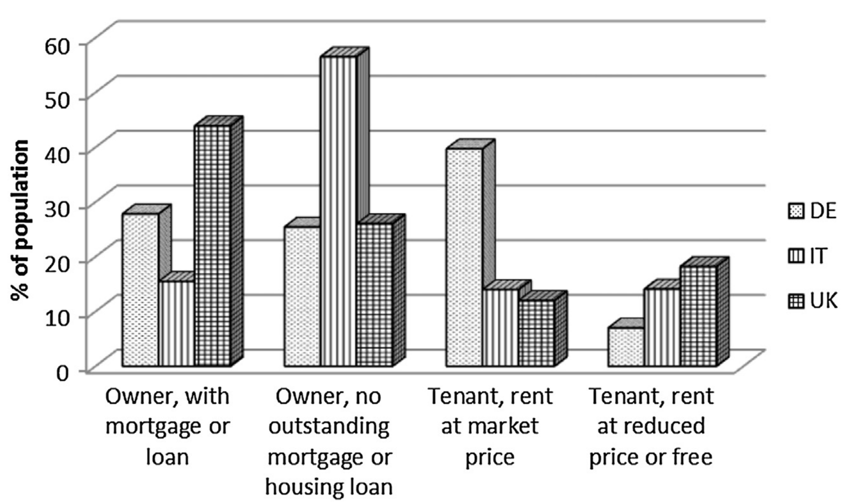

Fig. 4. Distribution of population by tenure status (Germany, Italy, UK, year 2010).
Source: Eurostat (2012): New Cronos.

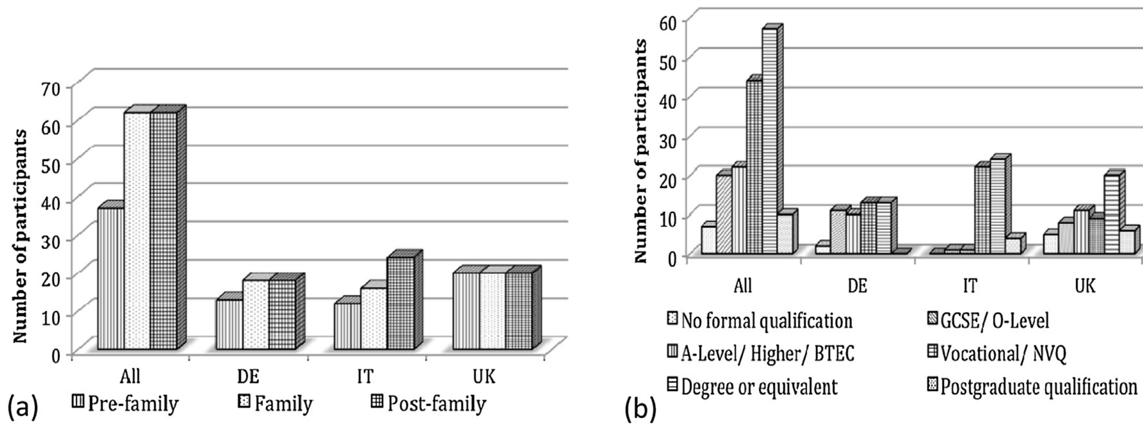

Fig. 5. General characteristics of public workshop participants: (a) age and (b) qualification. (The educational categories were based on the UK system which created bias in capturing differences in Italian system.)

build sub-groups that helped to cover the opinions and arguments of different groups within each country. Broad characteristics of the participants (age and qualification) are presented in Fig. 5.

Recruitment was undertaken through a research recruitment company and the participants were paid an incentive in order to compensate for their time.

4.2. Methods and materials

It was deemed important to elicit existing understandings and associations of home and energy use before any information on smart homes was provided. Hence, the first stage of the workshop was carried out in sub-groups where participants were asked about their views on and understanding of their home, appliance and energy use, energy saving, and homes in the future.

