Electronic Devices & Networks Annex EDNA

User-Centred Energy Systems

Are We Getting the Best Out of Smart Home Technologies? The Role of Usability

OCTOBER 2021

Technology Collaboration Programme
by iea

The Technology Collaboration Programme on User-Centred Energy Systems (Users TCP) was launched in 2019 to provide evidence on the design, social acceptance and usability of clean energy technologies to inform policy making for clean, efficient and secure energy transitions.

The Users TCP's fifteen member countries pool resources and share knowledge to build the evidence base on which to establish and adapt energy policy centred on users. Our work programme includes the Behavioural Insights Platform, the Global Observatory on Peer-to-Peer, Community Self-consumption and Transactive Energy Models (GO-P2P) and Tasks focused on Hard-to-Reach Energy Users, Gender and Energy, and the Social License to Automate. The User-Centred Energy Systems Academy disseminates our work through a series of online webinars.

The Users TCP is established under the auspices of the International Energy Agency (IEA) as a functionally and legally autonomous body.

Current members of the Users TCP: Australia, Austria, Belgium, Canada, Finland, Ireland, Italy, Korea, the Netherlands, New Zealand, Norway, Sweden, Switzerland, the United Kingdom and the United States.

Further information on the Users TCP is available from: **www.userstcp.org**

The Technology Collaboration Programme on Energy Efficient End-Use Equipment (4E TCP) has been supporting governments to co-ordinate effective energy efficiency policies since 2008.

Fifteen countries have joined together under the 4E TCP platform to exchange technical and policy information focused on increasing the production and trade in efficient end-use equipment. However, the 4E TCP is more than a forum for sharing information: it pools resources and expertise on a wide a range of projects designed to meet the policy needs of participating governments. Members of 4E find this an efficient use of scarce funds, which results in outcomes that are far more comprehensive and authoritative than can be achieved by individual jurisdictions.

The 4E TCP is established under the auspices of the International Energy Agency (IEA) as a functionally and legally autonomous body.

Current members of 4E TCP are: Australia, Austria, Canada, China, Denmark, the European Commission, France, Japan, Korea, Netherlands, New Zealand, Switzerland, Sweden, UK and USA.

Further information on the 4E TCP is available from: **www.iea-4e.org**

The EDNA Annex (Electronic Devices and Networks Annex) of the 4E TCP is focussed on a horizontal subset of energy using equipment and systems - those which are able to be connected via a communications network. The objective of EDNA is to provide technical analysis and policy guidance to members and other governments aimed at improving the energy efficiency of connected devices and the systems in which they operate.

EDNA is focussed on the energy consumption of network connected devices, on the increased energy consumption that results from devices becoming network connected, and on system energy efficiency: the optimal operation of systems of devices to save energy (aka intelligent efficiency) including providing other energy benefits such as demand response.

Further information on EDNA is available at: **iea-4e.org/edna**

Are we getting the best out of Smart Home Technologies? The role of usability.

Energy Systems Catapult on behalf of the Users TCP and 4E EDNA: Plug & Play

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Contents

1. Executive Summary

Smart Home Technologies (SHTs) are believed to offer potential to support the global effort to reduce carbon emissions [1, 2]. This potential however is not yet being realised, particularly amongst domestic consumers [3]. The Energy Systems Catapult (ESC) have been asked to support the Users TCP and 4E EDNA by conducting an evidence review that looks to understand the extent to which poor usability, at set up and operation, is contributing to this problem.

In addition to seeking available evidence to explore the issue, the ESC engaged with a range of industry experts from a variety of roles, sectors and countries to collate their opinions on the matter. This helped to establish that, whilst usability is considered important by some, it is not a priority for the energy sector at present, with several – addressable – reasons provided. The literature reviewed supported many of the points raised in the expert interviews, as well as contributing additional issues that were not discussed. Largely, but not exclusively, the evidence points to issues with the following.

- The benefits of SHTs are being poorly or inaccurately communicated. This causes distrust and ultimately means users are reluctant to engage.
- SHTs fail to cater to user's complex, diverse and dynamic needs.
- The onboarding experience often fails to prepare users to operate their SHTs, with many feeling intimidated by the complexity of the systems. Errors made during installation further inhibit the ability to engage, or the accuracy (and therefore value) of the feedback provided.
- Automation holds significant promise, but users don't like to feel like they are not in control. When it is deployed poorly it undermines user trust and they intervene.

The findings however suggest an absence of evidence in some instances. This is largely attributable to a lack of evidence available from private industry. Experts explained that businesses did not want to publish findings that would help their commercial rivals bring competing products to market. As such the review is largely reliant on academic sources, which means insights are limited in some respects.

Most notably, the anticipated issue of interoperability is rarely reported. This was largely because trial participants had help installing SHTs into their homes. Despite this, this report is able to consolidate a number of recommendations of how the issues identified can be addressed. Where available evidence is lacking, the report has looked beyond the energy sector, seeking to learn from other experiences when deploying new innovations. These recommendations include.

- Encourage business to create usable, holistic solutions
- Develop shared infrastructures to help speed up understanding of usability issues in the energy sector

- Governments should design markets that flow the value of increased flexibility to the right place in the system, including the demand side.
- Don’t wait for usability issues to emerge, actively seek to uncover them now. The development of shared learning infrastructures can help speed this up.
- Invest in innovation to help the sector understand how to deliver positive and engaging user experiences.

2. Introduction

Smart Home Technologies (SHTs) are believed to have potential to support reduced carbon emissions [1, 2]. These technologies can include, but are not limited to, smart heating, lighting and cooling, electric vehicle charging and a broad variety of smart domestic appliances. Their contribution can be recognised through promoting efficient operation, demand flexibility and status reporting. Reports differ somewhat on the contribution SHTs can make to domestic energy use, but figures generally indicate a potential reduction of between 10-40% is possible [1, 4, 5, 6]. This potential however is not being recognised within the residential sector [3]. Whilst a number of contributing factors are known, one area where there is little understanding is the extent to which users are unwilling or unable to use devices as intended due to poor design, lack of interoperability or substandard installation.

An evidence review has been commissioned by the Users TCP and 4E EDNA to understand the extent to which "usability issues at set up and operation prevent smart devices performing efficiently in the home". The User-Centred Energy Systems Technology Collaboration Programme (Users TCP) brings together the world's leading socio-technical researchers and policy makers from 16 different countries to provide the evidence base needed to make better energy policy decisions. The 4E Electronic Devices and Networks Annex (4E EDNA) is an initiative of the International Energy Agency's 4E Technology Collaboration Programme (TCP). It is an international platform for collaboration between governments, providing technical analysis and policy guidance to its members and other governments concerning energy using equipment and systems.

The review has been conducted by the Energy Systems Catapult (ESC), an independent, not-for-profit centre of excellence that bridges the gap between industry, government, academia and research to facilitate the energy transition. The process implemented for the review consisted of engaging with a range of industry experts as well as reviewing relevant and varied sources. Further to meeting this core objective, the study seeks to explore the following.

- What usability issues restrict connected devices delivering benefits, and what is their relative importance?
- Do proprietary ecosystems cause these problems?
- What could solve these problems?
- What are the lessons from examples of best or worst practice in other sectors?

3. Methodology

3.1. Initial Search Results

As the market is in an early stage, it was unclear whether there would be enough evidence available to justify a full evidence review. Prior to commencing the review, initial search efforts were conducted. These were based on search terms agreed with the Users TCP and 4E EDNA (Appendix A). The findings indicated that there *was* enough evidence available to justify a full review, albeit with a few important considerations with regards to the type of evidence that was available and how this will impact the eventual conclusions of the project.

- **Approximately 70 sources were identified**. Around 60 of these were based on the agreed search criteria. The rest were identified from the EDNA library and the ESC's own project archives. 22 of these papers were considered to be highly relevant to the aims of the project.

- **Most of the available evidence focused on usability issues with smart heating, smart homes, or electric vehicles.** The other agreed search terms yielded far fewer relevant results. These included energy (management) services, hot water tanks, smart appliances, smart plugs, smart lighting, smart energy tariffs, and home battery storage.

- **Many sources were speculative about how the end user would experience the technology**. User engagement tends to focus on how users *think* they would react in a particular circumstance, rather than providing evidence based on lived experience. Furthermore, speculation on potential issues were sometimes made with no user engagement whatsoever e.g. citing a physiology paper that suggests issues are *expected* (but not known).

