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Culture, energy and climate sustainability, and smart home technologies: A mixed methods comparison of four countries

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Furszyfer Del Rio, D. D.1,3*, Sovacool, B.K.1,2 and Griffiths, S.3

* Corresponding Author

1 Science Policy Research Unit (SPRU), University of Sussex Business School, University of Sussex, United Kingdom

2 Center for Energy Technologies, Department of Business Development and Technology, Aarhus University, Denmark

3 Khalifa University of Science and Technology, Abu Dhabi, United Arab Emirates

Abstract: Smart home technologies (SHT) 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, how might culture shape the diffusion and use of the technologies used in smart homes? What cultural barriers may impede their adoption, or embed more carbon-intensive lifestyles? Lastly, do smart home technologies truly promote sustainability goals? Based on an extensive original dataset involving expert interviews in four countries—Japan, the United Arab Emirates, the United Kingdom, and the United States—and original media content analysis, this study explores the cultural aspects of smart home technology adoption as well as the consequent impacts on sustainability. In doing so, the study elaborates on an array of social, technical, political, economic and environmental dimensions of smart home technology diffusion, with clear implications for research, policy, and technology development. In this sense, we call for more comprehensive, progressive, innovative and sensitive technology design so as to advance SHT adoption and fulfill some of the sustainability and climate objectives their advocates continually promise.

Keywords: smart home technologies; smart energy management; smart grids; energy culture; smart meters; energy and buildings; energy feedback; smart grids; digital society

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1. Introduction

Smart home technologies (SHTs) refer to devices that provide some degree of digitally connected, automated, or enhanced services to household occupants [1,2]. Smart homes have become increasingly discussed in technology, innovation, and policy debates about energy efficiency and buildings, [3,4] climate change and resource efficiency, [5,6] and innovation and industrial strategy [7].

However, assumptions that SHTs may lead to reductions in energy consumption, displacement of greenhouse gas emissions, and improvements in social wellbeing are contested. In the energy domain, Hargreaves et al.[8] note that these technologies could increase energy consumption and this is corroborated by Nicholls et al. [9], when they suggest that adoption of energy efficient smart lighting can encourage extra use of electricity for lighting for security, ambience and entertainment reasons. Sovacool and Furszyfer Del Rio [10] not only highlight the potential for such rebound effects from SHTs, but also indicate how these technologies may lead to technical and social disruptions, promoting negative interactions within households. In addition, SHTs to improve users’ health [11] or enhance households’ security [12,13] may encourage surveillance practices, which may lead to negative social practices, such as cyber abuse [14], domestic violence [15,16] and stalking [17]. Other incidents are related to how these technologies may be hacked and controlled by others with implications for baby monitors [18], smart meters [19], smart speakers [20] cars [21] and even coffee makers [22]. Indeed, as reported by Mare et al., (23) “any malicious actor in the smart home ecosystem may pose a threat to a smart home user’s security, privacy, or safety”. In this context, smart homes have weaknesses that extend well beyond energy and climate change considerations and necessitate consideration of secure management systems capable of managing security in all technology layers whilst ensuring users’ data privacy.

Taking into consideration these issues, in our study, we seek to address how culture can shape the diffusion and use of SHTs. We define culture as combining the norms, practices and material artefacts in a society, at any scale, from individuals and groups, to organizations and even nations [24]. Utilizing this notion of culture, we ask: What cultural barriers may impede the adoption of SHTs, or embed carbon and energy intensive lifestyles? Do smart homes truly promote sustainability goals? Our core contribution is to contextualize the notion that SHTs per se lead to more sustainable homes. We call on the need for more comprehensive and progressive policies not only to advance SHT adoption but also for these technologies to deliver sustainable processes and outcomes.

2. Research design: Conceptualizing smart homes, case selection, and research methods

This section summarizes our research design, including how we define and conceptualize SHTs, how we selected our four national cases, and our original research methods.
2.1 Conceptualizing and defining SHTs

The concept of SHTs remains somewhat ambiguous, with no agreed upon definition adopted by the research community or even the industry [25]. Furszyfer Del Rio and colleagues [26] write that SHTs need to possess four of the following elements to be considered “smart”: 1- be digitally connected; 2- provide enhanced control to users; 3- allow automated processes and; 4- have the capability to learn. Drawing from original empirical data in Europe, Sovacool and Furszyfer Del Rio [10] identified 13 categories of SHTs, namely: safety and security, household appliances, baby and pet monitors, home robots, gardening, energy and utilities, lighting, entertainment, health and wellness, clothes and accessories, vehicles and drones, integrated solutions, and “others,” which are visualized in Figure 1.

Figure 1: Visualizing the interconnected categories of SHTs. Source: authors

In short, SHTs combine multiple forms of sensing with both local processing and cloud-based processing for the intended purpose of bringing insights, cost savings, convenience, and automation to users. Many SHTs allow users to interface with them through smartphones and other internet-connected products, which make the SHT landscape one that is constantly evolving.

Although the SHT landscape continues to evolve, there is little doubt that the smart home revolution has arrived [10, 26] and with it, these technologies could become a defining feature of sustainable energy transition at the scale of households, energy grids, and cities [27–29].

Indeed, the relevance of SHTs is reflected in the growing market for these technologies. For instance, consumer spending on smart home related hardware, services and
installation fees grew by 11% with more than 880 million devices sold in 2019 [30], while the number of devices connected to the internet is projected to reach as high as 21 billion by 2025 [31] and the total smart and connected homes market reaches $262.6 billion in the same year [32]. The World Economic Forum [33] estimates that SHTs will add $14 trillion of economic value to the global economy and an additional $100 billion in industry operating profits by 2030.  

Table 1 and Figure 2 breakdown regional market opportunities for smart homes and the relative share of SHT market segments in 2018.

| Market opportunity/region | Europe and Commonwealth Independent States | North America | Latin America | Asia-Pacific | Africa and Middle East |
|--------------------------|---------------------------------------------|---------------|---------------|--------------|------------------------|
| Market Size (2018)       | $ 53.90 billion                             | $47.08 billion| $3.02 billion | $51.69 billion| $2.39 billion          |
| CAGR (2018-2025)         | 6.3%                                        | 5.3%          | 9%            | 10.2%        | 9.3%                   |
| Smart homes penetration  | 22.2%                                       | 7.2%          | 1%            | 2.4%         | 2%                     |

**Table 1**: Market opportunities for smart home technologies. Information retrieved from Frost and Sullivan [32] but table created by authors

![Figure 2: Global market share of smart home technologies in 2018 by type of application. Information retrieved from Frost and Sullivan [32] but figure created by authors.](image)

2.2 Case selection

Given that we examine the social, economic and cultural contexts of SHTs, we intentionally selected four highly urbanized countries in four different regions with varying SHT markets, diffusion patterns, demographics trends and cultures (see Table 2): Japan (Asia), the United Arab Emirates (Middle East), the United States (North America), and the United Kingdom (Europe).
| Sociodemographic Characteristics | United Kingdom | United Arab Emirates | Japan | USA |
|----------------------------------|----------------|---------------------|-------|-----|
| Population \( a \)              | 67,886,011     | 9,630,959           | 126,264,931 | 328,239,523 |
| Square Kilometers (thousand) \( a \) | 241,930 Km\(^2\) | 83,600 km\(^2\)    | 377,915 km\(^2\) | 9.834 million km\(^2\) |
| GDP (Current US dollars) \( a \) | 2.8 trillion   | 421.1 billion       | 5.1 trillion | 21.4 trillion |
| GDP per capita 2018 \( a \)      | $42,300        | $43,103             | $40,246 | $65,118 |
| Expatriates                      | 9\% \( b \)   | 88.52\% \( c \)    | 2.6\% \( d \) | 28\% \( e \) |
| Population ages 65 and Above (% of total population) \( a \) | 18.50\% | 1.15\% | 28.02\% | 16.21\% |
| Population between ages 15 and 64 (% of total population) \( a \) | 63.79\% | 84.13\% | 59.42\% | 65.24\% |
| Crime Rate per 100,000 people \( f \) | 43.64 | 15.52 | 15.91 | 46.73 |
| Urbanization Population          | 84\%           | 87\%                | 92\%   | 82\% |
| Percentage of population living in urban areas (2019) \( a \) | Parliamentary constitutional monarchy; a Commonwealth realm | Federation of monarchies | Constitutional federal republic | Parliamentary constitutional monarchy |
| Political system                  | 5,130          | 11,088              | 7,819  | 12,997 |
| Electricity consumption (kWh per capita) 2014 \( a \) | 0.250 | Expats: 0.08/kWh to 0.12/kWh based on consumption level \( i \) | 0.252 | 0.129 |
| Residential electricity prices USD (PPP)/kWh (2018) \( h \) | | Nationals: 0.02/kWh on average \( i \) | | |
| Energy indicators                | CO\(_2\) emissions (metric tons per capita) 2014 \( a \) | 6.5 | 22.9 | 5.0 | 16.4 |
Table 2: Key market dynamics and policies for smart homes in our four selected case study countries

In addition, these countries have clear ambitions for the development and/or deployment of smart technologies. Each of the countries studied has launched a national artificial intelligence strategy and in fact, the UAE was the first country to create a Ministry dedicated to artificial intelligence [47]. Hence, each country has the intent to build the ecosystem necessary for SHTs to thrive. According to a McKinsey study [48], 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 Asia-Pacific given the significant competition posed by Singapore, South Korea and China and the somewhat lagging interest of Japan in smart technologies (Table 2). Significant levels of urbanization (Table 2) and smart city technology deployment indeed make our focus countries highly amenable to SHTs.