Then in plenary session, two short videos and a presentation on smart homes were given to participants. The stop-motion videos (produced by one of the academic project partners) presented contrasting perspectives (following [47]) on the benefits and shortcomings of smart technologies/systems (e.g. smart meters, dynamic tariffs, electric vehicles, energy efficient appliances, timed showers) in terms of how an individual (video 1) or family (video 2) household might experience them. This was then followed by a brief Powerpoint presentation that outlined a range of smart technologies and services that might be introduced (or, in some cases, already exist), focussing on the domains of healthcare, home security and energy consumption and management. The responses of the participants to the videos and presentation were then discussed in smaller groups. The aim was to elicit more informed opinions, attitudes towards and perceptions of smart homes of the participants. All materials (questionnaires, topic guides, videos, slides) were prepared in English and then translated into Italian and German contexts.

4.3. Data analysis

The data from the public deliberative workshops were analyzed using thematic analysis [48]. A topic discussion guide was prepared that was subsequently used across all research teams. This guide included detailed questions and probes to steer the discussions in the same way across three countries. The answers to each question were then summarized in a matrix format in Excel, including appropriate metaphors and analogies used by the participants. An iterative analysis between this matrix and transcripts enabled the identification of technical and economic barriers as perceived by the consumers, which are discussed in the next section.[18]

5. Results: techno-economic factors affecting smart home adoption

5.1. Retrofitting existing homes

In both the UK and Italy, public workshops revealed strong sentimental, aesthetic values towards the protection of old and historical housing stock, indicating another difficulty for retrofitting existing homes.

In the UK, many of the participants described living in older properties. When talking about smart homes, participants often could not envisage being able to have smart technology because their older homes were assumed to be completely incompatible. A number of younger participants (from the pre-family group) viewed smart home technology as irrelevant as most lived in older properties. Aesthetic appeal was a significant consideration, with many participants disliking the idea of living in modern properties as they lack '*character*'. Whilst they recognized that smart home technologies were more suitable for new builds, they were seen as impersonal. Perceiving living in older properties as more desirable, this left the participants with a dilemma that it would be quite difficult to update the old housing stock with the latest technology.

Similar concerns were raised in Italy. Younger participants from the big city location generally pointed out that '*it is easy to install smart technologies in new buildings, less easy for interventions in existing homes*'. Participants from the smalltown location, Gubbio – an old town with many houses dating to the XIVth and XVth centuries – were aware and proud of the historical and cultural heritage of their city ('*what I like about my house is that it is located in the city centre, although this makes it difficult any change*'), at the same time they were dissatisfied because of the high maintenance costs of their houses. The pre-family group, in particular, referred to possible technological barriers to the installation of smart home

[15] (2004/2005 data for the following age categories: <1919, 1919–1944, 1945–1964, 1965–1984, >1984).

[16] (2006 data for the following age categories: <1919, 1919–1948, 1949–1978, 1979–1986, 1987–1990, 1991–2000, >2000).

[17] (2001 data for the following age categories: <1919, 1919–1945, 1946–1971, 1972–1981, 1982–1991, >1991).

[18] The results related to perceptions on utilities and government and preferences for smart home acquisition are discussed in Balta-Ozkan et al. [62].

technologies in existing buildings (old or ancient) and to cultural worries related to the '*risk of losing tradition*'.

In the UK, some participants also commented on the suitability of smart technologies for newly built homes. They argued that newly built homes should be all smart or ready to be smart from the start and called for actions from both the Government and utility companies: '*There should never be a new house going up that hasn't got solar panel, hasn't got a wind turbine, that isn't completely self sufficient, they shouldn't be allowed to be built because these big companies are making enough money to do that*' ('City family' group; UK).

5.2. Smart technology as difficult to operate and unreliable

Across the three countries householders raised concerns over operating smart home technologies and their reliability.

In the UK, the participants raised concerns over how people from different socio-economic backgrounds can cope with operating smart home technology. The city family group assumed that smart home technology would require significant technical knowledge to operate. In parallel to this, the town family group speculated that smart technology would exclude those who are not computer literate. The connection of different devices and appliances to each other in a home setting raised concerns over the reliability of these technologies. Room sensors being triggered unintentionally or security systems malfunctioning or a remote control unit, designed to operate several household functions, stopping working were some of the issues undermining their reliability. Complete reliance on computer systems was not an idea that the participants were comfortable with.