- **Usability is often an 'after-thought' within several of the studies identified.** In several sources the "usability" aspect appears to receive little attention. Often reports focus largely on whether something can be delivered from a technical perspective. Engagement with the end user is often only a minor part of the study e.g. an opening focus group, or a closing survey.

- **The term "usability" is sometimes inappropriately used**. Many papers citing the term "usability" within the definition of their study tend to mean 'suitability' i.e. is the technology explored expected to be suitable for consumers in the context explored. The International Standards Organisation (ISO) however define usability as the extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use [7]. Ultimately suitability plays a part in usability, but it is an oversimplification to suggest it's the only thing to consider.

- **There is little evidence focusing on issues arising from initial "set up".** The onboarding/installation experience of the consumer is rarely discussed in the evidence identified. Furthermore, many observations are based on perception or conceptual acceptance, with only a few studies looking at operation.

- **Evidence has been identified from several regions around the world.** The UK, Central Europe, Southern Europe, Scandinavia, Africa, Central America, North America, Eastern Asia and Australia are all represented within the sources initially identified. Most evidence however is from North America and the UK.

- **Most sources are peer reviewed academic papers or journals**. Some policy reports summarising "lessons learned", publicised case studies, related literature reviews, and conference papers from industry experts were also identified.

3.2. Agreed Next Steps

After meeting with the Users TCP and 4E EDNA to present the findings from early efforts to identify suitable evidence, the following steps were agreed. It is worth noting that these steps meant that several new sources had to be added to the evidence list as many of the sources initially identified were agreed to be unsuitable.

- **Limit the number of sources that explore the same theme**. Once three or four high quality sources exploring similar subject matter have been identified and examined, discount any additional sources that cover the same subject matter. This will mean that the findings are more balanced with regards to the range of technologies explored.

- **Only include studies that specifically look at usability issues at set up and operation.** This means any study that discusses what users *think* they would do, with no actual evidence of use, are not suitable for further evaluation.

- **Focus solely on technologies that are used *within* the home**. This means any sources exploring usability issues with relevant smart technologies but that occur outside the home are not included. For example, usability issues when attempting to charge vehicles at home are included, but those encountered when attempting to use public charging points are not.

- **Include evidence from as many countries as possible.** Quality, relevance and recency remain the key criteria for inclusion. However, international sources that are of a reasonable quality and/or that are only slightly outside the optimal time period (previous 10 years) should be included wherever possible. To meet these criteria several of the new sources induced were taken from overseas studies (Appendix B).

3.3. Expert Interviews

As part of the evidence gathering approach the ESC sought to engage with several industry experts. This was to capture their informed opinion on the subject matter and enquire as to whether they could indicate any additional evidence sources. The Catapult interviewed 12 experts, from ten organisations within the UK, USA, Germany and Belgium.

- The following types of organisation/expert opinion are represented

    - Flexible energy platform providers
    - Network aggregators
    - Infrastructure/distribution experts
    - Energy suppliers
    - Installers (heat and cooling technologies)
    - Product/business strategy professionals
    - Innovators and start ups
    - Consumer/policy groups
    - System engineers
    - User interface and standards experts

4. New Sources

Very few new sources were identified following the expert interviews, particularly from those operating within a commercial environment. It was a commonly held notion amongst those working for these types of organisations that there was no value in promoting the mistakes made by your organisation. This was because it can enable business rivals to learn from the expensive lessons learned when attempting to bring competing products to market or can be reputationally damaging. Similarly, where success had been observed, it was considered 'bad practice' to let commercial rivals benefit from these learnings.

As such, the additional evidence identified through interviews with industry experts was *entirely* academic or policy driven in nature. Additionally, several new sources were identified once the review was underway. This occurred through detailed evaluation of the references and citations of the sources already identified if proven to be particularly rich in relevant detail. These too are largely academic studies.

5. Engaging with the experts

When engaging with industry experts on the topic, they were asked to reflect on their own experiences within the energy sector. Drawing on examples, they discussed how the issue of usability was generally considered within the organisations they were familiar with. They provided examples of times where usability issues had arisen, reflecting on why the issue had occurred, but also discussed times where they felt areas within the sector had managed to 'get it right'. Finally, they were asked to discuss what they feel needs to occur for the sector to get to a place where the issue can be appropriately managed, highlighting what they perceived to be the key challenges to accomplish this. The following opinions were shared.

Usability is *not* a top priority for the energy sector at this time. The 12 experts interviewed from the subsectors previously discussed all indicated that, in their opinion, the sector generally does not want to invest resource in better usability at present. This was not because usability was considered unimportant, but broadly for reasons that fell into four main categories.

- **Business prioritisation**
  Many markets in the energy sector are quite new, so often developing a functional product to enter the market is considered more important than investing in making it usable. Similarly, innovators and start-ups need to ensure they are financially secure to ensure the long-term status of their organisation. This means a lean approach is often favoured initially, with user experience seen as an expense that can be considered at a later stage.

"Why would we validate a device that works outside our parameters?"

– Business Strategy Professional

- **Lack of market access**
  The market rewards are not yet in place e.g. demand-side flexibility. This means adoption of interrelated technologies will be slow. This has caused some focus on the industrial sector rather than the domestic sector.

- **Network constraints**
  Products that rely on infrastructure in need of investment, but where the decision to invest is taken by 3rd parties e.g. the electricity grid, present a risk. This is because no matter how good the product may be, if the network can only support a finite number, then deployment of the product will be inhibited. They felt there is effectively no point investing in great heat pumps if you can't install many due to network capacity limits.

"If they're easier to use because they're more consistent, they [businesses] are not going to gain some special advantage."

- User Interface & Standards expert

- **The business case for improving usability is often weak**
  Improving usability can be difficult (and therefore expensive) due to the diverse needs and wants of users. Brand identity is considered to be important, conforming to an industry standard makes it harder to distinguish a business from its competitors. Offering interoperability offers risk (technical, reputational and commercial) but no tangible reward. Finally, rapid market change means some are cautious about investing more than the minimum, in technologies that may become defunct. Effectively improving

usability is considered something that can wait until the success of the product seems likely. This however assumes that product success and usability are independent, rather than being interrelated.

Whilst good usability is not a top priority, it was considered crucial to ultimate success. Despite the fact experts felt usability was not a priority for the energy sector, those interviewed from particular sub-sectors (platform providers and network aggregators i.e. those who are not developing the SHTs), indicate user adoption will be critical to their survival. If the home technologies that connect to their infrastructure are improperly used or rejected altogether, they feel the benefits that can be achieved will be severely limited. It was broadly agreed amongst interviewees that the user should be the one to decide what is best for the user.

Experts felt the cost saving benefits of SHTs are being poorly (or sometimes inaccurately) communicated. This can cause users to feel they have been deceived or feel let down by SHTs. This is because the product is unable to deliver the very outcome that motivated them to purchase it in the first place. When users realise the SHT is unable to deliver the value promised, they no longer engage with the system because they feel let down. This disengagement means they cannot act on the feedback provided by the SHT, contributing to inefficient operation. The following channels were where experts felt problems tend to arise based on their own experiences.

- Between those who develop the product and those who market it. Products are being sold based on what the organisation thinks customers will buy, rather than what the product can feasibly deliver i.e. significant energy bill savings.

- Between the installer and the user. Adequate end-user training is rarely provided. This can mean some users don't know how to operate the technology to achieve the outcome they desire. Furthermore, where (necessary) actions performed by the smart system are not understood, users can feel the system is behaving incorrectly or inefficiently, damaging trust.

- Between the engineers who develop the product and the end-user. Experts indicated that in some instance's product development and testing only involves those working within the organisation. Where product development only involves those with a high degree of technical proficiency, it is difficult to observe issues that may present to those less able. Experts felt set up and operation of SHTs should require no technical expertise. This would mean users are less likely to feel overwhelmed and have a more positive experience.

Awareness of how SHTs could help boost energy efficiency is generally considered to be poor. This is said to occur at both a consumer and industry level. At a consumer level it means that users are unaware of available schemes such as flexible energy delivery, but also that they do not see the value or feel motivated to participate in the schemes should they be presented with the opportunity. Lack of understanding at an industry level of how the flexibility market could operate means business often do not see the potential value in participating. Failure for businesses to fully engage with the opportunity results in low investment. Experts repeatedly highlighted the need for market price signals to reward electricity demand reductions at peak times.

