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Critically Reviewing Smart Home Technology Applications and Business Models in Europe

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Abstract: Smart home technologies refer to devices that provide some degree of digitally connected or enhanced services to occupants. Smart homes have become central in recent technology and policy discussions about energy efficiency, climate change, and innovation. However, many studies are speculative, lacking empirical data, and focus on costs and benefits, but not business models and emerging markets. To address these gaps, our study presents data from semi-structured expert interviews and a review of the recent literature. Although we draw from empirical data collected in the United Kingdom, we place our findings in the context of Europe because the UK has access to European markets for smart home technologies and platforms. Our sampling strategy included experts from Amazon, Microsoft, the International Energy Agency, government, academic, and civil society stakeholders. We identify a diversity of definitions associated with smart home technologies and draw from our data to discuss

applications centred on digital connections, enhanced control, automation, and learning. We analyse fifteen distinct business models for smart home technologies, ranging from energy services and household data monitoring to assisted living, security and safety, and new advertising channels (among others). Our assessment ought to guide future innovation patterns, technology deployment, and policy activity relating to smart homes, especially insofar as they can deliver energy services more affordably or help meeting carbon mitigation priorities.

Keywords: smart home technologies; smart energy; ‘prosumers’; decarbonisation

Common abbreviations applied: IoT (Internet of Things), SHT (Smart Home Technologies), ICT (Information and Communication Technology), IT (Information Technology), RD&D (Research Design and Development), SGTF (Smart Grids Task Force), LCICG (The Low Carbon Innovation Coordination Group), IEA (International Energy Agency) OECD, (Organization for Economic Co-operation and Development).

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1 Introduction

Smart home technologies, smart grids, and smarter energy use have become prominent themes in recent years. There is little doubt these technologies are spreading and growing in influence. For instance, the World Economic Forum and Accenture calculate these technologies will add \$14 trillion of economic value to the global economy by 2030 and an additional \$100 billion in operating profits across industry (World Economic Forum, 2018). Others have noticed substantial year-over-year growth in the number of connected devices as sales growth by 17% from 2016-2017 (McKinsey, 2016) and revenues in the smart home market are expected to reach US\$90,968m by the end of 2020 (Statista, 2019). Based on this, some argue that for consumers, at least in the UK and Europe, the smart home revolution has arrived (Intelligent Energy Europe, 2019; Sovacool and Furszyfer Del Rio, 2020; Statista, 2019). An example of a technology that has had a major impact in recent years is the smart speaker with voice assistant (Berg Insight, 2018; Sforza, 2019), such device, can provide real-time information about the weather, traffic and sports results (Intelligent Energy Europe, 2019) Tech giant Google, for example, through its smart speaker can interact with more than 20,000 devices across 1,200 brands and assist users in more than 30 languages (Bohn, 2019). Indeed, voice assistants are not constrained to a particular device and that is what it makes them more powerful; their ubiquity (Kinsella, 2019). Nevertheless, the term “smart” can refer to a variety of technologies, configurations, practices and types of software, and there is no single agreed definition; some consider (Accenture Strategy, 2015) that these technologies ought to include internet of things (IoT) and smart devices, along with (real-time) monitoring, sensor technologies and data analytics, customer interfaces and demand response technologies. In this sense, Consultancy Berg Insight, groups ‘smart home system’ into seven categories: “1. security and access control systems; 2. energy management and climate control systems; 3. audio-visual and entertainment systems; 4. lighting and window control systems; 5. healthcare

and assisted living systems; 6. home appliances and 7. service robotics” (Berg Insight, 2018). This paper attempts to unpack the business models around smart home technologies, and the importance of relevant policy.

An array of national and regional policies aim to support smart home technologies (SHT) development and to steer deployment patterns towards social priorities (Nicholls et al., 2020), such as secure and affordable energy, better management of energy consumption and the mitigation of carbon emissions. The United Kingdom (UK), for example, addresses smart homes in the context of climate change commitments (UK Government, 2008), the need to upgrade the energy system (Committee on Climate Change, 2008) and the economic challenges and opportunities of new technologies. The Government’s Smart Systems and Flexibility Plan (Ofgem, 2017) addresses smart homes and other technologies, and informs both the Industrial Strategy (BEIS, 2017a) and the Clean Growth Strategy (BEIS, 2017b). The document notes that the current energy system was not designed with new, smart technologies in mind, and seeks ways to remove barriers to smart technology and enable smart homes and businesses. It also highlights fundamental changes to energy markets, and new market opportunities such as reducing energy costs and facilitate means for firms to develop smart appliances and gadgets. The UK’s Industrial Strategy (2017a) examines the energy revolution and smart systems, with an explicit policy to boost the UK’s digital infrastructure “with over £1bn of public investment (pg. 73)”. The Clean Growth plan refers to smart systems as part of low-carbon growth, and lists government investments in clean technology research design and development (RD&D), including £265 million for smart systems and £184 million in homes (including heat and energy efficiency) (BEIS, 2017a). The Smart Systems and Flexibility Plan Progress Report, more explicitly, discusses removing barriers to smart technologies and enabling smart homes and businesses, while maintaining high standards and protecting consumers (Ofgem, 2018).

At the European Union (EU) level, the ‘Smart’ initiatives seem to be in two groupings: 1. smart meters and smart grids, and 2. smart cities and communities. The first, seeks to automatically monitor energy flows whilst helping to make distribution grids more flexible and to cope with variable renewable energy sources and new loads (European Commission, 2016). The second seeks, with digital and telecommunication technologies, to improve services such as transport, water supply and security. It asserts that information and communication technologies (ICT) could help meet the needs (e.g. mobility and medication) of the ageing population (European Commission, 2018). In addition, there is support for the ‘internet of things’ (IoT) and a single digital market (EC, 2015; e.g., EC, 2017). The European Commission even built the Smart Grids Task Force (SGTF) in 2009 (Smart Grids Task Force, 2011). The SGTF Mission statement mostly applies to the supply side; however, it includes smart meters in the plans for modernisation of European Grids.

Moreover, within the smart meter literature, there is a focus on empowering consumers, which suggests there might be benefits to consumers from smart meters and grids, such as greater control over their consumption and provision of real time information (European Commission, 2015b). While smart homes are not explicitly discussed in all documents, there seems to be a similar drive as in the UK, with smart meters and grids, alongside smart appliances, allowing an effective demand side response and “full participation of consumers in the market” (Bertoldi and Serrenho, 2017), meaning, among other things, that there is a possibility to produce, store and sell one’s own electricity.

In this paper, we approach the smart home technology discussion from the perspective of policy implications and market applications and business models. We see the market and business dimensions of smart homes as critical to policy, and vice versa. Emerging business models relating to smart homes can require shifts in the policies regulating and governing technical deployment, for an array of reasons including energy efficiency, support for

potentially beneficial new innovations, and consumer protection and privacy. Conversely, the evolution of national and regional policies towards deeper rates of decarbonisation or energy efficiency can necessitate, and even stimulate, changes in smart technologies. It is at this nexus between business models and policy that the paper seeks to address, unpack, and explore.

Drawing from a rich empirical dataset consisting of a literature review and semi-structured research interviews with experts, we ask: How are smart home technologies conceived and defined? What applications do they have? And, critically, what business models can capture value and propel technical development? Although we draw from empirical data collected in the United Kingdom, we place our findings in the context of Europe because the UK has access to European markets for smart home technologies and platforms. The article first discusses emerging definitions, conceptualizations, and applications for smart home services. It then examines findings from our literature review, focusing on tangible benefits as well as emerging barriers. It lastly identifies fifteen separate business models for achieving smart home development. It concludes with implications for policy and future research.

2 Literature review: Energy sustainability and the business implications of smart home technologies

This section of the paper draws from various bodies of academic and policy literature to define and conceptualize smart home technologies, discuss energy and sustainability related benefits and risks; and examine possible business model dimensions to the technologies.

2.1 Definitions and applications

A recent review of smart homes literature from a user perspective (Marikyan et al., 2019) considers different definitions and characteristics of smart homes from different sources. Their review, which focused on academic literature (articles and book chapters), found that most

scholars referred to technological attributes in defining smart homes. For example, building on several previous papers, Balta-Ozkan et al. (2013) offer this definition:

A smart home is a residence equipped with a high-tech network, linking sensors and domestic devices, appliances, and features that can be remotely monitored, accessed or controlled, and provide services that respond to the needs of its inhabitants. (p. 364)

Others focus on the systemic nature of the home, highlighting integration or cooperation of different elements such as this upfront definition – notice how the home is an ‘it’ which responds as a single entity.

A smart home is a home-like environment that possesses ambient intelligence and automatic control, which allow it to respond to the behavior of residents and provide them with various facilities. (De Silva et al., 2012)

Marikyan et al. (2019) further found that some studies defined smart home technologies through the services they provided – managing energy systems and improving users’ comfort, or emphasising the healthcare context for ageing population, enabling independent living. Overall, Marikyan et al. (2019) suggest three characteristics in common in the definitions they found: 1. technology, 2. services and 3. the ability to satisfy users’ needs.