German householders, across all groups, were concerned with dependency on technology and what happens if smart home technologies fail. Many consumers expressed concern about increased risks due to increased connectivity within their households. For example, a common concern was that if one item fails, other technologies in the house might also have issues. Another concern of consumers was that increased technology inside their homes would lead them to be more dependent on companies (possibly several) specialized in repairing smart home technologies. Specific concerns mentioned in Germany were: '*over mechanisation*'; '*information overload*' as well as '*time consuming*' updates and management of the different devices and services; and a possible bad cost-benefit relation. One participant suggested '*only repairing and maintenance by oneself guarantees full control and independency*'.

In Italy, difficulties related to the adoption and use of smart home technologies were mostly due to the alleged lack of technological competence and acquaintance in these systems that would result in '*the risk of being at the mercy of technologies*'. In particular, participants from the small town location emphasized the '*hard job for the elderly in putting such technologies in operation*' as well as, in general, '*the difficulty in managing anomalies or breakdowns of complex technologies*'. Older people also expressed the fear of damages if smart technologies are difficult to use; '*they ought to be simple and user-friendly instead*' and concerns about the presence of competent technicians and professionals '*if the smart home breaks down, who will fix it?*'. The lack of specific technological skills and knowledge also appeared to sway the consumers' views (notably in the small town context) on whether they would like to purchase these technologies and services in their homes.

5.3. Privacy and data security

Another recurring concern across the countries was the potential of smart home technology to compromise security and invade privacy. Participants expressed concern over third parties knowing daily routines and occupancy, data falling into the wrong hands, and the potential of smart systems to be compromised.

In the UK, a strong theme throughout the groups equated the household monitoring involved with smart technology with 'Big Brother' watching them. Even though participants viewed the personal information that would be collected on households as akin to the type of data collected on a supermarket reward or loyalty card, they noted a clear distinction between the monitoring of external and internal activities. They expressed concerns over the accumulation of a great deal of sensitive personal data including day-to-day activities, which were viewed as invasive to private lives. Concerns over the security of data were linked to who can access this data and how householders themselves access and control these smart home services. They expressed concerns over data falling into the wrong hands and its misuse in connection with knowing when they are in or out of their property as employees of these companies are '*not necessarily CRB* (Criminal Records Bureau) *checked*'. While participants embraced the concept of controlling smart home services by smart phone, this did not stop them considering this as both a convenience and a vulnerability. The threat of losing smart phones raised concerns about the security of their homes ('*If you lose your phone, somebody just walks into your house*').

Similarly, although consumers recognize the importance of data monitoring for the improvement of the functioning of the smart home, participants were concerned about potential risks of their '*energy profiles*' becoming available to third parties in Germany. Some feel that monitoring energy consumption or habits is only acceptable if the data is processed within the house to allow sensitive data to be used only when necessary for system optimization.

In Italy, concerns were raised by participants in terms of people's right to privacy because of the great amount of data that need to be stored and collected by smart homes in order to predict people's behaviour in an effective manner. This would also raise issues in terms of '*technological piracy*' and cyber-security. Both younger and older people in the city context expressed the '*fear of being too much controlled at home*', whereas family groups warned against the risk of technologies becoming too much intrusive and invading their own domestic privacy. Older participants also pointed out that smart home technologies would '*limit individual creativity and freedom to manage one's own time*'. Similar concerns were raised in the town context, where younger participants further emphasized that the application of smart home technologies in jointly-owned groups of buildings might be problematic since '*having shared services can lead to conflicts, limitations, less freedom*' as well as to reduced privacy for the end users.

5.4. Energy and cost savings from smart home technologies

The potential of smart home technologies to reduce the cost of energy and provide savings was an important factor for the appeal of smart homes across three countries. Some participants drew parallels with reducing energy use and protecting the environment.