Some of the experts interviewed think/hope the issue of poor usability will fix itself. It was suggested that energy has historically been a passive experience for domestic consumers, so there has been little need for technologies to evolve better usability. The energy transition however will require a more engaged user. Some experts felt that those who offer their users a better experience should naturally gain more of the market share. Good usability has become the differentiator in many other markets over time (e.g. iPhones vs previous era smart phones).

"I think it will come. And it'll come rapidly. And as soon as we see these user stories growing further across countries."

- Business Strategy Professional

But improving usability is complicated and could take several years to address. Experts indicated there are several highly complex areas to address that will prove to be particularly challenging if better usability is to be achieved. Response to poor usability however can be slow i.e. some manufacturers may only feel compelled to act if customers complain or refuse to buy their products. This means it could be some time before the sector even *begins* to tackle the issue, by this time however the climate emergency will be in even greater need of support.

- Systems are developed for average users, but this approach is exclusory. There is a vast array of complicated and diverse needs that need to be considered when seeking to support users using SHTs. Older or disabled residents for example, who often spend more time at home (meaning potential savings are greater), are said to be completely overlooked at present.

- It's very difficult to know what the user *actually* wants. A user who increases the temperature rapidly on their heating controls for example, may simply desire a warm radiator to dry clothes, rather than a change in room temperature. In the context of flexible energy delivery, this means the scope to alter the conditions within the home are unknown i.e. how much flexibility is there to deviate from what the user has requested.

- Users are increasingly mindful about how their data are being used. This means that even if different areas of the energy sector are willing to collaborate, they still need to find a way to convince the user to share their details, or crucial data may not be readily provided.

Automation is thought to hold the key to better usability and smart system optimisation, but it is not yet at the level required. Experts suggested the current level of understanding required by users to set up and operate their smart systems is too high. Automation can support users by reducing the burden of decision making whilst simultaneously seeking to optimise how the system operates. Experts felt that users should be able to simply connect their devices and start using them straight away, with no further demands made. This however is some way from being a reality. Furthermore, poor understanding of the role algorithms play mean users can feel like they are not in control and become

"I think that's the challenge, to try and automate that as far as possible. So, the consumer choice making is quite limited."

- Flexible Energy Platform Provider

frustrated. This could be particularly problematic if transitioning to a new technology that has a vastly different control mechanism to its predecessor e.g. from a traditional boiler to a heat pump. This means if automation is poorly deployed, it could further damage user acceptance.

And industry advancement can be inhibited by an inability to learn from the mistakes of similar organisations. As previously discussed, it was a commonly held notion amongst interviewees in the private sector, that enabling business rivals to learn from the expensive lessons learned when attempting to bring your own products and services to the market was 'bad practice'. This was mostly because it would provide rivals with a competitive advantage. There was seen to be no value in promoting the mistakes made by your organisation. As such, opportunities to learn can be missed, meaning mistakes can easily be repeated. Given the urgency to tackle climate change, this misstep could prove particularly damaging.

"I don't think working together at that stage would ever be possible. But, if we were to have a magical wand and say everybody should do X, that would mean a lot more focus on individual customers. "

– Infrastructure & Distribution Expert

System wide changes are believed to be needed. Experts suggested an overarching system/task force is required to steer the sector in the right direction. There were several different ways it was felt the industry should change but it was felt a unifying body would be required to promote collaboration and expedite the rate at which change was implemented.

- A universal language/standardised iconography for smart technology controls should be developed to support ease of use

- There should only be one application per device. Different functionality should not require different applications. For example, an electric vehicle owner should not require one application to monitor charge and another to pay for public charging points. These should exist as separate functions within the one overarching application. This is because it would mean the user only has to master one control system to operate their device, so the burden is reduced.

- The benefits offered to the user need to be broader. There is a tendency for smart devices to focus on cost savings, which can be nominal, particularly if there is a high initial outlay. Similarly, promoting the environmental benefits is not enough of a motivator for many users to engage. Smart devices need to augment and enrich the lives of users in a variety of ways to increase uptake to the extent required.

"A single manufacturer lacks the power to influence the whole market. You need the whole community to cooperate in order to reap the benefits of standardisation"

- User Interface & Standards Expert

- The market needs to support those who take the time to set systems up to work well and efficiently for the customer. In the heating sector for example, the market currently rewards those who can install quickly and cheaply. Those who fit multiple heating systems in one day have a commercial advantage over those who install only one system per day. Similarly, heating system manufacturers often sell oversized (and therefore more expensive) heating systems to consumers, where a less powerful system would suffice.

"We need a paradigm shift in how we train people, but that will upset certain fractions. We're teaching people to be qualified; we're not teaching them to be competent"

– Heating Systems Installer

6. Source Overview

As discussed earlier in the report, initial efforts to identify suitable sources to include in the review highlighted several issues with the evidence available. Many of these initial assessments held true following further evaluation of the sources. In particular, the following points were supported and should be considered when reviewing the insights that follow.

Most of the sources focus on smart heating, smart homes, and electric vehicles. Most of the insights which follow are taken from these technologies.

- The decision to focus solely on technologies used within the home mean the electric vehicles studies included only explore home charging.
- There are a limited number of papers that look at smart lighting, smart appliances, smart cooling, and energy management services, at least in the context of usability.
- There are no other technologies included within the review.

There is little evidence that focuses on issues that arise during initial set up of SHTs. Very few papers focus on initial set up. Those that do, tend to provide a brief overview with limited specifics shared. Installations referenced in the sources identified are almost entirely studies that explore thermostats and/or smart heating systems.

The sources identified are largely peer reviewed papers and journal articles. As indicated in the expert interviews, many commercial organisations see little value in publishing the mistakes or any best practices identified when seeking to bring a new product to market. This is largely because it can enable commercial rivals to benefit. This has several important implications for the evidence review.

- Users evaluated within academic trials sometimes use prototypes developed specifically for the project, rather than commercially available products. This means that the anticipated issue of "interoperability" often is not experienced as the technologies have been built to fit with the occupier's existing technologies.

- Studies are often short in duration. For example, they may consist of asking participants to live in a smart home for a couple of weeks to understand the experience. Furthermore, usability evaluations of an interface or product may take place within laboratory settings. The findings therefore are arguably less representative of how SHTs would be experienced at home.

- Some academic sources focus largely on whether something can be delivered from a technical perspective, with little focus on the user. Often this means samples are small and unrepresentative. Furthermore, engagement is often limited to a short survey or interview at the end of the trial rather than ongoing observation and engagement. Related studies indicate that a failure to represent a broad range of user types (those with limited access to technology or low digital literacy) in energy research mean opportunities to advance understanding within the sector are being missed [8].

- Academic sources from social science disciplines tend to focus on the social barriers preventing users from engaging with smart technologies in the first instance, rather than the socio-technical ones. This means the arising insights can weigh heavily on acceptance and engagement, with little focus on operation - although these areas are often related.

7. Usability issues that prevent smart devices delivering benefits

After reviewing the available evidence, several of the points raised in the interviews with industry experts were found to be supported. In addition to supporting these points, the sources explored also introduced several new themes relating to usability issues with SHTs that should be considered. The findings in this chapter are presented in a chronological fashion, that mirrors the customer journey. It starts with issues that arise when initially engaging with users about SHTs, progresses to discuss issues observed at installation and setup, before concluding with observations of day-to-day problems that arise once the SHT is fully operational.

7.1. Engaging with users about smart home technologies

There are several issues with how smart technologies are presented to users in the first instance. As was indicated during the expert interviews, miscommunication of the benefits of smart technologies can cause users to feel frustrated and disengage. The evidence supports the points raised by experts, namely that the energy bill savings are often promoted as a reason to purchase SHTs, but the cost savings observed by users are often negligible [9, 10, 11, 12, 13, 14]. This issue is exacerbated due to increasing energy costs (which mean energy savings are more difficult to notice), poor energy bill understanding, and the high initial costs to purchase SHTs [12]. As uptake of renewable electricity rises, the value could increase, if markets are designed to allow this value to flow to end users. At this point, it is unclear how, or indeed whether this will happen [15, 16]. This failure to meet expectations directly impacts user engagement with the technologies but also their willingness to engage with flexible energy delivery programmes [9]. Also supported is the argument that the rewards to motivate users to engage with certain energy schemes or products are not yet in place e.g. flexible energy markets or electric vehicle grants and incentives [14, 17, 18, 19]. Furthermore, some smart technologies are promoted as novel and ground-breaking, which tends to only appeal to early adopters [18]. It may be that the rest of the market will need some more tangible user benefit before it is willing to engage.