Definitions emerging from the private sector, e.g., consultancies and the ICT sector, and even groups such as the think tank Green Alliance (Green Alliance, 2007) have less of a focus on users’ needs. For example, a market analysis consultancy emphasises communication and home ‘solutions’:

Smart homes and home automation are ambiguous terms used in reference to a wide range of solutions for controlling, monitoring and automating functions in the home. Berg Insight’s definition of a smart home system requires that it has a smartphone app

or a web portal as a user interface. Devices that only can be controlled with switches, timers, sensors and remote controls are thus not included in the scope of this study.

(Berg Insight, 2018)

Another definition from the private sector also emphasises information and control:

Smart Buildings can be described as a confluence between architecture, urban planning and ICT. The principle components of Smart Buildings are automation systems, sensors, integration into Smart Grids via smart meters, energy use analytics, forecasting and the better detection of faults through the use of monitoring technologies. For instance, data collected via smart meters and other smart home solutions can be communicated to users via their smart device, allowing users to monitor their energy use, control building functions such as lighting, cooling or heating, and detect faults or abnormalities early – all remotely. These solutions could be applied to large commercial and industrial complexes or smaller homes and condominiums, helping to drive the more efficient use of resources and energy. (Accenture Strategy, 2015)

Consequently, the number of smart homes already in existence depends on how these are defined. Market Analysts Berg Insight (Berg Insight, 2018) estimate that at the end of 2017 there were 22.5 million smart homes in the EU28+2ⁱ, or 9.9% of European households. They forecast a growth of ~30% a year, or 84 million smart homes by 2022. The UK, France and Germany are leading the European smart technologies market (Sforza, 2019). In this sense, to have a better understanding of smart home technologies been deployed already, policies aimed at supporting a shift to a smart energy system rather than individual smart home technologies, would benefit from a standardised definition. Allowing, in turn, for a consistent estimate of the number of smart home technologies in the market.

ⁱ The 28 EU countries (when the UK was still a member) plus Norway and Switzerland

2.2 Benefits and barriers

Smart homes have a variety of potential benefits – some of which are unproven expectations. A recent review (Marikyan et al., 2019) distinguishes between papers that analyse the *potential* benefits of smart technologies, and studies that revise users' *perceived* benefits of smart technologies. They group benefits in four categories: 1. health-related, 2. environmental, 3. financial, and 4. psychological (i.e., wellbeing and social inclusion), and find the largest number of papers discuss health benefits.

Marikyan et al. (2019) list a number of papers suggesting energy and emission savings through monitoring, consultancy, management & optimisation and controlling consumption patterns. However, actual effects on energy use and greenhouse gas emissions are complex and not forgone conclusions. There is a fear that increasing data and the 'internet of things' could greatly increase global electricity usage (Vidal, 2017). The IEA (2017) acknowledges that although these technologies could improve energy efficiency, some could also induce rebounds effects that increase overall energy use. Particularly, those outside the energy sector, such as e-commerce and e-services, could enhance convenience, which ultimately leads to encourage consumers to greater use of these services. In contrast, other reports suggest great energy savings and enable large emissions reductions, significantly more than offsetting the growing direct energy usage of ICT (Accenture Strategy, 2015). The Accenture report, which was produced for Global e-Sustainability Initiative (GeSI) – a global ICT industry association, estimates that ICT avoided emissions are equivalent to 9.7 times the ICT sector's "emissions footprint". Finally, Hittinger and Jaramillo's study (2019), conclude that although there is no clear evidence to the increased energy used to power IoT devices, IoT is likely to result in a net reduction in energy used to provide fixed level services.

Questions about energy savings are apparent in recent reviews of smart meters being rolled out in the UK. These suggest that household reduction in energy consumption and energy bills could be considerably less than anticipated by government, with energy savings averaging 1–3%, as opposed to the projected 5–15%, and bill reductions as low as £11 a year (Patel, 2018; Sovacool et al., 2017). Centre on Innovation and Energy Demand (CIED) research on the socio-technical challenges facing the smart meter roll out addresses questions of consumer resistance and ambivalence, expectations under changing policy goals, and suggests small ($\leq 3\%$) energy savings (Hielscher and Kivimaa, 2018; Sovacool et al., 2017). Similarly, energy savings from ‘smart thermostats’ have been revised down by Tirado Herrero et al. (2018) and the Behavioural Insights Team (2017) found evidence of around 5.8 % savings in household gas consumption, this equates to savings of £25 per year for medium houses and between £35–40 per year for larger houses.

Much of the research on smart technology has as many questions as answers about energy savings, and highlights current hype and inconsistencies, e.g., a recent review of ICT usage revealed significant differences in estimated energy savings, giving both positive and negative numbers (Horner et al., 2016). Lunde et al. (2016) found that the smart grid hype “embodies several implicit expectations that serve to guide research and investment and to attract new players into the field”, they suggest a scenario process that can articulate such implicit assumptions – a process based on developing probable futures, analysing conditions for realising specific visions, and including a large number of participant institutions in the process.

The Low Carbon Innovation Coordination Group (LCICG) (2016) suggest there is potential for large savings to domestic energy use from innovations including smart technologies and systems, but *“Note also that these savings are reliant on energy performance improvements due to smart systems occurring as well as expected. More research into the*

effects of such systems is needed, as the interactions between householders and such systems are complex and not yet fully understood.” Energy savings are also predicted as remotely accessible apps and displays raise users’ awareness of their energy consumption and allow a response from a distance and real-time notifications. In addition, data analytics allow urban planners, utility companies and architects to understand demand patterns for better planning and maintenance (Accenture Strategy, 2015).

In this sense, from an energy policy perspective, we emphasise that it cannot be assumed that ICT and smart systems will reduce energy consumption. We, however, suggest that flexible and adaptable regulation, based on continued research and in interaction with energy businesses, is needed to achieve smart home technologies’ promise to facilitate a low-carbon transition path.

2.3 Business models

The transition towards smart homes entails a collective and perhaps potentially profound reformulation of urban structures, strategies, ecosystems and technologies. In other words, this transition may fundamentally challenge long-established business models around homes and the value they offer, as well as unlock new business models (Schiavone et al., 2019). Some scholars consider business models as a mean to create and deliver value to customers and thus to the organization (Demil and Lecocq, 2010; Teece, 2010). Others, however, such as Magretta (2002) perceive them as a value chain divided in two parts. The first, captures all activities associated with creating the product (e.g. purchasing raw materials and manufacturing). The second, includes all activities related to selling the product (e.g. reaching customers and delivering a service). Lewis, (1999) on the other hand, approaches business models from a more simplistic perspective and regards them as a “term of art” on how manufacturers generate capital and thus profits. Based on these views, we agree with Kavadias and colleagues (2016),

when they refer to business models as a system whose various features interact, by different and complex means, to determine a given venture, technology, or company's success. However, different to traditional approaches, successful platform-based business models share, at least, three of the following elements in common: they are open, connected and scalable (Guillen and Reddy, 2019).

It is here that smart homes business models may differ from more conventional ones. Schiavone and colleagues (2019) use the term “smartization” to assess the broad canvas of activities that smart technology may entail, those that can affect not only the role of partners and ecosystems in urban value creation and its entrepreneurship mood (Aljēna, 2015) but also individual benefits and shared goals. This framework takes on more relevance when others have used it to analyse smart cities. For instance, Diaz-Diaz et al., (2017) focuses on four blocks of the model (customers, offers, infrastructure and financial viability) to reveal that IoT devices generate value by cutting costs in the long term. Indeed, research in IoT-enabled business models has also been explored by others such as Dijkman et al., (2015) and Kralewsky (2016) who based their work on the elements of Osterwalder and Pigneur's framework (2010).

Also operating in this space, Suppatvech et al., (2019) employs a different method, a “servitized” approach that classifies emergent business models utilising IoT and reports on a wide range of applications. These may include *subscriptions*, where customers are charged for unlimited access to the product service and *pay-per-use*, where customers are only charged for the usage off the product or service. Based on this, Suppatvech et al., (2019) work from the premise that servitized business models operate, again, at two levels. First, the operational level, that is, the functionalities of smart devices used in offering services. And second, a strategic level, where devices are classified according to their use. In this sense, smart home technologies offer additional services to the existing product or service. In turn, firms can gain additional revenue from providing such services (Dijkman et al., 2015; Kralewsky, 2016;

Rachinger et al., 2019) and “*generate income more steadily as long-term contract replaces sales*” (Suppatvech et al., 2019)” .