Due to the increasing price of energy and the economic crisis in the last few years, many UK householders reported changes in their behaviour as a result; e.g. less use of tumble driers and an increase in drying the clothes in the open air. Respondents in all groups talked about their awareness of household energy consumption, some of which were due to owning in-home display units, enabling them to monitor their energy usage much more closely. Possibilities around being able to produce and sell energy back to the grid were accepted with enthusiasm. Nonetheless, cost saving potential of smart technologies was received with cynicism: for some householders, if savings via dynamic and differentiated tariffs were minimal or would require inconvenient changes to household routines, they were disregarded. On the other hand, whether the householders would actually receive these benefits were questioned, highlighting issues around 'trust' ('*if the companies see they're not making any money, they'll put up tariffs to make up the difference because all they're worried about is profit and shareholders' premiums*'). However, energy efficient appliances that were shown to have significantly cheaper running costs were not subject to these concerns, maybe because their benefits and costs stay with the householders directly. Some UK participants (most obviously family and post-family groups) mentioned that saving energy is good for the environment. The participants raised their sense of control and agency in the extent to which they felt they could influence/save the environment as long as the costs were not significantly higher than for alternative technologies.

In Germany, while energy awareness is high for most groups, basing purchasing decisions on energy use is most often identified in older non-urban groups. Similar to the UK, although price generally trumped environmental concerns as a driver for smart home acquisition, the environment was still a factor for a substantial number of participants, stating that both money and the environment were important to them. One participant stated, '*for me, sustainability is more important than price*'.

Reducing energy usage emerged as a major driver in Italy across different household types and locations – notably through the purchase of more efficient devices and/or changes in habits. The high cost of energy is considered, by most, the main driver for modifying habits and behaviour towards a more efficient use of energy within their lifestyle ('*I control my energy consumption and expenditure*', '*I've changed my habits*', '*I look for a less consuming way of living*'). Family groups seemed to be generally more aware of and very sensitive to energy and environmental issues that were perceived as strictly linked to each other. Interestingly, different solutions to reduce energy use were proposed depending on the living context: city families showed a preference for community-based solutions to be agreed in accordance with their own neighbours whereas town families put more emphasis on behavioural changes.

5.5. Smart technologies enabling transparent information about energy costs

The participants in Germany and Italy expressed a strong desire that their energy bills and energy usage were more transparent. Hence, smart technologies' potential to enable this emerged as a driver in these countries.

In Germany, householders highlighted that additional information about saving money and energy (e.g. to know when tariffs are reduced or itemized billing) would be interesting and welcome, as long as the information was provided in a manner that was not intrusive (e.g. receiving unwanted text messages or phone calls). At the same time, it was expressed that not all responsibility should lie on the side of the consumer, as one participant stated, '*saving energy should be implemented inside the devices itself and not need to be constantly monitored by myself*'.

In Italy, the participants discussed how easy and transparent access to information about energy costs and consumption can be crucial in adapting new habits. Because of the relevant burden of electricity bills on family budgets, technologies that allow consumers a real-time monitoring of tariffs and of actual energy consumption received a great deal of attention, in particular among the older participants. Post-family groups also underlined the importance of '*using domestic appliances when the cost is cheaper*' or when strictly necessary. Among the younger participants, those from city location requested more information about the costs of appliances, services and technologies whereas those from the small town location were more interested in monitoring energy consumption. Some of the latter group participants pointed out smart meters as a good solution to know energy consumption at different times of the day or to compare the efficiency of devices.

5.6. Smart home technology as prohibitively expensive

A recurring theme across three countries was concerns over the installation as well as maintenance costs of smart home technology. Uniformly across the countries, smart repairs and maintenance were perceived both too costly and complicated.

In the UK, some participants speculated that smart technology would end up as a commodity for the white, affluent middle classes unless they are not supported via some government programmes. On the other hand, given the owner-occupied characteristic of the UK housing stock, many participants felt that first time buyers would be unable to afford smart home services.

In Germany, some smart home goods and services are considered mostly '*luxury items*' or for specific groups, such as technology-savvy people: '*Maybe only nice for tech geeks that want to ease their daily life*'. These concerns are expressed more often by younger groups, but are still made by older groups. As there are no offers for the mass market, the question of cost and benefit is not yet clear.

In Italy, in addition to acquisition, operation, management and maintenance costs of smart home technologies, installation costs in existing buildings were mentioned as a strong concern because of the '*high investment*' needed and of the '*time required to write off expenses*'. Such a concern added up to the alleged technical difficulties to '*intervene in a significant way on old houses*'. These issues came out strongly among older participants that warned against the '*technical and economic complexity of maintaining a* '*technological*' *house*'.

