Policy mixes for more sustainable smart home technologies

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Policy mixes for more sustainable smart home technologies

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Abstract

Smart home technologies refer to devices that provide some degree of digitally connected, automated, or enhanced services to household occupants. Smart homes have become prominent in recent technology and policy discussions about energy efficiency, climate change, and the sustainability of buildings. Nevertheless, do they truly promote sustainability goals? Based on an extensive original dataset involving expert interviews, supplemented with a review of the literature, this study elaborates on an array of social, technical, political, and environmental risks facing smart home innovation, with clear implications for research, policy, and technology development. Only with a more thoughtful and coordinated mix of policies in place will smart home adoption begin to fulfill some of the sustainability objectives their advocates continually promise.

1. Introduction

Smart home technologies (SHTs) refer to devices and systems of devices that provide digitally connected, or enhanced services to household occupants through the monitoring, management and control of home functions related to energy use, safety and security, health and wellness, entertainment and other aspects of home life that may benefit from automation and control. Popular examples of SHTs include Amazon’s Alexa (which offers voice activation for music or internet searches), Nest’s thermostat (which enables programmable or automated heating), or Ring’s security doorbells (which enable video displays and remote monitoring of who is outside a home).

Market forecasts suggest that the SHT market will grow substantially, and that they could become a defining factor of future energy transitions (Wilson et al 2017). Indeed, Gemserv (2019), an internet security firm, projects that the number of devices connected to the internet will reach 20.4 billion by 2020, and already the global annual market for digitally connected devices and services is estimated at approximately $2 trillion. Frost and Sullivan (2020) more specifically projects that for smart and connected homes the market will grow rapidly, reaching $262 billion by 2025 at a compound annual growth rate of 7.5%. Although this market and growth is dominated by home entertainment, home energy management systems are expected to grow at a compound annual rate of 21.0% until 2025, which demonstrates the rapid evolution of the overall sector (Frost and Sullivan 2020).

Despite the many benefits offered by SHTs, in this study, we critically examine the sustainability risks of SHTs and provide a set of policy recommendations to improve the sustainability of smart home adoption and use. Based on research conducted as part of a project at the Centre for Energy Demand Solutions, we collected primary data from 38 formal, semi-structured research interviews with experts across five different types of institutions in four countries in four different regions (Japan in Asia, United Arab Emirates in the Middle East, the United Kingdom in Europe, and the United States in North America). We supplemented this with an interdisciplinary review of the recent academic and policy literature on smart homes.

Our core contribution is to challenge, contextualize, and contest the idea that SHTs per se will lead to more sustainable and efficient homes. Instead, we call on the need for more comprehensive and progressive policies to achieve sustainability and efficiency and
also tease out implications for future SHT innovation and development. Our intent is to elaborate the important notion that smart technology is not an end in itself but rather a means of exploring and achieving a sustainable future for humanity and nature (Zhang and Shenjing 2020).

2. Smart homes and the contested contours of sustainability

SHTs hold immense promise for making homes more efficient and sustainable but also can embed unsustainable practices and risks (Sovacool and Furzyfer Del Rio 2020) that extend from the household to the city scale (Ahad et al 2020).

For instance, rewards in the form of economic savings are employed under the premise that individuals will engage in sustainable energy behavior with the objective of achieving financial benefits (Penner et al 2005). However, this assumption has been contested and researchers suggest that to achieve long-lasting energy behaviors from either engaged or disengaged energy users, appealing to elements of behavior such as routines, norms, and values achieves greater results (Allcott and Rogers 2014, De Dominicis et al 2019). That is, deeper motivational drivers behind energy use, such as attaining adequate warmth, protecting the environment, or achieving high standards of luxury can all significantly shape the adoption of use of SHTs. Moreover, the smarter homes become, the more complex and interconnected they are, which can create dependences that can erode reliability. For instance, smart devices may simply not work in an electricity blackout or may confuse a cat with a burglar and trigger false security alarms.

Furthermore, SHTs may introduce vulnerabilities and therefore, inefficiencies and waste, especially when they are from different manufacturers or use different functional protocols that lead to a lack of interoperability. Hargreaves and Wilson framed the interoperability challenge in three dimensions: compatibility with non-smart home devices and appliances, compatibility with busy lives and routines, and compatibility with existing support systems (Hargreaves and Wilson 2017). Interoperability becomes especially acute when one ‘inherits’ a bundle of SHTs when moving into, or purchasing, a new house. Thus, interoperability requires not only technologies to work together, but also different SHT manufacturers and operators to ensure that SHTs items can be replaced without disrupting the operational performance of a smart home (Jungwoo et al 2018).