As further rationale for our selections, each country we examined has a constantly evolving set of smart technology deployment initiatives. Indeed, Japan is now positioning itself as a world leader in smart city developments with around 160 projects funded by the national government up to 2014 [49]. After the Fukushima disaster, national Japanese government rapidly centered its efforts in building more resilient homes [50] and smart grids have been increasingly regarded as an enabling technology for a successful post-Fukushima energy transitions [51]. Indeed, within the domestic market, the national government has prioritized energy conservation and disaster resilience through the development of local renewable energy and smart grid projects [50, 53]. This approach may help understanding the development of Society 5.0, where the Japanese government aims to resolve a number of social challenges through the incorporation of IoT, big data, artificial intelligence, robots and the sharing economy to transform the Japanese way of life [54].

In the UAE, smart city strategies are evolving within different emirates, Abu Dhabi and Dubai being the most prominent. Abu Dhabi has launched the Zayed Smart City Project for demonstration of smart city technologies [55]. Another example within Abu Dhabi is
Masdar City, which is positioned by the Abu Dhabi government as an initiative to “demonstrate the state-of-the-art in sustainable cities” and has in fact been a demonstration of the potential pitfalls involved in putting technology first in smart, sustainable city design [56]. Dubai, on the other hand, 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 [57]. Dubai’s global model for clean energy and green economy with an estimated value of Dh 500 million, includes disruptive technologies such as but not limited to artificial intelligence, unmanned aerial vehicles, energy storage and IoT devices [58]. Smart Dubai is the government office that has been established with directing Dubai’s smart transformation and has an extensive set of smart city initiatives underway [59].

The US Department of Energy (DoE) states that U.S. utilities have invested approximately $144 billion in electricity generation, transmission, and distribution infrastructure during 2016 with annual smart grid investments increasing by over 40% between 2014 and 2016 from $3.4 billion to $4.8 billion [60]. Such investments have sought to build a more resilient grid, reduce CO₂ emissions, improve energy management, deliver innovative business models, ease the integration of renewables sources in the grid and build a more flexible energy system [62, 63]. If fact, some have argued that the building of a smart grid is key for the country to become the leading economy of the 21st century, lead the clean energy revolution and encourage “American innovation” [64].

The UK’s Industrial Strategy [65] 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) [66]. The UK, moreover, has invested £11 billion in infrastructure for the rollout of smart meters [67]. Research indicates that the implementation of a smarter energy system is vital in shaping the UK’s efforts to reduce greenhouse gas emissions to net-zero by 2050 [69, 70].

2.3 Research design

With our four case study countries selected, we executed a research design focused on a mixed methods approach, including original expert interviews as well as media content analysis. We thought these two methods worked well together given our topic of culture was fairly complex, making it well suited for expert interviews as opposed to layperson interviews. Media content analysis is also particularly helpful at revealing the meaning or cultural symbols apparent in advertising. We felt these two methods were better than relying on focus groups (which could result instead in consensus-oriented discussion) or surveys (which would reduce our cultural questions to quantitative ones, whereas we wanted our study to remain primarily qualitative).

Our expert interviews followed a qualitative approach similar to that of Noel et al., [70] and Harrell and Bradley [71], who used them to provide guidance to participants while providing flexibility to the interviewees. This, in turn, generates a channel for spontaneous responses that adds narratives and overall depth to the research [70]. Our sampling strategy was purposive, and designed to include experts from five different types of institutions:

- Government, including national authorities such as the Department for Business, Energy & Industrial Strategy (BEIS) in the UK, the Ministry of Economy in Japan
(METI), Department of Energy (DoE) in the US and Dubai Future Foundation in the UAE (11 participants);

- Academic institutions such as the University of East Anglia and Oxford University in the UK, Massachusetts Institute of Technology and University of California Berkeley in the US, University of Tokyo and Kyoto University in Japan and Khalifa University of Science and Technology in the UAE (14 participants);

- Private sector firms, including major software and technology companies such as Amazon, Panasonic, IBM and Microsoft (8 participants);

- Civil society and independent research institutes such as Citizens Advice, the Green Alliance, Energy Systems Catapult, and Boston Consulting Group (3 participants);

- Other stakeholders, which included industry, international organizations and trade groups such as Smart Energy GB in the UK and the World Bank in the US (2 participants).

In total, we conducted 38 interviews from November 2018 to August 2020. Most of the participants were not known to the authors, and were selected based on their expertise rather than a snowballing methodology. Although most of the interviews were conducted online (via Microsoft Teams, Zoom and Skype) due to travel restrictions related to the COVID-19 pandemic, we had the chance to conduct a few interviews in person before the pandemic started. The average duration of each interview was 45 minutes, and participants were asked:

1. How might SHTs be used differently in your communities due to local culture?
2. In what ways does culture shape SHT use and how might SHT use lead to enhancements in sustainability, or trade-offs in sustainability?
3. What SHT technology advances are still needed to make SHTs culturally acceptable and to accelerate their adoption?

To encourage candor and protect participant identities, all interviews were treated as anonymous; however, each expert was given a respondent number as shown in Table 3. Given that we did full transcription, all interviews were recorded so that statements could be checked for accuracy. Our coding scheme was thorough and inductive, meaning we coded every response and then analyzed the full sample inductively.

| Respondent Number | Gender | Nationality | Company/institution            | Category     | Country |
|-------------------|--------|-------------|--------------------------------|--------------|---------|
| JP01              | Male   | Japan       | Ministry of Economy            | Government   | Japan   |
| JP02              | Male   | Canada      | Rikkyo University             | Academia     | Japan   |
| JP03              | Male   | Japan       | University of Tokyo           | Academia     | Japan   |
| JP04              | Male   | Japan       | Kyushu University             | Academia     | Japan   |
| JP05              | Male   | Japan       | Kyoto University              | Academia     | Japan   |
| JP06              | Male   | United States | Tohoku University         | Academia     | Japan   |
| JP07              | Male   | Japan       | Osaka University              | Academia     | Japan   |
| JP08              | Male   | Japan       | Panasonic                    | Industry     | Japan   |
| UAE01             | Male   | UAE         | Smart Navigation System       | Industry     | UAE     |
| UAE02             | Male   | UK          | Dubai Regulatory and Supervisory Bureau | Government | UAE     |
| UAE03 | Male | UAE | Khalifa University of Science and Technology’s Emirates ICT Innovation Centre (EBTIC) | Academia | UAE |
| UAE04 | Male | Italy | Boston Consulting Group | Industry | UAE |
| UAE05 | Male | Italy | Khalifa University of Science and Technology’s Intelligent Systems Institute | Academia | UAE |
| UAE06 | Male | United States | Khalifa University of Science and Technology | Academia | UAE |
| UAE07 | Male | UAE | Dubai Future Foundation | Government | UAE |
| UAE08 | Male | UAE | Dubai Electricity and Water Authority (DEWA) | Government | UAE |
| UAE09 | Male | UAE | Dubai Electricity and Water Authority (DEWA) | Government | UAE |
| UK01 | Male | UK | University of East Anglia | Academia | UK |
| UK02 | Male | Cyprus | Amazon | Industry | UK |
| UK03 | Female | UK | Oxford university | Academia | UK |
| UK04 | Male | UK | University of East Anglia | Academia | UK |
| UK05 | Male | United States | Microsoft | Industry | UK |
| UK06 | Male | UK | BEIS | Government | UK |
| UK07 | Male | UK | Green Alliance | Charity | UK |
| UK08 | Male | UK | Citizen’s Advice | Civil Society | UK |
| UK09 | Female | UK | Smart Energy GB | Marketing Company | UK |
| UK10 | Male | UK | Energy Systems Catapult | Civil Society | UK |
| US01 | Female | NA | MIT | Academia | USA |
| US02 | Female | United States | US Department of Energy (DoE) | Government | USA |
| US03 | Female | United States | University of California Berkeley | Academia | USA |
| US04 | Male | NA | World Bank | International organization | USA |
| US05 | Male | United States | Energy Technology Area - Energy Technology Area - Berkeley Lab | Government/Academia | USA |
| US06 | Male | United States | International Business Machines (IBM) | Industry | USA |
| US07 | Male | United States | Energy Technology Area - Berkeley Lab | Government/Academia | USA |
| US08 | Male | NA | McKinsey& Company | Industry | USA |
| US09 | Female | United States | National Renewable Energy Laboratory (NREL) | Government | USA |
| US10 | Female | United States | Environmental Protection Agency (EPA) | Government | USA |
| US11 | Female | United States | Major semi-conductor Company (anonymity requested) | Industry | USA |

Table 3: Summary of participants for semi-structured research interviews (N=38). Source authors