5.7. Smart home technologies as long-term investments for home owners

In the UK and Germany, the perceived high costs of smart home technologies have led householders to think of them as long-term investments, making them viable for home owners only.

When discussing the cost saving potential of smart home technology, respondents tended to assume it would involve a long-term investment. Therefore consumers would have to live in a property for a number of years before recouping costs and making significant savings. The tenant participants and pre-family participants (most of whom are renters in individual or shared properties) in particular felt these technologies and services were exclusive to them as a result. The difficulties and problems experienced currently when changing their energy suppliers led them to question how they can take their smart home services to the next property they move into and how complex it might become.

Similarly in Germany, some groups are concerned with increasing rent prices in the city and expressed concern regarding purchasing energy efficient technologies because of cost barriers they experienced as renters. Other groups voiced concerns that there would be potentially large limitations to energy efficiency measures if they live in a rented place or if the property is an existing building.

5.8. Usability: tangible benefits

Participants across all groups in all countries tended to favour smart home services they perceived as practical with tangible outcomes beyond controlling for energy use.

Table 2
Overview of drivers.

Theme	Description	UK	Germany	Italy
Energy and cost savings	Increasing energy prices and a desire to reduce costs through household energy savings	√	√	√
Tangible benefits improving quality of life	Services that are perceived as practical and with the potential to improve quality of life	√	√	√
Environment	Saving energy for the environment	√	√	
	Preservation of environment to improve quality of life			√
Transparency	Gaining additional information about saving money and energy		√	√

Table 3
Overview of barriers.

Theme	Description	UK	Germany	Italy
Retrofitting existing homes	Value of historic or aesthetic buildings hinders consumers' willingness to alter them	√		√
Reliability	Concerns on how to operate smart technology	√		
	Reliability of smart technology	√	√	
	Concerns on increased connectivity in homes and their risks	√	√	
	Lack of technological competence and acquaintance			√
Costs	Associating smart homes with luxury items and high costs	√	√	
	Concerns about the costs associated with acquisition, operation, management and maintenance of smart home technologies.	√		√
Privacy and data security	Compromise security	√		
	Invasion of privacy	√		√
	Concerns about misuse of personal data	√	√	
Tenure	Renters may be less likely to invest in smart homes	√	√	

In the UK, fire, air quality, carbon monoxide detection, and security systems tended to fall into this category. Automatic lighting, keyless locks and programming remotely via mobile phones created enthusiasm in the participants. The advancements in wireless technology were welcomed as they allowed the householders to use space more efficiently with fewer wires, cables and clutter (which were viewed as a premium by the family sub-group). The householders recognized the benefits of smart home technologies to provide support for assisted living for the elderly and those with disabilities. The participants pointed out the need for smart home technologies to convince householders that they would have a '*positive impact on general wellbeing*' for their mass adoption.

Some smart home services received a generally positive response from the majority of consumers in Germany. Security-related services were the most well-received, as many consumers were interested in services that would give them more home security control, such as receiving updates on their phone while away if a door or window opened at their home. In addition, health-related services were often viewed positively by many consumers. Preferences varied between those services which focused on the home, such as to monitor air quality, to those that allowed for monitoring personal health (e.g. blood pressure). More specifically for energy consumption services, German consumers are interested in having some automatic smart home features and having a clear sense of control of different aspects of their house, though preferred features vary across the groups. Some (pre-family) groups prefer services that allowed them to control different aspects of their home (most often related to heating) from an external device. Other (family) groups are more interested in higher comfort services like communicative appliances and controlling lights while the older (post-family) groups are also mostly interested in items that increased comfort in terms of reducing effort, such as self-cleaning windows.

