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Sanna Tuomela

SMART HOME ENERGY TECHNOLOGIES: ADOPTION, USER EXPERIENCE AND ENERGY SAVING POTENTIAL

*UNIVERSITY OF OULU GRADUATE SCHOOL;
UNIVERSITY OF OULU,
FACULTY OF INFORMATION TECHNOLOGY AND ELECTRICAL ENGINEERING*

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Abstract

The research aimed to gain insight on the values and user experience of smart home energy technology to improve the effectiveness of smart home energy management systems (SHEMS). There are many facets to the values and preferences of the smart home energy technology users including values held by smart home energy technology stakeholders, sensory user experience of SHEMS, real-life impacts of SHEMS on energy consumption, drivers of and barriers to adoption and gendered roles in smart home energy technology adoption and use. The diverse aspects of the research topic called for a variety of methods, approaches and techniques, which merged value-sensitive design, sensory ethnography, practice-oriented human–computer interaction (HCI), laddering technique, critical theory and quantitative data analysis. In a value-sensitive design framework and applying sensory ethnography lens, 28 households were selected, representing new, prospective and experienced SHEMS users. The users were interviewed and observed. Energy consumption data of 10 households was analysed to understand changes in energy consumption due the SHEMS. The qualitative and quantitative real-life data gave a comprehensive picture of the SHEMS users' values as well as the drivers and barriers to adoption, in-depth understanding of the contextual factors influencing the use of SHEMS, and changes in the volume and profiles of energy consumption due to use of SHEMS. The findings revealed that SHEMS users seek primarily economic gains through SHEMS. Environmental friendliness is an important second-tier value, followed by comfort of living, security and curiosity about new technologies. However, users' awareness was low concerning the connection of smart home energy technology to the larger energy system and increased use of renewable energy, for example by providing demand flexibility through SHEMS. The findings also revealed that energy conservation after the adoption of SHEMS was up to 30% during the winter months. The daily consumption profile changes when consumption is shifted to low-peak hours instead of peak hours. Nevertheless, there was much variation in energy conservation among households and even in the same household in different winter months. The findings indicate a need for further knowledge about social aspects such as values, home practices and roles in the context of SHEMS user experience. In addition, increased awareness of energy transition and how home practices relate to the larger energy system is required. The findings contribute to the sustainable HCI research, smart home technology design, energy research and energy policy planning.

Keywords: energy community, sensory ethnography, smart home energy management system, value-sensitive design

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Tiivistelmä

Tavoitteena oli selvittää älykkään kodin energiateknologiaan liittyviä (SHEMS) arvoja ja käyttökokemusta. Perimmäisenä tavoitteena on vähentää energiankulutusta ja lisätä uusiutuvien energialähteiden käyttöä digitaalisten ratkaisujen avulla. Tutkimuksessa selvitettiin kontekstuaalisia tekijöitä, jotka vaikuttavat SHEMS-käyttäjien arvoihin, mieltymyksiin, älykkään kodin energiateknologioiden omaksumiseen ja käyttöön. Laadulliset ja kvantitatiiviset tosielämän tiedot antoivat kattavan kuvan SHEMS:n käyttäjien arvoista, motiiveista, SHEMS:n käyttöön vaikuttavista kontekstuaalisista tekijöistä ja SHEMS:n vaikutuksesta energiankulutukseen. Arvoperustaisen suunnittelun kehikon pohjalta ja soveltaen sensorisen etnografian tarkastelukulmaa ja laddering-tekniikkaa haastateltiin ja havainnoitiin käyttäjiä 28 kotitaloudessa, jotka edustivat uusia, potentiaalisia ja kokeneita SHEMS-käyttäjiä. Lisäksi 10 kotitalouden energiankulutustiedot analysoitiin SHEMS:n käyttöönoton aiheuttamien muutosten ymmärtämiseksi. SHEMS:n ja energiayhteisön arvoja ja käyttäjäkokemusta käsittelevä tutkimus ei ole aiemmin selvittänyt SHEMS:n todellisten käyttäjien arvoja ja käyttökontekstia. Lisäksi saatavilla oli niukasti tietoa SHEMS:n todellisista vaikutuksista energiankulutukseen, koska aiempi tutkimus perustuu pääosin simulaatioihin todellisen kokeilun sijaan.

Löydökset paljastivat, että SHEMS-käyttäjät tavoittelevat ensisijaisesti taloudellisia etuja, ympäristöystävällisyyden ollessa tärkeä toissijainen arvo. Muita kodin älykkääseen energiateknologiaan yhdistettyjä arvoja olivat asumismukavuus, turvallisuus ja uteliaisuus uusia teknologioita kohtaan. Käyttäjien ymmärrys järjestelmistä ja niiden yhteydestä laajempaan energiajärjestelmään ja uusiutuvan energian käytön lisäämiseen esimerkiksi tarjoamalla kysyntäjoustoa oli kuitenkin hyvin vähäistä. Tutkimus osoitti myös, että SHEMS voi talvikuukausina tuoda jopa 30 % säästön energiankulutukseen. Lisäksi järjestelmä muutti päivittäistä kulutusprofiilia niin, että kulutusta siirtyi huippukulutuksen ajoilta vähemmän sähkönkulutuksen tunneille. Kuitenkin energiansäästöasteessa oli suuria eroja kotitalouksien välillä ja jopa samassa taloudessa eri talvikuukausina.

Löydökset osoittavat, että tarvitaan lisää tietoa kotien älykkäiden energiateknologioiden käyttäjistä ja rooleista ja käyttäjille tietoa energianhallinnasta ja oman kulutuksen yhteydestä laajempaan energiajärjestelmään sekä aktivointia osallistumaan energiasiirtymään. Tulokset edistävät kestävien digitaalisten energiajärjestelmien tutkimusta, älykkään kodin teknologioiden suunnittelua, energiatutkimusta ja energiapolitiikan suunnittelua.

Asiasanat: arvoperustainen suunnittelu, energiankulutuksen ohjausjärjestelmä, energiayhteisö, sensory ethnography

Preface

This research is an outcome of four years of research, discussions and readings in user experience of smart home energy technologies and related subjects. My energy technology user experience research emerged from BCDC Energy research consortium work starting from 2016, which led to a research project "Iisisti Energinen" in the small town of Ii. There, I had the chance to conduct empirical research in households which used smart home energy management systems. Later, an online survey concerning energy communities was conducted for more than 1300 contacts, continued by telephone interviews on values related to energy communities. The results of the last two studies have not yet been published or included in the five papers included in this thesis. This thesis takes a view on the present situation of user experience of the smart home energy technologies. The future articles will be based on the research presented here and combine gained knowledge with the results of two energy community studies to draw design implications for future smart home energy technologies.

The articles included in this thesis are based on interviews, observations and data collection in 28 Finnish households. The first article "User values of smart home energy management system: sensory ethnography in VSD empirical investigation" (2019) presents the key user values of smart home energy management system (SHEMS) users. The second article "Warmth is more than temperature: it is a feeling" (2020) describes the sensory user experience related to SHEMS and energy use, but also to home environment.

I believe technology is not value-free but needs a social basis. Technology is affected by society and values, and on the other hand technology influences the society and values. Conductive values and structures sustain certain technologies, and technological changes precipitate social, structural and value changes. Energy transition accelerates development and diffusion of energy management technologies and services, and these will be adopted increasingly in homes. Energy is a vital part of everyday life and thus energy transition touches us all. New energy technologies and digital services may influence our practices and values, and reciprocally our values and practices direct us to use (or not to use) digital solutions in certain ways, resulting different impacts on environment, society and individuals. The aim of my work is to understand what values are related to smart home energy management systems and energy communities, and how these values should be taken into consideration in the design of technologies, services and structural changes.

I am deeply grateful to professor emeritus Rauli Svento, who was the first to hear and discuss the thesis idea, for strong encouragement and involvement throughout the process, and to professor Netta Iivari for her dedication and treasured support which was influential in shaping my theories, methods and academic writing. I would also like to express my sincere gratitude to all colleagues in the BCDC Energy research consortium and in Micropolis of Ii, to all the participants in the empirical studies as well as to Iin Energia, Motiva, Optiwatti and Cleworks. I would like to extend my sincere thanks to Professor Pedro Nardelli and Professor Minna Isomursu for their mentorship, and Mauricio de Castro Tomé for his contribution to the article number 3. Furthermore, I thank for the funding of the thesis the Fortum and Neste Foundation, grant numbers 20190098 and 20200099, the Academy of Finland Strategic Research Council project BC-DC (AKA292854), the University of Oulu and SITRA (The Finnish Innovation Fund). Finally, I dedicate this thesis to my dear children Pipsa and Pietari, to my partner, and to the rest of my family for their loving support.

30.8.2022 Sanna Tuomela

Abbreviations

EV	electric vehicle
HCI	human-computer interaction
HEMS	home energy management systems
RE	renewable energy
REC	renewable energy community
RES	renewable energy (re)sources
SETS	smart energy technologies and services
SHCI	sustainable human-computer interaction
SHEMS	smart home energy management systems
UI	user interface
UX	user experience
VSD	value-sensitive design

Original publications

This thesis is based on the following publications, which are referred throughout the text by their Roman numerals:

I Tuomela, S., Iivari, N. and Svento, R. (2019). User values of smart home energy management system: sensory ethnography in VSD empirical investigation. In *Proceedings of the 18th International Conference on Mobile and Ubiquitous Multimedia (MUM '19)*. Association for Computing Machinery, New York, NY, USA, Article 32, 1–12. https://doi.org/10.1145/3365610.3365641.

II Tuomela, S. Iivari, N. and Svento, R. (2020). Warmth is more than temperature, it is a feeling: Sensory user experience of smart home energy technologies. In *Proceedings of the 28th European Conference on Information Systems (ECIS)*, An Online AIS Conference, June 15-17, 2020. https://aisel.aisnet.org/ecis2020_rp/24.

III Tuomela, S., de Castro Tomé, M., Iivari, N. and Svento, R. (2021) Impacts of home energy management systems on electricity consumption. *Applied Energy*, 299, 117310. https://doi.org/10.1016/j.apenergy.2021.117310.

IV Tuomela, S., Iivari, N. and Svento, R. (2021). Drivers and Barriers to the Adoption of Smart Home Energy Management Systems – Users' Perspective. *In Proceedings of the Australasian Conference on Information Systems, 2021, Sydney.*

V Tuomela, S., Iivari, N. and Svento, R. (2022). Gender inclusiveness in adoption and use of home energy technologies. Manuscript.

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1 Abstract

The aim of this research was to gain insight on the values related to and user experience of smart home energy technology. The intention was to obtain information that can guide the design of smart home energy management systems (SHEMS) and improve the use and effectiveness of these systems. The goals of reducing energy consumption and increasing the use of renewable energy resources through digital solutions formed the basis for this research. SHEMS was chosen as the intervention to address the contextual factors that contribute to user values and preferences as well as adoption and use of smart home energy technologies. This was done through empirical qualitative and quantitative research on SHEMS adoption and use. Using a value-sensitive design framework, the researcher interviewed and observed 28 households representing new, prospective and experienced SHEMS users. The sensory ethnography lens and laddering technique were applied. Energy consumption data from 10 households was analysed to understand changes due to the adoption of SHEMS. The qualitative and quantitative real-life data gave a comprehensive picture of the SHEMS users' values and the drivers and barriers to adoption as well as in-depth understanding of contextual factors influencing the use of SHEMS and changes in the volumes and profiles of energy consumption due to the use of SHEMS.

Literature on values and user experiences of SHEMS and the energy community was analysed, and certain critique points were noted. Past research has tended to be limited to potential rather than actual users of SHEMS. Furthermore, limited knowledge is available on the real-life impacts of SHEMS on energy consumption, as the data were largely derived from simulations rather than real-life experiments. The research question in this study is as follows: What are the values and user experience of the users of smart home energy technology? There are many facets to values and preferences of smart home energy technology users. These include values of smart home energy technology stakeholders, sensory user experience of SHEMS, real-life impacts of SHEMS on energy consumption, drivers and barriers for adoption and gendered roles in smart home energy technology adoption and use. The diverse aspects of the topic called for a variety of methods, approaches and techniques that merge value-sensitive design, sensory ethnography, practice-oriented HCI, laddering technique, critical theory and quantitative data analysis. To address the critique points and explore user experience of and values related to home energy technologies, the researcher used a value-sensitive design framework. This approach provided a theoretical and

methodological framework to address the diverse aspects of SHEMS user experience.