"The amount money they could earn or save was not enough to make them actually align consumption and production" [19]

Study Overview: *"Smart home technology - comparing householder expectations at the point of installation with experiences 1 year later"* [14]

A variety of SHTs were fitted in 20 different homes. These smart technologies included smart thermostats, wireless radiator valves, brightness sensors, smoke alarms and various home security features. Households were interviewed prior to installation to understand their expectations. They were again interviewed one year later to understand their experiences and whether they wanted to keep the SHTs or have them removed.

Prior to installation households had indicated they expected the SHTs would help to reduce their energy consumption which would subsequently result in energy bill savings and help the environment. At the end of the trial however households could not say for certain whether they had made any saving (although some felt they may have). Variable weather conditions and nominal reductions using zonal controls meant some were sceptical of any *cost* benefit. As such, some felt they could not justify incorporating the technology into their daily lives (but they might do, if the technology offered any other benefits).

Cost savings are believed to be specific to certain user types, yet suitability is not established upfront. In addition to the points raised in the expert interviews, was the notion that significant cost savings *are* something which can be achieved, but these savings are specific to users who meet certain criteria [9, 14, 18, 19, 20]. These studies suggested that where no initial effort is made to establish the suitability of a user prior to purchase, the potential for dissatisfaction and ultimately disengagement is high. User types who are expected to be most likely to make cost savings when using SHTs are indicated below:

- Those who are at home most of the day and have rooms at the property which are frequently unoccupied. This is specific to those who have zonal control and can choose only to heat occupied rooms/zones.
- Those with predictable routines/occupancy patterns, although those with unpredictable routines may still benefit from SHTs in other ways e.g. increased convenience [14]
- Those who are able (and willing) to consume most of their energy outside peak hours
- Those who drive a particular type of electric vehicle or are atypical in how they drive (and subsequently the frequency at which they have to charge) their vehicle.

"To support the availability of range in the EV, households had developed a set of charging routines. However, these routines also seemed to clash with household electricity production." [19]

User needs are complicated and diverse. Smart systems need to take account of this to boost acceptance and engagement. The evidence available points to a vast array of variable user needs in the context of SHTs. User age, culture, attitude, climate, lifestyle, interest in technology, routine, gender, homeowner status, economic status, definition of comfort, typical driving range, trust in data sharing, and various psychological factors (e.g. perception, attention and retention) are all said to contribute [10, 11, 14, 19, 21, 22, 23, 24, 25, 26, 27, 28, 29]. These factors influence how users engage with smart technologies, the support they require, the outcomes they seek to achieve and ultimately how the success of the smart technology is measured. SHTs however generally do not seek to cater to different user types by offering different user experiences. This means the needs of users are often not met and the product has therefore failed to meet their expectations.

Study Overview: *"Making energy visible: A qualitative field study of how householders interact with feedback from smart energy monitors"* [12]

275 households trialled three different smart energy monitors of varying levels of sophistication. The duration of use varied across all households and ranged from 1 month, to 1 year. 15 households took part in qualitative interviews seeking to understand the different reasons households had for installing the monitors, how the monitors were used and the impact the feedback had on their energy consumption.

The findings suggested that different household members often had different reasons for using the monitors. They wanted different things from devices and so some perceived them to be more effective than others. The findings further indicated that different user types (gender, age and attitude) had differing needs and preferences which had implications for what type of information was best to display, how the information should be presented, and how likely users are to engage and act on the feedback.

7.2. Issues that arise at installation

Users require a lot of support during installation, but this is not always provided. There are several steps across the installation experience that the available evidence deems to be problematic. The early issues at this critical step mean users are often distrusting or unwilling to operate the SHT. This misstep damages engagement with SHTs right from the offset.

- Some users are said to feel anxious prior to installation where the works are expected to be particularly invasive. This is due to concerns about available space, equipment aesthetics, increased reliance on industry experts, and how the new technology will interact with their existing ecosystem [14]

- Installations of SHTs are often (or at least appear) complicated. This can cause some users to feel intimidated, worrying that the system will be difficult to control, and therefore become reluctant to engage [11].

- New products can often fail, which damages trust, even if they are later repaired [14, 27]. Reliability is of key importance to most users.

Household conditions are variable, but this isn't always considered during product development. Products are often developed and tested in (optimal) laboratory settings. If similar "perfect" conditions are assumed for the homes in which they are deployed, issues can arise. This is because homes are often inefficient and/or have different logistical constraints which need to be overcome during installation. In some instances, household preferences, or decisions taken by the installer when fitting the device may further impact how efficiently the device is able to operate. Inefficient installation can result in inaccurate readings or missed feedback by the user. Quick and accurate feedback from smart technologies is said to be *crucial* to provoking user action and engagement [12, 13, 21, 22, 27, 30]. Evidence of the following issues was identified.

- Internet connectivity is *critical* for smart technologies, but the strength and reliability of connection is said to be out of scope for both the manufacturer and the installer [31]. This can cause functional and therefore user experience issues [20, 21, 31, 32]. It can also mean key components e.g. a control panel displaying important system information, are placed in suboptimal locations such as next to a WIFI router, rather than where it is most visible. Interestingly, more than one of the studies to raise this issue are recent publications i.e. long after the ownership of devices such as tablet computers and smart phones became widespread. This indicates that ownership of connected devices with portable screens does not seem to resolve the issue, although the sources do not discuss why this is the case.

- Aesthetic concerns can result in technologies being installed out of sight or in technically suboptimal locations, such as in cupboards or behind furniture [13, 14, 31]. In some instances, when users upgrade their technology, they may choose to install the new device in the same location as an older device to prevent having to repaint a wall e.g. a thermostat. This means installation errors made may be repeated multiple times. Furthermore, there is a difficult balance to strike with regards to the installation of smart home monitors. One study suggested they should be unobtrusive enough to minimise objections on an aesthetic level, but noticeable enough to promote user interaction [27]. It seems that understanding how and when is best to alert users to engage with their SHTs will be amongst the key challenges to overcome. This is because too little engagement may result in users feeling they are not in control and/or mean they do not act on the feedback provided. Too much engagement could potentially cause annoyance or have negative consequences for how the SHT operates, if the user choses to manually override the decision taken by the SHT.

- Variability in how users furnish their home, or the layout of their property can also impact how well smart technologies perform or are experienced [13, 14, 19]. A room with a thick carpet and heavy curtains for example will retain heat better than a room without. Furthermore, some users are far more receptive to retrofitting their home with energy efficiency upgrades than others, which can improve the performance of SHTs [14, 33]. However, this is not investigated prior to purchase, nor is it explained to users how their home design choices could impact performance.

"In the household with several EVs we found that it was more difficult to schedule charging as the infrastructure of their house didn't allow multiple EVs to be plugged in at the same time" [19]

- Some technologies are simply installed poorly, impacting performance [13]. For example, installing thermostats at an angle, in poorly lit areas, or in hard-to-reach places. This makes it even more difficult for users to operate and engage with the SHTs.

7.3. Problems that present when starting to use smart home technologies

Often, users are not adequately prepared (or able) to set up their new SHTs. It is a widely held notion that one of the major failings of SHTs is insufficient training and support for new users, to help teach them how to get the most from the technology [13, 14, 21, 31, 34]. In addition to the vastly different needs users can have, which has already been discussed, users existing knowledge and behaviours are also said to be a major influence in how new smart technologies are set up and operated. This means the level of initial support required can vary significantly. The need for professional set up is itself a symptom of an industry that is not focused on delivering intuitive user experiences. The usability issues that can arise during initial set up are as follows.

- Sometimes the household member who instigates the purchase of the smart technology (and may even have set it up) is not the "primary user" [10, 11]. This may be the occupant who is home most often. This can result in the system being operated by someone who does not understand or even want the system, which furthermore may not have been set up to meet their own individual needs and preferences.

- The variable needs and preferences of different occupants within the same household can cause issues when choosing how to set up the device [12, 14, 31]. This is because a compromise will have to be reached when deciding how best to set up the technology. Ultimately, this compromise will mean some (or all) are not getting exactly what they want from the system.