However, even when tapping into these levels and layers of smart business models, industries may still encounter barriers. As identified by the World Bank (2017), for business models to thrive, infrastructure must exist and be reliable. Specifically, the lack of consistent standards ruling smart connected products networks such as low-power wide-area could dampen large-scale investments. The same report indicates that lack of market readiness represents one of the biggest barriers. Certainly, the government needs to prescribe the market through further regulations and policies since these aspects have not been defined yet. In this sense, the Organization for Economic Co-operation and Development (OECD) (2016) argues that the risk is not sufficiently reduced or defined for business to act. In this way, although for internet giants such as Google and Amazon, using consumers data to drive revenues is at the core of their business models, data ownership remains fragmented and no business model have yet emerged with respect to monetization of data (McKinsey Global Institute, 2015; World Bank, 2017) . We will return to these aspects of business model innovation again in Section 6, the Conclusion.

3 Research methods

Our empirical method of data collection for the study was qualitative semi-structured expert interviews, supplemented with the review of the recent academic and industry literature presented above in Section 2.

We employed expert interviews as this approach allows for an in-depth exploration of pertinent processes including but not limited to policies and political issues (Beamer, 2011; Dexter, 1969). In turn, this offers a richer but cost-effective means to generate unique data to analyse the complexities of markets, policies and politics (Galvin, 2015). Qualitative research

interviews have been extensively used both in this journal (Dapeng and Weiwei, 2009; Earl and Fell, 2019; Goldblatt et al., 2005; Noel et al., 2020) and the broader energy social science community as an established method of collecting data (Sovacool et al., 2018). Moreover, rather than providing numbers, percentages or magnitude of relevant factors, our qualitative data analysis provides context and insights about the current options of smart home technologies available in the UK and Europe. Qualitative expert interviews were employed to fit the dual aims of this study, namely 1. To gain a more comprehensive view about what smart home technologies are and 2. To assess promising business models for these technologies in the UK and Europe.

The first and second authors conducted 31 semi-structured qualitative expert interviews from November 2018 to February 2019. In this research, we agree with Otto-Banaszak et al., (2011) that experts are persons responsible for the development and implementation of solutions, strategies and/or policies. Experts thus have privileged access to information and possess a high level of aggregated and specific knowledge that is otherwise difficult to access. Our sampling strategy was purposive, and included experts from six different types of institutions:

1. Government, including national ministries such as the Department for Business, Energy & Industrial Strategy (BEIS) and Ofgem as well as local government such as Bristol City Council;
2. Academic institutions such as the University of East Anglia, Oxford University, Loughborough, and Nottingham;
3. Private sector firms including energy suppliers such as Engie and NPower as well as software and technology companies such as Amazon and Microsoft;
4. Civil society and independent research institutes such as Citizens Advice, the Green Alliance, Energy Systems Catapult, and Price Waterhouse Coopers;

5. Industry and trade groups such as Smart Energy GB and the Alliance for Decentralized Energy;
6. Intergovernmental organizations such as the European Commission and the International Energy Agency (IEA)

This study focused broadly on the commercial availability and viability of smart home technologies within Europe. The majority of interviews were undertaken in the UK, as 1. The UK is reflective of the European market (Berg Insight, 2018) and 2. A representative number of European services and technologies are available here (BEIS, 2017a; Berg Insight, 2018). The research interviews generally lasted between thirty and ninety minutes, and participants were asked several questions, including:

- How does one define SHTs? What are they?
- What technologies or options for SHTs are available here in the UK and Europe?
- What business models have the most promise at capturing benefits?

All interviews were treated as anonymous to encourage candour and protect respondents, and each was given a respondent number (e.g., R2 for respondent 2). Most interviews were recorded so that transcriptions and statements could be checked for accuracy. After collection of the interview data, each interview was subsequently fully transcribed, and then coded. Our coding scheme to identify market and business model applications was exhaustive and inductive, meaning we coded every response and then analysed the full sample inductively.

To supplement our interview data, and also to better situate it within the body of growing research, we lastly conducted an interdisciplinary literature review of smart home technologies studies published in reports, academic articles, and industry assessments. We searched for studies on “smart homes,” “smart home technologies,” “smart home services,” “smart

buildings,” and “automated homes.” The resulting corpus of studies is cited throughout this article to help situate our findings within the literature.

4 Results: Business models for achieving smart homes

Our own empirical data support what the literature suggested in section 2.1; a broad plurality of definitions of what smart home technologies are or what can accomplish. However, we raise concerns that a missing definition of what smart home technologies are allows regulation gaps (e.g. in terms of waste of electrical and electronic equipment). Appendix A, for example, shows all 31 definitions offered by respondents, none of which is the same. However, we found that such definitions did revolve around four key components: smart homes are digitally connected, enhance household control, attempt to reach higher levels of automation, and promote learning (either by households or technology). 19 of our expert respondents suggested that digital connectivity was a key component of SHTs; 12 mentioned automation; 10 mentioned control; and 9 mentioned learning.

For instance, R2 suggested that *“SHTs are a diverse constellation of technologies which provide households with greater controllability over a variety of domestic systems, processes and services. This can range from heating and lighting to electricity use and appliances, to security, safety, and so forth.”* R6 elaborated that they distinguished *“two fundamental categories of types.”* One was *“switching and sensing what used to be the province of human beings in the home getting delegated to the technology.”* The other was *“connectivity, how smart technology changes the boundaries of the home by bringing it more obviously into the IT and electricity system.”*

Our empirical data from the interviews recognized the complexity of possible smart home benefits and costs, as well as the duality or plurality of potential applications. R14 mentioned this “complexity of benefits” in the following manner:

One can of course categorize different types of benefits, things like efficiency, doing more with less, or creating light, or enhancing and improving user experiences, to the assisted living and health and wellness aspects. Other benefits can be about convenience, or connecting you to people who you love, or even extending your health and lifespan. To some people, the benefits of adoption relate most to aesthetics, to people being drawn to beautifully designed or new things, or to show they are ahead of the curve. These are all the complex reasons and motivations influencing adoption, and they defy any single logic or rationale.

By contrast, R2 commented more about different phases of smart home development, moving from smart appliances to energy management to more automation and controllability. As they remarked:

I think about smart homes in terms of phases, or three successional waves of product being pitched to consumers. The first phase, emerging as early as the 1990s, were smarter kits focused on entertainment, such as stereos or DVD programming. A second phase emerges a decade later, in the 2000s, where systems start to offer improved home energy management. The value proposition pitched to consumers is that smart kit can save them money. Most recently, another decade later, starting around 2015, you see this third wave focused on automation, hyper-convenience and controllability, hence the interest in linking voice control. This third wave is all about making life easier, more fun, or more interesting.

Given that smart homes do not follow a prescribed standard model, and also that they have developed across different phases, it may come as no surprise that our empirical material led to an abundance of business opportunities or models, which we define as the ability for a business to capture value from. As Table 1 summarizes, our fifteen business models are presented here, ordered by the frequency by which they arose across our expert interviews.

Table 1: Smart home technology business models mentioned by expert participants (N=31)

Rank	Frequency by interviews		Business model
1	19	61.3%	Energy services provision (electricity, heat)
2	14	45.2%	Household data and surveillance capitalism
3	9	29.0%	Bundling and integration of services
3	9	29.0%	Subscription models and digital platforms (e.g., Netflix, AirBnB)
4	7	22.6%	Health care
4	7	22.6%	Convenience or accessibility
5	6	19.4%	Demand response
5	6	19.4%	Security and safety
6	5	16.1%	Capturing savings (economic, energy, time, emissions)
6	5	16.1%	‘Prosuming’, peer-to-peer trading and/or Blockchain
7	4	12.9%	Mobility, Electric Vehicles (EVs), and Vehicle-to-Grid (V2G)
7	4	12.9%	New advertising channels
8	3	9.7%	Pay as you go
9	2	6.5%	Coupling with retrofits
9	2	6.5%	Insurance models

Source: Authors

4.1 Energy services provision (electricity, heat) or monitoring

Significantly, the most frequently mentioned business model application for smart homes were those related to energy management, energy services provision, or energy monitoring. Hargraves and Wilson (2017) assert in their assessment of smart home users how Rheinisch-Westfälische Elektrizitätswerke (RWE) had a commercially available monitoring and control system for space heating. British Gas had the Hive that allowed users to set different heating

and hot water schedules. Vera's Z-Wave offered real-time feedback on electricity use as well as electric appliances using smart plugs (Fell et al. 2017).

R13 mentioned that *"the idea of energy as a service is probably something where companies will be interested in and is very simple for consumers. I can easily see people engaging. I mean people know what they are buying: they are buying 21 degrees for three hours this evening. To me, this is as a quite viable business model."* R14 underscored that "energy is the gateway into the home" insofar as once energy systems become familiar to households, they are likely to be more willing to consider other smart home offers:

It will be smart energy services that potentially unlocks and enables so many other business models. The core is that the consumer is able to say what they want, choose an outcome or a range of options, and the service provider can charge them for that outcome or service. Unless you have that ability for the consumer to specify the outcome and the supplier to specify and put a price on it, it is very difficult to lead to other business models. So the core energy service model is the most important, whether it's cascading to mobility as a service, or heat, or retrofitting the home. Energy is the enabling factor or the other business models, for the private sector to understand consumer expectations and also get consumers familiar with smart home technologies products.