The findings revealed that SHEMS users seek primarily economic gains from using SHEMS; environmental friendliness is an important second-tier value, followed by comfort of living, security and curiosity about new technologies. Users' awareness was low concerning the connection between smart home energy technology and the larger energy system and the increased use of renewable energy (for example, by providing demand flexibility through SHEMS). In addition, the adoption and use of SHEMS is highly gendered. A large segment of potential users is ignored in the design and targeting of SHEMS and other smart home technologies. The research also revealed that energy conservation after the adoption of SHEMS can be up to 30% during the winter months. The daily consumption profile is altered as consumption is shifted to low-peak hours instead of peak hours. The changes were observed even in homes that valued comfort over economic savings and environmental friendliness. Nevertheless, there was wide variation in energy conservation rates among the households and even in the same household in different winter months.

The findings indicate the need for more knowledge on social aspects such as values, home practices and roles in the context of SHEMS user experience; such knowledge should be used in designing inclusive smart home energy technologies. In addition, increasing people's awareness of energy transition and how home practices relate to the larger energy system is required. The findings contribute to sustainable HCI research, smart home technology design, energy research and energy policy planning.

2 Introduction

Residential energy management technologies are increasingly becoming a vital factor in clean energy strategies and energy citizenship. The aim of this research is to understand the values, preferences and contextual factors of smart home energy technology end users. Such knowledge can guide designs and improve the use and effectiveness of smart home energy management systems (SHEMS). The main research questions are 1) What values do users hold related to SHEMS and to practices and spaces entailing energy use? and 2) What is the interrelation between the values people hold and the use of SHEMS?

Users' values were elicited in interviews and observations and a sensory ethnography lens was applied. The interview results were triangulated with quantitative energy consumption data. The findings indicated that the key values regarding SHEMS varied across households, although economic gain was usually the driving value. Environmental friendliness was an important second-tier value for some users. In addition, regardless of specific values, most households made significant savings in energy consumption and peak shaving. However, a lack of awareness of SHEMS and how household energy consumption relates to the larger smart grid may be a barrier to the wider adoption of SHEMS.

The importance of this work lies in understanding the human factors in energy technology adoption and use. The findings can inform the design of SHEMS and other home energy technologies and digital services. The theoretical and methodological insights deepen the knowledge about SHEMS end users in the field of sustainable human–computer interaction (SHCI) research. In addition, the research provides an understanding of the values and contextual factors of energy end users for energy policy and strategy makers.

2.1 Background and research environment

Residential energy consumption is a major cause of global greenhouse gas (GHG) generation. Energy consumption produces about 73% of all GHG, of which the generation of heat and electricity is responsible for most emissions, or about 30% of total GHG (IEA, 2019). In the EU, households represent about 26.3% of all energy consumption (European Commission, 2019), contributing greatly to CO_2 emissions.

Rapidly growing use of weather-dependent renewable energy sources (RES) and increasingly decentralised energy generation into the power grid – including households' own energy production – are placing new demands on home energy management. The next decade is likely to witness a considerable rise in the use of home energy technologies and digital services (European Commission, Directorate-General for Energy, 2020). It is estimated that by 2050, 115 million EU households will have an electric vehicle (EV), 60 million homes may have solar panels and 42 million may have stationary batteries on their premises (CE Delft, 2016). About half of all EU households (113 million) may produce energy, either individually or through an energy community, and about 161 million may provide demand flexibility because of owning an EV, electric boiler or batteries (CE Delft, 2016).

In future strategies for energy transition and smart grids, energy consumers will become 'energy citizens' who actively manage their energy demand and supply together with other smart grid stakeholders (European Commission, 2019), (Pahkala, Uimonen, & Väre, 2018), (Goulden, Bedwell, Rennick-Egglestone, Rodden, & Spence, 2014). They will participate in energy markets, selling and buying micro-generated energy and demand flexibility (Schick & Gad, 2015), (McIlvennie, Sanguinetti, & Pritoni, 2020), (Steg, Perlaviciute, & van der Werff, 2015), (Schick & Gad, 2015). Furthermore, householders will face new guidelines and regulations, such as the revised European Performance of Buildings Directive (European Commission, 2020) and the Smart Readiness Indicator (European Commission, 2021), aimed at increasing energy efficiency and conservation or providing demand flexibility through automation and energy management systems (European Union, 2018).

However, most households lack the means to manage their energy use and demand flexibility in a sophisticated way (Buchanan, Banks, Preston, & Russo, 2016). Energy users find it hard to make a connection between their daily activities and level of energy consumption (Neustaedter, Bartram, & Mah, 2013) or may fail to perceive how their daily practices influence the broader energy system (Sugarman, 2015). Therefore, technologies and digital services are necessary for managing the production and consumption of energy in the residential sector to increase energy efficiency and energy conservation, demand flexibility and the use of RES. and understanding of household energy consumption for reducing energy-related emissions and mitigating climate change.

SHEMS and energy communities offer new possibilities to manage one's energy consumption and production and to participate in energy markets through technological solutions. SHEMS, also called home energy management systems (HEMS), are a technology that optimises energy consumption and/or shifts the periods of energy consumption to hours of excess energy. These methods reduce the energy costs and CO_2 emissions caused by peak-hour energy production. The energy community, from the end user's point of view, is a digital service for buying, selling or sharing energy from local RESs. These services also provide demand flexibility and/or investment in community renewable energy technologies, such as solar panels and energy storage.

Digital technology plays a major role in energy transition by providing the means to empower energy end users and communities, thereby contributing to a more sustainable and democratic or fairer energy system (Van Summeren, Wieczorek, & Verbong, 2021). Hence, there are significant economic, environmental and ethical implications in the choices people make when it comes to energy consumption and smart home energy technology use. Studies on human values related to these technologies enable home energy technologies to be designed in a way that incorporates people's values – rather than merely functional requirements – into the design. This makes technological innovation a responsible innovation (Van den Hoven, Vermaas, & Van de Poel, 2015).

Despite providing economic and environmental benefits, smart home energy technologies have not been widely adopted (Delta-EE, 2020). The development of smart technologies has largely focused on technical solutions rather than on the user experience (Ardito, Buono, Desolda, & Matera, 2018). In the design of an end node of a complex energy system, not only functional requirements but also individual and social values should be addressed (Ligtvoet, et al., 2015). Human interaction with technologies should be studied in real-life conditions, with a situated view (Luck, 2016). Such research must be conducted in homes. 'Home' is a special place with a private and intimate nature, where people feel a sense of belonging. However, the home as a research environment is growing in importance across many disciplines (Easthope H. , 2004), including technology research (Coughlan, et al., 2013). There is an acknowledged need to study energy management technologies in real-life experiments and in the authentic context of use and to identify the role of factors such as gender in the adoption and use of these technologies (Sovacool & Furszyfer Del Rio, 2020), (Sovacool, Kester, Noel, & Zarazua de Rubens, 2019). When users' values are implemented and even enhanced in the design of energy technology, that fosters acceptability, adoption and more efficient use of smart home energy technologies. Yet few HCI researchers have addressed the question of values and smart home energy technologies (Pierce & Paulos, 2012).

2.2 Objectives and research questions

This thesis investigates what kinds of values and goals people have in the context of smart home energy management technologies and how the current technologies address these values. Furthermore, the research explores how these values are manifested in the home, how key values can be addressed through current and future smart home energy technologies, what kinds of value conflicts or barriers exist for people to act according to their values and how such conflicts can be resolved. The research empirically investigates user values of SHEMS, factors influencing SHEMS adoption and the impacts of SHEMS on energy consumption. SHEMS users' values and adoption rates were examined through semi-structured interviews with 28 households, representing three user groups: new, experienced and prospective SHEMS users. The contribution thus comes from discussions with real users in the real context of use and real-life data on consumption changes. Furthermore, the research adds to current knowledge through an overview of how users perceive the role of smart home energy technologies in the transition to using clean energy. The main research questions were as follows:

1. What values do the users hold related to SHEMS and to practices and spaces entailing energy use?
2. What is the interrelation between the values people hold and their use of SHEMS?

These research question were broken into sub-questions in the articles, as follows:

- RQ in article I: What are key user values related to SHEMS?
- RQ in article II: What does sensory user experience of home energy technologies consist of?
    a) What implications do sensory experiences of home and practices entailing energy use have for the design of home energy technologies?
    b) How does sensory user experience influence SHEMS use?
    c) How do energy and SHEMS use influence the sensory user experience?
- RQ in article III: What kinds of changes occur in the electricity consumption after the adoption of a SHEMS in terms of consumption volumes and the times of use, reviewed with the household values?
- RQ in article IV: What are the drivers of and barriers to the adoption of SHEMS?

– RQ in article V: How does gender inclusiveness emerge in the adoption and use of SHEMS and in the interest in energy communities? How could gender inclusiveness be further fostered?

2.3 Ontological and epistemological approach

In this research, user interaction with smart home energy technologies is understood as a dimension of everyday
practices. The topic is approached with the sensory lens in the context of home, from the sustainable HCI point of view. The complexity of the phenomenon under investigation and the research context required mixed methods, that is, both qualitative and quantitative research.

Technology can lead to value change by bringing a previously unattainable goal within the realm of choice or by making certain values easier to implement than before (Mesthene, 1997). Smart home energy technologies offer several opportunities to implement some values, whereas they limit others. These technologies are installed into homes with existing social, cultural and material practices (Hargreaves & Wilson, 2017), (Mitchell, ym., 2014), (Strengers, 2013). For householders, energy is an enabler, a constituent of practices and an aspect of lifestyle and 'making a home', rather than being an independent variable to be managed separately (Shove & Walker, 2014). In recent years the scope of HCI has widened to explore how people live with new technologies and on human agents, their activities and values (Bannon, 2011), (Pereira, Baranauskas, & Liu, 2015). User experience (UX) is increasingly addressed in a holistic way, aimed at understanding users' values related to technology and going beyond a single interaction (Obrist & Fuchs, 2010).

In homes, technology and users form a socio-technical system which evolves as the elements interplay. Greater awareness is needed of the consequences of practices and lifestyles as well as means to make changes to them. Technology can help people to become more aware of otherwise invisible energy and give them more control over it. Today, people are balancing technology transfer and their current practices with the energy (Spigel, 2005). Therefore, it is necessary to understand the values which users impart to technologies and the values that underpin their home practices involving the use of energy.

In the classical HCI approach, research has focused on interactions between the user and technology. In recent years, there has been growing interest in practice-oriented HCI as an alternative or complementary approach to this 'interaction' perspective (Kuutti & Bannon, 2014). By adopting practice theory, which emerged in the social sciences (Reckwitz, 2002), practice-oriented HCI 'examines historical processes and performances, longer-term actions which persist over time, … are situated in time and space, and are dependent on many features of the surrounding material and cultural environment, which cannot be simply seen as a surrounding "context", but must be interwoven within the practice' (Kuutti & Bannon, 2014). Besides interaction between a user and technology, how technology is a part of a person's everyday practices is an area of growing research interest (Kuutti & Bannon, 2014).

The HCI community has a long tradition of addressing sustainability challenges. A practice-oriented approach has been widely adopted in the field of sustainable HCI to better explain the complexity of sustainability problems (M. SilbeNathan, et al., 2014), (Pierce, Strengers, Sengers, & Bødker, 2013), (Entwistle, Rasmussen, Verdezoto, Brewer, & Andersen, 2015), (Katzeff & Wangel, 2015), (Hasselqvist & Eriksson, 2018). 'Sustainable HCI' (SHCI) as a term was established in 2010 to describe the research that intersects between HCI and sustainability (DiSalvo, Sengers, & Brynjarsdóttir, 2010), with the aim of enabling sustainability through design (Mankoff, ym., 2007). User experience and end-user interaction with energy technologies have been topics of interest within SHCI (Hansson, Pargman, & Pargman, 2021). This study addresses the need within SHCI to understand the practices, needs and values of the people who are expected to use technologies that support socially and environmentally sound practices (Hansson, Pargman, & Pargman, 2021), (Heitlinger, Bryan-Kinns, & Jefferies, 2013).

2.4 Research methods

In this study, the values and user experiences related to SHEMS are analysed along with their quantitatively measured impacts on energy consumption. A broader range of energy system and sustainability dimensions is also examined. This research is multidisciplinary. The main focus is users' experience of energy technology and the interaction between end users and energy technologies. However, the research overlaps with ethnography, philosophy – particularly ethics – as well as social sciences, psychology and environmental research.