The literature also distinguishes between different types of learning necessary for adoption: practical learning (how to configure and use the technology), cognitive learning (understanding what they can do or be used for), and symbolic learning (incorporating devices into routines and practices) (Hargreaves and Wilson 2017). When any of these forms of learning break down, users can become frustrated and as a result, cease to use SHTs or even misuse or abuse them (Nicholls et al 2020, Strengers and Kennedy 2020).

There is a final risk that increasing data and the ‘internet-of-things’ (IoT) could require a ‘tsunami of data’ and greatly increase global electricity usage from the devices that collect these data as well as from the hardware that runs the algorithms that process these data (Vidal 2017). Strengers and Nicholls (2017) show how the convenience of smart devices could transform everyday practices in ways that increase not only energy consumption, but also household labor for use of the devices while additionally leading to more energy consumption for activities like air conditioning or electricity use in general (Strengers 2013). Tirado Herrero et al (2018) also find that SHTs can reinforce unsustainable energy consumption.

As a result of these concerns, a substantial policy architecture has emerged, especially in the European Union (EU), to regulate smart grids and the smart homes that connect to them (see table 1). However, much of this policy focuses on things like interconnection standards or EV charging, with only a small sample of policies focused on data protection and none explicitly looking at how to make smart homes more sustainable.

3. Research methods

It is precisely this gap of defined and clear policy to increase the sustainability of smart homes that we seek to fill with our study. To do so, we relied on qualitative expert interviews in four countries—Japan, the United Arab Emirates, the United Kingdom, and the United States. Our sampling strategy was designed to include experts from five different types of institutions: government, academic, private sector, civil society, and intergovernmental organizations. In total, we conducted 38 interviews from November 2018 to August 2020 (see table 2). One of the questions we asked in every interview concerned which technology or policy advances are needed to make smart homes more acceptable and sustainable.

4. Policy mixes for more sustainable smart homes

Drawing from our interview material, by far the most strongly suggested policy domains recommended for improvement were consumer protection, privacy, and data security. Indeed, the data protection policy frameworks internationally and in the countries we studied are highly fragmented (see figure 1). The interview responses covered many aspects of SHTs, from data control and restrictions, to encryption, to clear guidelines for ownership of data, to
Table 1. Smart homes supportive technologies legislation and regulations in the EU.

| Policy emphases                  | Interconnection standards | Smart meters | Demand Response and dynamic pricing | Electric vehicles | Data protection and cybersecurity |
|----------------------------------|---------------------------|--------------|-------------------------------------|------------------|-----------------------------------|
| Directive 2001/77/EC             | ✓                         | —            | —                                   | —                | —                                 |
| Directive 2003/54/EC             | ✓                         | —            | ✓                                   | —                | —                                 |
| Green Paper (2005)               | —                         | ✓            | —                                   | —                | —                                 |
| Green Paper (2006)               | ✓                         | —            | —                                   | —                | —                                 |
| Directive 2006/32/EC             | —                         | —            | ✓                                   | —                | —                                 |
| COM (2007) 723 final             | ✓                         | —            | —                                   | —                | —                                 |
| Directive 2009/72/EC             | —                         | ✓            | —                                   | —                | —                                 |
| Conclusions of the European Council of 4 February 2011 | — | ✓ | — | ✓ | — |
| Commission recommendation on preparations for the roll-out of smart metering systems (C/2012/1342) | — | ✓ | — | — | — |
| EC standardization mandate for smart meters (M/441) | — | — | — | — | — |
| EC standardization mandate for electric vehicles (M/468) | — | — | — | ✓ | — |
| EC standardization mandate for smart grids (M/490) | — | ✓ | — | — | — |
| Commission recommendation of October 10, 2014 on the data protection impact assessment template for smart grid and smart metering | — | — | — | ✓ | — |
| Directive 2014/94/EU on the deployment of alternative fuels infrastructure | — | — | — | — | ✓ |
| Commission recommendation (2014/724/EU) on the data protection impact assessment template for smart grid and smart metering system Directive (EU) 2016/1148 concerning measures for a high common level of security of network and information systems across the union | — | — | — | — | ✓ |
| General Data Protection Regulation (EU) 2016/679 | — | — | — | — | ✓ |

Notes. We exclude two general policies: Regulation (EU) No. 347/2013 on guidelines for trans-European energy infrastructure and the 2008 Directive on European Structures (2008/114/EC). Source: Based on Brown et al (2018).

safeguards against hacking and piracy. As UK06 and USA05 respectively commented ‘stronger consumer protection and regulation is a must, regulation to protect consumers is essential’ and ‘if we do not figure out how to secure IoT devices in terms of privacy and data management, the smart homes revolution is destined to fail’. Certainly, the urgency increases when sensitive data based on the private lives of users is shared with third parties and results in discrimination from insurance companies, financial institution or employers (Wachter 2019).