Energy monitoring, through the use of smart meters, was a recurrent theme. The results from Hargreaves et al. (2013), Pereira et al. (2012) and Ueno et al. (2006) demonstrate that energy users start paying less attention to feedback and the interaction between user and device decreases over time. This was also a concern identified through our participants' experience. To that, R18 commented: *"the work that we have done with smart meters, is that a lot of the energy consumption reductions come immediately, so it is like you get your smart meter, you get your In-home display unit, maybe you are surprised by one or two appliances that use energy and you change your habits and you get some reduction immediately. However, the*

worry there is that behaviour decays over time. But there are other appliances like with Nest, that you might expect to get better over time due to its algorithm”.

4.2 Household data and surveillance capitalism

The second most mentioned business model relates not to energy services, but data and even “surveillance capitalism,” as it is argued that data driven optimization is at heart of the digital society, generating revenue or capturing value from individuals’ behaviours, habits and household data (Sandys et al., 2017). R20 pinpointed: *“My observation is that the companies that are pushing smart home technologies the most effectively, are so called platforms companies. Which a hundred years ago we would have called monopolies, their business model is surveillance capitalism.”* R22 added that *“the real value we are dealing with right here is information; is the data. So, we might move away from the business model where we are selling energy, to a little bit closer on how a lot of services online are now working. Where we are getting Facebook and all of that supposedly for free but paying with our data. And if the short-run marginal cost if we want to get technical of energy keep going down, it might make sense to allow people to get energy and just collect the data.”*

One element of this business model is related to moving beyond households to collecting data on actual people through “smart clothing” and accessories such as smart watches or jewellery. Figure 1 shows an array of such “smart clothing” for sale at a retailer shop in London.

Figure 1: Smart clothing and accessories for sale in London, January 2019

Source: Authors

Data is a key element surrounding SHTs, thus, if unethical data practices and privacy concerns are not addressed, this could retard or even impede the uptake of potentially data-based solutions, including those related with smart energy services (Véliz and Grunewald, 2018; Wilson et al., 2015). Hence, as the use of data could enhance the benefits of smart home technologies – the more data users ‘give away’ the better the services they will get – it could entail a barrier or a risk, both to personal privacy and falling foul of regulations such as the European Union’s Data Protection Regulation (GDPR)ⁱⁱ, if not regulated properly.

ⁱⁱ Regulation (EU) 2016/679 protection of natural persons with regard to the processing of personal data and the free movement of such data

4.3 Bundling and integration of services

A third business model focused on how smart technology can bundle or integrate previously disparate services or products. Sandys et al., (2017) showed that local authorities are already implementing this approach by delivering bundled service offers with integrated energy supply built into new housing, with balancing and distributed energy resources included in rental agreements. R8 explained bundled services on its own experience as follows:

The Smart home does not sit nicely into a particular market and different markets have different business models that are dominant. If you are a mobile phone operator, then you come into the home with broadband. My mom has a BT broadband, so she has a BT television smart box. In my family we all have iPhone, so it made sense to have Apple TV and Apple products. Those with Google will go with that line of products, such as Nest. You can see packages and services coming together. They are all competing business models, converging on the house.

R12 added that “*I see whole home solutions as the most attractive business case, as they can bundle or integrate solar photovoltaic with say smart appliances, home energy management systems, batteries/storage and electric vehicles. Firms can work on offering more efficient, independent, controllable homes with a bundle of technologies.*” R30 concurred as well, stating that “*the most successful business models would be those that offer a package of things, like Virgin Media that offers, internet, telephone and TV. But maybe, in the future, a particular company might offer certain elements of security and health too. So maybe we should look at what business models could be integrate it and definitely at a cheaper rate than the current ones.*” If these projections become true, they also illustrate the power that incumbent technology firms will have in supplying homes a suite of options, perhaps even making them dependent on home energy services from a single provider.

There are also risks of data and monopoly of services in the digital arena of bundled services. The tech giants (Amazon, Google and Apple) are expanding their influence on non-platform companies, by integrating other services within the smart homes market. For example, Amazon bought Whole Food's Market, and security camera maker, Ring (Stone, 2018). On the other hand, we have Google Nest, deploying an array of bundled smart home devices, ranging from thermostats, to security cameras. Google is even developing Wymo - self-driving cars. Energy providers such as Centrica, through Hive, are building their own smart homes, by also offering security sensors, thermostats, plugs and hubs. Consequently, we can see an oligopoly where despite the intentions of GDPR, where firms cannot lock out competition, we can see few companies fixing prices and limiting the ability from consumers to switch from one ecosystem to another.

4.4 Subscription models and digital platforms

Another collection of business model relates not to technology in the home, such as BT broadband or kits from Amazon, but the facilitation of digital platforms that often rely on subscription models for access. A report by OECD (2018) highlighted the potential of a subscription model as it enables the possibility to pay for the hardware costs upfront, or alternatively, to stagger them so they cover the duration of the contract as part of the subscription. This model also provides consumers the do-it-yourself option, where if consumers want enhanced services, they can pay a subscription to the manufacturer to obtain additional functionality (ibid). Similar to the OECD findings, R21 remarked that:

We have studied this a lot and the most promising is a platform or subscription base model. Because, if it is about having a product, people buy the hardware and they feel like they own it. A subscription-based model is the one that continues to make sure that

people can use it, it takes care of all of the updating, maintenance, security, and data management for you. You pay for the service, not the technology.

R24 clarified that the business model that could be “*the most useful for consumers*” was one that simply relies on a “*subscription to get smart features, stuff like geolocation and the algorithm learning of your plans. To me, that it is kind of the way we should go to, because you, as a customer, will have a direct service. I think Nest and Hive will have to do it as well and they have to bring a new revenue stream.*” Such models could be similar to the energy as a service or mobility as a service markets where users pay not for hardware or technology but a particular desired service (Nolden et al. 2016; Nolden and Sorrell 2016; Axsen and Sovacool 2019; Sovacool et al. 2019).

4.5 Health care and assisted living

A fifth business model centred on improved health care services and assisted living. As noted by the OECD (2018), this model goes beyond household electronics and extends to household objects that traditionally have never been digitally or electronically connected, such as smart mattresses that can track your sleep, heart rate and respiratory rate. Or smart toilets, for which R11 mentioned: “*there are companies putting sensors in toilets to track how many times toilets are flushed and with that data, evaluate users’ healthy habits. Some may even track hormones, if users smoke, drink alcohol, or have high blood sugar, offering such information and health profiles to insurance companies.*” Then, R11 added on health care “*home care is an extremely viable business model ... because if you look at the demographics among western countries, and countries like the UK, our care services are not in great condition. The budgets of our health service are stretching all the time, you can see a significant growth market on finding ways to ensure that people can be cared through their homes just because is the most economical way to manage elderly care.*” R28 added that “in

terms of health, smart health devices would not only provide benefits to the consumer but would also reduce the loads on the public services.” R31 concurred and stated that “in health care you can see some of the biggest personal and national benefits in smart technology. Since we have a lot of problems with an aging population... You can also tell if people are heating their homes properly and make sure of that. Which eventually, can lead to help saving the National Health Service a lot of money. These technologies can also let you know if elderly people are actually using energy or not, how often they use the kettle and if you spot something wrong, you can phone your mama to see that everything is alright.” Figure 2 shows some monitoring devices available in the UK. Indeed, Fell et al. (2017) conducted a review of the smart systems available for health care in the UK and documented many services using smart plugs or monitoring to raise alerts if when occupants deviate from normal or expected patterns.

Figure 2: Health monitoring smart home watches and phones for sale in the UK, 2019

Source: Authors

4.6 Convenience or accessibility

This business model focuses on two key elements of what we found to comprise “smart”: control and automation through a range of in-home technologies that allow users to control on site or remotely.

For example, learning algorithms can allow smart technologies to automate certain household chores, which could ultimately result in enhanced convenience to users. As Apple displays on its Home App’s website (Apple, 2019) *“Your home at your command...control your house from just about anywhere...put your home on autopilot...and you’re done”*. In this sense, convenience through automation can take many forms. R20 illustrated that: *“you’ve got people trying to sell the robot vacuum cleaner model because who the hell wants to vacuum. So the robot does it for you...although, God knows how they are regulated from the energy perspective”*. Furthermore, R5 explained that *“there is a large market for technologies or applications about making homes more useful or simpler with the technology they have ... This business model is not about smart home technologies are necessarily new but enabling things that we already have but in a smarter way, convincing people that you could do it anyway but now better and easier. It is about putting everything together in one thing and in a way that is fun to use.”*

Others discussed elements of convenience that enhanced accessibility or fit into pre-existing norms and routines. R18 reflected that these business models *“ask very little from the consumer in terms of how active they need to be, they don’t require changes in behaviour, they just make existing behaviour more effortless or easier.”* R9 added there were a whole class of consumers wanting to *“be able to control the home better ... When users buy an Amazon Echo it’s not a radical revolution in the home, they are merely enhancing another form of*

convenience.” R21 agreed when they said “people buy these devices is because they seek convenience. They are essentially buying convenience, so they can control their homes, check and have access to their homes when they are away or travelling at any time. If they forget something, they do not need to be at home to do something, they can do it remotely, which is why convenience is the main thing.”