Mixed methods were used to examine SHEMS end users' values and user experiences. Primary data was collected in 28 formal semi-structured research interviews and sensory ethnographic observation in the context of use of SHEMS (i.e., in homes). There was also structured data collection on the electricity use in

10 households with SHEMS. The analysis of user values and user experience of SHEMS is supplemented with a critical view on gender inclusiveness in the use and adoption of these technologies.

Value-sensitive design (VSD) is ‘a theoretically grounded approach to the design of technology that accounts for human values in a principled and systematic manner throughout the design process’ (Friedman, Kahn, & Borning, 2006), (Friedman, Hendry, & Borning, 2017), (Davis & Nathan, 2015). Several methods can be applied and integrated in VSD processes in all phases of technology development for purposes such as stakeholder identification and legitimation, value representation and elicitation and value analysis (Friedman, Hendry, & Borning, 2017). VSD represents an interactional stance on human values and technologies. VSD researchers posit that people shape the technologies, tools and infrastructures they design and implement; similarly, technologies shape human experience and society (Friedman, Hendry, & Borning, 2017). Paper I examines user values related to SHEMS by applying VSD stakeholder analysis. The data from ethnographically informed, value-oriented semi-structured interviews were used in all papers (I–V).

Sensory ethnography is a ‘methodology, which puts the sensory, experiential and affective elements of lived reality to the forefront of research design, conduct, analysis and representation’ (Pink, 2012), (Pink, 2015). In this research, sensory ethnography was applied as a lens during the interviews, observations and re-enactments of household practices in the homes of new, experienced or prospective users of SHEMS. Sensory ethnographic materials were used to unveil non-verbal aspects of user experience and values related to home energy technologies. They were also employed more broadly to examine home practices entailing energy use, how householders use different spaces in homes and what meanings they give to spaces and practices. Sensory user experience of smart home energy technologies and services is discussed in detail in paper II.

The researcher experimented with the laddering technique, which was employed to elicit the users’ values in interviews and to examine those values in the data analysis. The laddering technique is both an interview technique and a method to consolidate, analyse and visualise the results of interviews (Reynolds & Gutman, 1998). By using the laddering technique, the researcher was able to identify the SHEMS users’ values. The laddering interview began with questions about concrete attributes of the technology; thereafter, interviewees were asked *why* the attribute was important for them, finally ‘laddering’ up to the level of values. In addition to attributes, consequences and values, the linkages between these elements were identified (Zaman & Abeele, 2010), (Leitner, Wolkerstorfer, Sefelin,

& Tscheligi, 2008). The laddering technique posits that people adopt technologies which have features they associate with the consequences they desire. In addition, the rationale behind why those consequences are important is viewed as a personal matter or as a social value system (Reynolds & Gutman, 1998). Following this literature, in this study the values were viewed as what is considered important, and what is the final point in the interview, from which 'why -questions' do not lead any further.

The abstraction levels of the laddering technique were thus attributes, consequences and values. These levels were applied in the analysis of the interview data. The laddering technique and user values of SHEMS are discussed in detail in paper I, and the three most important values for each interviewed family are listed in Appendix 1. Additionally, articles II, III, VI and V are built on knowledge gained about the values of SHEMS users and an understanding of the SHEMS user experience.

In addition to qualitative data, real-life energy consumption data was collected and analysed from 10 households before and after the adoption of SHEMS. The data was weather-corrected using heating day degree (HDD) (see formula in Appendix 2.). The changes in both monthly and daily consumption were analysed and visualised together with the values the households held concerning energy use and SHEMS. The analysis and charts are discussed in article III.

The used methods were selected because, when combined, they unveil different facets and provide an understanding of the values and user experience of smart home energy technologies. VSD provides researchers with a theoretical framework and methodology, yet it does not limit the methods selected for use in empirical investigations. Sensory ethnography represents an innovative alternative and a lens for user interviews and observations of the user–technology interaction. This approach expanded the understanding of values related to SHEMS and energy consumption in homes. The laddering technique was found to be the best interview procedure for this value-sensitive investigation. The methods used in this study are explained in greater detail in chapter 3.

2.5 Structure of research

In this research, I focus on the values of SHEMS users in paper I. Paper II focuses more broadly on values in the sensory user experience of SHEMS. The elicited values of SHEMS users are reflected in paper III along with the quantitative data on energy consumption. Paper IV presents the drivers and barriers to adoption of

SHEMS. Paper V focuses on a selected value of gender inclusiveness in the adoption and use of SHEMS.

This thesis is structured as follows. Section 1 gives an overview of the background and the research environment regarding the values and user experiences of smart home energy technologies. The second section examines the theoretical background in each study and synthesises them. In the third section, the methods are described, and in Section 4 the findings are presented. These results are followed by a discussion and implications for home energy technology research and design.

3 Literature review

3.1 User experience of smart home energy management systems

Energy technologies refer to a ‘combination of hardware, techniques, skills, methods and processes used in the production of energy and the provision of energy services, i.e., the way we go about producing, transforming, storing, transporting and using energy’ (International Energy Agency, 2020, s. 27). This research focuses on the values and user experience of smart energy technologies in homes. SHEMS is a technology used in homes to monitor, control and automate energy-intensive processes, mainly heating and hot water boilers, but also other areas such as ventilation and the charging of EVs (Zhou, ym., 2016). Increasingly, home electricity generation (e.g., solar panels), storage (e.g., EV battery) and security features are integrated into these systems (Zhou, ym., 2016).

SHEMS can reduce overall energy demand and shift consumption to off-peak hours while enhancing household comfort (McIlvennie, Sanguinetti, & Pritoni, 2020), (Hargreaves & Wilson, 2017). With distributed and weather-dependent RES, it is increasingly important what time of day people use energy. Shifting energy use to off-peak hours helps to avoid energy generation in often fossil-fuel based peaking power plants and consequently reduces CO_2 emissions (Cozzi & Goodson, 2020), (Ford, Stephenson, Brown, & Stiehler, 2014). SHEMS can make a home the end-use node of a smart grid and can enable demand flexibility (Parag & Butbul, 2018), (Eid, Koliou, Valles, Reneses, & Hakvoort, 2016), (Siano, 2014). In turn, these features can advance the use of RES, reduce emissions and mitigate climate change (Elkhorchani & Grayaa, 2016), (Hargreaves & Wilson, 2017), (Shakeri & Amin, 2018), (Christensen, Gram-Hanssen, & Friis, 2012).

User acceptance and adoption of smart home energy technologies depends largely on how much value people obtain, without compromising other values in the home. Meanings associated with the use of energy and energy management technologies are created within social and everyday situations (Maréchal & Holzemer, 2018). Therefore, energy use should be studied as part of a wider experiential environment and flows of practical activity (Leder Mackley, Mitchell, Pink, Escobar-Tello, & Bhamra, 2013). Despite the significance of engaging users in the use of home energy technologies, research on SHEMS has mostly focused on the technical characteristics of the systems, and there is a need for research on the user perspective regarding SHEMS (Marikyan, Papagiannidis, & Alamanos, 2019). The values of SHEMS users, users' experience of SHEMS and the extent to which SHEMS can increase the flexibility of domestic electricity consumption have not been studied in depth.

Given the lack of actual users, current knowledge of users of SHEMS is largely based on data of potential or new users, or stakeholders other than actual users, or on simulations instead of real-life experiments (e.g. (Yousefi, Hajizadeh, Soltani, Hredzak, & Kianpoor, 2020), (Jin, Baker, Christensen, & Isley, 2017), (Dittawit & Aagesen, 2014), (Rasheed, et al., 2016)). Although simulations can present user-related variables, they do not always capture people's usage in realistic ways (McIlvennie, Sanguinetti, & Pritoni, 2020). There is a call for greater understanding of user experience and user values of SHEMS as well as actual energy savings and demand management outcomes among the adopters of SHEMS (Sanguinetti, Karlin, Ford, Salmon, & Dombrovski, 2018), (McIlvennie, Sanguinetti, & Pritoni, 2020). This research answers the call for studies involving real users of SHEMS who have direct experience of the technology (Sovacool & Furszyfer Del Rio, 2020).

Knowledge of people's values regarding smart home energy technology can be applied in designing both SHEMS and user experience of energy digital services. The contribution of this research comes from empirical studies with real users in the real context of use, including often hard-to-reach groups of non-users or prospective users. Furthermore, this research adds to current knowledge through an overview of how users perceive the role of SHEMS in their path towards clean energy use.

3.2 Values and technology in sustainable HCI

'Human values' refer to enduring beliefs that people hold concerning desirable modes of conduct or end-states of existence in various situations, societies and cultural contexts (Rokeach, 1973; Almond & Wilson, 1988). Desirable modes of conduct could be, for example, caring for loved ones or being active and healthy. A desirable end-state could be a preference for peaceful existence or democracy (Leong & Iversen, 2015). The values people hold and prioritise are the criteria they use to select their actions and to evaluate other people and situations (Schwartz S. H., 1992) as well as 'what a person or group of people consider important in life' (Friedman, Kahn, & Borning, 2006). Values can be psychological, practical or social, and they may occupy different levels of ethical importance (Nurkka & Kujala, 2008).

Values are the principles that guide people when faced with a choice that cannot be resolved as before (Pereira, Baranauskas, & Liu, An Essay on Human Values in HCI, 2018), (Kujala & Väänänen-Vainio-Mattila, 2009). Values may conflict at the societal and individual levels because different values are not prioritised consistently (Schwartz S. H., 1992), (Rokeach, 1973, pp. 5-11). Although the universality of values is debated (e.g., (Brocki, 2016)), following Schwartz (1992), in this study a group of values is considered universal even if it manifests differently in diverse cultures (see universal values by Schwartz mapped in Figure 1). According to Mesthene (1997), technology impacts values directly by creating new opportunities and therefore also new options for people to choose from. Technologies may shape the way people use energy and their awareness of the consequences of their actions for the larger energy system. Technologies may thus 'affect the set of affordances of and constraints to users' (Van den Hoven, Vermaas, & Van de Poel, 2015).

The importance of values in determining people's behaviour and choices has gained interest within several disciplines and research fields (e.g., (Lai, 1995), (Winter, Forshaw, & Ferrario, 2018), including HCI (e.g., (Iversen, Halskov, & Leong, 2012), (JafariNaimi, Nathan, & Hargreaves, 2015), (Kinnula, Iivari, Isomursu, & Laari-Salmela, 2018), (Kujala & Väänänen-Vainio-Mattila, 2009), (Sellen, Rogers, Harper, & Rodden, 2009), (Pereira, Baranauskas, & Liu, 2018). HCI research has addressed values in research and design practice (e.g. (Iversen & Leong, 2012), (Miller, Friedman, Jancke, & Gill, 2007)) as well as values related to the use of particular technology (e.g. (Zaman & Abeele, 2010), (Kinnula, Iivari, Isomursu, & Laari-Salmela, 2018), (Leitner, Wolkerstorfer, Sefelin, & Tscheligi, 2008)). In HCI, user values are defined as internal perceptions of what is important in a certain usage context (Kujala & Väänänen-Vainio-Mattila, 2009), and on the other hand as 'value for the user', which the product provides during the user's interaction with it (Kujala & Väänänen-Vainio-Mattila, 2009), (Nurkka & Kujala, 2008). The interaction between values and technology is studied and designed with awareness that the design choices may highlight certain values at the expense of others. The studied values of users and society are not always moral ones, although in certain cases they may include moral values (Vermaas, Hekkert, Manders-Huits, & Tromp, 2015). There are many value-based approaches and methodologies in HCI research, such as Values at Play (Flanagan M & Nissenbaum, 2007), (Flanagan, Howe, & Nissenbaum, 2005), the VSD model of Friedman et al. (Friedman & Hendry, 2019), (Friedman B. , 1999), Cockton's value-centred HCI and worth-centred computing (Cockton, 2009) and Iversen et al.'s value-led participatory design (Iversen, Halskov, & Leong, 2012), (Iversen, Halskov, & Leong, 2010), (Iversen & Leong, 2012).

People are not always free to prioritise and realise their values. They may be forced to abandon some values and adopt others, due to circumstances. Climate change, energy transition and rapidly developing energy technologies mean that many people face new choices and circumstances (e.g., (Steg, Perlaviciute, & van der Werff, 2015), (Huizenga, Piccolo, Wippoo, Meili, & Bullen, 2015). Values motivate people's preferences and drive their decisions, hence shaping energy behaviour and sustainable energy consumption (Van Deth & Scarbrough, 1995, ss. 5-6). For these reasons, values have gained increasing interest in human-centred energy research too (Ingeborgrud, ym., 2020). Understanding the values people have in relation to energy use and smart home energy technologies may advance the design and adoption of such technologies and improve people's practices regarding energy use (Shove & Walker, 2014).