- Some are wary about sharing personal data, so chose not to [21, 27]. This can prevent the system optimising based on their needs. Furthermore, it may not always be obvious to the user why this personal data is required e.g. occupancy pattern to schedule lights to turn off.

- Lack of an adequate explanation means users are less willing to opt into certain energy saving functionality e.g. flexible energy delivery [23]. This is because they do not understand why it is necessary or how it will impact their experience.

- Criteria, which mean some households are better suited to flexible energy delivery than others, are not established upfront [29, 33]. This is different to the suitability point discussed earlier i.e. user suitability as an indication of how likely they are to see to see some degree of benefit from the SHT. These criteria effectively establish how much flexibility the network has with regards to how the energy is delivered. They include home energy performance, potential load shift, typical driving range and occupancy patterns. Failure to investigate suitability upfront, can mean the user experience (and the benefits of their involvement) vary drastically.

Study Overview: *A data-driven study of thermostat overrides during demand response events* [23]

The thermostat overriding behaviour of more than six thousand households, whose air conditioners were subject to demand response events, was monitored. The project took place across one summer, with events tending to occur in the afternoon i.e. when temperatures were at their highest.

Those who had previously experienced demand-side events and/or had received an explanation of what the events were (and why they were necessary) were more willing to take part. Furthermore, those who understood the need were seen to override their system during an event far less often.

Once "set up" users can encounter a range of issues using their SHTs. Once smart technologies have been installed, and users have gone through the process of configuring the system, it can begin to operate. At this stage however poor usability has been seen to cause issue with how users engage with SHTs on a day-to-day basis.

- Poor user interfaces can mean that users feel overwhelmed, or struggle to find the options they want if the process doesn't follow what they perceive to be a logical flow [9, 10, 13, 21, 24, 26, 30, 31, 35]. Variability in user need/desire for information makes it very difficult to get the balance right.

- As a consequence of feeling overwhelmed by the controls, many users elect to stick to the basic options given to them [14, 22, 31]. Further to this, they are wary of making changes if *reasonably* content, fearful they won't be able to revert to these settings if they experiment.

- Some systems perform crucial tasks whilst in standby mode. Users sometimes do not understand this and elect to turn their device off completely, preventing SHTs from performing as intended [21].

- SHTs can cause annoyance when operating. This can result in users attempting to trick the system, disconnect or override it. In some cases they may reject the technology/feature altogether and seek removal [10, 21, 22, 23, 31]. Some of these user interventions prevent optimal operation which contribute to increased energy consumption. This consequently results in higher energy bills and even greater user dissatisfaction. Specific examples include:

    - Noise from radiators/radiator valves and the risk of overheating means some are resistant to letting their systems run overnight, meaning opportunities to exploit renewable electricity are lost [21, 31].

    - Sensors can be overly sensitive. For example, a passing car may trigger a motion sensor and cause an indoor light to activate which causes annoyance, so they are disconnected [14]. Interestingly, one study suggests that the range covered by sensors at present is not far reaching enough to deliver maximum benefit [20]. Should the range be increased, issues with oversensitivity are likely to be greater.

- Presenting users with cost information can cause anxiety, sometimes resulting in over-engagement. This is because it can cause users to fixate on how much they are spending [12]. This is particularly problematic for those who struggle financially [9]. Some studies however have suggested presenting energy poor households with feedback can help them to reduce energy costs [36]. Furthermore, some users have been shown to be distrusting of the cost information displayed, which can reduce engagement or even result in users purchasing and installing their own meters [19].

Study Overview: *Facilitating energy savings with programmable thermostats: evaluation and guidelines for the thermostat user interface* [13]

Five (different) commercially available residential programmable thermostats were analysed to understand which design characteristics helped or hindered operation. 31 participants were given five tasks to complete using the thermostats. This helped to evaluate their usability and effectiveness.

Subjects were more successful completing the tasks with thermostats that followed certain standards. These standards included providing users with feedback, following a simple decision pathway, using consistent language and iconography, and providing navigational prompts to make clear the options available to the user.

Furthermore, user needs are dynamic and change over time. In addition to the diversity of user wants and needs, is the added complexity that needs are not static. The evidence suggests that needs change over time or can vary under particular circumstances [11, 12, 14, 19, 24, 25]. Furthermore, smart home devices may be used by multiple household members. The needs of one household member are not necessarily consistent with what is needed by the other household occupants in a given moment, as was discussed earlier in this report. Examples of variable needs include the following.

- A high degree of information is required when users first engage with smart technologies, but this declines as they become more familiar.
- If issues arise, such as a technical malfunction or having received a higher than usual bill, users can again require more information.
- Software updates or some seasonal interactions (which are subject to memory decay), may cause users to require temporary access to additional support and information.
- Contextual data is sometimes needed to understand the information presented by the smart device e.g. historic energy consumption. Too much data however can overwhelm users, particularly when it isn't being used.

7.4. The automation paradox

Users don't like to feel they're not in control, yet desire technologies to be less demanding of their time. During the expert interviews it was a commonly held opinion that increasing the level of automation would be key to both improving user experience and maximising the potential of SHTs. Generally, it was agreed however that the ability for smart systems to automate decisions has not yet evolved to a place where it can contribute to the level required and, if automation offers a poor experience, it can be damaging to user acceptance. Similarly, the evidence explored makes the point that automation will play a crucial role in enabling SHTs to run optimally [11, 17, 20, 21, 25]. Furthermore, the evidence supports the opinion that automation of SHTs is not yet able to contribute in the manner desired. Several factors where automation can contribute to poor usability were discussed.

- User behaviour isn't easily rationalised, automation can only do so much. Furthermore, users sometimes want SHTs to perform actions beyond the capability of the technology [10, 14].

- Perceived lack of control causes users to intervene [10, 21, 23, 25, 31]. If they don't understand what the system is doing or why it is doing it, they can feel frustrated and attempt to trick the system or override it. This can result in the system running less efficiently.
- If systems are highly automated, user engagement can decrease [19]. This may mean that benefits achieved through the provision of feedback to the user are not sustainable.

- Some automated actions can be perceived as wasteful/suboptimal causing distrust or for users to override. This tends to occur if the system is taking an action that does not appear to relate to what the user has requested [10, 21, 23, 34, 35]. Furthermore, some automation *can* be more wasteful e.g. automated lighting may switch off after a period of inactivity, a manual switch can be turned off the moment a room is vacated [20].

- User preference may vary based on the circumstances. Automation has no awareness of context [22]. For example, a house may wish to prioritise cost savings in most circumstances, but favour comfort (at greater expense) when guests are visiting.

- Sometimes what's best for/desired by the user is different to what is best for efficient operation or the needs of the wider network/energy system [22].

- Some users worry about their increased dependence on smart technologies that effectively make decisions for them. Furthermore, some are reluctant to engage with advanced technologies that they cannot maintain themselves and require specialist support [14].

When considering all the different perspectives on automation raised in the reviewed literature, it seems what concerns users is not that the product is automated, but that automation could prevent them from achieving the outcome they desire. The user wants to feel in control and be in control. Automation can still decide how to deliver the outcome they have requested but the user wants the ability to override this action if they disagree.

Study Overview: *Domestic demand-side response with heat pumps: controls and tariffs* [21]

76 properties with heat pumps were monitored. 31 of these had a control system installed to enable their electricity demand to be spread out over the whole day to reduce demand peaks. This control system meant home were sometimes warmed at times the occupants may not have expected.

Households reported issues with overheating at night and being woken up by noise from the radiator valves and/or heat pump fan. There was a lack of feedback from the control system to explain why their home was being heated overnight (when they hadn't specifically requested this). Some attempted to intervene by changing their control settings. Some opened windows and doors to cool the room, others closed doors so the system wouldn't have to work as hard (and would be quieter). A small number of households requested the control system be removed altogether.

8. The issue of interoperability.

The issue of interoperability was rarely encountered. Interoperability is the ability of a system or component to function effectively with other systems or components. One of the ambitions of this review was to understand whether proprietary systems were a contributor to poor usability. A home that incorporates many different smart technologies for example may cause the user issues if the different technologies cannot work together seamlessly. As previously discussed, the academic nature of the evidence identified has meant usability issues arising from lack of interoperability are rarely discussed. Broadly, this is because experiments often take place in laboratory conditions or technologies were installed, and sometimes developed, by those conducting the research i.e. prototypes. This meant that users did not have to attempt to incorporate the technologies into their home ecosystems themselves as this had already been addressed on their behalf. Despite a lack of evidence in the sources evaluated, interoperability was commonly cited as being crucial to the success of SHTs [14, 20, 22, 23, 27].