Certainly, much of the smart home technologies narrative is around convenience. However, as indicated by Strengers and Nicholls (2017) the use of smart home technologies could entail new forms of household labour, given that many of these technologies involves programming, updating technology and customisation: activities which could be viewed as essential labours or everyday chores, such as washing the dishes or doing laundry (Strengers and Nicholls, 2017). This duality was well expressed in R8’s answer, where they explained: *“Convenience is probably what people are looking for, but there is an effort, a cost-benefit relationship, where if you have to put a lot of effort into getting the technology to work for you, then people don’t tend to do it. And then technology is just intended to work for his user. Which is a little bit of a circle really”*.

4.7 Demand response

Demand response stood out as a distinct model for its ability to enable energy suppliers or network operators to manage flows in homes, as opposed to business model 4.1, which lets consumers do it (Parrish et al., 2020). R15 mentioned that *“one business area with much potential is demand response. We are very interested in evidence on take up of smart devices, such as fridges, washing machines, and autonomously controlled appliances. The potential for mutually beneficial savings is real.”* R27 added that *“demand response as a business model takes away risks on the behalf of the consumer and therefore, in order to manage that risk, that where some sort of autonomous controlled of the devices in homes become really attractive,*

because the energy service provider probably would know which kind of services require the least amount of energy inputs, certainly the least demand of high peak priced energy input and therefore, been able to moderate your demand through all the various connected devices. It is the energy suppliers who already have a deep understanding of your energy use and may know how to manage it best.” In the United Kingdom, for example, the Smart Systems and Flexibility Plan update (Ofgem, 2017) highlights the Government’s call for evidence on the Capacity Market and Emissions Performance Standard Review, seeking views on “how new smart technologies, including demand side response, can be facilitated fairly in the Capacity Market” (p. 39). At the European level, smart homes can help in integrating renewables by enabling grids to better match energy demand. According to the IEA (2017), increased storage and demand response could reduce the curtailment of solar photovoltaic (PV) and wind power from 7% to 1.6%. Such an integrated practice could potentially avoid around 30 million tonnes of CO₂ emissions by 2040.

4.8 Security and safety

Other respondents supported the security and safety business aspects of smart homes. This business model goes beyond the traditional security systems as some of them (e.g. Netatmo, Ring and Arlo) use artificial intelligence and machine learning to run their facial recognition software, allowing them, to recognize what represent real threats.

This category is not only limited to security cameras, it also includes smoke alarms, carbon monoxide detectors and water sensors which offer automated control to help mitigate damage. On this, R27 commented: *“We are doing fieldwork and I found some of these technologies a bit creepy. So, video cameras with face recognition that are outside your house. It recognizes how your family looks and only alerts you with strangers. I found a bit creepy just having a camera inside and outside your home which is always watching you.”* Indeed,

this could be “frightening” for two reasons. First, if users can login to devices remotely via their smartphones that means someone else could penetrate users’ home network too. An investigation by the New York Times (Bowles, 2018) revealed that networked home devices have been used as a new pattern of behaviour in domestic abuse to harass, stalk, intimidate and monitor people, where most of the victims were females and the perpetrators were male. And second, the data these devices collect within users’ home, allow manufacturers to have greater insights about users’ preferences, habits and behaviours, allowing them to better target services (Stokel-Walker, 2018).

In contrast, R5 argued that *“Security seems promising ... better being able to deter thefts or break-ins or notify emergency services such as the police or fire stations.”* R21 agreed that *“improving the safety of the home is an alluring business offer.”*

4.9 Capturing economic, time, energy, or emissions savings

This business model was one of the most diffuse, and it related to indirectly capturing value or savings from things like displaced energy consumption, improvements in efficiency, time savings, and avoided emissions. R1 commented that *“smart technologies that automate savings in homes so people can find cheap energy carriers have potential.”* R18 discussed an approach where *“household energy appliances are given away for free, but then companies make money on the energy they save. In the United States, some solar companies operate under this business model where they install solar panels for free and then take a percentage of the money that is generated from the solar panels over the first ten years.”* R27 also elaborated on how smart devices that save time, lower costs, or avoid emissions could offer *“amazing opportunities for new business models.”*

Tying smart systems to saving energy and reducing emissions is a theme that has been discussed for over a decade, with the Green Alliance (2007) linking the Climate Change Act

to smart meters (which the government must ‘get right’) and smart homes more broadly. They recommend using existing (at the time) policy mechanisms –e.g. Home Information Packages building regulations – alongside new ones to encourage smart features. In the context of meeting the UK’s emission targets, the governmental LCICG (2016) highlights how innovations in domestic building operations could potentially save “the most carbon, most quickly, predominantly from the existing building stock”, and highlights economic benefits of energy savings and global market potential of innovative products.

Although, as mentioned in our literature review section by (Hargreaves et al., 2018; IEA, 2017; Strengers and Nicholls, 2017; Tirado Herrero et al., 2018; Vidal, 2017), we need to be careful regarding energy saving in the smart home technologies arena, as real savings are unclear and difficult to assess (Horner et al., 2016). This uncertainty was also addressed by R27 when they stated:

I think Artificial Intelligence will slightly increase the baseload of energy required because it adds an increment on to it, doesn't necessarily increase it in your home; some of the bits will, but it will also increase somewhere else. So, there is obviously these processes algorithms and services that are connected and that a dumb lightbulb obviously doesn't need. So, there is that, I think you are committed to an incremental per device energy usage increase. But then comes the question if with that data you can optimise the system in a better way so everything from learning more about our homes, occupants and energy performance and then run the system in a better way? But do we need all that data to realize the system benefits? So, are you adding an increment because of having everything smart or could you have done it with smart meters only? I think this is a grey area that will certainly come up in the future.

This statement underscores some of the uncertainty and anticipation that arises when trying to calculate future economic or environmental benefits via business models.

4.10 'Prosuming', peer-to-peer trading and blockchain

A tenth business model cuts across active energy production (e.g. 'prosuming'), peer-to-peer trading and/or the possible "making" of Bitcoin or the use of other blockchain technologies. R15 noted the potential for smart homes to lead to "*peer-to-peer trading, new providers of energy services.*" R13 agreed when they noted that "*peer-to-peer trading is probably something that might take-off, because there is quite a lot of investment into domestic renewable energy, like solar and I can easily see something that engages people who are interested already in that area.*" R27 added that "*When looking at segments of electricity and utilities customers, one significant tranche does not trust anyone. When we offered them which business models they would like to have, they answered peer-to-peer because it puts them in control, and you cannot ignore segments of people who will inherently not trust anyone.*" Indeed, a report by Ofgem (2018) mentions the lack of trust from energy consumers to the energy industry. Hence, peer-to-peer could become something beyond a label, since it offers consumers a possibility to know their supplier directly, building potential bonds of trust and transparency between both; consumer and energy producer.

R3 lastly added that "*smart homes could also tie homes truly into the Internet of Things, they could even start using blockchain and making crypto currency.*" In this context, the IEA (2017) stressed that since blockchains are transparent and trustworthy, they could facilitate direct exchange of value between parties, such as peer-to-peer, without the need for a third party intermediary. The IEA (2017) see potential for blockchain to solve vital energy sector challenges, such as but not limited to co-ordination between increasing number of heterogeneous devices, operators in smart grids and automated trading to enable flexibility.

4.11 Mobility, EVs, and V2G

This business model focuses on better integrating and managing mobility or passenger vehicles into homes, something known as “vehicle-to-grid,” “vehicle-to-home,” or “vehicle-grid integration” as found in the literature (Noel et al. 2019). R6 made this point when they said *“the business model for EV charging in a single home application has immense potential. Already car manufacturers selling EVs with smart chargers as part of the package. Seems like a very concrete and obvious business model.”* R11 noted that they have been *“doing a great deal of work on EVs, so households now get the ability charge and manage EVs at home. That is a very significant driver of electricity demand, potentially going forward, good news for our utility guys.”* R8 agreed when they said that *“energy companies are very interested in using surplus energy from homes or the grid to feed into EVs, and then you can put it from your electric vehicle back into the home or trade it to the grid.”*

Sandys et al. (2018) stress how mobility and EVs can create new business dimensions, that require stronger contracts and enhanced consumer protection. R27, illustrated this idea with electric vehicles in a connected home: *“in the future, it is quite possible that you are going to own an EV that it may or may not come with its own energy contract and you might have an electricity supplier and home storage batteries. If the car goes wrong and it’s not charging at the right time or whatever it might be, it shouldn’t matter if you go to Volvo, E-on or Tesla for the battery, one of those should pick it up and say: yes, we will sort it. And they will seamless do that because you are going to need that in the future. This has to be spectacular good in a connected world”.*

Figure 3, for instance, shows an advertisement from Tesla about coupling EVs with sources of home energy storage and renewable energy production.