SHCI concerns two strains of sustainability: 1) sustainability in design, i.e. the carbon footprint of technology products and their use; and 2) sustainability through design, i.e. the carbon handprint or how well-designed technology can reduce emissions and energy consumption in people's lives (Preist, 2017), (Morley, 2017). SHEMS offers opportunities to implement some values and limits others. These systems can help people to become more aware of abstract energy consumption and give them greater control over it. Complex systems such as SHEMS also represent other smart grid stakeholder values. When the SHEMS in homes is scaled up, changes in energy consumption – such as load shifting and demand flexibility – may impact the smart grid by flattening demand peaks. In turn, these changes can enable greater use of RESs (Walker, 2013), (Elkhorchani & Grayaa, 2016). SHEMS is used in the home, a highly personal and private space which carries many socially constructed meanings (Easthope H. , 2004). People express and realise their values at home more than in other environments. People demonstrate their values to reflect their identities and tell their stories. Smart home energy technology thus needs to fit these aspects, if it is to be appropriated (Després, 1991), (Sellen, Rogers, Harper, & Rodden, 2009). The holistic approach of practice theory and sustainable HCI makes it possible 'to grapple with the complexities of sustainability in terms of how people go about their everyday lives' (Pierce, Strengers, Sengers, & Bødker, 2013). In addition, this approach contextualises and informs the design of future sustainable technologies (Clear & Comber, 2017).

Friedman et al.'s VSD was used in this research as it is one of the most widely applied among value-based methodologies and is often recognised as the most extensive approach for addressing human values in technology design (Albrechtslund, 2007), (Le Dantec, Poole, & Wyche, 2009), (Davis & Nathan, 2015). VSD is a framework and methodology which proactively aims to consider human values throughout the process of technology design (Borning & Muller, 2012), (Friedman, Kahn, & Borning, 2006), (Davis & Nathan, 2015). In this study, VSD is used in an innovative way to guide descriptive empirical work on values, which can be applied in design in future research. The key principle of VSD is that technology is not value-neutral and that certain technologies are more suitable than others for supporting given values (Friedman, Kahn, & Borning, 2002), (Friedman & Kahn, 2002), (Davis & Nathan, 2015). VSD defines values as 'what is important to people in their lives, with a focus on ethics and morality' (Friedman & Hendry, 2019). Most VSD work has emphasised human wellbeing, dignity and justice (Friedman & Hendry, 2019). People's values influence the choices they make concerning energy use, energy conservation and energy technologies (Matschoss, Repo, & Timonen, 2019). Smart home energy technologies offer opportunities to implement certain values held by end users and other stakeholders, while limiting others. The values of different stakeholders may conflict; for example, householders may not be interested in providing the grid with demand flexibility, whereas this issue is of interest to smart grid operators. The values a technology represents may also be a barrier to adoption of the technology. For example, otherwise interested consumers may be deterred from purchasing technology products if the product carries unwanted value connotation (Gromet, Kunreuther, & Larrick, 2013).

VSD has been criticised for considering certain values universal (e.g., (Borning & Muller, 2012), (Le Dantec, Poole, & Wyche, 2009)). However, the use of VSD does not obligate a researcher to take the same stand as any previous VSD research concerning universality of values; rather, it is up to each VSD researcher to adopt and support their own position in the context of a particular project (Borning & Muller, 2012), (Davis & Nathan, 2015). Another point of critique has been quite the opposite, namely, that VSD fails to make concrete ethical commitments (Davis & Nathan, 2015). For example, (Albrechtslund, 2007) stated that VSD researchers should commit to ethical theory so that VSD is not vulnerable to uses that might support harmful values. According to (Manders-Huits, 2011), VSD requires a complementary ethical theory not only to demarcate moral values but also to provide a basis for designers to determine which values are crucial to support (Davis & Nathan, 2015). Furthermore, VSD does not provide a systematic and comprehensive method for identifying relevant stakeholders or for addressing the

use of methods and tools to promote joint reflection on values during the design process (Manders-Huits, 2011), (Yetim, 2011). However, VSD has in recent years been enriched with different methods to incorporate greater stakeholder participation (e.g., (Friedman, Hendry, & Borning, 2017)).
VSD is defined as 'a theoretically grounded approach to the design of technology that accounts for human values in a principled and comprehensive manner throughout the design process' (Friedman, Kahn, & Borning, 2002), (Friedman, Hendry, & Borning, 2017). VSD is grounded on the foundational premise that technologies embody values. It provides a framework and methodology for assessing the current design of technologies while proactively guiding the development of technologies from the early phase throughout the design process (Friedman, Kahn, & Borning, 2006), (Friedman B. , 1999) (Umbrello, 2018). Originating in HCI, VSD is one of the most studied and applied design-for-values approaches for interaction design (Friedman & Kahn, 2000), (Friedman & Kahn, 2002). VSD has also been applied in the development of other technologies, such as energy technologies (Correljé, Cuppen, Dignum, Pesch, & Taebi, 2015), (Mok & Hyysalo, 2018), sensor technology (Dechesne, Warnier, & van den Hoven, 2013), engineering science (Van De Poel, 2009) and nuclear engineering (Taebi & Kloosterman, 2014).

A challenge for VSD is how to use the identified values to (re)design technologies and socio-technical structures (Correljé, Cuppen, Dignum, Pesch, & Taebi, 2015). Another challenge of VSD lies in following the tripartite methodology of VSD, as the approach lacks a clear methodology for identifying direct and indirect stakeholders and for assessing and systematically including stakeholders' values (Manders-Huits, 2011). Therefore, social-scientific empirical methods need to be applied in VSD (Correljé, Cuppen, Dignum, Pesch, & Taebi, 2015).

3.3 Theoretical background in studies

3.3.1 User values of SHEMS users

Paper I concerns key user values of SHEMS users. Previous studies have investigated user perspectives regarding SHEMS (e.g. (Balta-Ozkan, Davidson, Bicket, & Whitmarsh, 2013), (Wilson, Hargreaves, & Hauxwell-Baldwin, 2015), (Wilson, Hargreaves, & Hauxwell-Baldwin, 2017)) or stakeholders of smart grids (e.g. (Connor, Axon, Xenias, & Balta-Ozkan, 2018)), but little is known about the values of users of SHEMS. The values of SHEMS users appear implicitly in many studies on smart metre acceptance and adoption (e.g. (Abdmouleh, Gastli, & Ben-Brahim, 2018), (Buchanan, Banks, Preston, & Russo, 2016), (Connor, Axon, Xenias, & Balta-Ozkan, 2018)), smart home technologies (e.g. (Haines, Mitchell, & Cooper, 2007), (Hargreaves & Wilson, 2017), (Lobaccaro, Carlucci, & Löfström, 2016), (Marikyan, Papagiannidis, & Alamanos, 2019), (Mennicken & Huang, 2012)), and energy and sustainable behaviour (e.g. (van den Broek, Bolderdijk, & Steg, 2017), (Huizenga, Piccolo, Wippoo, Meili, & Bullen, 2015), (Labanca & Bertoldi, 2018), (Maréchal & Holzemer, 2018)).

Ligtvoet et al. (2015) elicited values in expert group discussions in a VSD study on the smart metre rollout delay and SHEMS standardisation in the Netherlands. The elicited values were categorised based on the 23 values found in the VSD literature. The authors argued that the universal values of Schwartz (1992) are not highly suited for research on technological artefacts and technology use. The expert group ranked the following top five values for SHEMS: economic development, universal usability, privacy, autonomy and reliability. It should be considered that these values were derived from an expert group, not end users. In addition, the study was an ex-post analysis, and the values were not elicited for implementation into a design.

Pre-defined values were applied in the participative design of interfaces for SHEMS in three eco-communities in Scotland (Peacock, et al., 2017). The concepts were evaluated on the feature matrix of two value axes: hedonic quality and pragmatic quality. The results of the user evaluation confirmed the difficulty in designing a solution which is both innovative and creative (hedonistic value) and usable (pragmatic value). The users hoped to have more pragmatic value and task-related information for load-shifting behaviours. Another case of applying predefined values was Sandström's (2007) doctoral thesis concerning smart home users and their values. Three predefined values – usefulness, usability and accessibility – were used to evaluate the user experience of life with smart home technologies. People were interviewed before they moved into a smart home to learn what they expected from it and again after they had lived in the apartment for some months. People appreciated the 'smartness' of their new home, since all extra features meant more value for money; however, they seemed uncertain about why they should have any smart technologies at home and they did not have particular goals for using smart technology. The values of usability, usability and accessibility were evaluated after the people had lived in the homes for some months. People did not consider the energy measuring function to be highly useful, but they suggested the control of indoor temperature and a device to control lightning as desired functions for a smart home. The technologies were easy to apply, according to users, yet people used them relatively little and selectively. During the research, the chief technological developer of the smart home technologies closed its business and many functions were left unstable or not fully installed. The trust of the users in the technologies and information the technologies presented was therefore low. In conclusion, the energy technologies were rarely used and the information they presented was at times unreliable, and though the systems were easy to use, they did not offer much value to the users.

An LEEDR study examined household energy consumption, home practices and smart home technologies. The researchers elicited specific user values with photographs, a form of cultural probes (Buswell & Webb, 2015), (Haines, Mitchell, & Cooper, 2007), (Mitchell, ym., 2014). Eight non-expert users photographed the things they valued in their home, technologies they liked to use and those they did not like, and things they did in the home to save energy or help the environment. They then discussed the photos. The results revealed that people valued other people (especially family), home spaces and memories most highly. Technology and automation were viewed as saving people time and making household tasks easier rather than adding unique value.

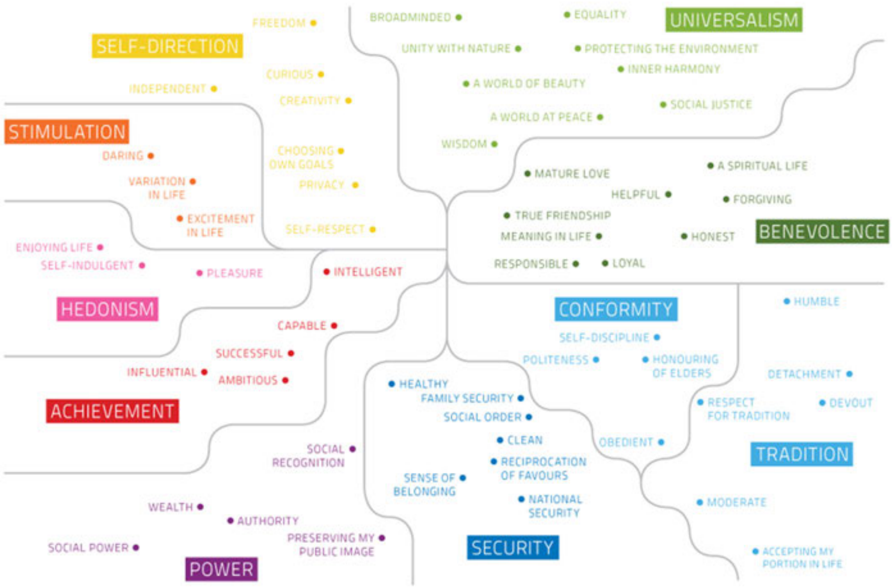


Fig. 1. Schwartz's universal values, adapted from Public Interest Research Centre (2011).

3.3.2 Sensory user experience of smart home energy technologies

In paper II, the sensory user experience of SHEMS was defined according to the user interviews and the sensory ethnography lens. Energy use in the home is involved in residents' everyday practices and is an outcome of several factors at the material, social, individual, technical and economic levels (Levold & Aune, 2003); (Aune, 2007); (Shove & Walker, 2014). The meanings of the use of energy and energy management technologies are created within social, everyday situations (Maréchal and Holzemer, 2018). Energy use in homes should therefore be studied as part of a wider experiential environment and flows of practical activity (Leder Mackley et al. 2013). Echoing the practice turn in social sciences during recent decades (Schatzki & Knorr-Cetina, 2001), practice-oriented home energy technology research examines people and technologies in time and place, such as how the technology fits into our everyday practices (Kuutti and Bannon, 2014) and how energy use is hidden and intertwined in everyday and digital practices and routines (Byrne and Bartiaux, 2017), which can be studied with ethnographic research methods. In HCI, various approaches have been proposed to study and design sensory interaction (e.g. (Hornecker & Buur, 2006); (Kapoor & Picard, 2005); (Slater, Usoh, & Steed, 1995); (Haque, 2004)). Furthermore, a sensory lens has been applied to themes in sustainable HCI (e.g., (De Giorgi, Lerma, Allione, & Buiatti, 2011); (Mo, et al., 2009)) or more specifically in energy use and related technologies (e.g. (Haines, Mitchell, & Ross, 2015), (Pink, ym., 2013)). Nevertheless, previous HCI research has failed to address what has been called the 'sensory user experience' of ubiquitous HEMS.