Respondents also suggested the need for stronger regulations for energy services or IoT. Indeed, in order to protect user privacy, the European General Data Protection Regulation (GDPR) constitutes a first good scheme to enhance trustworthiness, to treat users fairly and protect them from harm (Véliz and Grunewald 2018) by making data protection by design and by default a mandatory requirement (Véliz and Grunewald 2018).

In the technical domain and related to trust in SHT manufacturing companies, experts discussed the
need for both innovation and technical learning, as well as the necessity of standards, especially concerning obsolescence (guarantee longer product lifetimes and warranties) and interoperability (between devices as well as technology providers). On the latter, our research indicates that when technology systems communicate with each other, their value increases, which makes interoperability key for maximizing benefits to users and the energy system. On this point, research indicates that interoperability among systems is required to capture 40% of the potential value within the IoT (McKinsey Global Institute 2015, Noura et al 2019). Governments were identified as needing to play an essential role in creating an environment where the smart home sector can both learn what policymakers want and deliver it in ways that protect consumers. This suggestion was followed by setting standards—across a variety of domains, including technology, advertising and marketing. The promotion of required interoperability and upgrades is yet another vital area for governments to address. Hargreaves and Wilson (2017) note that clear national policy guidelines can ensure hardware and software is compatible not only with the home, but also with

| Respondent number | Company/institution | Category | Country |
|-------------------|---------------------|----------|---------|
| JP01              | Ministry of Economy | Government| Japan   |
| JP02              | Rikkyo University   | Academia | Japan   |
| JP03              | University of Tokyo | Academia | Japan   |
| JP04              | Kyushu University   | Academia | Japan   |
| JP05              | Kyoto University    | Academia | Japan   |
| JP06              | Tohoku University   | Academia | Japan   |
| JP07              | Osaka University    | Academia | Japan   |
| JP08              | Panasonic          | Industry | Japan   |
| UAE01             | Smart Navigation System | Industry | UAE     |
| UAE02             | Dubai Regulatory and Supervisory Bureau | Government | UAE     |
| UAE03             | Khalifa University's Emirates ICT Innovation Centre (EBTIC) | Academia | UAE     |
| UAE04             | Boston Consultancy Group | Industry | UAE     |
| UAE05             | Khalifa University's Robotics and Intelligent Systems Institute | Academia | UAE     |
| UAE06             | Khalifa University | Academia | UAE     |
| UAE07             | Dubai Future Foundation | Government | UAE     |
| UAE08             | Dubai Electricity and Water Authority (DEWA) | Government | UAE     |
| UAE09             | Dubai Electricity and Water Authority (DEWA) | Government | UAE     |
| UK01              | University of East Anglia | Academia | UK      |
| UK02              | Amazon              | Industry | UK      |
| UK03              | Oxford university   | Academia | UK      |
| UK04              | University of East Anglia | Academia | UK      |
| UK05              | Microsoft           | Industry | UK      |
| UK06              | Department for Business, Energy & Industrial Strategy (BEIS) | Government | UK      |
| UK07              | Green Alliance      | Civil Society | UK      |
| UK08              | Citizen's Advice    | Civil Society | UK      |
| UK09              | Smart Energy GB     | Industry | UK      |
| UK10              | The Catapult Network | Civil Society | UK      |
| US01              | Massachusetts Institute for Technology (MIT) | Academia | USA     |
| US02              | US Department of Energy | Government | USA     |
| US03              | Berkeley University | Academia | USA     |
| US04              | World Bank          | Intergovernmental organization | USA     |
| US05              | Energy Technology Area- Energy Technology Area- Berkeley Lab | Government/Academia | USA     |
| US06              | International Business Machines (IBM) | Industry | USA     |
| US07              | Berkeley Lab’s Energy Technologies Area | Government/Academia | USA     |
| US08              | McKinsey & Company  | Industry | USA     |
| US09              | National Renewable Energy Laboratory (NREL) | Government | USA     |
| US10              | Environmental Protection Agency (EPA) | Government | USA     |
| USA11             | Major semi-conductor Company | Industry | USA     |

Source: Authors.
communications portals as well as energy suppliers or system operators, especially during periods of peak usage. This latter issue is central to the evolution of smart grids that are connected to smart homes. The authors also suggest creating national systems of independent certification schemes for SHT assessors, installers, and finance providers.