In addition to interviews, given our focus on culture, we systematically searched and reviewed media archives to identify how SHT advertising is influenced by culture. We
looked for advertisements for what we consider prominent SHT platform and technology developers, including Google, Amazon, Panasonic and Philips. This corpus of media content analysis included both print and video material as summarized in Table 4.

| Brand               | Source of advertisement (video/print) | Type(s) of product          | Country/region |
|---------------------|---------------------------------------|----------------------------|----------------|
| Panasonic           | Video                                 | Appliances                 | Japan          |
| Panasonic           | Video                                 | Panasonic Home             | Japan          |
| Google Nest Home    | Video                                 | Integrated solutions       | Japan          |
| Amazon              | Video                                 | Integrated solutions       | Japan          |
| Amazon              | Print                                 | Integrated solutions       | Japan          |
| Panasonic           | Print                                 | Thermostat                 | Japan          |
| Panasonic           | Print                                 | Appliances                 | Japan          |
| Panasonic           | Video                                 | Panasonic Home             | USA/UK         |
| Amazon              | Video                                 | Integrated solutions (Echo show) | USA/UK       |
| Google Nest         | Video                                 | Thermostat (Nest Thermostat E) | USA/UK       |
| Google Nest         | Video                                 | Integrated Solutions (Max hub) | USA/UK       |
| Samsung             | Video                                 | Appliances (Fridge Hub)    | USA/UK         |
| Amazon              | Print                                 | Integrated solutions       | USA/UK         |
| Google              | Print                                 | Thermostat                 | USA/UK         |
| Philips             | Print                                 | Lighting                   | USA/UK         |
| LG                  | Video                                 | Appliances (Fridge)        | Middle East    |
| Panasonic           | Video                                 | Air conditioning           | Middle East    |
| Philips             | Video                                 | Lighting                   | Middle East    |
| Amazon – Ring       | Print                                 | Indoor/outdoor camera      | Middle East    |
| Amazon              | Print                                 | Integrated solutions       | Middle East    |

Notes: [72], [73], [74], [75], [76], [77], [78], [79], [80], [81], [82], [83], [84], [85], [86], [87], [88], [89], [90]

Table 4: Advertisements for smart home technologies in Japan, USA, UK and the Middle-East. Source authors

3. Background and literature review: four streams of scholarship on smart homes

In the following section, we present a brief review of four different streams of scholarship or analysis relevant to our study as background and context to our results and conclusions. We first introduce relevant literature that contests the intrinsic sustainability of smart homes, then, we focus on the role of culture in the adoption of SHTs and final, we address the social risks of a digitalized culture. We also highlight the specific cultural dimensions mentioned in the literature concerning SHTs and our four-case study countries, and summarize recent depictions from the media.
3.1 Contesting the intrinsic environmental sustainability of smart homes

SHTs are often marketed under the premise that automation and digitally connected devices deliver a large range of home improvements and enhance users’ experiences [26] with energy reduction from use of these technologies often marketed as a side-benefit [91]. This point is seconded through a qualitative content analysis of 270 retrieved consumer articles that show, among other things, that smart energy technologies (i.e. those designed to save energy) are likely to have limited sustainability impacts if they continue to be resource and material intensive [92].

Nevertheless, these technologies are often labelled as sustainable through functions such as personalized feedback [94, 95] or specific automation services that modulate energy consumption, such as Home Away or Eco Mode1 -- features offered by Google Nest [95]. Indeed, the Google Nest claims that consumers can, on average, save between 10-12% on heating consumption and ~15% on cooling consumption. Therefore, Nest users could potentially save between $131 to $145 a year on their energy bills [95]. However, research conducted in the UK found evidence for energy savings of only around 5.8%, leading, in turn, to customers saving between £45-65 per year and demonstrating the potential uncertainty in SHT sustainability claims [96].

From another angle, Walzberg et al. [97] fear that because smart homes are more energy efficient, they are intrinsically prone to increased overall energy consumption through rebound effects. Similar concerns have been raised by the IEA, when they caution that the rebound effects from automation and enhanced convenience in the digitalization era may result in doubling total energy use by 2040 [29]. It is under this context that the Low Carbon Innovation Coordination Group [98] calls for more “research into the effects of such systems”.

As a harbinger of unsustainable SHT impacts, projections have been made that global electricity emissions from use of connected devices could surpass emissions from the aviation and shipping sectors by 2020 and reach 14% of the global total carbon emissions by 2040 [100, 101]. Of course, we recognize that digital technologies utilize electricity and so emissions are dictated by the structure of the electricity system in which the technologies operate. High electricity demand in completely decarbonized electricity would have no impact on emissions and so environmental sustainability would not be compromised due to energy use alone.

Further, in the context of environmental sustainability, some question the value of SHTs while others believe these technologies are inherently energy efficient [29, 102]. It can be argued, however, that it is how individuals use these technologies that ultimately determines energy efficiency, and perhaps SHT design teams are too often overly optimistic about the intrinsic sustainability of the technologies they design [102]. This aligns with what Horner and colleagues suggest when they note that although the technical potential of net energy savings from ICT is ‘likely positive’, the real savings are unclear and difficult to assess, since these will mostly depend on users’ behaviors, interactions and broader societal factors [103]. From a users’ perspective, Bhati et al., [104] show that Singaporean people have contested the sustainability of smart homes when they state, for instance, that interviewed Singaporean’s were “less convinced that the technology was capable of helping them to save energy, in comparison to using energy efficient appliances directly”. A similar view is held in the UK, when a research study participant discussed energy display monitors

1 These features are activated after the devices senses that the home is empty
by stating that “it just slightly changes the way I use things but that’s as far as it goes [105]”. Given such perceptions, the key means by which smart homes may be able to provide energy savings is not by working in isolation, but rather as part of a broader transactive system that incorporates demand response via smart grids. Coordination between electricity utilities and neighborhoods via SHTs provides an opportunity for energy efficiency at a systems level while allowing for SHTs to provide the comfort and convenience often more important to homeowners than energy efficiency (Figure 3). In this context, to encourage energy conservation behaviors in a smarter energy system, Wang [106] suggests providing energy users with a comparatively high value stream (financial and convenience) not only to decrease energy use at the residential level, but also to enhance grid services.

Figure 3: How smart home technologies can enable smart electricity infrastructure

For Wajcman, digital technologies have emerged not focused on sustainability, but in tandem with the movement known as ‘Getting Things Done’ (GTD) “centered on a time management system that promises to unlock your full potential and master the art of stress-free productivity [107]”. In contrast, others claim that the smart homes revolution has created a “neoliberal culture of generalized anxiety” [108]. Perhaps, as Neff and Nafus [109] explain, this is because people use “self-tracking” technologies to track all of their everyday activities, from hours of sleep, to calories consumed, to steps taken, to ironically, time spent staring at their mobile phone screens.

Taking a broader view of sustainability, the spectrum of ‘smart’ technologies can be contested across all stages: from conception when software algorithms are trained [110] and resources are extracted for products [111] to the electricity demanded from data centres [113, 114]. Human exploitation [114] and the impacts of artificial intelligence (AI) on human rights [115] are also significant considerations not directly related to energy. All of these issues ultimately must be considered when reviewing the sustainability SHTs.
3.2 The role of culture in SHT adoption and risk assessment

There is not much research directly related to the influence of culture in the adoption and use of SHTs. For instance, an outdated study [116] revealed that the attitudes of Taiwanese families play a role in the adoption of mobile healthcare services, particularly by older Taiwanese individuals who are in need of affordable and accessible long-term care. Chung [117] shows that the decision of adopting SHTs in elderly populations is not only limited to the individual users, but also to care providers, peers, and most importantly, to family members. Chung explains that this may be due to the fact that adult children are expected to look after their elderly family members with the intent to repay their parents’ efforts and sacrifices, which is the norm of reciprocity [117]. A comparative study conducted in Japan and the USA found that the main factor for consumers’ technology acceptance was trust in the technologies being able to perform desired tasks. Users’ satisfaction increases when there is a personal or emotional element connected with how a device conducts a task [118]. In this sense, Harari [119] warns that ethical concerns arise from users engaging sentimentally with technologies. For example, in Japan, robot owners become so attached to their robotic dogs that when they are unrepairable, owners hold funerals as a way of saying goodbye [120].

Shifting our attention to the adoption of SHTs, Wilhite and Diamond [121] argue that to further advance their adoption, first, it is necessary to engage with people’s culturally fixed expectations and experiences, as well as with their know-how about how to accomplish heating, cooling and ventilation. On a similar vein, energy use and the adoption of SHTs is strongly influenced by national and socio-economic contexts as culture shapes household energy use in ways that are often not anticipated in energy policy [122-124]. As noted by Sovacool and Griffiths [24], culture can reflect “local societal practices, beliefs and behavioral routines, as well as their socio-material or socio-technical manifestations”, which in turn, can influence different dimensions of sustainability.