The human body, as a spatiotemporal entity, is present and involved in all practices a person performs, from sleeping to cooking and eating (Wallenborg & Wilhite, 2014). Many bodily practices are repetitive, but they are adjusted and changed if the demands or conditions of a situation so require (Thévenot, 2001). Perception and interpretation of the bodily and material sensations affects energy use and consequently how SHEMS is used in homes. For example, the perception of comfort has changed over the decades, as we have been able to heat our homes and water without much effort. Householders prefer to live in relatively spacious homes, thus consuming more energy for the heating and maintenance of the building (Ortiz, Kurvers, & Bluyssen, 2017). Homes are equipped with an increasing number of energy-consuming appliances and devices, and the expected level of functionality in homes is rising. However, research on home energy and SHEMS use has generally been based on an assumption that individuals are rational, and the social, material and perceptual aspects have received little attention until recently (Wallenborn and Wilhite, 2014).

The experiential position of SHEMS users in a smart grid can be viewed as being part of an 'energyscape' in which energy flows across social and physical spaces. The cultural, social, economic and technological value of the energy shifts as it flows from one domain to the next (Käkönen & Kaisti, 2012), (Strauss, Rupp, & Love, 2013, pp. 22,110). According to Appadurai's (1990) theory of scapes, the energyscape is a disjunction of material, cultural, economic, technical and political components which is perceived differently by various actors. This definition questions the traditional models of energy systems with centre–periphery, consumer–producers and push–pull.

A place is a situated location with cultural patterns and norms (Harrison & Dourish, 1996), and home is a special place with a private and intimate nature, where people feel a belonging. Although people usually describe an ideal home a free-standing, square, detached, single-family house and yard (Cooper, 1974/2014), home is more than just a physical building. Home is an expression of self rather than merely a shell and defender of the self (Cooper, 1974/2014). Moreover, it is a social construction (Easthope H. , 2004). For many householders, the most important meanings of home are 'home as relationship with family and friends' and 'home as reflection of one's ideas and values' (Després, 1991). Yet there are many ways in which the meanings related to home and the use of home energy technology emerge and are experienced (Gieseking & Mangold, 2014).

Home as a technology research environment is growing in importance (Easthope, H. 2004), (Coughlan et al., 2013). Homes and families can foster ecologic sustainability through smart home technologies, yet few HCI researchers have studied homes and the sustainable digital practices of families. Home as a research environment poses special features and challenges. For example, home is a private space, and for a researcher it can be a challenge to gain access there. However, householders' perspectives of privacy are dynamic and vary by person (Coughlan et al., 2013). Besides the different and dynamic levels of privacy, the borders of the home are marked in different ways. For example, taking one's shoes off in the vestibule before entering marks the border of private space (Rybczynski, 1986 / 2014). Often the idea of the 'home' also includes other meaningful places in the vicinity of the main building, such as a garden, yard, river shore or garage. As a sensory place, home is a mix of multiple sensory spaces, e.g., thermal, acoustic and olfactory spaces. Immediate sensory perceptions are interpreted through cultural and social norms and values, which influence how the home as a sensory place is experienced and modelled (Hall, 1966, p. 2). A researcher applying a sensory lens in the study of home technology use would focus on the interactions between the material environment and people and among people (Pink et al., 2013). Social relationships form a significant part of the meaning of home and the roles and activities played there (Coughlan et al., 2013). Particular sensations, such as comfort and relaxation, are of great importance to people in the sense of home. Usually, in the home, other people or memories and spaces are valued more than technologies or material objects. Technologies may help to save time, creating the desired sensation, or for other goals; however, sometimes they may also invoke feelings of pride, appearance and prestige (Haines, Mitchell and Cooper, 2007). Energy use in homes has evolved from complexity to simplicity and is changing to complexity again as people no longer need to carry, store and manage solid fuels. Humankind is today living a period of invisible and effortless energy (Lewis, 2011). However, energy production is becoming more decentralised, including many small energy producers and variable or weather-dependent energy production. These changes cause changes in residential energy use. Householders are also increasingly becoming ‘prosumers’, who not only consume but also produce, store and sell energy (Kotilainen, Sommarberg, Järventausta, & Aalto, 2016). The energy markets and smart grids are constantly evolving, and there are many uncertainties. The transition requires supportive technologies and services in homes, such as SHEMS.

3.3.3 Impacts of SHEMS on energy consumption

Paper III analyses the quantitative impacts of SHEMS on energy consumption. Smart home energy technologies are attracting considerable attention due to the global energy transition (McIlvennie, Sanguinetti, & Pritoni, 2020), (Steg, Perlaviciute, & van der Werff, 2015). SHEMS can reduce energy demand and shift consumption to off-peak hours while at the same time enhancing household comfort and convenience (McIlvennie, Sanguinetti, & Pritoni, 2020), (Hargreaves & Wilson, 2017). Yet the extent to which SHEMS can increase the flexibility of domestic electricity consumption has been demonstrated only through simulations (e.g. (Yousefi, Hajizadeh, Soltani, Hredzak, & Kianpoor, 2020), (Jin, Baker, Christensen, & Isley, 2017) (Dittawit & Aagesen, 2014), (Rasheed, ym., 2016)) rather than in real-life experiments. There is a need for research on actual energy savings and demand management outcomes due to SHEMS (Sanguinetti, Karlin, Ford, Salmon, & Dombrovski, 2018), (McIlvennie, Sanguinetti, & Pritoni, 2020). Furthermore, there is an identified need to combine energy consumption data with information on user values to gain a holistic understanding of energy-efficient behaviours (Johansson, Gentile, & Neij, 2021), (Ingeborgrud, et al., 2020), (Van Deth & Scarbrough, 1995, pp. 5-6). Because values strongly influence people’s practices and technology adoption and use, they may either foster or hinder sustainable energy consumption (Amasyali & El-Gohary, 2016), (Fornara, Pattitoni, Mura, & Strazzera, 2016), (Perlaviciute & Steg, 2015), (Frederiks, Stenner, & Hobman, 2015). Understanding the values people hold in relation to energy use and digital technologies, specifically energy technologies, can help researchers to advance the design and dissemination of energy technologies such as SHEMS (Matschoss, Repo, & Timonen, 2019).

Energy conservation and demand flexibility are main considerations in the transition towards the use of renewable energy resources (RESs). ‘Energy conservation’ refers to reducing end-user demand for energy by reducing the service demanded; for example, reduce demand for electricity for space heating can be achieved by lowering the thermostat in a home (Cleveland & Morris, 2015). ‘Demand flexibility’ refers to measures employed to adjust people’s consumption based on the availability and price of electricity. Examples include reducing (peak shaving, conserving), increasing (valley filling, load growth) or rescheduling (load shifting) the energy demand. Demand flexibility can be accomplished by individuals changing their energy use, or with the aid of energy storage, authorising the electricity utility or distributor to manage the demand side, or with the use of home automation systems. End users’ proactive reduction of their consumption during peak hours is cheaper and simpler than installing home technologies. However, this method is not sufficiently reliable because people lack knowledge regarding the level of their energy consumption and hourly demand variations and they are not willing to spend time thinking about and planning their energy use (Shakeri, et al., 2017). By contrast, SHEMS do so automatically.

Earlier research on smart home energy technologies and their impact on energy consumption has generally focused on energy consumption feedback (e.g., (Ueno, Inada, Saeki, & Tsuji, 2006), (Wood, et al., 2019), (Sanguinetti, Dombrovski, & Sikand, 2018), (Buchanan, Russo, & Anderson, 2014), (Lynham, Nitta, Saijo, & Tarui, 2016). The savings in energy consumption due to feedback fall within a wide range of 5% to 20% (Darby S. , 2006), (Roberts & Baker, 2003), (Faruqui, Sergici, & Sharif, 2010), (Zvingilaiteand & Togeby, 2015). In more recent studies on SHEMS that offer functionality beyond scheduled thermostats and/or feedback on energy consumption, the savings potential of SHEMS has been estimated to range from negative (i.e., consumption has increased) to over 20% (Karlin, et al., 2015, pp. 45-50), (Ford, Stephenson, Brown, & Stiehler, 2014), (Yousefi, Hajizadeh, Soltani, Hredzak, & Kianpoor, 2020). Simulations of energy consumption scheduling through SHEMS have brought about a 20% to 41% reduction in electricity bills (Yousefi, Hajizadeh, Soltani, Hredzak, & Kianpoor, 2020), (Ahmad, et al., 2017), (Dittawit & Aagesen, 2014) and a 21% to 25% reduction in peak-to-average ratios (Ahmad, et al., 2017). The New York State piloted SHEMS in 50 households during 2016 and 2017 and reported yearly energy savings of up to 16% (NYSERDA, 2017), (King, 2018). However, the study did not analyse changes in consumption profiles. The real-life trial of SHEMS by (Peacock, et al., 2017) focused on the participatory design of the SHEMS user interface rather than measuring changes in energy consumption levels and daily profiles. Real-life experiments on the impacts of SHEMS on energy consumption are rare and are expensive and time-consuming to organise (McIlvennie, Sanguinetti, & Pritoni, 2020), (Darby, 2006), (Karlin, et al., 2015), (Ford, Stephenson, Brown, & Stiehler, 2014).

Home heating and the provision of hot water account for 83% of all Finnish home energy consumption. About half of all detached houses in Finland use electric heating as the primary heating technology (Tilastokeskus, 2018), (Tilastokeskus and LUKE, 2018). Heating during the consumption peaks in winter offers potential for the demand side management in the residential sector (Lund, Lindgren, Mikkola, & Salpakari, 2015). Energy conservation and demand flexibility through SHEMS require both quantitative and qualitative changes in energy consumption, as users need to identify and record the optimal system settings but must also reconsider their practices and requirements in terms of comfort. SHEMS causes quantitative and qualitative changes in homes. Energy consumption should decrease and the time of using energy should shift. In addition, users may note other qualitative consequences, such as a more stable indoor temperature, more awareness of energy consumption and behavioural changes due to increased awareness. Values both inform and are affected by the use of HEMS. In this study, we sought to determine the connection and feedback between the values and quantitative changes in energy consumption.

Several studies have analysed the human behavioural and demographic factors influencing energy consumption and the adoption of energy technologies (e.g. (Mills & Schleich, 2012). However, few have evaluated people's values related to changes in household energy consumption. Additionally, there is considerable ambiguity about the association between values and energy-use behaviours. Amasyali and El-Gohary (2016) surveyed the energy-related values and satisfaction levels of residential and office building occupants in three US states. They identified seven energy-related values: thermal comfort, visual comfort, internal air quality, health, personal productivity, environmental protection and energy cost savings. Health was ranked as the most important value by the survey respondents. Significant differences were found in the importance rankings of residential versus office building occupants, with energy cost savings being more important for residential occupants and visual comfort and personal productivity more important for office occupants. Although values underpin behaviour, people often do not act according to their higher values (Flynn, Bellaby, & Ricci, 2009), (Frederiks, Stenner, & Hobman, 2015), (Mack, Tampe-Mai, Kouros, Roth, & Taube, 2019). Because of this value–action gap (Barr, 2006), (Huddart-Kennedy, Beckley, McFarlane, & Nadeau, 2009) and hedonic or pragmatic moral hypocrisy (Lindenberg, Steg, Milovanovic, & Schipper, 2018), in addition to verbal interview sensory ethnography lens with observations and re-enactment of home practices in the context of energy use can reveal which values drive home energy use in practice. For example, if householders value comfort, this value affects the amount of energy used for space heating (Hansen, Madsen, Knudsen, & Gram-Hanssen, 2019). On the other hand, environmental values may lower the price sensitivity towards technologies that promote sustainability (Hahnel, Ortmann, Korcaj, & Spada, 2014). Savings in energy consumption depend largely on how efficiently users apply the features of SHEMS, the behaviour of residents (e.g., whether doors between rooms are kept open or closed), their required comfort level and characteristics of the home.