Other subjects that were covered by experts is the need for a more open market as well as protections in place to minimize vulnerability and ‘smart poverty.’ In their systematic review of the smart homes literature, Marikyan et al. (2019) warned that regulation and legal stipulations have fallen behind innovation, with many gaps in national policy and legislation. As a consequence, UK08 stated that regulatory protections are ‘inadequate’ that that there is a ‘clear regulatory policy and architecture problem.’ Respondents also mentioned the need to protect vulnerable groups, especially those that could be ‘left behind’ in a smart economy, leading to aforementioned notion of ‘smart poverty.’ While USA03 added: ‘The last thing we want is a smart system that only benefits some in the society and in the western world. We must always hedge against this distribution risk and make sure no vulnerable groups are left behind.’

Research already warns that lower income households, vulnerable groups, the elderly, or those in rural areas with poor internet access are late adopters SHTs (Hargreaves and Wilson 2017) and smart meters (Sovacool et al. 2017). This became increasingly apparent during the COVID-19 health pandemic (Lake and Makori 2020). Grants, subsidies, and free technical advice could be targeted at these groups, as well as efforts to improve high-speed internet access.

While SHTs hold the promise to deliver energy savings by helping consumers change their behavior and use resources more efficiently, it is unclear whether these savings outweigh the energy production footprint and rebound effects that may derive from SHT use (Hittinger and Jaramillo 2019). Here the term rebound effect is used to describe sudden or unexpected increases in energy consumption or waste following the adoption or use of a more energy efficient SHT device. Given the potential for energy rebounds and waste, respondents discussed the importance of ensuring that SHTs deliver on improvements in efficiency, emissions reduction, energy consumption, and sustainability. As our respondents put it:

**UK01:** I am most interested in scripting, how to design hardware, control systems, algorithms, and other factors that push energy downwards. This SHTs are not neutral, cannot be controlled any way they like. We need to make smart tech directional, to design it to explicitly reduce energy. There are a multitude of ways to do that, from building it into the kit, or making it the default, a ‘harder’ path, to merely allowing people to set controls a certain way, a ‘softer’ path. The result would be setting constraints on people, SHTs allow people to do some things, but it also does not allow them to do others.

**USA07:** Technologies can be programmed to respond to grid signals, I think that’s where the real potential is. Otherwise the cost is too high, you cannot spend a lot of money in each home doing big installations, integration and all the labour to set up the network; it has to be plug and play. I think smart homes have the potential to overcome that barrier, but the technology has to be better before we really get to that point.

**JP01:** These technologies can reduce household energy consumption and improve efficiency. Thanks to these technologies consumers now have a better understanding of how much energy they are using.
and governments now understand how much electricity they need produce. Making sure that we all share this view is the greatest potential of the digital revolution.

UK01 added that without scripting (or explicit programming), ‘until reductions in energy demand or carbon are guaranteed, there is no case for smart energy homes.’ Such scripting would automatically cutoff smart home devices if they exceed a certain threshold in terms of emissions or energy consumption. Respondents also suggested that SHTs only be broadly deployed to meet policy objectives when coupled with investments in other sustainability measures, such as energy efficiency, passive design of infrastructure, or fuel poverty mandates. This would ensure that all households are supported, not just those rich enough to afford smart technology.

One implication from these points is that consumers may need more than ‘nudging’ to make their use of SHTs more sustainable or environmentally friendly. They may need pushed, incentivized, or even coerced and forced via punitive measures that are more akin to ‘command and control’ policymaking than those relying on the voluntary goodwill of actors (Dubois et al 2019). Punitive measures, however, often end up hurting the most vulnerable in a society and so issues of ‘flexibility justice’ (Powells and Fell 2019) or ‘data justice’ (Taylor 2017) need considered to ensure that sustainability goals are balanced with consumer protection for vulnerable groups.

Another clear implication from these points is that the sustainability attributes of smart homes are neither predetermined nor certain; they will depend upon context and how such technologies are incorporated into homes and the domesticated and daily routines of actors. The sustainability of smart homes will thus exist on a spectrum as shown in figure 2, with some attributes such as vulnerability and materials intensity leading to socially and environmentally unsustainable homes, and attributes such as strong privacy protections and resource efficiency leading to more socially and environmentally sustainable homes.