Figure 3: Tesla advertisement for an EV-solar-powerwall hybrid to “Self Power Your Home”, London, 2018

Source: Authors

4.12 New advertising channels

This business model revolves around the provision of new marketing and advertising messages, rather than energy services or cost savings. R20 mentioned that *“clearly the kind of the big tech business model has nothing to do with the recovering cost out of products. Many business models, like VISIO, are based on monetizing your data and then advertising specific things to you. So, the goal of the business model is to create a revenue stream based on your data and advertising opportunities with seven years of life you keep that TV for.”* R23 added that *“for making money, advertising is obviously a huge business model smart home technology*

facilitates, everyone kind of forgets that in amongst all of their phones, PCs and smart home kits, Google is in the business of selling adverts, that is what they do, they are an advertising company.” R21 noted that even Alexa, the famed Amazon voice activated system, tried to do advertisements for a while, but people reacted negatively to it, so they stopped it. As R21 concluded, *“in this sense, the advertisement revenue model is very volatile.”* Nonetheless, R28 suggested that *“if your business model is advertising, if you build a very cheap robot you can deploy them for free and offset the costs with marketing campaigns.”* Figure 4 already shows multiple digital apps (with the capability to provide advertisements) displayed on the screen of a smart refrigerator. Certainly, this is an area that needs to be better regulated. As other concerns are raised on profiling and how, although GDPR addresses this issue in its Article 22, their scope and limits are open to debate due to the lack of authoritative guidance concerning their interpretation (Privacy International, 2018).

Figure 4: A smart home refrigerator showing multiple popups and apps for Facebook, Twitter, and others

Source: Authors

4.13 Pay as you go

Many homes in both Europe and the United Kingdom do not have contracts or monthly bills for energy services, they instead use “pay as you go.” Some respondents discussed how

smart home technologies could only enhance the availability or effectiveness of pay as you go platforms. R4 stated that *“many interesting business models involve pay as you go... smart homes could combine trends of cutting-edge technology and move away from asset ownership. I think those models become really exciting. People should pay for the service they get rather than wanting to own something, but only pay for the service they use.”* R31 focused more on the ability for pay as you go help destigmatize those in poverty. They remarked that *“smart prepay is brilliant, I use it and it makes absolute sense for people and I think generally speaking, people owning prepay are the ones that gained the most from this rollout of smart meters Smart prepay will completely remove the stigma of being on prepay meter and a lot more people will migrate because it is easier to manage. With pre-pay metering, you are not just handing money to your energy suppliers, you are literally paying for what you use and that is what we should be doing.”*

4.14 Coupling with retrofits

A business model of coupling smart home technologies with the retrofitting of homes came up in some interviews. R12 explained this approach as follows:

Whole home solutions seem attractive, and a business case can be made for integrating solar PV with say smart appliances, home energy management systems, batteries/storage and electric vehicles. Firms can work on offering more efficient, independent, controllable homes as either new builds or retrofits. In fact, retrofits seem like an excellent window of opportunity to install new kits because the home is already accessible to installers.

Balta-Ozkan et al. (2014) picked up on this theme and identified “retrofitting existing homes” as one of the three most promising pathways for smart home development and adoption.

4.15 Insurance models

A final business model was the least frequently mentioned, but it involved one particular sector, insurance, and many aspects above (household data and surveillance capitalism, bundling of services, health, advertising) integrated together. R11 suggested that *“rather than smart heating controls, smart meters, or more efficient appliances, I see the real advantage of smart homes as not getting you to use more or less energy, the real advantage might be in providing this as an insurance product to health care, pharmaceutical companies or some other industry. Those business models have not emerged yet, but you can see a pathway were they are likely to emerge over the upcoming years.”* R23 put it this way:

I know that a lot of insurance companies are getting really into the mix of health and general lifestyle. Which, to be honest, turns out to be a bit sinister because there are reasons to know about it is not always healthful... But an insurance business model would first look more precisely at household data such as what food are you buying, how often you go the gym, if you drink, smoke, or where do you live, that is interesting because probably the street where you live tend to have less healthy people, so you lose points for that. And then you become a customer based on that whether you are a desirable customer or not... And it is actually the smart home that will generate that wealth of data, which allows them to go through everything into machine learning.

Affirming this point, a report conducted by McKinsey (2018) suggests that by 2030, Artificial Intelligence (AI) will inform every major decision an insurance company makes under the basis of shifting the paradigm of “detect and repair” to “predict and prevent”. Thus, this business model may in fact be layered on top of other business models, with perhaps insurance companies coming to purchase other smart home providers or entering into cooperative agreements to share data and pool resources. In fact, we can already start seeing

alliances between smart wearables and insurance companies. Take for example, Vitality and Apple watch. Where policyholders can earn discounts, rewards and gift cards for hitting healthy lifestyles points. In this sense, it is worth questioning if users that do not hit “healthy targets” would that mean that Vitality could thus punish customers failing to meet their targets?

5 Discussion and policy recommendations

Our literature review and interview findings reveal that advancements in smart home technologies are in tandem with rapid changes in energy systems, creating new opportunities and challenges for consumers, energy providers and regulators. However, to meet these promises, this research identified several policy implications that need to be addressed.

Certainly, it is a positive development to have many options available in the smart home products dimension, yet, moving forward with these requires significant capital expenditures and operating expenses investments. For instance, Business Model Mobility, electric vehicles EV and V2G – which might contribute to transport emissions reductions – represent a major challenge for private and public entities. In Europe, the cumulative cost for public charging for the 2020-2025 period is estimated at €12 billion (European Commission, 2019a). At the local level, combined investment and installation costs for charging points (EV connector and connection cable) are €12,000 (San Román et al., 2011).

However, the implications of EV business models are not limited to investment costs, but also challenges for grid infrastructure associated with increases in total electricity and peak demand (Sbordone et al., 2015). If current trends continue, it is expected that most people will charge their vehicles when they arrive home from work, when the grid is already working at or near maximum capacity (Hardy and Morris, 2019). As such, this model of electric transport could have significant impacts on local electricity networks which would affect other business models identified within this research, such as ‘Prosuming’, Peer-to-Peer, Energy as a Service,

Demand Response and Coupling with Retrofits. Where prosumers, if they manage this right, could become the most important value creators within the smart grid (Parag and Sovacool, 2016).

Other policy measures for these business models could be executed through the creation of new markets for flexibility, as indicated, by Hall and colleagues (2020). In their study, they suggest that business models such as “third party control” and energy service companies could have control over electric vehicle charging, flexible heating and smart devices. This, in turn, could facilitate the integration of renewables by enabling grids to better match energy demand.(National Grid, 2018) and allowing long-sought low-carbon business models to prosper.

The next policy relates to data, our second most mentioned business model. Given that digital technologies operate by collecting and communicating data, the biggest material risks for industry and users are determined by cyber and data security (Djankov and Saliola, 2019; International Monetary Fund and World Bank, 2018). Thus, we first suggest that cyber security and privacy measures, be fully integrated into the development of new processes from the start. Further, in order to enhance smart home technologies’ regulations, policies for standardization on data and cyber security should be implemented. We recognize that the EU’s GDPR represents a good start-point for delivering a contemporary legislative regime. Same that sets the legal relationships between institutions and individuals around digital data and retains a ‘household exemption’ clause, which leaves domestic data practices beyond its reach (Goulden, 2019).

However, as noted by Testa and Marelli (2018), this instrument still has several weaknesses, for instance, Recital 159, which given the broad definition of activities that fall under “scientific research” users can unknowingly provide companies with sensitive personal data. Another weakness, as Wachter (2019) indicates, is that GDPR focuses mainly on

protection at input stage, when data is collected, but rarely during or after analysis. Consequently, threats to privacy can arise following data collection owing to inferential analysis. Thus, we suggest that governments and industries prioritise privacy over convenience and make it easier for users to navigate and understand consent forms. Perhaps, governments and industries should make the default for users to opt in if they want to have their data collected. Unfortunately, achieving this will be hard as it would reduce the ability of governments and industries to understand, predict and manipulate our behaviour (Zuboff, 2018).

Indeed, the mere fact of users giving away their data may expose them to constant risks of being hacked, violations of privacy and data misuse. This takes more relevance when there is no agreed-upon regulation about who, for instance, have access to data recorded by smart TVs, black boxes in cars and smart speakers (Brogan, 2020). To prevent such practices and ensure human interests and wellbeing are prioritised, Calvo and team (2020) suggest using Environmental Impact Assessments as a blueprint to procure human-technology interactions. Their framework, which they term the Human Impact Assessment for Technology (HIAT) suggests predicting and evaluating the impact of new digital technologies on individual wellbeing as well as society as a whole. The assessment prioritises individual privacy and autonomy by considering which parties are responsible for managing data and maintaining ethical standards as well as ensuring accountability for whoever is responsible when things go wrong in a connected home. According to Calvo et al., (2020) specific policy measures as these ought to enhance regulatory environments and build trust in smart connected products.