The opportunity of improving the quality of life emerges as a strong and multi-faceted driver for smart home market development in Italy. On the one hand, quality of life has been frequently linked to the environment so that better management of energy use and consumption at home minimizes the environmental impact of current lifestyles. This concept came out strongly in the smalltown context where participants showed, on average, a higher sensitivity to environmental issues than their big-city counterparts. In particular, couples with children generally seem to be placing a greater emphasis on these kind of environment-preserving issues related to their energy use ('*a house supporting both the economy and the environment*'). On the other hand, the assisted living services that could be provided by smart home technologies created most interest in pre-family and family groups that were concerned about the need to support their older parents and the possibility of having more free time for themselves. For instance, pre-family groups were highly interested in devices that automatically contact care providers or third-person assistance as well as devices that monitor blood pressure by sensors.

5.9. Summary of findings

This section provides an overview of the major themes that emerged from the public workshops across the UK, Germany and Italy. Four key themes are identified as drivers to the potential development of smart home markets as summarized in Table 2 below. When a particular driver applies to a country, it is indicated with a check mark.

Table 3 summarizes potential barriers to smart home uptake in the UK, Germany and Italy. The barriers emerged in the participatory research are presented in broad categories of themes emerging from the literature. Eleven issues are identified as potential barriers to smart home uptake in the UK, Germany and Italy. Those identified as a potential barrier within a country are indicated with a check.

6. Conclusions

This study analyses perceived technical and economic barriers for the development of the European smart home market by focusing on the UK, Germany and Italy. Despite an overarching goal of decarbonization of energy systems, these countries are following different paths to this end. Germany's highly distributed energy system sets a big contrast to the more centralized energy systems of the UK and Italy. On the other hand, while Italy has rolled out smart meters nationally, the UK has a mandate to complete the national rollout by 2019 with expectations to initiate demand response to meet its very ambitious emissions reduction target of 80% from 1990 levels in 2050. These differences are deepened when other socio-economic characteristics are taken into account. The older and occupier-owned housing stock of the UK and Italy contrasts to Germany's more tenant-occupied and relatively newer housing stock.

The findings from the study highlight key issues that might affect whether and how the smart home market develops in Europe. Against increasing cost of energy prices, not so surprisingly, householders across three countries are interested in reducing their energy use. Hence, the potential of smart home technologies and services to reduce energy costs against increasing energy prices and the effects of economic crisis is a strong driver. On the other hand, for many householders the potential of smart home services beyond energy consumption and management was the main appeal. The householders would like to improve their wellbeing via services that contribute to their daily lives and routines. However this emerges as a significant barrier which we discuss next.

In particular, privacy and data security emerged as a common concern across three countries. The relatively higher UK citizens' concern about use of personal data other than its original aims were prevalent in public workshops and this perception might be linked to only 33% of the UK population being aware of the existence of a national public authority (Information Commissioner's Office) to enforce this [49]. Concerns around the reliability of smart home technologies are another common barrier. While in the UK and Germany these concerns are mostly focused around technological failures, in Italy these seem to be generated from a lack of technological acquaintance with smart home technologies and services and more generally with high-tech products and services. While this needs to be investigated further, it might be linked to relatively lower interest in new scientific discoveries and technological developments as well as lower levels of Internet access compared to Germany and the UK as evidenced in Eurobarometer surveys [50]. This is a somewhat surprising finding as a key enabler between home and electricity grids, smart meters, are widely rolled out nationally in Italy. On the final technical concern, given the older housing stock of Italy and UK, householders expressed strong sentimental and aesthetic values towards the protection of these buildings, hindering consumers' willingness to alter and retrofit them. On the economic issues, householders in all countries expressed concerns over the high costs of smart home technologies (both initial capital as well as maintenance). In Germany and the UK they were even branded as luxury items, only affordable to wealthier sections of society. A contrasting finding in the UK and Germany is the public's perception of these technologies as being long-term investments and as a result their perceived viability only for homeowners. While this could be due to high tenancy rates in Germany, it can be due to a higher awareness of costs and economic circumstances in the UK.

Despite promises of smart home technologies to contribute to the achievement of Europe's energy and climate goals [51] by providing transparent information about energy use as well as generating cost and energy savings, our study also reveals a number of important barriers that will affect whether they can actually fulfil this potential [52]. In fact, it is also possible that new habits and conventions might emerge as smart home technologies become mainstream, some of which may reinforce potentially unsustainable and energy intensive lifestyles, in turn becoming new norms and practices [53]. In some instances these rebound effects may even increase the energy consumption and greenhouse gas emissions of households [54].