Concerning the link between culture and deployment of SHTs, Nicholls et al. [9] suggest that smart technologies may pose a risk by reducing the cultural transmission of values associated with energy conservation. For instance, lighting automation is advocated to remove a major source of contention between parents and children — “a perceived need to ‘nag’ children to turn unused lights off”. In such a case, the transmission of energy efficiency and conservation values, which ultimately would translate to social norms, are lost to the expediency of technology. This notion is further corroborated by Hargreaves and Middlemiss [124] when they note that a better understanding of social relations is fundamental to improving familiarity with energy demand patterns, improving energy system flexibility and supporting energy system decarbonization. Energy users are much more than household inhabitants in a smart energy system as they can be prosumers and legitimators as well [125]. This makes them key players in shaping a low-carbon energy transition [124].

3.3 Specific cultural dimensions of SHTs and our four case study countries

Although there is little research on the cultural dimensions of SHT adoption, it is important to briefly highlight how the cultures of the countries studied differ and how such differences may influence lighting, heating and cooling at home. In general, the UAE, given its form of government (Table 2), is particularly hierarchical relative to Japan, the US and the UK, which are more democratic and further characterized by uncertainty avoidance [126]. Japan is also somewhat communitarian, hierarchical and further a male-dominated, long-term oriented and uncertainty avoiding culture. In contrast to both the UAE and Japan, the western
societies we studied, the US and the UK, have cultures that share a high sense of individualism and have less risk-averse and more indulgent cultures [126].

Translating culture to sustainability, we start with Japan, where Wilhite and team [127] found that Japanese heating and lighting habits are more disciplined and less culturally significant in contrast with bathing routine, which is not only extremely important to the Japanese culture but also a very energy intensive practice. When it comes to heating, Japanese tend to have individual heating systems [128], as illustrated by kotatsus, an instrument often placed under the dining table that traps the heat around the lower torso for those who are close to it [127]. Sovacool and Griffiths [129] note that in Japan, additional heating needs are also met by inefficient electric carpets or small kerosene heaters. Another Japanese cultural aspect linked to sustainability is the short lifespan of buildings, which tends to be only 20 to 25 years [130], a timeframe that has been shortening since the Second World War [131]. The relatively short building lifetimes is a result of attitudes and aspirations, geographic-upward social mobility and induced middle class lifestyle changes, which have generated a culture of disposal housing [132]. In addition, Berg [133], notes that building code revisions to improve earthquake resilience lead to the knocking-down of houses after 20 to 30 years while others argue this practice is related to a ritual that refreshes spiritual bonds between the people and the gods [134]. In terms of appliances, Japanese have tended to prioritize air conditioning because it is often related with modernity and what it means to be a progressive Japanese family [135].

In the UK it is first worth noting that home heating systems are accountable for about 19% of the total UK carbon emissions [136]. This is due, in part, to inefficient domestic heating systems [138, 139] and consumers’ apathy for retrofitting their homes [139] as homeowners want to preserve old buildings rather than upgrade to newer technologies or building facades [140]. Indeed, UK policy makers and homeowners have prioritised building preservation over energy efficiency measures [142, 143]. It is under this context that Sovacool and Griffiths [24] argue that “British households are reluctant to compromise the aesthetics of their home or building for the sake of energy efficiency”.

Shifting our attention to the UAE, a key consideration is that nearly 90% of the country’s electricity consumption is attributed to the buildings sector [143]. This is largely due to UAE’s extreme climate, where the average temperature in summer can reach up to 42°C [144]. As a consequence, peak energy demand in the UAE occurs during the summer and as a result, air conditioning in the UAE and across the rest of the Arabian Gulf region accounts for as much as 70% of annual peak electricity consumption and as such is key target for energy efficient technologies [145]. In addition, due to the abundance of oil and low electricity and water prices (Table 2) [146, 147] energy waste is a common practice in the UAE [147]. In this sense, Min and Azar [148] suggest that to reduce energy demand from buildings design features such as passive design can be implemented to provide improved lighting and window glazing designs that can not only to reduce cooling loads, but also encourage energy conservation behaviours. Referring to the local culture, Bande et al. [149] and Al-Masri and Abu-Hijleh [150] suggest that having zones separated by interior partitions and better-planning of building orientation during the design phase can bring energy savings from reduced cooling loads.

In the USA, Sovacool [151] notes that energy users believe they are entitled to energy-intensive standards of living. Meanwhile, utility companies believe it is their duty to provide energy at the lowest cost possible. In the residential sector, 51% of a household’s annual energy consumption comes from just two energy end uses: space heating and air conditioning [152]. However, despite the USA being the second largest CO₂ emitter globally,
Brown [153] indicates that energy efficiency benefits are often meaningless to energy consumers since such benefits are not often directly observable nor tangible. In fact, some studies even indicate consumers’ resistance towards renewable energy sources given that consumers only desire what electricity enables rather than the sustainability attributes of the electricity itself [155–157]. This is perhaps due to a culture of abundance, with Sovacool [151] suggesting that economic and resource prosperity not only affects the way Americans use energy but also government energy policies.

3.4 SHT media analysis

Given that SHTs do not center on one specific theme and do not follow a prescribed standard model, our empirical material assesses the extent to which SHTs are considered, adopted and used differently in various cultural contexts. To complement our interview data and to give a useful comparative overview, we undertook an SHT media analysis and divided the contents into 5 different categories (explained below) across three cultural contexts (Western (USA/UK), Middle Eastern (UAE) and Asian (Japan)).

- **Enhanced control**: SHTs allow users to control multiple devices for diverse functions (e.g. lighting, temperature) regardless of their location and customize settings according to preferences.
- **Improving lifestyles**: SHTs can assist users with busy lifestyles allowing them to find time to do the things they care about the most. SHTs, also allow users to have peace of mind and through their use, households can enjoy personalized and enhanced experiences.
- **Protect what you love**: SHTs can turn users’ households into secure and safe spaces.
- **Improve family interactions**: SHTs facilitate family interactions, not only through security and health functions but also by allowing family members to more easily connect with each other.
- **Green living**: SHTs can help users better manage their household energy consumption and hence pave the way towards a low-carbon future.

The frequency with which each category was found in the media we analyzed is shown, and ranked, by cultural context in Table 5 and Figure 4 below.

| Rank | Frequency | Theme                  |
|------|-----------|------------------------|
|      |           | **Japan**              |
| 1    | 5         | 71%                    |
| 2    | 5         | 71%                    |
| 3    | 2         | 29%                    |
| 4    | 0         | 0%                     |
| 5    | 0         | 0%                     |

| Rank | Frequency | Theme                  |
|------|-----------|------------------------|
|      |           | **UAE**                |
| 1    | 3         | 60%                    |
| 2    | 2         | 40%                    |
| 3    | 1         | 20%                    |
| 4    | 1         | 20%                    |
| 5    | 0         | 0%                     |

[Table 5 and Figure 4]
Table 5: Media content analysis by cultural context ranked from high to low according to themes. Source: authors

| Rank | Frequency | Theme                  |
|------|-----------|------------------------|
| 1    | 4         | 71% Improving lifestyles|
| 2    | 4         | 57% Improve family interactions|
| 3    | 3         | 43% Enhanced Control   |
| 4    | 2         | 29% Protect what you love|
| 5    | 1         | 14% Green living       |

Figure 4: Graphical analysis of media examined on smart homes. Source authors

As our results indicate, the promise of SHTs currently revolves mostly around improving users’ lifestyles. As illustrated in Figure 5, while one might consider smart air conditioning systems to provide the most value via improved energy efficiency, the advertisement emphasizes instead peaceful rest and personal comfort. In this sense, manufacturers seem to suggest that by adopting SHTs, users will experience greater comfort and be able to find time to do the activities they care about the most; whether these are related to spending more time with family members, finding a space for enhanced social interactions or simply relaxing and having greater peace of mind. Indeed, green living was conspicuously absent from most of the media content we analyzed. These results corroborate some of the market trends portrayed in Figure 2, where home energy management systems are shown to have represented only 2.2% of the global market share for SHTs in 2018.
Figure 5: Media advertisement from Panasonic used in Japan to link smart air conditioning systems with peaceful rest.

Although our sample is small, the media content analysis does reveal that key messages change based on cultural context. In the Western countries, which share many of the same cultural traits as noted in Section 3.3, the main messages are related to unlocking convenience through improved lifestyles followed by improving family interactions while in the UAE, the category of family interactions went by unnoticed while green living was prominent. The prominence of green living as a theme in the UAE SHT media is perhaps surprising given the country’s comparatively high per capita CO₂ emissions and household emissions (Table 2). The result is not so surprising, however, when one considers the country’s significant efforts to promote an image of sustainability through developments like Masdar City and the establishment of a Ministry of Climate Change and Environment. Clearly our media analysis reflects broader messaging aligned with environmental sustainability.

In both the West and the UAE, it is clear that SHT adoption is oriented toward convenience but SHT is not considered as important for family interaction in the UAE. The Japanese society seems to have greater interest in control when it comes to SHTs.