3.3.4 Drivers and barriers to adoption of SHEMS

Paper IV focuses on the drivers and barriers to adoption of SHEMS. The process of and factors in technology adoption have been widely studied with technology acceptance models TAM1-3 (e.g., (Davis F. D., 1989), (Venkatesh & Davis, 2000), (Venkatesh & Bala, 2008), (Frontiers, 2008) and the unified theory of acceptance and use of technology (Venkatesh, Morris, Davis, & Davis, 2003). This research builds on the conceptual framework of the TAM model. Inspiration is also derived from the social shaping of technology approach in the Science and Technology Studies, which has been applied in research on technology design, adoption and use (Rohracher, 2003), (Hyysalo, 2021). Following the same approach, this research aims to develop a broad and socially grounded understanding of users and their needs (Rose, 2001). We consider the drivers of and barriers to the adoption of SHEMS as socio-technical factors which shape technology during the technology lifecycle, from innovation and design to use and implementation (Mackay & Gillespie, 1992).

Adoption of new technologies can be partly explained by demographic factors. For example, tech-savvy people may be willing to adopt new technologies (Ram & Jung, 1991), and young and educated people may be early adopters of home energy technologies for environmental reasons (Mills & Schleich, 2012). However, adoption of new technologies involves much symbolic, practical and cognitive work beyond the initial purchasing decision (Schot, Kanger, & Verbong, 2016), (Hyysalo, 2021). Therefore, the focus here is on the wider context of adoption, i.e., home and the users' motives for adopting SHEMS. Furthermore, the users' perception of SHEMS as a technology for supporting the use of clean energy is discussed. Research on SHEMS has largely been conducted under the umbrella of smart home technologies (e.g., (Balta-Ozkan, Amerighi, & Boteler, 2014), (Hargreaves & Wilson, 2017), (Wilson, Hargreaves, & Hauxwell-Baldwin, 2015), (Dütschke & Paetz, 2013), (Lewis, 2011)). Energy management is one of the key functions of smart homes (Hargreaves & Wilson, 2017, p. 41). Smart home research has largely focused on the technical characteristics of smart homes (Petkov, Köbler, Foth, Medland, & Krcmar, 2011), but in the last decade some studies have focused specifically on the adoption of SHEMS (e.g., (Connected Devices Alliance, 2018), (Werff & Steg, 2016)). Within the HCI field, there are studies on SHEMS interfaces and design (e.g., (Schwartz, Denef, Stevens, Ramirez, & Wulf, 2013), (Peacock et al., 2017), (Zhao, Zhang, & Crabtree, 2016), (Alao, Joshua, & Akinsola, 2019), (Castelli, et al., 2017), (Alan, et al., 2016)) and SHEMS users and user experience (e.g., (Rodden, Fischer, Pantidi, Bachour, & Moran, 2013), but little is known about the adoption factors among SHEMS users in different phases of adoption.

According to recent studies on smart homes and SHEMS, the most obvious and common driver for the adoption of SHEMS is saving energy (Karlin et al., 2015), (Hargreaves & Wilson, 2017), (Balta-Ozkan et al., 2013). Users want to save energy for economic gains and for environmental reasons (Karlin et al., 2015), (Balta-Ozkan, Amerighi & Boteler, 2014), (Sovacool & Furszyfer Del Rio, 2020), (Paetz, Dütschke, & Fichtner, 2012), (Petkov et al., 2011). Many users expect SHEMS to provide insight regarding their energy consumption and costs (Karlin et al., 2015), (Balta-Ozkan, Amerighi & Boteler, 2014), greater ease in the control of energy use (Karlin et al., 2015), increased comfort (ibid.; Sovacool & Furszyfer Del Rio, 2020) and security in the home (Hargreaves & Wilson, 2017, p. 51). For some adopters of SHEMS, the novelty of technology and desire to optimise their home functions with new technological solutions is an important driver (Karlin et al., 2015).

Certain barriers slow down the adoption of SHEMS. The price of the system is considered too high and payback time too long. In some cases, retrofitting a house would be too costly and complicated and is suitable only for homeowners with a large house and no plans to move for many years (Balta-Ozkan, Amerighi & Boteler, 2014), (Balta-Ozkan et al., 2013), (Bjelica, 2018). In addition, many householders are unsure what energy efficiency actions to take and how, or they lack the time to study their options and adopt new measures (Paetz, Dütschke & Fichtner, 2012). Data privacy issues concern some smart home users (Paetz, Dütschke & Fichtner, 2012), (Balta-Ozkan et al., 2013). There are also trust issues when comes to utilities, SHEMS providers or even the government in promoting smart home energy technologies (Balta-Ozkan, Amerighi & Boteler, 2014), (Paetz, Dütschke &

Fichtner, 2012), (Balta-Ozkan et al., 2013). Demand flexibility through SHEMS may evoke questions about giving up control of household energy consumption and adapting everyday routines to fit with the electricity tariffs (Paetz, Dütschke & Fichtner, 2012), (Ruokamo, Kopsakangas-Savolainen, Meriläinen, & Svento, 2019) or a fear of volatile prices (Balta-Ozkan, Amerighi & Boteler, 2014).

3.3.5 Gender inclusiveness in the adoption and use of smart home energy technologies

Paper V focuses on gender inclusiveness as a value in the adoption and use of SHEMS and other smart technologies. The study draws from critical theory (Iivari & Kuutti, 2017), (Obrist & Fuchs, 2010), (West & Zimmerman, 1987) and VSD in HCI (Friedman, Hendry, & Borning, 2017). It takes a broader view on the interrelationship between technology and society. Critical theory stems from the Frankfurt school of critical social theory and later French postmodernists, who perceived reality to be distorted by history and power structures (Iivari & Kuutti, 2017). Critical theory aims to empower people who are in disadvantageous positions in power structures by seeing through distortions and making them explicit (Bardzell, 2013), (Iivari & Kuutti, 2017). Critical theory has recently gained interest in HCI (e.g. (Bardzell, 2013), (Iivari & Kuutti, 2017), (Obrist & Fuchs, 2010), (Grimes & Feenberg, 2013)) as a method of understanding the dialectical nexus between technology and society (Obrist & Fuchs, 2010). This interrelation of society and technology can be elucidated for example by studying values related to technologies and contextual multisensory user experiences of the technologies. VSD as a theoretical framework acknowledges the dialectical rapport between people, social systems and individual behaviour with technological development and new technologies (Friedman, Kahn, & Borning, 2002).

In recent years, gender inclusiveness has been recognised as a value in HCI (Stumpf, ym., 2020), (Carpendale, Bardzell, Burnett, Kumar, & Balaam, 2018), (Sefyrin, 2010). Inclusiveness in technology design takes into account people who may have challenges or diverse conditions in their use, for example because of disabilities, medical conditions, age-related characteristics (Keates, 2015), (Cozza, De Angeli, & Tonolli, 2017) or social situations (Barcham, 2021), (Sanchez Guzman, Giffinger, Parra-Agudelo, & Bogadi, 2020). Inclusive technologies are accessible to a broad population of potential users (Abascal & Azevedo, 2007) and can improve customer churn (Looms, 2011) and quality of life among the users. Gender inclusiveness pays special attention to the gender issues in technology design and use and to the broad social, cultural and economic context (Stumpf, ym., 2020).

In the ongoing energy transition, energy consumers are expected to become active and empowered energy citizens (Kampman, Blommerde, & Afman, 2016), (Lennon, et al., 2019). Recent socially and politically oriented energy research expects home energy technologies and energy communities to enable reorganisation of political and economic power structures concerning energy to advance energy justice and democratisation (e.g., (Heldeweg & Séverine Saintier, 2020), (Hanke, Guyet, & Feenstra, 2021), (Burke & Stephens, 2018). However, interest, adoption and use of home energy technologies are not shared by all people equally.

Gender shapes people's choices and opportunities to use home energy technologies. In a survey concerning solar panels, a male household member was often regarded as the person who knew best about the household and was responsible for it (Poier, 2021). Women and men often have different economic, social and cultural capital, and this influences their interaction with technology in the transition from consumers to solar prosumers (Standal, Talevi, & Westskog, 2020). According to German studies (Yildiz, ym., 2015), (Fraune, 2015), renewable energy community (REC) members are typically middle-aged men with high income and a technical higher education background. Additionally, (Hanke, Guyet, & Feenstra, 2021) in a study on 71 RECs in Germany, France and the Netherlands, only 16% percent of REC members were women. In Germany, among the boards of 696 energy communities, 580 were fully occupied by men (83%), 101 were occupied by both men and at least one woman (14,5%) and 15 were occupied only by women (2,1%). Contextual factors such as wealth gap and gender-specific occupational segregation affect the gender gap in RECs (Fraune, 2015). MacGregor (MacGregor, 2016) found that more women adopted 'low-tech' energy-saving strategies such as energy-efficient light sources, whereas men showed more interest in – for example – solar panels. Additionally, women were found to have slightly stronger environmental values than men (Sovacool, Kester, Noel, & Zarazua de Rubens, 2019) and were more interested in reducing their energy consumption for environmental reasons, whereas men were highly interested in reducing their costs (MacGregor, 2016). Women often work in different types of productive activities from men and have different access to energy technology, energy markets, energy infrastructure and skills (Pueyo & Maestre, 2019). In households, men are considered the principal decision-makers concerning energy decisions, and women may be relieved when men take care of energy and related technologies, thus having 'one thing less to think about' (Strengers & Kennedy, 2020).

The level of energy consumption is different for men and women (Grünewald & Diakonova, 2020). In Europe, men consume more energy than women (Räty & Carlsson-Kanyama, 2010), and the consumption patterns and timing differ between the genders (Grünewald & Diakonova, 2020). Research often focuses on the household level of energy consumption, which hides the fact the home practices entailing energy use may vary between genders (Tjørring, 2016), (Clancy & Roehr, 2003). Studies on perceived comfort levels with indoor heating confirmed that women were subject to more discomfort than men with lower levels of indoor temperature, which may be one of the consequences of energy conservation strategies with SHEMS (Karjalainen, 2012), (Carlsson-Kanyama & Lindén, 2007).

The designers of smart home technologies such as SHEMS are overwhelmingly male (Strengers, 2013), and the 'smart technology agenda focuses on a masculine ideal consumer' (Strengers, 2013), (Strengers & Kennedy, 2020), (Sovacool & Furszyfer Del Rio, 2020). According to Strengers (2013), this 'resource man' is the 'energy sector's ideal smart energy consumer, intended to realise the industry's ambitions of reducing or shifting a home's consumption through the use of smart home technology'. In most cases among the users of smart home technologies, a man takes the lead in planning and deploying these technologies in the home (Strengers & Kennedy, 2020). Often the ambitions of the main user conflicted or were undermined by the home practices of other people in the household. For many male users, smart home technologies are 'fun' rather than 'necessary', whereas women have a pragmatic 'voice of reason' in the family (Strengers & Kennedy, 2020). Women have been largely ignored as a design resource by the smart home technology industry, which often 'assumes a deficit model where male technology use is normative, while women need to "catch up" to levels of their male counterparts' (Rode, 2011), (Strengers & Kennedy, 2020).

The pragmatic role women play in the acquisition process and use of smart home technologies is acknowledged as the 'wife acceptance factor' (Strengers & Kennedy, 2020). However, a woman is seen as an appendix of a man, and single women – either living alone, single mothers with children, or elderly single women – are not considered (even by themselves) to be relevant users of home energy technologies (Strengers & Kennedy, 2020). According to Sovacool et al. (2019), smart home systems linking EVs to the home electricity system and the grid are sexist and ageist: 'The smart consumer … is a techno savvy white boy in the suburbs … the smart customer is never a woman with two children at home'.

Women own EVs less often than men, drive fewer kilometres by car and use more public transportation (Sovacool, Kester, Noel, & Zarazua de Rubens, 2019).

Gender equality and women's empowerment is one of the universal values of the United Nations Sustainable Development Group (United Nations sustainable Development Group, 2021), and gender diversity in the energy sector has been declared vital by the International Energy Agency (IEA, 2019). Yet, the energy sector, including the electricity sector, is one of the least gender-diverse sectors and is overwhelmingly occupied by men (e.g., (Pearl-Martinez & Stephens, 2016), (Carlsson-Kanyama & Lindén, 2007), (BP, 2021), (Kashar, 2019), (Clancy & Roehr, 2003), (IEA, 2019). In the OECD countries, the share of female inventors of environment-related technologies is only 10% and is even lower (8%) for power generation and general engineering technologies (OECD, 2020). There is a risk that such an unbalanced energy technology sector produces solutions which further deepen gender inequality rather than increasing a democratic energy transition. Furthermore, to achieve higher adoption rates of the technologies intended for reaching energy goals and decreasing emissions, the gendered assumptions these technologies are built on should be revised (Anfinsen & Heidenreich, 2017). Gender has been identified as an important perspective in energy research (e.g., (United Nations Development Programme, 2012), (Feenstra & Özerol, 2018)); however, there remains a need for empirical research on the effects and implications of gender imbalance and of gendered stereotypes and assumptions (Anfinsen & Heidenreich, 2017), (Sovacool, 2014).