We also call for further regulation on energy use from data collection, transfer and remote processing, given that the entire digital universe is expected to reach 44 zettabytes by 2020 (Desjardins, 2019). This energy use could potentially offset the energy savings offered by smart devices. Cisco expects that global internet traffic will nearly increase threefold in the next five

years for two reasons. First, they estimate that the number of internet users will increase from 3 billion to 4.1 billion in 2020. Second, global internet protocol networks would have to support 26 billion new devices and connections (CISCO, 2018). As a result, data centres would require over 100 TWh of electricity a year by 2020 (Shehabi et al., 2016). Hence, we urge better regulation on data collection since with it, we could address both in terms of privacy and energy use.

Moreover, due to the rise in IoT devices, one study estimates that the market is expected to grow to over \$3 trillion annually by 2026 (Newman, 2019). Our research raises concerns regarding energy and materials use. Given that smart home technologies need to be connected to appliances to deliver optimal services (e.g. thermostats, fridges and security cameras), which consumed roughly 3-5% of the world's electricity in 2015 (Andrae and Edler, 2015), our study indicates that if poorly regulated, this appliances could lead to increased electricity consumption. In fact, some estimate that the global emissions from the information technology sector could surpass aviation and shipping, reaching 14% of the global total carbon emissions by 2040 (Rob van der Meulen, 2017; Vidal, 2017).

Nonetheless, not all studies reach the same conclusions. For instance, Grubler et al., (2018) in their Low Energy Demand (LED) scenario, consider the development of information and innovation, which involves: ICTs, sensors, processors, wireless communications and control functionality in energy-using technologies and daily routines, as a key element for a feasible supply-side decarbonisation within a 1.5°C emission budget. In their work, Grubler and team consider these technologies crucial to reduce energy-demand and achieve the 1.5°C target, without the need to deploy negative emission technologies with significant sustainable development co-benefits (Grubler et al., 2018). Wilson et al., (2012), complements this when they argue that greater efforts from governments and industry are needed to untap the full potential of efficient end-use technology to achieve climate protection.

For efficiency to be improved, energy consumption optimized, and sustainability achieved, however, smart home technologies shall meet sustainability goals and have transformative impacts for achieving reductions on energy demand. As for now, as noted by Sovacool and Furszyfer Del Rio (2020), policies to address this issue appear to be working in silos, rather than integrating a policy framework that not only protects consumers, but also set restrictions to ensure that devices meet climate and energy goals. In this sense, although the EU introduced specific requirements for network connected devices in 2013 (European Commission, 2017b), we suggest that EU eco-design requirements should be modified. Such changes should focus on technologies adopting a smaller ratio than 3 to 12 Watts to meet the target of reducing emissions by at least 40% below 1990 levels by 2030.

Regarding material use, the trend of possible waste and inefficiency seems to escalate as well. McKinsey estimate that the number of IoT connected devices will increase worldwide to 43 billion by 2023 - almost a threefold increase from 2018 (McKinsey, 2019). Certainly, the rapid development of smart home technologies is leading to electrical and electronic equipment becoming one of the fastest growing waste streams, with around 12.3 Mt generated in the EU 2016 and 44.7 Mt worldwide (IMPEL, 2019). Moreover, as noted by Hittinger and Jaramillo (2019), although materialization and efficiency improvements of electronics could lead to a smaller manufacturing footprint, the rapid increase in number of IoT devices being deployed in the market may lead to an overall increase in energy use, not only for material extraction and processing, but also, for component manufacturing. Thus, policy issues surrounding material and energy use and waste streams must be addressed in tandem. We do not want, for example, to ameliorate one environmental concern through the creation of another. Smart devices, such as those that regulate energy consumption, should not have planned obsolescence built into them, but instead, have long lifespans paired with free downloadable software.

Moreover, the successful implementation of these business models holds the promise to promote social inclusion for underserved populations (Djankov and Saliola, 2019). Not only by creating opportunities to reduce energy costs and enabling energy suppliers to offer lower tariffs through better balancing the grid, but also, by narrowing information asymmetry, as digital channels, unlike physical infrastructure, could enable millions of people with mobiles phones to access myriad of services (International Monetary Fund and World Bank, 2018). (Ofgem, 2017) (International Monetary Fund, 2019). As this research has shown, this is not limited to the payment of services (i.e. water and electricity through pay-as-you-go), but also access to insurance, investment and credits (OECD, 2018b).

Certainly, further development of these business models must work in tandem with democratic and socioeconomic objectives, especially those related with tackling exclusion and marginalization. As by 2019, according to International Telecommunications Union (2019), half of the population lacked internet access. To bridge this gap, the Alliance for Affordable Internet (Alliance for Affordable Internet, 2018) suggests governments to reduce costs to no more than 2% of average monthly income for one gigabyte of data. Others suggest to support local digital businesses and to reduce taxes on telecoms equipment (International Telecommunication Union and United Nations Educational Scientific and Cultural Organization, 2019). Poster (2018) suggests, in order to bridge the gender and digital divide, that the implementation of programmes that promote technology, specifically for young women and girls. Such programmes include for instance *girls who code*ⁱⁱⁱ, which aims to increase women in computer science and engineering. Whilst we agree with the previous suggestions, we recognize that connectivity alone is not enough, but also, issues around technological literacy (NCAL, 1999; OECD, 2000) and linguistics through the domination of the English language in software must be addressed (Montaner, 2018). In this sense, policies

ⁱⁱⁱ Further information can be found at: <https://girlswhocode.com/about-us/>

to promote equal educational opportunities and access to hardware and software ought to be implemented in addition to investments in new roles of teachers and learners.

6 Conclusion

This paper has drawn from a rich set of interviews and literature to explore emerging definitions, conceptualizations, business models and policy implications for smart home technologies. Figure 5 encapsulates the collection of business models for smart home technologies along with their revenue streams. As previously explored by (Díaz-Díaz et al., 2017; Dijkman et al., 2015; Kralewsky, 2016; Schiavone et al., 2019; Suppatvech et al., 2019) this diagram depicts the broader canvas of activities that smart technology entails. It shows that these 15 business models tend to cluster around the six thematic areas of data inferences, advertising, brokerage, services, and assets.

Figure 5: Visualizing business models and revenue streams for smart home technologies

a. Top panel: by business model and revenue stream

a. Bottom panel: by theme

Source: Authors

With this in mind, we offer the following six conclusions.

First, the smart home itself represents a bundle of different applications and degrees of smartness, all of which cascade into different business dimensions. Some focus on enhancing the control of users, such as energy services provision, other companies', such as household surveillance or demand response. Some emphasize financial considerations, such as saving money, others feeling good, security and safety, or convenience. Some revolve around the technology itself, the product, others the things the technology does, i.e. saves energy or displaces emissions, still others the options the technology enables, i.e. access to data or new

advertising channels. A coherent definition covering all of these aspects is difficult, but based on the evidence we collected, we offer a comprehensive definition as follows:

Smart home technologies are connected devices that can communicate with each other and react to internal or external signals to enhance the energy services delivered to consumers. Smart home technologies can generate benefits to the greater system, although that system could be local, national or international. These technologies must possess the ability to interpret available data through a learning algorithm that can predict behaviours and recognize those that are unusual to call for users' attention. These devices ought to automatically program themselves and act on predefined routes to provide the services that the user requires. Technologies could be controlled either by users or delegate it to the system and could be controlled in-site or remotely so users can have access to the services delivered by the home regardless of their location.

This definition nicely incorporates differing scales of smart home technology, from the local to the transnational, as well as different forms of control, directly by households or energy suppliers to system operators or third parties remotely.

Second, the set of business models presented in Section 4 have the potential to reshape user experiences by redefining their interaction with systems of energy use and supply. Changes could range from enabling bundling and integration of services, for instance, the sale of electricity, DSR services and V2G charging provided by the same supplier, to local energy projects delivered by community groups, such as peer-to-peer trading and virtual marketplaces. Moreover, smart home technologies can, in some configurations, facilitate the growth of decentralized sources of power, and thereby, offering alternatives to large-scale energy use and supply services (Braunholtz-Speight et al., 2018). Far from impacting only direct energy consumers, a smart homes revolution could reshape the entire electricity sector by enabling power systems to integrate greater shares of variable renewables. In addition, the four key

components of smart home technologies identified in our research (digitally connected, enhanced control, automation, and learning) have the potential to better connect power supply with the top three energy demand sectors, namely: transport, buildings and industry (European Commission, 2019b).

However, our evidence also suggests that although smart home technologies could facilitate the transition to a net-zero carbon economy, issues around data processing, energy and material use could lead to unsustainable patterns of energy consumption, carbon emissions and rebound effects, thus, offsetting in part or whole the energy savings generated from smart devices. In this sense, government policies are crucial to steer developments towards lower energy, resource and emissions pathways. For example, mandatory regulation to enhance energy performance standards, reducing standby losses of networked devices, incentives to build more efficient data transmission networks and running data centres through the most efficient means, could be paramount to achieve a smart home technology pathway that is also compatible with the goals of a low-carbon transition.