Although uncommon, a small number of usability issues arising from lack of interoperability did present in the evidence explored.

- Some households had to be excluded from trials because their existing heating systems were incompatible with the smart controls [14].
- New smart phones were purchased as the application used by smart technologies required a specific operating system [14].
- A desire (not a *need*) to upgrade other technologies in the house, which now appear outdated compared to the new SHTs was observed [11].
- On a non-technical level, some features of SHTs (flexible energy delivery) are deemed to have poor compatibility with certain property types i.e. those with low thermal efficiency [23].

"In short, the introduction of the SHTs caused other technologies to be re-domesticated in ways that made them seem old and in need of replacement." [11]

But uptake of SHTs is relatively low at present. This is expected to change in the coming years. Uptake of SHTs is considered to be lower than initially anticipated, however growth is projected [3]. Global changes in energy policy mean that new markets are emerging quickly. Additionally, other anticipated technological advancements are likely to contribute to growth in this area. e.g. the Internet of Things. It is therefore logical to predict that SHTs will not only become more prevalent in the coming years, but the variety of technologies available is also likely to increase.

As uptake of SHTs increases, it is likely issues owing to lack of interoperability will also grow. An increase in the variety of SHTs available, and the manufacturers who develop them, will likely mean a broader (and potentially more complex) range of functionality will be offered to users. If brands are reluctant to conform or offer interoperability (as has been suggested in the expert interviews), the issue of interoperability is likely to become a much greater issue. This however will not happen until later in the SHT adoption curve.

9. How the energy sector can deliver better user experiences

In the reviewed evidence, several lessons were learned in the deployment of SHTs. In some instances, these were practices that had been implemented during the experiments that had been seen to work well. Often however recommendations were speculative. This was where the approach deployed had encountered an issue, with the author then drawing on the lessons learned to recommend an alternative to their approach. These alternative approaches however remain untested, so may present issues that the author has not anticipated. This should be considered when reviewing the recommendations made.

It's worth noting that industry will likely learn many of the lessons raised in this section of the report. Manufacturers will simply have to develop good user experiences if they want to differentiate themselves from competitors. Poor usability however can slow markets from forming, meaning change will take time. To cut carbon emissions in the time available, steps will need to be taken to speed up the natural process.

9.1. Rethinking how to develop and promote smart home technologies

Be wary of promoting SHTs solely as a means to reduce energy bills. As was discussed previously, energy bill savings from SHTs are often said to be nominal, particularly when considered in conjunction with high initial outlay to purchase the equipment. Where significant cost savings are possible, these are said to be unique to certain types of users. To address this issue, manufacturers should seek to communicate the range of benefits offered by SHTs. This can include cost, but should also incorporate benefits such as increased convenience, better comfort, reduced emissions and the provision of actionable insights with regards to energy use [17, 29]. Where these core benefits are not delivered, users are likely to reject the technology, even if they are able to save a small amount of money.

Implement a more robust approach to identifying user suitability. Where users or their homes are not optimal for a particular smart technology, this should be identified and communicated prior to installation [9]. This could be achieved by asking questions about the property or the user's behaviour prior to purchase. Further support should be offered by manufacturers or energy service providers to households who are not expected to make significant savings, to help them configure their system and maximise any opportunity to make *some* saving. Preferable criteria for participation in certain energy saving schemes i.e. flexible energy delivery, should also be established upfront [9]. This can enable the experience to be tailored e.g. shorter events.

Industry wide change should be considered to develop products that better meet the needs of users. There are several ways in which the development and promotion of SHTs is perceived to be flawed. These issues promote a negative and often disjointed experience for the user. Several suggested ways in which organisations could change was discussed within the evidence.

- A user's relationship with their utility companies is said to directly impact their acceptance of energy saving technologies and schemes. Efforts should be made to improve this relationship [9].

- Supply chains would benefit from being better integrated. This would promote consistency and collaboration. Those marketing the product should align with those who have developed it, to ensure the benefits are being accurately communicated. Customer support, servicing and installation training should be integrated to ensure consistency in understanding [10].

- As the market develops, industry will need to find a way to understand the consequences of their design choices. Developing and testing user interfaces with non-technical experts will help understand any issues with onboarding and operation. Involving stakeholders in the process will help them to understand where the product needs to improve. The systems should be developed for convenience of use above all else [11, 13, 22].

- "Perfect homes" are assumed in the development of SHTs. This shouldn't be the case. Products developed in ideal laboratory settings can fail to transfer the benefits to normal, suboptimal, households [9, 21].

- Research should be conducted to understand contextual conditions of SHT operation, and user preference so needs can be better met [22, 27].

- The facilities to share data/knowledge with other organisations needs to be in place to expedite the learning process [22, 23]. Feedback data to enable organisations to learn how their devices are being used are also crucial in this same respect [27].

- The rewards for participating in energy saving schemes should be better. This will promote user engagement [19].

"It can be difficult to make people change their consumption patterns by themselves without considerable motivation such as earning or saving money." [19]

9.2. Good practice when installing smart home technologies

The "out of the box" experience is crucial to user acceptance and engagement. SHTs should be quick and easy to set up. This includes installation and maintenance, as well the onboarding experience [11, 14]. Furthermore, it is important to establish trust early in the user journey. Users should feel confident that the product is reliable and trust that their private data will be looked after [11]. Issues at this early stage may not only prevent devices being set up correctly but may cause users to be wary of engaging with smart devices once they are operational [14]. Optimising this early step in the customer journey is therefore likely to be highly impactful to promoting increased engagement.

Develop and implement a thorough programme of support to help teach users how to operate their SHTs. The operation of SHTs should be intuitive wherever possible [30]. However significant support should be available to users to help them learn how to operate and optimise their system [9, 31, 34]. This support will likely have to come from those who have a shared interest in helping households to reduce their energy consumption e.g. energy service providers. Where users have a better understanding of how to operate and optimise their SHTs, they are likely to have better experiences and may even operate them more efficiently. Furthermore, users with a better understanding of energy saving schemes are more willing to participate in them [9].

Learn from installation issues and embed the lessons learned into new processes. Several installation issues were cited in the evidence reviewed. Where errors have occurred, clearly the process would benefit from being amended, to prevent the issue from being repeated. Often however, there is a commercial trade off that businesses will have to make to afford to implement these measures. The challenge will be for policy makers to design a market that is able to deliver these things. The following recommendations were made.

- Involve all household members in the discussion when installing SHTs [14, 32, 34]. This should cover where to house certain components, but also when choosing how the system is set up initially. Any difficult conversations should be had upfront. This includes limitations of the technology or any disruption the occupants are likely to experience.

- The reliability and range of Wi-Fi should be within the scope of those developing and installing the SHT [20, 31, 32]. Connectivity is of such importance to the success of SHTs that it cannot be overlooked.

- Thermostats should always be located on an internal wall and ideally in a central location [13]. Whilst it is important to be mindful of aesthetic concerns, if thermostats are positioned in a suboptimal location to appease household members, they will fail to deliver the intended benefits, meaning dissatisfaction is still likely to occur.

- Display monitors should be moveable [12]. This will enable them to be positioned where they are most visible to the occupants. Where feedback is visible to the occupant, action is far more likely. It may be that this consideration becomes less important as automation gets better at understanding what users want, or if users are willing/able to receive the feedback on their smart phones. Movable components should also be labelled so they can be returned to the correct location and readings remain accurate e.g. sensors [32].

- SHTs and their components should be easily “swappable” to minimise disruption if breakdown occurs and repairs are required. Remote diagnosis should also be a prerequisite for all SHTs [21].

- 24-hour support should be offered wherever possible [32]. It should also be made very clear to the user who to contact if they have an issue e.g. is it the utility company or the manufacturer?

- Thermal modelling should be considered prior to installation to predict the homes response to certain actions e.g. flexible energy delivery [22].

- Some sectors of the population will always require a stand-alone, simple, non-networked device for operation, so these should be made available [13].

9.3. Promoting better operation of smart home technologies

Implement standards into user interface design to help support better understanding and operation. Once installed and operational the biggest barrier to engagement with smart home systems is the user interface. This is because it can confuse or intimidate users. There are several lessons learned in this regard which could be addressed in design of future interfaces.