4. Cultural applications and uses of SHTs

In our interview data analysis, we focused on identifying the most salient themes that emerged across cultures regarding SHT adoption and use, barriers to SHT adoptions and the interplay between SHTs and sustainability. Table 6, first presents the seven general adoption and use themes that emerged from our expert interviews, ordered by the frequency by which they arose.

| Rank | Frequency by interviews | How SHTs are used across cultures or due to culture |
|------|-------------------------|--------------------------------------------------|
| 1    | Japan: 3  UK: 3  USA: 4  UAE: 4  Total: 14 | 37% Varying and differentiated social uses |
|   | 2 | 4 | 2 | 5 | 2 | 13 | 34% | Assisting with aging and living with the elderly |
|---|---|---|---|---|---|-----|-----|-------------------------------------------------|
| 3 | 2 | 4 | 1 | 5 | 12| 32% | Pursuing luxury and status                        |
| 4 | 5 | 1 | 0 | 4 | 10| 26% | Attaining a more resilient home                  |
| 5 | 1 | 1 | 4 | 3 | 9 | 24% | Enthusiasm for new technologies                  |
| 6 | 1 | 1 | 0 | 2 | 4 | 16% | Achieving trust, safety and security             |

Table 6: How smart home technologies are used across cultures as mentioned by experts (n=38). Source authors

In the sections that follows, we discuss these themes and provide sample interview statements that provide insights into how the themes were uncovered.

4.1 Varying and differentiated social uses

The most prominent theme brought by our experts was the social uses of SHTs. This partly relates to the fact that the home is a unit of social interaction; a socio-spatial system that encapsulates basics forms of social relations [157]. It is under this context that our experts saw the potential of SHTs as a means to enhance such dynamics. For example, research indicates that smart homes can facilitate social connectedness in two ways. First, through connections between the user and the devices in his or her smart home. And second, by generating connections between the smart home devices in other people’s homes [158].

While the first means of connectedness represents the technology as a social agent able to provide social support, the second seeks to connect with other SHT users in terms of affectivity or even to promote economic activities (e.g. peer2peer). Our experts noted these applications of SHTs when they commented:

UAE07: So a friend of mine, his family usually travelled during summer to France, but he stayed in Dubai because of work and he wanted to see his children. So he asked his family to buy an echo device in France so that he’d be able to break the local firewall and see them virtually. So that is sort to say how people may use these technologies here, through hacks to see their families every day. This also shows how due to cultural barriers, technology could be used for purposes that were not originally intended.

JP01: I think that SHTs cannot only influence local users, but also communities by changing people’s lifestyles. For example, cultural changes could come in neighborhoods, people could start sharing the use of electricity and digital technologies will facilitate this. Communities can share their EVs too, so I see SHTs changing cultural lifestyles and creating more interactions within our neighborhoods.

US11: There were some discussions in the USA about politeness and children and the use of voice assistants. There was the idea that you should teach your children to be as polite to the voice assistant as you would be to a human. Otherwise, children could think that just by commanding things, they’ll get what they want, and I do not see any value in that.

These quotes underscore the variegated uses of SHTs, from remaining connected to distant family members, to sharing lifestyle norms, to disseminating news about electric vehicles, to establishing norms of politeness.
4.2 Aging and living with the elderly

This collection of evidence from interviews all pointed to interactions with the elderly, especially from Japan, given the country’s significant elderly demographic (see Table 2). Smart home technologies provide applications that go beyond the social space and can also operate as means to monitor the well-being and activities of their users, improve overall quality of life and promote independence [159]. Indeed, many of these applications have been developed to support older adults’ well-being and to help them in making their daily tasks easier. Particularly, SHTs aim to assist the elderly with maximizing their physical, cognitive, and sensory capabilities [160]. Our experts commented on these cultural attributes of SHTs as follows:

JP02: I think there is a lot of potential with the ageing population in Japan, so the monitoring systems to see whether if your grandma has fallen or if she’s doing fine are important. That kind of markets have huge presence here.

JP06: So, this is a cultural application of using SHTs for monitoring the health of the elders. In smart cities the focus is on the health of this population segment, and I can see that this may become the main application for smart homes.

US10: We found that the elderly population is surprisingly very interested in these technologies and are very engaged with them. For instance, my father in law is the one that first recommended me to buy a smart speaker.

These quotes all connect SHTs to the needs of an aging society.

4.3 The pursuit of luxury and status

Homes are associated with social status, economic capabilities and even identity [161] and housing often signals relative levels of income and wealth [162]. While other studies suggest that individuals that are up to date with the latest technology convey a certain level of status [163], the relation between technology and status, is not new and can be seen in different technological objects ranging from vehicles [164,165] to smart phones [166,167]. Experts during the interviews commented on the cultural links between signalling status and the adoption of SHTs when they stated:

UAE04: I can see these technologies as not really offering anything new to the consumers but rather only serving to allow them to have cool stuff in their homes but without any benefits. SHTs here are not really targeting a mass market but instead the rich who can afford them.

UK04: SHTs are currently driven by status – not environmental motivations. It’s technophilia, rather than technophobia, with people needing to possess and purchase the coolest gadgets… SHTs remain high end goods and are bound up in identity and significations of wealth and social status. Smart homes become a way of showing off to friends as well as demonstrating competency. So people who work at home—cooks, musicians, childminders—may start to indoctrinate the idea that to do these things well, you need smart home systems … The sole purpose of SHTs is to keep going further and faster along current trajectories, not about transforming the system or questioning its underlying assumptions.
These quotes reveal that SHTs can perpetuate feelings of being “cool” and enhancing one’s social status.

4.4. Attaining a more resilient home

Given the increasing dependence on electricity for most daily activities and vital services, there is a need to enhance the resilience of electricity delivery, especially in the case of extreme weather conditions and natural disasters [168]. In fact, research indicates that disruptions in power systems from natural events pose a real threat in today’s technology-driven culture [169]. It is in light of these considerations that our interviewees mentioned utilizing SHTs to achieve resilience within their culture, especially after disasters, as might particularly be expected in Japan.

JP03: Emerging models of smart homes are more resilient than those of the traditional centralized model. Particularly looking at what some disasters, such as earthquakes and typhoons, could cause. People became extremely concerned about the resilience in the energy systems after the Fukushima accident. What people do not see is that models such as peer2peer can facilitate decentralized distributed energy systems and do not rely on centralized big power plants, making distributed energy models more resilient to natural disasters.

JP06: There is this emphasis on resilience towards natural disasters in smart grids and smart homes. I think this is the defining attribute of Japanese technologies. I do not think you’ll find the same focus in other countries. Here in Japan, it is all about seismic resilience and the market does not value other attributes of smart homes, such as energy efficiency.

UAE03: SHT initiatives are driven by the government to prevent fires in buildings, museums and schools and also to prevent other sorts of incidents. So, although these technologies are not yet very popular among customers, the potential the government sees in terms of prevention and resilience is huge.

These quotes emphasize the resiliency benefits of SHTs, especially when earthquakes, fires and perhaps other security “incidents” are salient to the users.

4.5 Enthusiasm for new technology

Digital technologies have penetrated most aspects of our society, including markets, labour relations and institutions. Their impacts have also shaped cultural, social and civic practices [170]. Advancing digitalization has become a priority for most countries as lack of connectivity could lead to barriers to participating in economic and social activities [171]. This growing prominence of digital technologies is foundation to another cultural element emerging from our data, enthusiasm for SHT adoption and a fascination with high technology:

UAE02: Income is going to be a big driver for SHT adoption, so probably these are not going to take off amongst the lower income segments of society. However, in the UAE, you have a good mix: reasonably high-income levels, an indigenous society very keen on technology and the segment of expats that have decided to buy their properties and are keen in making their homes more efficient.

JP06: Another thing is this fascination with technology rather than structure. The disadvantage is that both elements go out of fashion real quickly. And because
technology and structure grow old so quickly, there is no value for them in the market.

US07: Absolutely, it is a little tricky because there is a lot of individual variation even within a society, even in my town, in Berkeley, some people are technology evangelists or early adopters and other people are technophobes. This duality happens within the bay area where there is a big tech industry.

These quotes bracket enthusiasm for SHTs and how such enthusiasm circulates around income, technological literacy, and a desire to be an “early adopter”.

4.6 Trust, safety and security

The next theme highlights how trust in technologies influences that perception that homes are secure places. Yet, we note that trust represents a trade-off between the intrinsic value of SHT and the vulnerability they can create [172]. Therefore, another cultural dimension emerging from our data was related to trust, safety, and security, and how people may willingly share their data or be monitored:

UAE08: In terms of data, people in the UAE are not very resistant to share their data. Basically, because the government itself has communicated to the whole society that data is important to improve the society’s wellbeing. However, I know that not everyone will buy this, and people will look deeper into it.

JP07: Younger generations have also welcomed SHTs. For them, these technologies are easy to use and they are not very concerned about privacy. They learned to give their personal information away and grew up knowing these tech companies.

US09: I heard about the different bins of people and the different marketing strategies targeted. I think there is a whole issue around security, and I think that has a lot to do with where you happen to live. I mean, I live in a town where when I go out, many times, I don’t even lock my door. But it’s just where I live. In most areas within the US, that wouldn’t be the case.

Such quotes contextualize SHTs and somewhat dissonant notions of privacy, control, and personal security.