Further the study highlights the following key issues that need to be taken into account by both the policy makers and energy companies:

- Familiarity with smart meters is not necessarily a precursor for the acceptance and understanding of smart homes as observed in Italy. Whilst this might be linked to relatively lower interest in new technologies in Italy, nonetheless it highlights the need for communicating the benefits of smart energy systems (from homes to networks to cities) clearly to the consumers. This is especially important for countries like the UK or other EU Member States which will follow the European Electricity Directive to achieve deployment of smart meters to 80% of consumers by 2020 [55]. Otherwise, the expected benefits [56] may not be realized.
- Highly decentralized energy systems as in Germany did not allay consumer concerns regarding the cost of these technologies or privacy, which emerged as a common barrier across these countries.
- Whilst the householders recognize the need for consumer data being used to deliver a variety of services, it mattered for what purposes this data has been used for. This indicates the need for guarantees and laws ensuring that their data is not misused as well as the development of 'privacy friendly' techniques [57]. The storing of individual consumer data, who can access their data and what happens if it falls into the wrong hands is an area that will require policy makers and industry to work together.
- In the UK and Italy, the public expressed strong reservations on the suitability of older housing stock to install smart technologies. In this regard, it was interesting that some UK participants highlighted the need for newly built homes be smart or smart-ready. Whilst this is an important barrier already highlighted in the literature, construction of newly built homes as 'smart' (most likely via building codes and legislations) and communication of associated benefits to the public in clear and simple terms can help with changing perceptions on the unsuitability of smart technologies for older buildings. Otherwise, this might hinder the uptake of smart technologies where older buildings are concerned.
- Perceptions on the suitability of smart home technology and services mainly for home owners indicate policy leadership should make sure 'people are not disadvantaged' and that no further divisions are created in society, which we think is the real risk for the development of smart energy systems in general (for a discussion of these social issues see [58]).
- In addition to the initial costs of appliances, the householders assumed maintenance costs for these technologies and services will be high. Given existing behaviours to discount the future savings against high initial capital costs, as a result of the inconspicuous nature of energy consumption, perceptions around high maintenance costs indicate the need for the development of new business models such that these costs are spread over the lifetime of these technologies and services.
- Most probably the most important finding is that the presentation of smart homes benefits only around energy consumption and management is not effective and not very appealing for the public. Investing in these technologies and services just to be able to control and monitor energy use does not seem to create a sufficiently strong driver for the consumers. The benefits these technologies offer need to be more directly linked with their daily lives and how their wellbeing is improved (e.g. use of sensors to monitor air quality to deal with asthma). In this sense, the development and delivery of wider benefits in relation to smart grids and smart cities is an area that both the academic community

and industry need to work on together, calling for more in-depth research in this area.

- Across all three countries, the public showed great interest in services such as indoor air quality monitoring, security, and comfort and convenience (e.g. being able to turn off all lights via a switch). Similar to Jeong et al.'s [14] findings on cultural preferences, we found that while participants in Germany revealed strong interest towards automation and convenience-related services, in Italy householders seem to be keen on health related services.

We argue that the provision of smart home services together with these other services beyond energy consumption and management can help to mitigate against concerns around privacy and their costs [59]. On the former, Townsend et al. [60] provide evidence on motivated cognition theory [61] in the context of smart home technologies. They reveal that some older adults are willing to trade privacy (by accepting monitoring technologies) over autonomy, including video cameras, the most intrusive form of sensor technologies. On the latter, whilst it is yet to be seen whether such a holistic approach can imitate iPhone's success as Holroyd et al. [16] discuss, nonetheless it would create a stronger benefit case, which has to be supported via a user-friendly design. This way, smart home technologies will need to be treated like a platform, building on '"plug (and) play" and scalable solutions, using a mobile apps model'[19] so that different services and functions depending on householders' needs, preferences and choices can be integrated and added over time. Given the existing infrastructure characteristics (the UK having the highest Internet access in homes whereas German householders' preferences to have bundled services), it needs to be investigated further how such a 'mobile apps model' can develop.

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