As a promising sign, policymakers have begun to erect more robust regulations, standards, and other policy incentives intended to steer SHT development in positive ways. Woetzel et al (2018) already report that Dubai and Abu Dhabi in the UAE are the most advanced cities in the Middle East for smart city technology deployment while London in the UK is the most advanced in Europe and all of the most advanced cities in the North America are in the US. Tokyo in Japan is the tied with Beijing in fourth place in the Asia-Pacific. Abu Dhabi has launched the Zayed Smart City Project for demonstration of smart city technologies as well as Masdar City, which is an Abu Dhabi government initiative to ‘demonstrate the state-of-the-art in sustainable cities’ (Griffiths and Sovacool 2020, p 5). Dubai has ambitions to become the smartest city in the world, investing in up to Dh 7 billion in the short, medium and long-term to achieve this objective (WAM 2019). Japan is positioning itself as a world leader in smart city developments with around 160 projects funded by the national government (Nyberg and Yarime 2017). The US Department of Energy (DoE 2018) states that U.S. utilities were investing roughly $3.4–$4.8 billion per year in 2016 in smart grids and smart meters with the intent of making American homes more energy efficient. The UK’s Industrial Strategy has examined the energy revolution and smart systems, with an explicit policy to boost the country’s digital infrastructure with more than £1 billion of public investment (BEIS 2017).
Table 3. Holistic policy recommendations to improve the sustainability of SHTs.

| Dimension     | Illustrative stakeholders                                      | General policy advice (from respondents)                                                                 | Detailed policy recommendation |
|---------------|----------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|--------------------------------|
| Social        | European Union; United Nations; OECD; national regulators for advertising, data protection, and privacy | Craft strong and transparent consumer protections concerning household privacy and data security; better regulate the IoT | UK                            |
|               |                                                                  |                                                                                                        | Paragraph 26 of the GDPR (The European Parliament and The Council of the European Union 2016) ignores the fact that risks to privacy could arise after data collection due to inferential analytics (Wachter 2019). We suggest this legislation should be expanded to focus on data during and after analysis. Paragraphs 38 and 58 of the GDPR focus on transparency; however, is not mentioned the format in which information is going to be delivered. To better protect consumers, we recommend avoiding technical formats that are difficult to understand for an average user. Paragraph 159 of the GDPR provides a broad definition of activities that fall under ‘scientific research’, a theme that includes ‘technological development and demonstrations’, ‘applied research’ and ‘privately funded research’. These provisions could allow digital technology companies to process personal data with the scope of scientific research activities (Testa and Marelli 2018). Thus, it is suggested to make this definition more protective of consumer interests. Article 9 of the GDPR focuses on what constitutes sensitive data. However, we propose that sensitive data could be anything that is detrimental to users’ privacy, even if revealed indirectly through inferential analysis. |
|               |                                                                  |                                                                                                        | US                            |
|               |                                                                  |                                                                                                        | The USA does not own a federal legislation impacting data protection and policies are often at the state level. Although the US does provide certain protection to users through the United States Privacy Act and niche-specific laws that focus on financial and health services, the protections are not inclusive. For instance, the Health Insurance Portability and Accountability Act only applies to ‘covered entities’—defined as health plans, health providers, and healthcare clearinghouses. This limitation also holds for ‘protected health information’. We thus, urgently call for federal regulation in this area, perhaps, something similar to the California Consumer Privacy Act along with creation of federal institutional mechanisms to protect users’ data; a similar instrument to the Task Force on Data Protection from the EU. |
|               |                                                                  |                                                                                                        | UAE                           |
|               |                                                                  |                                                                                                        | In the UAE, federal regulation differs from regulations that are imposed in free zones that include Abu Dhabi Global Market (ADGM), Dubai Healthcare City and Dubai International Financial Center (DIFC). The Abu Dhabi Global Market (ADGM) has implemented the ADGM Data Protection Regulations 2015 (DPR 2015). These regulations were subsequently amended by the Data Protection (Amendment) Regulation 2018. The Dubai Healthcare City (DHCC), a healthcare free zone in Dubai, implemented DHCC Health Data Protection Regulation No. 7 of 2013 (which repealed and replaced the DHCC Data Protection regulation No. 7 of 2008) (HDPR). DIFC Law No. 5 of 2020 is based on the EU’s GDPR and the California Consumer Privacy Act. We therefore expect that issues around privacy and data protection, such as privacy during data transfer and analysis and privacy during decision-making based after decisions are made, will persist in this legislation. The UAE does not have a comprehensive federal data protection law but does have a number of laws in place that govern privacy and data security as well as sector-specific data protection provisions in certain laws. Similar to the US, the UAE would benefit from clear federal regulation on data protection. |