- SHT feedback has to be clear, complete, immediate and user specific if it is to translate into action [12, 13, 24, 27]. Furthermore, logging in to access this information should be as simple as possible to encourage frequent use [27].

- Connect the user interface with a tangible outcome [10, 12, 21, 24, 25, 27]. Avoid all jargon and simply link the action with the outcome that the user will experience. For example, don't ask users to indicate a "set point" temperature, simply ask if they wish to be warmer or cooler.

- SHTs should not overpower the user with too many options or hard to use controls [11, 21, 31, 37]. Furthermore, the user interface should ease the burden on the user wherever possible e.g. graphical representation of data [9, 10, 12, 13].

"We find that a system's self-declaration should focus on being socially meaningful rather than technically complete, for instance by relating itself to people's activities and the home routines." [27]

- User interface design should facilitate the adoption of *convenient* behaviours [11, 19, 21, 22, 30]. The advice provided should not be overly demanding of the user. Both cognitive and practical workload should be minimised.

- Include command prompts, cues and the ability to undo actions to help users with navigation. This will also give users the confidence to experiment with changes [9, 13, 27, 30, 35]. Users should not have to rely on memory to operate SHTs.

- Iconography and terminology should also be standardised across the sector. Plain language should always be used rather than abbreviations [13, 30, 37]

- Use clear affordances for touchscreens, buttons should look like and act like buttons [13, 30].

- Consider implementing some constraints to prevent misbehaviour [30]. However, be wary of implementing too many rules as this can cause users to feel restricted [24].

- Historic data should be available to the user so they can learn about their energy use and take action. Baseline data can also help users understand "normal" use i.e. before installing SHTs. This can help contextualise the information being shared [19, 21, 27].

Seek to reap the benefits of offering a bespoke experience. The diverse and dynamic requirements of users mean creating a single user interface that meets all possible needs is an impossible task. Allowing users to tailor the display to suit their own individual needs and preferences means they can resolve the issue of what information to display themselves. Furthermore, tailoring specific experiences, like flexible energy delivery can also offer value to the user and subsequently the network. There are several recommendations in this respect.

- Operating systems should support multiple user profiles – this will enable different household members to personalise the information/icons displayed [10, 19, 22, 24, 27].

- SHTs should fit in with users current and changing lifestyles [11]. This could be addressed by allowing users to decide what icons they wish to display [10, 27]. Additionally, it should be possible to personalise the layout or flow of information on the interface [24]. This is because some users favour quicker processes, whilst others prefer a more "fun" experience, even if it requires more of their time to operate.

"SHTs should not merely 'fit in' with current household aesthetics and routines but need actively to support and augment households' social goals and values." [11]

- Features that are not used should be hidden to simplify experience, with the ability to reactivate them if needed [10, 13, 22, 27, 30]. Only the most important, and most frequently used should be displayed by default.

- Some of the technical components provided should be bespoke to the needs of the household. For example, the number and type of sensors provided should be based on individual need, rather than seeking to supply all users with the same type/amount [35].

"There is not a generic perfect mix of sensors: each case must be evaluated independently and designed for the specific needs" [35]

- Experiences should be tailored to match suitability, for example homes that participate in flexible energy schemes but have poor thermal efficiency should be subject to shorter events than those with more efficient properties [21, 23, 33]. Utilities should further develop an understanding of overriding mechanisms. They can then develop strategies for avoiding or anticipating overrides and seek to address.

- It should also be possible to tailor experience based on user willingness [19]. For example, some households may be far more willing to change their routines to consume more energy outside peak hours than others.

9.4. Helping users to accept and embrace automation

Understanding what users want the system to control (and when) will be key to gaining acceptance of automation. Automation can offer real value to users by reducing the number of decisions they have to make, whilst seeking to optimise how the system operates [17, 21, 31]. Furthermore, users have been shown to be more willing to participate in complex processes like flexible energy delivery, where some of the actions are automated [19]. Users must be trusting of automated processes however, if they are to enable smart systems to act on their behalf.

- Increased automation/more intelligent control should be deployed to maximise the energy saved; however, users should retain the option to take control [21, 23, 31, 33]. For example, studies show users strongly prefer to have override buttons but (with education) rarely use them.

- Smarter control algorithms should be developed that incorporate a variety of environmental conditions as well as user preferences [20]

- System behaviours should be made transparent to the user to build their trust in the technology [9, 10, 23, 27].

- Automation should seek to augment user engagement with SHTs, rather than taking full control [27].

"Rather than demanding control and information from users, the system should unobtrusively support them in their lives" [27]

- In some cases, there should be a balance between automation and user control [20, 26]. For example, a flashing light may prompt the user to turn a device off, but if this has not happened after a certain period the system can deactivate itself remotely.

- Some technical parameters/changes can help e.g. more effective zoning, temperature caps when automated process are ongoing (max and min) [14, 20, 21].

"In summary, automation is not a substitute for awareness, and awareness boosts the impact of automation." [9]

9.5. Preparing for the challenge of interoperability

Some speculative suggestions about overcoming the challenge of interoperability were raised. Whilst the issue of interoperability rarely presented in the evidence reviewed, several reviewed sources anticipate an issue if better interoperability isn't achieved within the energy sector. From this speculation, some recommendations were made.

- Integration of smart technologies into people's homes will naturally happen in increments, rather than all at once. It is therefore important to respect existing technological arrangements at every stage of the process to preserve experience [11, 14].

- Some specific features/functionality offered by SHTs are expected to be better received as part of a broader application [20]. For example, controls to operate smart lighting may be better received as a sub-feature of a broader whole home application, rather than requiring its own application. Consolidation effectively lessens the demand on the user, as it means they only have to master one control system.

10. Learning lessons from beyond the energy sector

Whilst there is a reasonable amount of evidence of common usability issues for technologies within this energy sector, there are clearly some limitations to consider. Specifically, the evidence available is (in some instances) minimal e.g. usability issues relating to interoperability. Findings are presented largely from an academic standpoint. Evidence provided by industry based on the experience of bringing products to market would surely be richer with details of poor usability. Several arising insights only have a small number of sources to support the point raised. Many of the studies have a minimal focus on the user, meaning findings relating to poor usability can be brief, overgeneralised and lacking in detail. If we consider these shortcomings along with the expert opinion, that seeking to understand and improve issues of poor usability is not a priority within the energy sector at present, it indicates that we may have to look to other sectors to learn valuable lessons.

Looking beyond the energy sector, studies seeking to understand the process of successful diffusion of technology innovations have highlighted the importance of taking a whole system approach, including considering the non-technological (human) parts of the system. This is because changes in one part of the system (e.g. supply, network capacity, energy products or services) can impact other parts of the system (e.g. in how people consume energy) in complex and dynamic ways [38]. Integration of technology into existing systems requires both technical adjustments, as well as organisational and behavioural adjustments [38, 39]. If policymakers and regulators are able to design and manage a system which support these needs, then the energy sector could see a similar degree of success to other sectors where this approach has been taken e.g. telecoms. Failure to consider all aspects of the system can lead to unexpected consequences across the system and failure of the technology to be accepted and used.

Several factors have been identified as influencing the likelihood of technology acceptance. These include cost, social influences, technology self-efficacy, system design features, perceived usefulness and perceived ease of use of the technology [40, 41, 42]. Perceived usefulness and perceived ease of use/usability however have been consistently shown across a variety of technologies (in particular, health technologies and applications, and e-learning technologies) to be important predictors of eventual technology acceptance and use. Ease of use, often incorporating usability, includes the extent to which the user experiences it as being efficient, effective and satisfying as well as a belief that using the system will be free from effort. Perceived usefulness is a measure of how much the user believes that using the system will help them or improve their outcomes.

Whilst perceived usefulness is found to be the greatest predictor of eventual use, many things influence this perception, including ease of use and the extent to which it can be integrated into existing technologies and practices. For example, although people were enthusiastic about the possibilities of the first internet enabled smart-phones and camera phones, in reality their usability was limited as they were hard to navigate, it was difficult to carry out required activities and the handsets were considered ugly and cumbersome compared to existing mobile phone handsets [43, 44]. The lack of supporting infrastructure, in terms of the number of websites that were mobile-friendly and the limited number of supported email clients, made them both harder to use and reduced their usefulness. Finally, the lack of a critical mass of users, limiting the number of others to send emails or photos to, also reduced their initial usefulness.