4.7 Cultural uses in comparison

Interestingly, regardless of the country examined, some socials aspects of SHTs seem transversal or commonly shared across cultures. For instance, we found that in Japan and the USA, a key social aspect of SHTs was related to procurement for the elderly, while in the UAE, SHTs were often seen as a mean to stay connected with friends and family. Meanwhile, in the UAE and the UK, a recurring perception was that SHTs are related to status, whereas in the USA and Japan, this was not as relevant. The ability of SHTs to turn homes into more resilient places was a notable theme in Japan and while of little concern in the UK and USA. These perceptions in Japan’s are likely related to the country’s history of natural disasters as well as the Fukushima nuclear power incident as we have noted in Section 2.2. Regarding tech enthusiast societies, the UAE led this theme followed by the USA. Perhaps, the enthusiasm for technology, particularly in the UAE is related to a youthful demographic (see table 2). Indeed, research indicates that younger generations are more likely to embrace digital technologies in comparison to older generations [173]. Corroborating this perception, UAE06 noted: “here, the generations are very young, they
...grew up knowing what it meant to be connected and many aspects of their lives are taking place online…this segment of the society is driven by technology in most aspects of their social lives”.

5. Cultural barriers to adoption of SHTs

Although discussion of cultural applications and uses to drive SHT adoption were prominent in our interviews, so were potential cultural barriers. Our material revealed seven interconnected barriers to adoption as shown in Table 7.

| Rank | Frequency by interviews | Cultural Barriers to adoption |
|------|-------------------------|-------------------------------|
| 1    | 4 8 8 8 28 74%          | Privacy, security and mistrust |
| 2    | 2 4 7 1 14 37%          | Digital skills gap            |
| 3    | 2 5 6 0 13 34%          | Lifestyle compatibility       |
| 4    | 2 5 4 1 12 32%          | Resistance to control and dependence |
| 5    | 1 3 1 4 9 24%           | Home ownership                |
| 6    | 0 1 1 4 6 16%           | Religious and gender roles    |
| 7    | 2 0 0 2 4 11%           | Linguistic challenges         |

Table 7: Culture barriers to smart home technology adoption as mentioned by experts (n=38). Source authors

5.1 Privacy, security and mistrust

In order to maximize their efficiency and performance, and also to move up to greater levels of smartness, SHTs need to collect a great deal of information about houses, affiliated technologies (such as appliances and even vehicles), user demographics and consumption patterns [174]. However, this creates a risk that such data can be stolen or misused. Our experts commented on these aspects when they stated:

UAE02: Here in the UAE, there is a very strong emphasis related to the privacy of the home. Here, the home could be seen as a sacred place, so there might be issues around invading people’s home with these technologies.

JP03: In Asia, the idea of protecting privacy is different in the sense that people would be more willing to provide data in exchange for a service without worrying so much about their privacy.

US04: I do not have Ring cameras for instance, because I have significant concerns about my privacy and the privacy of guests coming to my house. With Ring camera, we know Amazon owns it, so all the data that the camera collects goes to Amazon and Amazon can use these data in many different ways without my guests really knowing that their data has been used. So if you have a Ring Camera, any visitor you have at your home will have their privacy violated. Amazon’s facial recognition software allows Amazon to know that you came to my house, but you never agreed to that, you never agreed on having your information being sent to Amazon.
UK05: At the highest levels of smartness, homes are especially vulnerable to hacking and security breaches. So, it’s a paradox, the smarter your home is, the more vulnerable you become. Current security experts talk about how even a simple smart device like a toaster can be an entry for a hacker into the entire home. It creates a soft underbelly that thieves and hackers can exploit.

These quotes add contrast to the more ebullient thoughts displayed in Section 4. Here, we see SHTs being critiqued for invading privacy, for enabling surveillance capitalism, and for increasing vulnerability to hacking and other malicious digital acts.

5.2 Digital skills gap

Difficulties in SHT usability and learning also arose as a risk. Issues include SHTs being perceived as not being easy or intuitive to use, not only by households but other elements of the smart tech ecosystem. SHTs require that users “adapt” or “domesticate” them into their lifestyles. Respondents framed this by noting:

UK03: A final thing I want to stress is learning. SHTs require user learning, but learning isn’t limited to users. System operators and business facilitators also have to learn, so do regulators; learning occurs across all of these actors, and accountability becomes even more important in a smart system, precisely because it is so distributed.

US06: I guess the only cultural matter for me would be not regarding ethnic roots but rather culture in terms of being tech savvy or young people versus elderly people. That is the only difference I see. But I am not sure if a Hispanic home would use Alexa differently or if here, in the US, we will use some IoT devices differently than in Europe. I guess that the main aspects of some these technologies is to improve efficiency so people that are not very tech savvy, would not use these technologies in the most efficient way, which could certainly lead to trade-offs in sustainability.

These quotes underscore the notion that SHTs may not benefit those who have difficulty in learning digital skills and may exclude those who do not consider themselves technologically savvy.

5.3 Lifestyle compatibility

This third category of barriers to SHT adoption concerned incompatibilities with lifestyle. We note that the transition towards a digital society has put pressure on personal and public values such as autonomy, privacy and dignity. In turn, this dynamic has made SHTs conflict with certain lifestyles as illustrated by our experts below.

JP04: Unconsciousness is very important to us, we do not order commands to the devices, the devices should recognize what we want to do. One company started developing a technology that actively talks to users, so instead of you ordering Alexa to do something, the device would say: Dylan, would you like to watch TV, now? So the system operates the other way around as Amazon does where you command the technology.

US01: This could be related to a very specific group of users. But elderly people do not want to give away their tasks. They often say: these are the only tasks we have during the day, we do not want a machine doing them for us and taking away what we can still do. People want to be active, otherwise, they perceive themselves as not having healthy lifestyles.
UK07: The first word that this brings to mind is terrifying. SHTs are terrifying because homes should be a place of seclusion and safety, while SHTs typically require a digital intermediary that is connected to the home via the internet and a set of hardware which is, by design, insecure and not updatable.

These three quotes reveal how SHTs may not be compatible with those that desire to be in control of technology (rather than the other way around), that value manual tasks, or that are wary of relying on digital “intermediaries.”

5.4 Resistance to control and dependence

Other evidence from our interviews involved opposition to the loss of control or increased dependence brought by SHTs. Indeed, research in this area has explored how SHTs could deliver conditions where people serve the systems, rather than the systems serving the people [10]. While other studies have highlighted that ceding autonomy and independence in the home for increased technological control is the main perceived risks from a users’ perspective [175], our experts elaborated:

US07: As a cultural market barrier, I would say that most of the devices are made by large companies that are aiming to control the smart home ecosystem and lock users within their own ecosystems. If companies were willing to work together, the market could encourage further developments in terms of automation.

UK03: Interoperability issues and incumbency can get in the way of smart tech uptake. It may also mean people get left with stranded assets, some specialized pieces of tech that no longer work, but the companies making them have gone out of business.

These quotes reveal possible business concerns over SHT switching, interoperability, and planned obsolesce.

5.5 Home ownership

Homeownership was another notable barrier to SHT adoption. Research in this area indicates that home-owners are more likely to invest in energy efficiency measures and renovations [176,177]. On the other hand, landlords and tenants of rented accommodations, although are aware of the opportunities for SHTs, are less likely to make such investments unless governments provide assistance [178]. On a similar vein, experts we interviewed made comments on such matters:

UAE02: The majority of people (who are expatriates) rent rather than buy a home. If you live in an apartment building the air conditioning use is usually included within the rent, so the landlord will pay for those charges. So why would anyone want to invest in more efficient technologies if they do not have any incentive to do so?

JP07: Now, rather than owning a home, people are deciding to rent and when people are renting, they do not have any incentives to invest in their homes to make them smarter.

UK09: There are a lot of people who aren’t going to be incentivized to buy these sorts of technologies and landlords are not incentivized to provide them either. I think property ownership has been a huge barrier for us regarding smart meter deployment.
and I think it’s been a huge barrier for other areas too. We have seen it before in the rollout of super-fast broadband where governments had to intervene because landlords didn’t give access to broadband connections for superfast connection installations.

These quotes rightly identify concerns that SHTs will not necessarily be appealing to those renting (rather than owning) homes, who constitute a substantial share of the population in all of our case study countries.

5.6 Religious and gender roles

Roles and norms about religion and gender also came up as SHT adoption barriers during our interviews. The quotes presented here are not only related to the unequitable distribution of benefits resulting from digitalization among genders, but also the potentially harmful gender biases entrenched by SHTS [179]:

UAE03: many women need to cover their faces, so having cameras around or even services such as Zoom are not very welcome among segments of the population. Probably very conservative people would not like to see their family members using Zoom.

US11: And of course, there’s the misogyny that comes out of SHTs, particularly with voice assistants and smart speakers, where people are just terrible towards them. There are stories about people sexually harassing Alexa and Alexa not being programmed to push back to sexual offenses. This sort of trains a man to think that a woman will just accept sexual harassment. I think there is a lot of stuff there to look at and this needs to be addressed. It would be very interesting to study the interaction between males and females with voice assistants depending on the country.

These concerns draw attention to issues of SHTs and digital harassment as well as forms of patriarchy.

5.7 Linguistic and software challenges

A final interesting barrier to SHT adoption was language. As our evidence confirmed:

UAE02: There might be language issues, how many of these technologies are available in Arabic versus English?