The technology sector is similarly male-dominated. Technologies are largely made by men, for men, and the gender of designers may influence the gender inclusiveness of a technology. An example is how designers might acknowledge the motivations and experiences of software use that can be differentiated as being typical for men and typical for women (Burnett, 2016). Also, different styles of user interface design may influence the sense of belonging for different genders (Metaxa-Kakavouli, Wang, Landay, & Hancock, 2018). Regardless of campaigns and initiatives for gender equality, the ICT sector has move backward on gender diversity in the last decades (Strengers & Kennedy, 2020), (UNESCO and EQUALS Skills Coalition, 2019).

Research on energy technology adoption, energy use and energy poverty usually use the ‘household’ as the unit of research subjects. This choice hides the individual and gendered differences behind one neutral consumption unit. Also, in energy research, often ‘household’ refers to a traditional family composition; families where gender is constructed non-traditionally, such as same sex couples, single parents raising children or elderly people living alone – typically women, as they tend to live longer than men – are rarely studied (Fathallah & Pyakurel, 2020). However, the number of 'non-traditional' families is large and growing. In EU, women living alone accounted for a quarter of all women (24.5%), whereas men living alone accounted for less than a fifth of the male population (18.9%) (Eurostat, 2020). Among women aged 65 or above, 40.1% live alone, compared with 19.4% of men in the same category (Eurostat, 2020). In the EU, 14% of households are single parents with children (Eurostat, 2021), and households with a single adult and dependent children are more often headed by women (11% in 2019) than men (3%) (European Union, 2017). Households with a single female adult usually are not considered in the target group of home energy technologies, such as SHEMS and solar panels. However, energy policies, energy technology and service design, marketing and research should not take for granted a traditional family composition of two parents of different genders who have children. Doing so excludes too many households. In paper V, I explore social structures, processes and values leading to a need for stronger gender inclusiveness concerning home energy technologies and services. Gender is understood in the paper as something people routinely 'do' and perform in their everyday interactions; it is also a basis for evaluating other people according to how they accomplish societal expectations about what is appropriate for one's sex category (West & Zimmerman, 1987).

3.4 Theory synthesis

Pellicer-Sifres (2020) proposes that the energy transition should be based on four central values in human development: sustainability, diversity, equity and participation. Until now, energy technologies and digital services have been strongly driven by market incentives and regulation. However, to increase the awareness and adoption of SHEMS and other home energy technologies, and to gain better understanding of their socio-technical consequences, it is necessary to attend to the end-user values that are addressed in this process (Ligtvoet, et al., 2015). SHEMS and other home energy technologies as well as their socio-technical environments embed latent values. As these values are made explicit, they can be accommodated in the design of smart home energy technologies and socio-technical structures.

In recent years, practice-oriented SHCI has focused on the user experience of sustainable technologies. Nonetheless, there is a call for more extensive user-centred research on smart home energy technologies. Previous sustainable HCI research has failed to address the values and user experience of smart home energy technologies. This research sheds new light on the values of SHEMS users, the drivers and barriers to adoption of SHEMS, actual impacts of SHEMS use and SHEMS sensory user experience.

4 Research design and methods

This research examines multiple factors in the adoption and user experience of SHEMS. A mixed-method approach was applied, with both qualitative and quantitative data collection and analysis. I explored the values surrounding the adoption and use of SHEMS, sensory user experience of SHEMS and the impacts SHEMS has on energy consumption in a real-life experiment. Overall, the emphasis was on the qualitative research. Within the VSD framework, semi-structured interviews and observations were conducted with a sensory ethnography lens; techniques such as laddering, house mapping and everyday routine re-enactment were used. VSD is both a research framework and a design methodology (Friedman, Kahn, & Borning, 2002) and this approach was used to structure the research. Qualitative data was combined with quantitative consumption data for a complete understanding of SHEMS user experience.

4.1 Value-sensitive design framework and methodology

VSD is both a framework and a methodology for identifying key values, value priorities, value conflicts, and barriers to implementing values. It enables designing for values (Friedman, Kahn, & Borning, 2006) (Friedman B. , 2012) (Friedman B. , 1999), (Friedman & Hendry, 2019). VSD adopts the position that a given technology is suitable for certain activities and readily supports certain values, while rendering other activities and values more difficult to realise (Friedman, Hendry and Borning, 2002; 2017). VSD identifies values in the context of technologies and addresses them throughout the design process (Friedman, Hendry, & Borning, 2017), (Friedman B. , 1999), (Friedman, Kahn, & Borning, 2002). In HCI, a number of value-led approaches have been proposed during recent years (e.g., (JafariNaimi, Nathan, & Hargreaves, 2015), (Le Dantec, Poole, & Wyche, 2009), (Leitner, Wolkerstorfer, Sefelin, & Tscheligi, 2008)) together with value-oriented design methods (Friedman B. , 1996), (Kinnula, Iivari, Isomursu, & Laari-Salmela, 2018), (Leitner, Wolkerstorfer, Sefelin, & Tscheligi, 2008), (Miller, Friedman, Jancke, & Gill, 2007). However, VSD is one of the best known and most widely used theoretical frameworks and methodologies for studying values in technology development (Davis & Nathan, 2015), (Friedman, Kahn, & Borning, 2006), (Friedman B. , 1996), (Friedman B. , 2012), (Friedman, Kahn, & Borning, 2002), (Friedman, Hendry, & Borning, 2017). According to Umbrello (2018), VSD is distinct from other value-centric design approaches for the following reasons:

- it helps to direct the development of technology in the early stages of design, not only during the design process
- it incorporates not only the values of designers or those directly involved as stakeholders but also of the public at large and industry or other sectors
- it does not focus solely on the values gained through empirical studies but seeks to account for all relevant values with particular weight, such as justice, human rights and human welfare
- it consists of three separate but integrated types of analyses: conceptual, empirical and technical
- it does not see values as passively coming from societal forces, nor as a necessary feature of a technology, but as 'interactional' – meaning that values are dynamic, as technology affects individual behaviour and society affects technological progress
- it considers some values (e.g. freedom, trust, equality and privacy) to be universal across cultures and societies, although manifesting in varying ways

VSD proposes an iterative tripartite process for design with conceptual, empirical and technical investigations (Friedman, Kahn and Borning, 2002). Conceptual investigation is a theoretical study of values in the design context in question, and it usually relies on previous research. Empirical investigation informs of the context in which the technology is situated (Friedman, Kahn and Borning, 2002). Any suitable quantitative and qualitative methods can be applied, e.g., interviews, observations, surveys and measurements of user behaviour. In empirical investigation, researchers seek answers to questions such as how the users apprehend individual values in the use context; how they prioritise values; whether there are gaps between values and actual behaviour; and the reasons for those gaps (Friedman, Hendry, & Borning, 2017). Technical investigation focuses on how technology supports values and how a new technology is designed to support selected values.

This research builds on a VSD empirical investigation among SHEMS users. The sensory ethnography lens was applied to conduct semi-structured interviews and observations, to gain understanding of the current state of the users of home energy technologies for informing the future designs of SHEMS. Following Friedman et al. (Friedman, Hendry, & Borning, 2017), two heuristics were used to elicit people's values through interviews and observations. First, probing 'why' questions were used to get behind the judgements and experiences of the users; second, we asked about values indirectly, for example by interviewing people about a hypothetical situation or a common everyday event or behaviour in their lives. In the analysis, elicited values were identified and defined using Schwartz's universal values (Schwartz S. H., 1992), values of the Rokeach value survey (Rokeach, 1973) and the list of values of smart grid users by Ligtvoet (2015). However, none of these value schemes was found adequate in its own right. In studies I–IV, the values of SHEMS users were elicited in interviews and practice re-enactments. In paper V, we drew upon observations in the adoption process and use of SHEMS in 28 households, with a focus on gender roles and responsibilities. Paper V consists of a conceptual investigation of a pre-defined value of gender inclusiveness in the adoption and use of SHEMS. Paper V is based on findings that emerged in VSD empirical studies and on literature and statistics. The presence of women was assessed among the self-selected telephone interviewees concerning the REC.

4.1.1 Sensory ethnography

In this research, a sensory ethnographic intervention was conducted as a part of a VSD process because it is one of the most suitable approaches to study user values related to practices and technologies in homes. Sensory ethnography (Pink, 2015), (Pink, 2012) was applied as a lens in the SHEMS interventions in homes to make visible the meanings people give to practices, spaces and sensory and social aspects in their homes and to 'uncover the complex relationships among values, technology and social structure' (Friedman & Hendry, 2019). Sensory ethnography focuses on the interaction between the material and social environment and people (Pink et al., 2013), (Pink, 2015). Sensory ethnography aims to make explicit otherwise often unverbalised and tacit factors in what makes home feel like home, how people move and spend time there, their values (i.e., what is important in the home) and the reasons. It brings 'the sensory, experiential and affective elements of lived reality to the forefront of research design, conduct, analysis and representation' (Pink, 2015, p. 4-8). There has been increasing interest in the use of sensory experience and sensory methodologies across disciplines in recent decades (Pink, 2013), a change often referred to as a 'sensual revolution' (Bull & Howes, 2016), or a 'sensual turn' (Howes D. , 2005, s. 29). A growing body of literature has examined sensory experience, and the sensory lens has been applied in architecture (e.g. (Holl, Pallasmaa, & Pérez-Gómez, 1994), (Pallasmaa, 2005)), phenomenology (e.g. (Merleau-Ponty, 1964)), psychology, physiology (e.g. (Breslin & Huang, 2006), anthropology (e.g. (Howes D. , 2003, pp. 29-58) and marketing research (e.g. (Valtonen, Markuksela, & Moisander, 2010). It is used in the humanities, social sciences and arts (Howes, 2003, p. xii-xxiii). Recently, domestic energy and home technology use were studied through a sensory lens in the UK-based LEEDR project (Buswell, Webb and Mitchell, 2015) and in the Australian project on automated smart homes (Pink, Strengers, Fernandez, & Sabiescu, 2016). By observing and modelling everyday practices at homes, researchers came to understand how people create meanings and make their homes 'feel right' and how they use energy to do this. Understanding everyday practices in the home revealed what constitutes energy demand and what the residents' goals and values were.

Mixed methods were used in this sensory ethnography study, as proposed by Pink (2012; 2015). Diverse perspectives help to capture and illustrate the invisible and complex sensory user experience of SHEMS. Figure 2 illustrates the methods and techniques applied in the sensory ethnography intervention within a VSD framework.

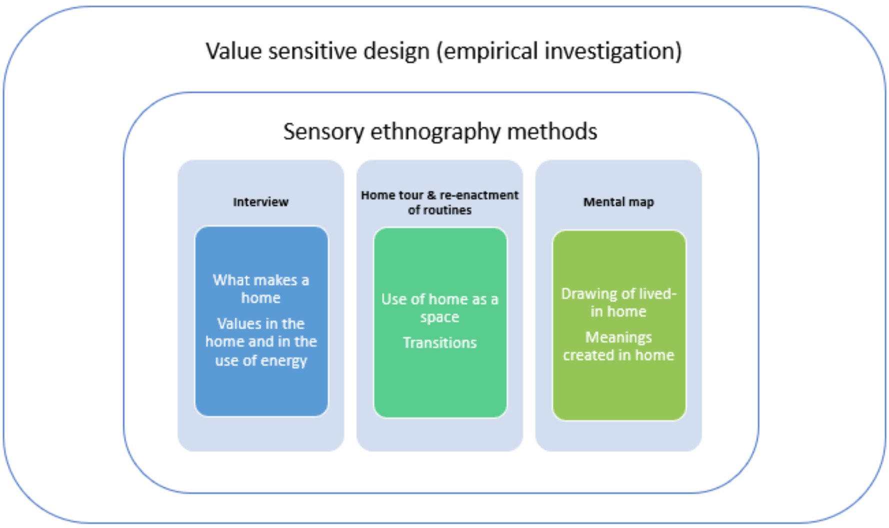


Fig. 2. Methods used in the study of sensory user experience of SHEMS.