Widescale adoption of web-enabled phones only occurred when both usability and infrastructure issues were resolved. This process also revealed new and unexpected uses and practices as people appropriated the technology into their lives. For example, early studies of camera phones looked to understand why so few people were sending photos to each other and found usability issues preventing this. They also revealed new design directions when it was understood people didn't just want to send pictures to each other - they actually captured and shared photos in a variety of unexpected ways for a wide range of reasons [44]. This evidence demonstrates the importance of studying and involving users to enable faster innovation. In complex systems such as the smart energy system is impossible to understand all use implications before deployment since they emerge as a result of the process of innovation and use. Early user research can help discover the emerging requirements and to uncover unanticipated value [45]. Identifying and promoting features that offer value to users could be key in increasing early adoption.

As there is a need for the development and uptake of smart energy technologies and services, to make the energy system work more efficiently, ensuring end-user adoption will be critical. Uptake of these technologies and services however is unlikely, if people perceive very little benefit for the associated costs. Adoption will only happen if these technologies are perceived to be useful and usable. To achieve this not only requires technology innovation to provide solutions to infrastructure and technical problems, but also useful and usable solutions that can add real value to users lives. Technologies which are not well integrated into people's lives, current technologies, and the other benefits provided by different actors in the smart-energy system are unlikely to provide the usefulness and ease of use solutions needed to create acceptance and drive adoption.

11. Discussion & conclusion

In summary, there are many wide-ranging usability issues that mean users are unwilling or unable to use devices as intended due to poor design. Whilst many of these occur at set up and operation, more damaging perhaps is the fact that market penetration of SHTs is relatively low at present. The consequence of this is not only that opportunities to benefit the energy system are lost, but also that opportunities for the sector to learn of (and therefore resolve) usability issues are limited. This means we do not have a clear picture of how widespread or how damaging usability issues are.

SHT usability issues however will likely become a bigger problem over time. This is because more people will have SHTs in their homes. The problem may appear relatively minor today, but this is because SHTs are still somewhat uncommon. Additionally, many of those who own SHTs are likely to be early adopters. Early adopters are often more tolerant of poor usability. Unfortunately, the urgent need to reduce global carbon emissions means that waiting for the sector to evolve better usability over time, in response to complaints from disappointed customers, could be highly damaging to these ambitions.

In addition to addressing the usability issues identified within this review, there are several ways in which the energy sector could increase the likelihood that SHTs will be able to contribute to reducing global emissions in a meaningful way. This can be achieved by taking steps to uncover usability issues before the technologies become widespread, but also by laying the appropriate foundations to support increased collaboration within the sector.

Encourage business to create usable, holistic solutions. For example, technology-neutral policies (e.g. petrol/diesel ban) can force business to find ways to combine components into simple solutions (e.g. thousands of components to design great electric vehicles).

Develop shared infrastructures to help speed up understanding of usability issues in the energy sector. Improving usability can be complicated and time consuming. Supporting innovation by providing access to tools to support better understanding of usability issues would help. This could include innovator test beds or living labs. Given the identified resistance for privately owned organisations to share their knowledge with commercial rivals, this should be publicly funded. This will enable the learnings to be more easily disseminated for the benefit of others within the sector.

Governments should design markets that flow the value of increased flexibility to the right place in the system, including the demand side. How best to do this could come from the learning environments previously discussed, as has been suggested in other studies [15, 16]. This makes sure that business models stack up, so innovators can justify the cost of investing in good experiences.

Invest in innovation to improve user experience. Usability testing can be expensive, and the evidence suggests the sector does not prioritise it at present. Innovation funding has historically helped to de-risk the development of technology components. This could be expanded to help fund improved user experiences.

Help private industry work together for the betterment of the sector. In exchange for all this public support, strongly encourage industry to voluntarily specify interoperability standards, with the potential for governments to set them if they fail to do so by a certain point in time. Encourage them to use living labs to define them and prove they can work. The labs should champion the lessons learned about how to design and deliver smart products/services that consumers will buy, so they can deliver the flexibility the system needs.

Ultimately, taking these steps could help the sector reach a place where it is easy and enjoyable for all groups across society to set up and operate smart home technologies to get what they want. Furthermore, the need for different products and services to work together, so people can seamlessly integrate them into their homes or upgrade and change products if desired, will also be achievable.

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13. Appendix A: Search Criteria

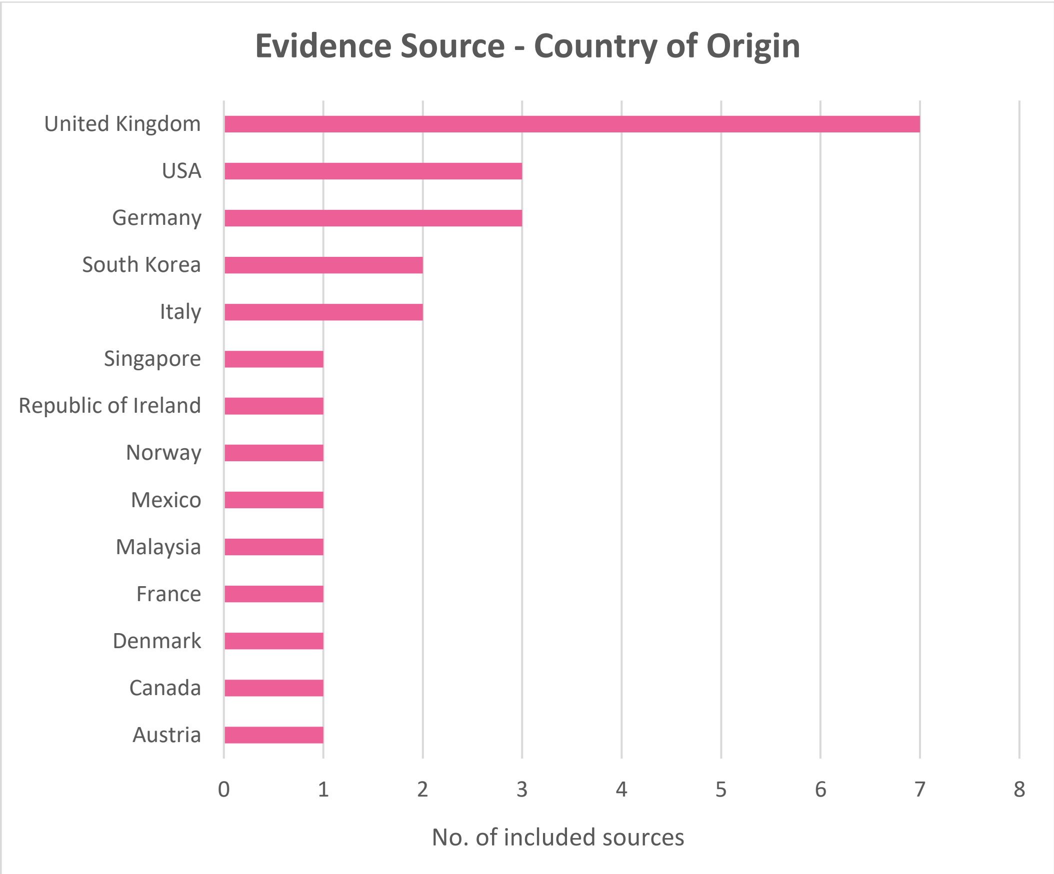
When seeking to identify suitable evidence to include within the review, it was agreed that sources should meet at least one criterion from both column a, and column b.

Note: Sources evaluating the usability of electric vehicles were later discounted when it was agreed the project would focus solely on technologies used *within* the home.

Column A: Source area of focus	Column B: Research Activity/Context
Smart: Home/Heating Controls/Energy Services /Appliances/Plug/Lighting/Washing Machine/Hot water tank/Tariff/Storage	Usability/User Evaluation
	Ergonomics, Human Factors
Time of use tariff/Agile	
	Human Centred Design/ Human Computer Interaction
Demand side response/management/reduction/flexibility	
	Consumer Trial
Batteries: Domestic/Home/Storage	
Heat pumps	
Electric vehicles/EV/Smart Charging/Managed Charging	

14. Appendix B: Source Origin

The graph below details the country of origin for the sources included within the evidence review. Note that the country of origin denotes the location of the end user and not the research body. For example, one study conducted by academics at a Danish university explores US citizens thermostat overriding behaviours. This has been deemed to offer insight from an American perspective so is cited as a US source.



The graph above details the number or sources included within the evidence review from each represented country