Third, given the comprehensiveness and diversity of smart applications, they revolve around and involve a mosaic of very different technology providers and firms. The smart business environment involves the commonly known smart tech providers like Sony, Apple, Yale, and Ring, and software or platform providers like Netflix or Amazon. However, it also involves energy or electricity or heat suppliers, grid operators and distribution network operators, and architects and builders for retrofits. Then you have the involvement of energy service companies or integrated energy service providers, advertising and marketing firms, and insurance companies. Any single type of company or firm does not dominate the business space.

Fourth, our literature review and experts' interviews foresee potential downsides regarding energy rebounds, privacy invasion, misuse of personal information, and hassle to use SHTs

along with interoperability. In contrast, their promise to reduce energy demand, improve the system and ease users' life it is still unclear. We conclude that if we get smart home technologies right, we could achieve the further decarbonisation of electricity and enhance our energy system and services; however, if we get it wrong, this could lead to huge downsides. To avoid this, we suggest further research ought to focus on developing regulatory frameworks addressing sustainability, looking particularly at using smart home technologies to better integrate with and optimize energy systems, and ensuring consumer protection. On sustainability, regulation should focus on ensuring these technologies do not induce energy rebound effects as to date there is no clear evidence as to whether SHT will reduce overall energy demand. Regarding energy systems, we consider smart home technologies come as technically disruptive devices that have the potential to turn the energy market into a more dynamic one, where more players will be involved instead of just a few. Regulation, thus, should focus on how to make this market more open and transparent. Whilst for consumers, research should focus on how to enhance regulation to protect users in a connected home with bundled services and on standards for interoperability to avoid misspent capital. Finally, we need further research on how consumers perceive and use these technologies.

As such, fifth, we need a more sophisticated understanding of how these technologies operate in the real world and if automation, as a result of the interaction between learning algorithms and users' behaviours, have the ability to capture real value. Not only in terms of efficiency, energy savings, comfort or security, but also in generating *real* wealth to societies as a whole. Although the most promising business models were "Energy Services Provision" and "Household Data and Surveillance Capitalism", we believe that the fast development of these technologies and machine learning capacity it is still developing and has not yet delivered --from the consumers' perspective-- a compelling enough device/app that all households will utilise.

Finally, and less obviously, smart home technologies are changing the very meaning of the home and domestic life in subtle but important ways. Many of the business models identified move away from the traditional concept of what the home is, a space for private domestic life. Instead, people can begin to control their home remotely through an app, altering the notion of home occupancy. Many smart home devices try to simulate presence when you are away. Others seek to remotely control some aspects of the home users might feel that indeed they are carrying a part of it when they are not there. Smart home technologies are altering the ability for a house to operate as a social space to receive friends and family, to protect occupants from intrusion, to keep private life private. It is perhaps this lasting mark on the home, and on concepts of private space and domestic practices, where the impact of smart technology will be the most prosaic, but also the most lasting.

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Appendix A: Thirty-One Definitions of Smart Home Technologies

Respondent	Definition
R1	There is a range of different smart devices, but the distinguishing factors that make them smart are system functionality and how their systems communicate and operate.
R2	SHTs are a diverse constellation of technologies which provide households with greater controllability over a variety of domestic systems, processes and services. This can range from heating and lighting to electricity use and appliances, to security, safety, and so forth.
R3	Smart home technologies are intelligent operating systems which allow users to operate different parts of the house, the environment and ambient. With the goal of easing the life of users.
R4	Smart home technologies are eclectic products that are installed at homes through internet or external networks connected. They are everyday objects enabled by smart services that should do more than they could do before.

R5	Smart home technologies are devices that are able to make decisions; thus the smartness. These devices should be able to make those decisions based on users' behaviours, commands and preferences.
R6	I see two categories of smart home technologies. The first, is the smart home with an emphasis on what happens in the home; there are sensors around the place and could be remotely controlled. The key elements in this category are "switching and sensing," with what used to be the province of human beings in the home getting delegated to the technology. The second category, is how smart technology changes the boundaries of the home by bringing the Information Technology (IT) into the electricity system. Here, the key word is "Connectivity" and should provide users with the possibility of changing local network operation as the result of what happens in the home
R7	Smart home technology is any device that helps the user to do certain tasks more efficiently; whether these tasks are related to security, improving the energy efficiency of the house or by adjusting to users' daily routines. So basically, anything that is useful for the user and connected from (IoT).
R8	Smart homes are an extension of an everyday technology. There is an implication that it is digital. If a smart home is digital, then it has the ability to learn and adapt to people and extend the capabilities of people.
R9	Smart home technologies are internet connected technologies which can monitor or control aspects of the home.
R10	Smart home technologies are devices within the home that possess network connectivity. Hence, are able to cooperate through computation to enable things to happen with all the other connected devices in the home.
R11	Smart home technologies are everyday objects and devices that connect to the internet and to each other; not computers, smartphones, or tablets. Smart devices

	often connect to apps on mobile devices, allowing users to control them remotely.
R12	Smart homes should use information and communication technologies to enhance domestic life. In this sense, a truly smart home is the one which uses ICT through the use of interactive settings and feedback on the domestic environment.
R13	Smart home technologies are internet enabled devices that respond to signals. These could range from price signals to DNR signals.
R14	Smart can refer to how we can use the latest technology. Smart could also encompass ways of thinking, techniques and approaches. However, true smart, is about combining humans with technology to perform activities more effectively, about human software and technological hardware
R15	Smart home technologies are digitally enabled devices that provide opportunities to manage energy better. Where the digital component is key. Currently lots of things are called “smart” but are meaningless, it generally means moving from analogue to digital.
R16	Smart home technologies are connected interfaces or appliances within buildings that can be used to improve energy management.
R17	Smart home technologies need to have a learning algorithm through a machine that is connected to the internet and can do things like predictive maintenance or predictive behaviour to better manage cooling and heating within buildings
R18	A product or service that reacts to data either related to the households or external information, such as energy prices.
R19	Products or services that involve connectivity, digitalisation and automation. These could apply to energy use, lightning, electricity or gas.

R20	Smart homes technologies typically require a digital intermediary that is connected to the internet and a set of hardware which is by design insecure and not updatable. What smart homes could do, is to automatically manage your energy and automatically configure itself in order to provide the service that the user wants. Smart homes should use energy and –potentially water-- as efficiently, effectively, flexibly and as simple as possible.
R21	Smart home technologies are devices that automatically recognize the behaviour and changes in the environment based on the use of preferences and act on predefine routes to do something. As a result, users do not need to program them anymore. These technologies’ main goals are to improve the energy utilisation, comfort and safety of the home.
R22	Smart home technology is whatever the company is telling consumers about what it is manufacturing. Hence, it is usually presented as what kit/ technology the manufacturer has in their portfolio. A smart home should give users a lot of energy services, for little energy use
R23	Smart home technologies is anything that is using data above and beyond of what that piece of kit might usually do. Any device that enables that service.
R24	Smart home technologies are everyday domestic objects that are networked to other technologies.
R25	Smart home technologies are devices that improve the energy service delivered to the consumer and/or maintaining whilst delivering a service to the system. There are two different types of smart technologies. One type, assumes virtually no interaction with the consumer and they will only become widespread if are accepted and adopted by consumers. The second type, consists an additional functionality for the user.

R26	Smart home technologies are pieces of kits; whether a hardware or software that allow someone who lives or stays in the home to control features related to energy. Either the user controls it or delegates control to a system. The system could be within the home or it could be a national, regional or an international system where the smart component aims at enhancing the system.
R27	Smart home technologies are connected devices in one form or another that provide a service that uses available data in a new way. The smartness comes from been able to interpret the data available by an algorithm that brings useful elements in one way or another. The “smartness” comes from recognising what is unusual behaviour and behaviour that should brought to the attention of someone.
R28	Smart home technologies are devices that collect data and send it back to the consumers through different channels of communication, could be through a text message, call, voice, emails or displayed on websites. Smart home technologies should also be able to be controlled remotely and provide users with the ability to stay close to the appliances without been physically there. These technologies should also be able to be programmed to provide more comfort to users. I see them as a as a platform of information in which users can be coached whilst delivering better services to the population.
R29	A smart home should allow users to control the energy load in the house by looking at vectors in the following order: heat, motion, lightning and communication. Controlling those in a manner responsive to three elements: the first been commercial signals, essentially energy prices; the second is the ability to deliver the energy requirements to the home in a commercially efficient manner, so it is closely associated to automation; and third, it is responsive not only to commercial signals, but to ambient-environmental signals.

R30	The use of ICT on how we control and manage our homes. The utilisation of ICT by various apps and other technologies to control and manage our homes more intelligently. So it could be linked to energy or not.
R31	Smart home technology is a lifestyle opportunity that enables users to make things simpler and easier whilst improving lifestyles. However, the smartness goes beyond technology, it also entails data services which sit around and are overlooked behind the infrastructure.