(Continued)
| Dimension      | Illustrative stakeholders                                                                 | General policy advice (from respondents)                                                                 | Detailed policy recommendation                                                                 |
|---------------|-----------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|
| Japanese      | The Act on the Protection of Personal Information (APPI) in Japan seeks to protect the   | - The Act on the Protection of Personal Information (APPI) in Japan seeks to protect the rights and      | - The Act on the Protection of Personal Information (APPI) in Japan seeks to protect the rights and   |
|               |  interests of individuals whilst safeguarding data privacy and personal information.     | interests of individuals whilst safeguarding data privacy and personal information. We suggest that    | interests of individuals whilst safeguarding data privacy and personal information. We suggest that   |
|               | We suggest that APPI should adopt the GDPR differentiation between data controllers and   | APPI should adopt the GDPR differentiation between data controllers and data processors as the current   | APPI should adopt the GDPR differentiation between data controllers and data processors as the current   |
|               | data processors as the current term ‘business operators’ is rather long and ambiguous.    | term ‘business operators’ is rather long and ambiguous. On the same line, we further suggest APPI    | term ‘business operators’ is rather long and ambiguous. On the same line, we further suggest APPI     |
|               | On the same line, we further suggest APPI legally obligate entities to inform               | legally obligate entities to inform subjects in case of data breach, since currently this policy is not   | legally obligate entities to inform subjects in case of data breach, since currently this policy is not   |
|               | subjects in case of data breach, since currently this policy is not implemented. We also   | implemented. We also encourage APPI to raise financial penalties in case of data privacy and violations. | implemented. We also encourage APPI to raise financial penalties in case of data privacy and violations. |
|               | encourage APPI to raise financial penalties in case of data privacy and violations. In    | In the EU penalties can reach €20 million while in Japan penalties only go up to ¥500 000 (approximately  | In the EU penalties can reach €20 million while in Japan penalties only go up to ¥500 000 (approximately  |
|               | the EU penalties can reach €20 million while in Japan penalties only go up to ¥500 000     | €4100).                                                                                                  | €4100).                                                                                              |
|               | (approximately €4100).                                                                 |                                                                                                        |                                                                                                   |
| Technical     | Government bodies such as Ministries of Innovation, Trade, or Industry; civil society     | Promote innovation and technical development, but also ensure strong standards for obsolescence and     | The Project Connected Home over IP represents an international endeavor from major manufacturers and   |
|               | groups                                                                                   | interoperability                                                                                      | developers to join efforts to develop and promote the adoption of a royalty-free connectivity          |
|               |                                                                                          |                                                                                                        | standard. The aim is to increase compatibility among smart home products, with security as a           |
|               |                                                                                          |                                                                                                        | fundamental design premise (Project Connected Home over IP 2020). Although the project it is still   |
|               |                                                                                          |                                                                                                        | ongoing, the standard is expected to launch in 2021 with the following features:                     |
|               |                                                                                          |                                                                                                        | - A unified connectivity protocol                                                                    |
|               |                                                                                          |                                                                                                        | - SHTs designed to connect directly with standardized networking equipment instead of to a home       |
|               |                                                                                          |                                                                                                        | network using proxies                                                                                  |
|               |                                                                                          |                                                                                                        | - SHTs designed to be compatible with smart home services, including device provisioning/onboarding,   |
|               |                                                                                          |                                                                                                        | removal, error recovery, and software update.                                                        |
|               |                                                                                          |                                                                                                        | In addition, we suggest national legislations to include in their list of standards and/or specifications |
|               |                                                                                          |                                                                                                        | a de-facto communication standard. This, should be similar to those developed by the Internet          |
|               |                                                                                          |                                                                                                        | Engineering Task Force (IETF), the European Telecommunications Standards Institute (ETSI) and         |
|               |                                                                                          |                                                                                                        | Machine-to-Machine (M2M) for low end devices (Noura et al 2019) to achieve a feasible solution for the |
|               |                                                                                          |                                                                                                        | interoperability of smart homes. Further efforts should also be made to create cross-platform          |
|               |                                                                                          |                                                                                                        | interoperability to achieve cross-domain interoperability in IoT devices.                             |
|               |                                                                                          |                                                                                                        |                                                                                                   |
Table 3. (Continued.)