JP01: I think the main cultural barrier for their deployment is that people in Japan do not understand the purpose of the technology and also a big barrier is the name of the technology as it comes from oversea markets. In Japan, as our language is totally different to English people will face troubles with these technologies, particularly the elderly, who do not understand the name and/or the meaning of SHT. Maybe this is a particular challenge in terms of culture for Japan.

Related to these comments, studies have shown that SHTs from Apple, Google, IBM, and Microsoft not only do not support a large number of languages but also have racial biases embedded in their systems [180]. Others have warned that smart speakers may cause a loss of regional accents given that device interactions often require deliberate and clear speech
that conforms to “standard” dialects [181]. Moreover, the inability of smart speakers to understand users’ commands places certain groups (i.e. people with visual or movement disabilities who rely on voice recognition and speech-to-text tools) in a more vulnerable position [182]. For these groups, being misunderstood by SHTs could result in serious consequences for health and safety. **Table 8**, below, could help explain why some experts commented on how language signified a cultural barrier for SHT adoption, particularly, looking at smart home hubs. The major hubs from US manufacturers do not support the Arabic language or, in the case of the first-generation Amazon Echo Dot, Japanese. Similar to frustrations experienced by smart phone users, new devices and device models may have limited language support with the clear bias toward English.

| Device          | Supported languages related to this study | Sample users’ experiences (from Blogs and websites)                                                                                       |
|-----------------|-------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| Apple HomePod   | Japanese, English and Arabic.             | Wired magazine notes that Apple’s Siri was hit and miss with one customer in the article commenting “…all these apps are stupid. They’re supposed to be intelligent machines, but they’re useless.”. |
| Google Home Hub | English and Japanese                      | Often, users complained about Google not supporting Arabic languages which represent hundreds of millions of speakers. Ironically, some users commented that it does support very specific western languages. |
| Amazon Echo     | English and Echo (Gen 1), Echo Dot (Gen 1) do not support Japanese. Users will have to own the latest versions of these devices. | Amazon does have a roadmap to further support other languages. |

*Table 8* Smart Hub language support. Source authors.

These linguistic challenges buttress other concerns about software and culture. Face recognition, for instance, often fails when presented with women's face coverings or faces of people from African or Latin American decent [186]. Because artificial intelligence algorithms used in face recognition and language translation can reinforce human biases, designers and manufacturers must make further efforts to be culturally sensitive to ensure that diffusion of SHTs among diverse groups is not impeded.

### 5.8 Cultural barriers in comparison

Again, some of these elements seem common across different cultural contexts. Experts across our entire sample reached a consensus that the main barrier to adoption of SHTs is related to privacy, security and mistrust. Hence, our results, not only indicate that regardless of the user nationality these aspects represent a fundamental cultural barrier for adoption but also corroborate existent findings that note that security and privacy issues are the main deterents to SHT adoption [9,26,174, 187]. US06 made a statement on this subject when he noted: “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”. Regarding our second
most prominent theme, digital skills gap, this subject was more often noted by USA and UK experts. In contrast, only a few experts (three in total) from the UAE and Japan commented on this issue. Our results, furthermore, seem to indicate that both UK and USA citizen are more resistant to control and dependence from SHTs than those in the UAE and Japan. This is consistent with the modes of government and societal norms in these countries.

Moreover, home ownership was a barrier most commonly mentioned by experts from the UAE and this notably relates to the number of expats living in the UAE who rent property rather than own it (see Table 2). As UAE02 put it: “The lack of incentives for expats to invest in pricey digital technologies due to a lack of home ownership constitutes a huge barrier for SHTs’ adoption”. Religious and gender roles were themes more frequently brought by UAE experts, perhaps because of a more male dominated and religious society relative to either the USA, or the UK or Japan. Linguistic and software challenges, our last barrier, was only brought by experts from Japan and the UAE, perhaps for obvious reasons, as we have commented in section 5.8.

6. Sustainability and SHTs

Our findings on sustainability were more nuanced and complex, as we documented some instances where SHTs can enhance sustainability (see Table 9) but noted the troublesome ways in which SHTs can also degrade sustainability (see Table 10).

| Rank | Frequency by interviews | Cultural factors supporting sustainability |
|------|-------------------------|--------------------------------------------|
|      | Japan | UK | USA | UAE | Total | %   |
| 1    | 3     | 4  | 1   | 5   | 13    | 34% |
| 2    | 3     | 1  | 1   | 4   | 9     | 24% |

Table 9 Cultural factors supporting sustainability mentioned by experts (n=38)

| Rank | Frequency by interviews | Cultural factors inhibiting sustainability |
|------|-------------------------|--------------------------------------------|
|      | Japan | UK | USA | UAE | Total | %   |
| 1    | 3     | 5  | 6   | 3   | 17    | 45% |
| 2    | 3     | 2  | 6   | 2   | 13    | 34% |
| 3    | 2     | 4  | 0   | 2   | 8     | 21% |

Table 10 Cultural factors inhibiting sustainability mentioned by experts (n=38)

6.1 Desire to achieve living standards with greater efficiency or sustainability

An important benefit identified for SHTs was their ability to promote more sustainable behaviours. Indeed, SHTs could benefit users in myriad ways, but most notably, by shifting towards more sustainable lifestyles through personalised feedback and the social pressure of comparative information [93,94]. SHTs combined with smart meters are also
central to the operation of smart electricity grids that leverage demand response to help balance intermittent renewable energy [189,190]. Experts corroborated these perspectives when they expressed:

UAE01: Cities most often have these three elements that I like to call the three Ss if they want to comply with the living standards of the citizens. Cities need to be safe, sustainable and smart. I think these technologies aid the city in achieving these goals.

US07: I guess the bigger barrier is not SHTs per se but more affinity or interests in the culture of green living or living efficiently to reduce environmental impacts.

JP06: In Japan we have these massive developments with 300-400 rooms and each of these rooms have its own home energy management systems (HEMS) installed. This approach has huge advantages for smart grid management because you have a number of people sharing the same technology in their houses, so there’s better interaction with the energy system. HEMS, which are becoming the common living standard in some Japanese cities, could also provide individual benefits since systems could nudge users to change their behaviours.

JP01: From an energy system perspective, these technologies can facilitate uptake of distributed energy resources, such as solar PV and wind power. At the individual level, SHTs allow energy users to better understand their energy consumption and based on that, make better informed decisions to improve their homes’ efficiency.

These quotes illustrate some of the possible benefits of SHTs, including enabling smart cities, creating cultures of green cities, and facilitating other innovations such as renewable energy or energy efficiency.

6.2 Environmentally aware and conscious society

Other respondents discussed how SHTs could facilitate greater environmental awareness and help in promoting and maintaining inherently cultural values related to resource conservation. As such, experts stated:

UAE06: If you are looking at the region, sustainability was one of the main things promoted by early inhabitants and the idea of conserving resources was something commonly mentioned in the Islamic culture … if those values about sustainability are in the culture, they could definitely help and then SHTs can help nudge people to accept less comfortable conditions.

JP08: Japan is a very small country and we are an island, so there is this culture about conserving natural resources for the continuity of business. For example, we have a big dependence on the Middle East’s oil and smart homes represent an opportunity for autonomy with less reliance in energy imports.

These quotes support the sustainable credentials of SHTs by demonstrating how they can entrench sustainable values or help reduce energy imports.

6.3 Luxurious lifestyles

Contrary to sustainability, energy rebounds and wasteful consumption were raised as an issue in more than half of our interviews. This refers to the fact that many SHTs are not
about saving energy or becoming more sustainable, but prioritizing other issues such as comfort, luxury, or convenience.

UK04: There is little evidence smart technologies have a positive effect on sustainability. They are driven by other, non-environmental desires that often lead to increases in energy demand. People who adopt smart tech feel good, embodied in the sensory feedback of the devices, and other people say they look good with their smart tech, so the whole thing works against a culture of energy demand reduction. The culture of the home focuses on high tech, but not thoughtful consumption, not on efficiency, or simplicity. It is not a culture that prioritizes energy demand reduction as key form of social feedback.

UAE06: This brings me to the standard of living. Here, in the UAE, people have adopted a consumerism culture, where it is all about living conveniently. But this is not about nationalities, I think it is the culture of the city, how the business model of the city operates. I mean there are expats coming from other parts of the world, where their cultures are all about saving resources and they come here and adopt more extreme and extravagant lifestyles and that could reflect this kind of consumerism culture.

JP06: Most of the focus in the smart home advertising is that the advantage of using these technologies is related to comfort. I think that message is really selfish, the kind of message that says to the consumer: you can be happier and more comfortable living in this house by buying more stuff. There are no messages like “by decreasing your ecological impacts the earth can become cleaner and a more beautiful place to live”. There is nothing about that as it is all about being selfish and self-gratification for the consumers of the house. So the market is really focusing on framing these technologies as increasing comfort, which may very likely lead to rebound effects and more waste.

US10: Some of the data we’ve seen is that energy often comes as a tertiary benefit or driver for purchasing, not the first, not the second, but the third. People are more interested in control and convenience than in energy and sustainability.