| Dimension | Illustrative stakeholders | General policy advice (from respondents) | Detailed policy recommendation |
|-----------|---------------------------|-----------------------------------------|---------------------------------|
|           |                           | Given that currently there is no legislation to tackle planned obsolesce and increase product lifespan, we suggest the following policies to be implemented in national legislations: |
|           |                           | • Manufacturers to build products with a minimum durability criteria; |
|           |                           | • Manufacturers to include product lifetime in the labelling of their products; |
|           |                           | • Manufacturers to make repairs affordable and accessible. |
|           |                           | In line with these considerations, we echo the call from UNEP (2017) to build devices with a 'Right to Repair legislation; monitoring of trends in product lifetimes; and consumer education and information'. |
|           |                           | To mitigate planned obsolescence, we recommend that the European Commission should adopt the European Parliament resolution 2016/2772 (INI) (The European Parliament and The Council of the European Union 2017), which emphasizes the case of obsolescence caused by software updates. |
|           |                           | Technical concerns at the systems level are also related to the fact that integration of SHTs with smart grids and digital ecosystems is not standardized. The value of smart homes will only be fully realized through integration with the broader electricity grid. Particular issues of focus are: |
|           |                           | • Smart meters deployment and compatibility—homes need to be required to opt-in for smart meter installation. When choice is with the consumer, governments must ensure adequate standards are in place for data protection and cybersecurity in order to make consumers comfortable with the technologies. |
|           |                           | • Incentives for energy market participation as well as robust standards for interoperability between SHTs and smart meters. Such incentives would be beneficial as long as consumers are protected from tariff increases. |
|           |                           | • Demand response programs, dynamic pricing and household engagement in demand response—policies, regulations and automated mechanisms implemented to support consumers in accepting demand response programs that operate via SHT modulation. We stress, however, that care must be taken so that SHTs are not merely a subtle way of accessing previously unobtainable domestic electrical load profiles. |
|           |                           | Consideration of more forward looking system issues, like blockchain interoperability and integration into digital systems (Rocamora and Amellina 2018; Ahl et al 2020) is also a relevant consideration in contexts where peer-to-peer energy trading can be established. Here we recommend coordination with Energy Web (EW), which in 2019 launched the Energy Web Chain, the first open-source, enterprise blockchain platform tailored to the energy sector. The Energy Web Decentralized Operating System (EW-DOS) provides an important open-source stack of decentralized software and standards. |
|           |                           | Finally, particular focus should be given to addressing closed innovation ecosystems, which provides competitive advantage that companies will want to retain. Focus should be placed on ensuring basic function interoperability (on, off, time schedule etc) that is completely open to allow sustainability benefits to be achieved. Higher level functions that differentiating can be retained within the closed ecosystem. This mode of operation will likely result in less opposition to policy changes, which may be perceived as having a direct impact to commercial positions. |

(Continued)
### Table 3. (Continued.)

| Dimension | Illustrative stakeholders | Detailed policy recommendation |
|-----------|---------------------------|-------------------------------|
| Political | National political parties, trade and labor unions, charities and consumer watchdogs | Craft a more open market with minimal barriers to entry, enact protections for homes in poverty or at heightened levels of vulnerability. |
| Environmental | Ministries of energy and the environment, technology designers, and suppliers | Scripting/programming SHTs to meet sustainability goals, ensuring these devices are pro-sustainability. |

Product liability in the SHT arena is still an underdeveloped area. Given that liability only applies to products and providing data through an IoT system is considered a service, we suggest adding services to current legislations as a way to extend the liability to developers. An approved mechanism with binding and clear enforceable commitments from manufacturers could represent a good first step to addressing product liability on a global scale.

Data on energy use collected through smart meters can enhance the efficiency of SHTs at the system level by allowing electricity providers to enact demand response measures that lower energy consumption and help integrate intermittent renewable energy sources into power grids. Thus, we suggest that communications from such technologies focus on load profiles to enable consumers to achieve lower energy costs. This, however, must be done in a way that guarantees customer privacy.

Technology designers need to embed stronger scripts/programs or limitations within SHTs to ensure they operate in configurations that are as sustainable as possible. We note that none of the legislations we reviewed explicitly listed SHTs within their laws and regulations. For instance, in addressing issues related to alternative energy sources under the Electronic Equipment Regulations (EERs) (UK Statutory Instrument 2013) to explicitly list SHTs, either as an aspect of subsection (3) or (4) of Article 8, or as a new class. We similarly noted that none of their legislations addressed issues related with interactive packaging, a growing area of interest. Given these examples, we recommend that governments consider developing and implementing regulations that address these emerging areas.

Given the market projections for increased connected devices and the need to reduce standby electricity consumption, an issue that represents 1% of global CO$_2$ emissions (IEA 2014), we call for further advance in anticipation of future legislation. This measure is necessary for the stringent regulations addressing this issue to be fully adopted, as the Energy Star Program (2019) and the EU Directive 2005/32/EC (European Commission 2017) require that devices must not consume more than 0.5 Watts in standby or off mode. Nevertheless, we noted that the Energy Star program lacks regulation for networked standby devices while the EU directive includes this category within their regulation, stating that devices must not consume more than 3.9 Watts depending on the product. In these circumstances, we call for further advance in these areas.

In the countries studied, none holds regulation on data traffic and energy consumption. There is a need to develop a comprehensive legislative framework that addresses these issues. We recommend that governments consider developing and implementing regulations that address these emerging areas.

The list of manufacturers includes: IKEA, Amazon, Apple, Google, Legrand, NXP Semiconductors, Schneider Electric, Signify (formerly Philips Lighting), Silicon Labs, Somfy, and Wulian.

Source: Authors, based on information retrieved from expert interviews as well as DLA Piper (2020) and International Energy Agency (2013).
However, many of these policies focus on promoting SHTs via investment or learning, or accelerating the diffusion of smart technologies across households. Less covered are policies actively seeking to make SHTs more sustainable, or to moderate their diffusion so that they contribute to energy and climate goals. Therefore, we have mapped out very specific policy changes that could be implemented, immediately, across components of the European GDPR, standards on communications networks, regulations on technological obsolescence, directives on product liability, as well as Waste Electrical and Electronic Equipment Regulations (WEEE).

Table 3 summarizes our recommendations across the four dimensions of social, technical, political, and environmental sustainability. Where available and relevant, we include frameworks, and related framework gaps, from the countries studied.

Our evidence strongly suggests that we need an integrated set of smart home policies that not only protect consumers, but also set restrictions to ensure such devices meet other climate and energy goals (such as fuel poverty or efficiency), sponsor innovation and trials for learning, and set technical and marketing standards. Perhaps then, with a more thoughtful and coordinated mix of policies in place, SHT adoption will begin to fulfill some of the objectives their advocates continually promise.

We do note that our analysis relies heavily on European data protection schemes as best practice. However, laws and regulations are only as useful as the systems that implement them. Hence, GAIA-X has been launched as a European initiative to bring cloud computing infrastructure itself under EU oversight as opposed to international technology companies that largely reside outside of Europe. Although the full technical details of GAIA-X are outside the scope of this paper, figure 3 clearly shows the intent and potential of this initiative to not only alleviate SHT data privacy concerns, but also make SHT ecosystems much more efficient and effective. While we are not proposing by any means that the GAIA-X architecture is optimal for all locations, it does provide a useful model to consider regarding necessary coordination of policy and infrastructure.

5. Conclusion

To conclude, because not all smart home devices meet sustainability goals, and for the technology to have transformative impacts on reducing energy demand—or, even just incremental reductions in demand—the sector needs to be strongly guided by government policy. Such policies, currently, appear to occur in a fragmented manner across different silos such as smart meters, smart grids, or the IoT. This issue is one that needs to be addressed with some urgency given the important role that SHTs will need to play in achieving global sustainability targets across a broad range of sectors, not the least of which is energy. We have drawn significantly on EU policy and policy implementation best practices in deriving policy recommendations and suggest that policy makers globally consider these recommendations and tailor them to their own socio-political contexts.

Finally, while much of this paper has focused on the SHTs in the individual home, we do believe that...
great potential also exist in terms of systemic coordination at the neighborhood and city level, as these involve larger scales and thus significant volumes of energy consumption and corresponding greenhouse gas emissions. Here we note that emerging models for smart city governance may benefit from following a polycentric approach that is more inclusive to community and grassroots actors and hence may facilitate broad and beneficial SHT adoption (Nyangon 2020). Within the extended concept, technologies like smart grids and smart meters need to integrate with the full suite of SHTs to enable opportunities like demand response, which is a central means of achieving high shares of intermittent renewable energy and reducing energy consumption overall. It may be easier to implement policy that promotes sustainability across the broader electricity system than just to focus on individual households given that the focus would be shifted toward industry and government organizations. Such a systems perspective, a noted throughout this paper, can help achieve SHT sustainability objective even if some of the sustainability challenges noted, such as rebound effects, ultimately materialize.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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