These quotes collectively call into question some of the sustainability benefits of SHTs, noting that they can lead to energy rebounds, support the prioritization of excess and luxury over efficiency, entrench selfishness, and cause other values (such as convenience) to be placed ahead of the environment.

6.4 “Dispose of it” cultures and planned obsolescence

A related concern with SHTs was their disposability and short product lifetimes. This is closely related to the lack of legislation to tackle planned obsolesce and increase product lifespan. Improving product durability and reparability can save natural resources and money for consumers [191]. In this regard, experts noted

US05: My sense is that we are still falling short of the real potential of these technologies. People might buy this stuff and perhaps use it for a while, but if it breaks somehow, or if users changed their router or they turn it off and technologies stop working, what would users do next? At the moment, technologies seem very fragile for realizing their true potential.
UK05: A colleague, around 5 years ago, replaced every lightbulb in her house with a Philips Hue lightbulb. Philips came out with an update that required her to update every lightbulb manually. She spent days doing it. When she told me, I looked at her and said ‘I would have ripped out every single one and thrown each away’.

These quotes both detail the potential for SHTs with poor quality or intentionally short lifetimes to cement wasteful practices or result in the installation of seldom used systems.

6.5 Lack of awareness or concern for embodied energy and emissions

A closely related environmental risk is resource and materials intensity. Indeed, research indicates that SHTs have additional communication, processing and display requirements relative to traditional, “non-smart” technologies, and producing these components requires additional materials and energy [101]. Moreover, the increasing demand for connected products could lead not only to an overall increase in energy use for material extraction, but also material processing, and component manufacturing [26,101]. It is in this context that our interviewees commented.

UK03: There is a risk of using smartness in an overly-abstract way, something ‘whizzy and weightless’ … [but] a cloud is lumps of metal somewhere, lots of processors, materials, and energy usage. In the same way, smart technology requires extraction and processing of an abundance of materials. It has meaningful and measurable social and ecological impacts, given that many of those materials come from troubled parts of the world.

UK07: E-waste risk is obviously bad, it is quite a hidden thing, and not many people have looked into the environmental footprint of the manufacturing processes of these devices. It is often the case that waste gets shipped-off to west Africa and little boys and girls manually dissemble circuit boards, burn out plastic and inhale the horrific toxic fumes of these materials. By doing so, they get a little bit of copper out of it and dig the circuit boards with uncovered hands in pots of mercury to reach the gold and this gives them horrific mercury poisoning…this is a horrific supply chain.

These quotes bring to the fore issues over the embodied resource consumption, waste streams and supporting digital infrastructure (servers, data centres) resource consumption that are usually hidden in discussions over SHTs.

6.6 Sustainability in comparison

Again, in terms of comparative sustainability and the potential for SHT to pave the way towards a low-carbon future, UAE experts were the most optimistic on this matter. This reflects an awareness of sustainability intrinsic to the UAE culture but not evident in the environmental performance of a country historically reliant on fossil fuels to meet domestic energy needs and to generate government income. (see section 2.2 and Table 2).

Regarding our next theme, environmentally aware and conscious society, this was a most prominent theme among experts from the UAE and Japan. Possibly, this is because they see in SHTs a means alignment to their cultural values, as UAE01 stated “an Islamic doctrine is to look after limited resources…is to care for our planet” While JP07 corroborated noted: “elderly people in Japan experienced a scarcity period, so conservation is a big part of our culture. We have a culture of resource savings and SHTs can help us in reaching that goal and transmitting this value to younger generations”.
In contrast, the majority of UK and USA experts, rather than seeing in SHT a mean to promote resource conservation and efficiency, perceived these technologies as means to enhance comfort and convenience, which may as well lead to unsustainable energy practices. On this matter, US07 put it simply when he observed that: “energy efficiency and conservation is not going to sell smart home technologies, it’s got to be the convenience and added functionality”.

Another lever of unsustainability was related to the idea that SHTs promote a disposable culture, this theme was dominated by experts from the USA and Japan. For the latter, JP06 provided an explanation when he noted: “The average lifetime of the house in Japan is 30 years. Therefore, homes, like cars, are disposable and can be thrown away. This also happens to technologies within homes, their lifetimes are often short and then they are thrown away”. The final notable theme we found was related to concerns of embodied energy and emissions. This theme was predominantly highlighted by UK experts followed by experts from the UAE and Japan. We were a bit surprised to see that this theme was omitted by USA experts.

7. Conclusion

In conclusion, the findings of this work show that across cultures, SHT adoption is currently driven by the personal comfort and lifestyle benefits SHTs can afford and this is further reflected in current SHT market trends. This is consistent across national cultures and evident from both interview and media analyses. In considering the contexts of the countries we studied (Table 2), all are urbanized and upper income although with differing socio-political contexts. In the case of Japan, a distinct demographic also is present. Although Japan’s aging population and societal concern for resilience clearly impacts how SHTs are viewed in that country regarding opportunities for elder care and community resilience, SHTs are generally viewed across our sampled countries as leisure and entertainment devices for the affluent. Further, cross-cultural concerns exist regarding the intrinsic value of SHTs, particularly given the threats they may pose regarding privacy and cyber-security and the inability for those not technologically savvy to function successfully in an SHT-dominant context. Despite understanding sustainability concerns, we found that SHTs are generally not associated with sustainability. Only the UAE media seem to make this important connection and clearly there is yet to be any significant link to sustainability performance in that country (Table 2).

Therefore, realization of the potential sustainability benefits of SHTs requires that these technologies are designed and manufactured with consideration of not just economics, but also the social and environmental impacts of their use. Profligate energy consumption and associated greenhouse gas emissions are a pressing concern and therefore it is important that SHTs have intrinsic environmental sustainability from the perspective of both the design of the hardware and design of the software for energy efficient use. On this point, we have noted that SHT electricity consumption is not inherently counter to climate concerns if the electricity is from clean sources. However, accumulation of waste from discarded SHTs is equally as important and relates directly to the “dispose of it cultures” concept discussed in many of our interviews. Hence, advertisement and promotion of these devices should increasingly tie together strong and positive sustainability messages that are compatible with the lifestyle considerations that already are driving adoption. Unfortunately, this was not evident from our media analysis. Nonetheless, if a course correction can be made, consumers will benefit from seeing that the current drivers of SHT adoption, convenience and entertainment, can be entirely compatible with environmental sustainability. This, in turn
could have positive and long-lasting spill over impacts into other sectors in need of sustainability linkages. SHT ecosystems that move from household appliances and consumer electronics to smart and sustainable grids, neighbourhoods and cities need to be pursued at local, national and regional governmental levels.

In consideration of these points, our work shows that SHTs intersect with culture in compelling and myriad ways, across different applications and uses, barriers to adoption, and even dualistic tensions on sustainability. Our analysis further transcends the standard SHT dimensions discussed in the literature, such as Hargraves and Wilson’s [8] classification of challenges across hardware and software, acceptability and usability, and domesticating technologies into lifestyles, or the Osservatori Digital Innovation del Politecnico di Milano [192] view that the three main barriers to SHT market growth are the installation of products, the integration with valuable services and the presence of established brands. Instead, and as Figure 6 visualizes and summarizes, culture is both a catalyst and an impediment to SHT adoption and can shape SHT adoption and use as well as be shaped by it.
Figure 6: The interactive dynamics of smart homes technology and culture
Indeed, our research suggests that to further advance the adoption of SHTs and meet sustainability goals towards a low-carbon future that is resilient to climate change, manufacturers need to develop SHTs with Value Sensitive Design [193] and Responsible Research and Innovation frameworks in mind so as to better manage the direction of “science and technology in ethically acceptable, sustainable and societally desirable ways” [193 p.4]. This would help ensure that SHTs are designed with cross-cultural human values in mind while further ensuring that they are not be envisioned as standalone products, but instead, as part of a functional system addressing societal challenges. Such a framework is relevant given the rapid evolution of energy systems and the lack of attention paid to such matters in the cases we studied.

In addition, the diversity of our results across cultural uses, barriers, and sustainability underscores how smart homes impact different dimensions of sustainability. We see SHT patterns shaping some dimensions of social sustainability (consumer protection, usability and ease of learning), technical sustainability (reliability and interoperability), political sustainability (threat to governmental systems and, where relevant, loss of autonomy), economic sustainability (capital cost, energy prices, patterns of home ownership) and environmental sustainability (energy use, rebound effects and product materials intensity). Narrowing the discussion or debate about SHTs to only one or two of these dimensions risks obscuring salient patterns across the other dimensions. Sustainability is a multifaceted concept as evidenced by the many dimensions exemplified in our interviewee comments.

Further, consideration of technology justice [194] would help ensure that vulnerable groups (i.e. those with no internet access, the elderly and the those who are not tech savvy) are served well by SHTs [195]. This issue was surfaced in our interviews and reinforces the need for manufacturers to incorporate a systemic vision that considers human values and cultural aspects ‘beyond the western world’ (i.e. for UAE consider the privacy of the home and gender norms and for Japan concerns for resilience and care for the elderly), will the continuous promise for SHTs to improve users’ lifestyles while simultaneously generating economic, social and environmental benefits will be fulfilled.

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