In a sensory ethnography intervention, the role of the researcher is to share an experience with participants and 'be as loyal as possible to the context, the embodied, sensory and affective experiences, and the negotiations and intersubjectivities through which the knowledge was produced' (Pink, 2015). Sensory ethnography can be applied either as an independent study or as a part of a research or design process (Pink, 2015). The analysis begins from the first contact with the research participants; therefore, the researcher's experience and resulting understanding are more complete if the researcher personally conducts any transliteration and analysis.

Sensory ethnography was chosen as a lens to gain understanding of the roles and practices among SHEMS users, how they physically and sensorially interact with the SHEMS in the home and with each other, and how they move in their home and create meanings in different places. This understanding can be used to design intuitive and impactful smart home technologies, to 'renegotiate the home rules' and to design solutions that enhance and strengthen the values people hold – rather than threatening those values (Pink & Leder Makley, 2014), (Ingold, 2012).

4.1.2 Laddering technique

Laddering technique is both an interview technique and a method to consolidate, analyse and visualise the results of interviews (Reynolds & Gutman, 1998), (Zaman & V., 2010). Values are rarely expressed explicitly; usually they are embedded in everyday practices and talk (Halloran, Hornecker, Stringer, Harris, & Fitzpatrick, 2009). Various methods have been proposed to elicit values for design, such as cultural probes (Haines, Mitchell, & Cooper, 2007) and imagining meaningful alternatives (Iversen & Leong, 2012). In this research, laddering technique was applied to elicit values in the interviews and in the analysis of the interview data.

In the laddering interview, the interviewee was first prompted with questions about concrete attributes of the technology, followed by questions concerning desired consequences the user hoped or expected the technology to provide. Then the interviewer asked, 'Why is this attribute [or consequence] important for you?' until 'laddering' up to the level of values. In addition to attributes, consequences and values that users related to the technology, the linkages between these elements were identified (Leitner, Wolkerstorfer, Sefelin, & Tscheligi, 2008), (Zaman & Abeele, 2010). The elements and linkages were visualised as a value matrix (see Figure 4, in Results). Laddering technique posits that people choose products which have features they associate with the consequences they desire, and the reasons why such consequences are important are personal and social values (Reynolds & Gutman, 1998). This research experimented with the laddering technique to identify attributes and consequences SHEMS users considered important, and finally to elicit the key values in SHEMS adoption, usage and user experience. Values in this research were what people considered important modes of conduct or end-states in life (Iversen & Leong, 2012), (Rokeach, 1973); they were also the final point in the interviews, from which 'why questions' did not lead any further (cf. e.g. (Hawley, 2009)).

4.2 Quantitative analysis of consumption data

To obtain evidence on the impacts of SHEMS, the researcher collected data on the electricity consumption of 11 new SHEMS users during the winter months before the installation of the SHEMS and from the winter months following the installation. In one household, a previously cold attic was taken into use during the experiment, making the consumption figures of consequent winters incomparable. This reduced the number of analysed households to 10. The impacts of SHEMS on household energy consumption were analysed using monthly and hourly electricity consumption data in kWh. The quantitative consumption data were also analysed in the context of household energy behaviours, specifically in relation to the households' values regarding energy use.

Energy conservation due to SHEMS comes mainly from heating rather than other energy consumption in a household but is highly influenced by the weather. The proportion of heating in the total electricity consumption was estimated based on the consumption of the household in the summer months, and the estimated proportion of heating was weather-corrected using the heating degree day (HDD) factors provided by the Finnish Meteorological Institute (Finnish Meteorological Institute, 2018-2019). The formula can be found in Appendix 2. In addition to comparing the weather-corrected electricity consumption before and after the installation of the SHEMS, the researcher analysed changes in the daily consumption profiles and distribution of hourly demands of electricity in households (in Appendix 3). The data for hourly consumption was not weather-corrected because monthly HDDs are not pertinent in the analysis of daily consumption profiles and the distribution of low and high-consumption hours.

4.3 Research design

The research in papers I to V was based on the data collected in 28 Finnish homes in 2017–2019. Most interviews were conducted during autumn 2018. The research was a part of a local project in Northern Finland that aimed to increase households' energy efficiency and conservation. Altogether 28 households were interviewed, representing three user groups: 11 new adopters of SHEMS, nine prospective users and eight experienced users of SHEMS. The new and prospective users were recruited in the local project after they had participated in an open information event and left their contact details with the project coordinator. Some had instead contacted the project coordinator later to ask about SHEMS and the project. In the event, the project and two SHEMS were presented, and the public posed questions to the researcher, SHEMS providers and project manager. The local project financially supported the acquisition of SHEMS, covering half of the SHEMS acquisition costs (excluding installation and monthly fees). The price of the system, including installation, varied from 2000 to 3500 euros.

The prospective users had expressed interest in acquiring the SHEMS to the project coordinator, but eventually declined the offer. The experienced users had used SHEMS for 2–4 years and they were recruited through SHEMS providers. Three experienced users were in the Helsinki area; all other interviews were conducted in Northern Finland. All households lived in single-family detached houses with electric heating and a total living space of 130–200 m^2. New users were interviewed and observed three times: after they had decided to acquire SHEMS, during the installation and guiding on use of the system, and finally 3–6 months after installation. The first visit included the interview, sensory ethnography observation, mental map drawing and home practice re-enactment. Prospective users had been interested and reflected on the acquisition of SHEMS but then decided not to obtain SHEMS at that point. The prospective users were interviewed once about their initial motives, drivers and barriers, after they had let the project coordinator know they would not acquire the SHEMS. They also were asked to re-enact their daily energy-entailing routines and were observed by applying the sensory ethnography lens. Experienced users were interviewed about their motives for adoption and about their user experiences of SHEMS as well as household practices entailing energy use.

The sensory ethnography interviews and observations proceeded as follows: First the researcher interviewed the family members about their values, expectations and perceptions about SHEMS, using laddering technique to elicit values. Then the householders were asked to demonstrate their morning, afternoon and evening routines, which are usually the peak hours of electricity usage in a home. The re-enactment was video-recorded. Lastly, the participants were asked to draw by freehand a sensory and affective mental map of their home (house mapping), marking where the 'sense of home' was strongest and what meanings they associated with different area in the home. The drawings were discussed together with family members. The house mapping was used to understand the daily routines of participating family members and which spaces they spent time in at different times of day. The users were given a set of colour pens and were asked to draw mental maps of their homes, with colours, symbols and written words showing what places were important for them and what meanings they gave to those places. They were also asked to show how they felt; what were the sensory, social or other elements that contributed to those feelings; and why the area was important for them. They were asked to discuss places in the home that did not invite them to spend time there and what features triggered that feeling or lack of feeling. This technique has been used to study values related to domestic energy consumption by (Huizenga, Piccolo, Wippoo, Meili, & Bullen, 2015). Huizenga et al. also asked family members to use 'mood tokens' to represent their feelings, ranging from very good to very bad, within the house map. In the current study, the subjects were asked to describe freely the feelings and meanings in all dimensions, without restriction to 'very good – very bad', as this gave access to values underlying the feelings.

The quantitative energy consumption data before, during and after adoption of SHEMS was collected in 11 new users' homes. Only data from 10 households was used, because one household took their previously not-heated attic into use during the experiment. Consequently, there were significant changes in energy consumption for reasons other than adoption of SHEMS and the consumption before and after was incomparable. Consumption data was collected from the local utility, with the permission of the users.

The two SHEMS in this research aim to provide households with reduced energy consumption by lowering the temperatures at the user-defined times and in user-defined spaces in the home. They also aim to reduce energy costs by shifting the load to cheaper off-peak hours, thus increasing energy conservation and the use of renewable energy. SHEMS integrates data such as the user's settings, the weather forecast, information on electricity prices, outdoor and indoor temperatures and humidity to adjust and shift the energy consumption. A hot water boiler and air heat pump can be integrated into the system. The SHEMS used in this study were commercially available on the market and they were chosen for the project based on the tender price for a standard house. Both systems consist of sensors that communicate with a central unit through a wireless home network. The central unit is installed within the main switchboard of the house, and the sensors are installed in rooms for room-based control and monitoring. Users control and monitor their energy use with a control application on a computer, laptop, tablet or mobile phone. The control application is connected to the cloud service of a system provider.

Users can modify and create profiles for temperature settings, set the electricity contract type and price(s) and monitor room-specific electricity consumption for heating.

The two selected SHEMS differ in their main strategies for energy management. SHEMS 1 emphasises shifting consumption to off-peak hours. The system provider recommends that users choose a spot price-based electricity contract so that they can benefit from changes in the electricity price. Although most of the savings from SHEMS 1 are expected to come from automatic load shifting, users can also make hourly heating profiles to reduce their consumption at certain times of the day or week. By contrast, SHEMS 2 emphasises room-specific temperature reductions (e.g., during daytime, when householders are absent or during night hours). However, SHEMS 2 also promises to shift some consumption to other times, depending on the electricity price and the type of electricity contract in place. Furthermore, SHEMS2 provides users with an estimation of room-based energy consumption to help them target their energy-saving efforts. Both systems learn how a house reacts to changes in temperatures and settings and can thus be described as 'smart'. The cost of the SHEMS in this research consisted of once-off initial investments for the hardware and installation plus a monthly service fee. The SHEMS were selected in a bidding process, i.e., the two cheapest SHEMS for an example house. The adopters of SHEMS could choose which system they preferred, and they had the SHEMS installed in their homes because of the project.

The sensory ethnography study consisted of three parts, as presented in Figure 2. The first part was a discussion on the values related to energy use and demand flexibility through smart home technologies. The second part was drawing and discussing a mental map of the home with specific meanings and sensations. The third part was a video-recorded tour around the house, during which the users re-enacted their daily routines and explained how they used each space in the home and what meanings it carried for them. None of the research participants dropped out of the study during or after the research process.

The interview themes were the following:

1. Before adopting SHEMS or after deciding not to adopt SHEMS:

– - Why do you want / not want SHEMS in your home?
– - What expectations and doubts do you have?
– - Who will use the system, and how?

2. During the adoption of SHEMS

– - What are your first impressions of SHEMS?
– - Would you show me how you input settings into the system?

3. After three to six months of using SHEMS (or 2–4 years for the experienced users):

– - Have your expectations been realised through using SHEMS?
– - Have there been unexpected consequences of the use of SHEMS?
– - What are your overall experiences of SHEMS?

The material concerning people's interest in renewable energy communities was based on telephone interviews conducted with 96 households during summer and autumn of 2020, as illustrated in Figure 3. The interviewees had signed up for the telephone interviews in an online survey. In the telephone interviews, they were asked about their gender. The term 'gender' is used instead of 'sex' as the interviewees were asked to state their gender as they identified it themselves, reflecting their internal sense of self (Fathallah & Pyakurel, 2020). Only the data on the gender of interviewees is reported in paper V. The content of the telephone interviews is not reflected as it did not bring up any gendered issues.

Fig. 3. c Energy community telephone interviews.

4.4 Research ethics

All participants in the SHEMS research were contacted and asked for a face-to-face interview by the researcher. The interviews were conducted in the actual or potential usage context of SHEMS, whenever possible. Two interviews were conducted by phone and two in an office because the interviewees preferred that to meeting in their homes. Participants gave their formal consent to participate in the study and did so voluntarily, without payment. They could withdraw from the study at any time if they wanted, and they were fully briefed on the study aims and objectives, data management and privacy. No participants withdrew from the study. The roles of the two commercial SHEMS providers in this research were as follows: 1) providing contact details of experienced users for the researchers to approach for interviews; 2) scheduling installations of SHEMS for the new users, within the research timetable; and 3) giving technical specifications of the systems to the researchers.

The telephone interviews were conducted with a self-selected group of respondents of a survey. The subjects were asked for permission to record the phone interviews, and they could decline the interview if they wanted. The number of contacts and interviewees is illustrated in the Figure 3.

The reliability and validity of the results was certified by triangulation of quantitative and qualitative data. The sensory ethnography lens was employed for the interviews, home mental maps and quantitative data to unveil multiple layers of user experience of SHEMS and associated values. Conceptualisation of sensory user experience enhances the understanding of UX with social, material and sensory dimensions. However, I acknowledge the complexity of studying values and user experience through a sensory lens as well as the interactive role of the researcher in sensory ethnography research.

4.5 Qualitative data analysis methods

The qualitative data analysis was a continuous process from the first encounter with the research subjects. The interviews were voice- and video-recorded, and notes were made during the interviews and observations. The transliterations were written right after each interview. The interviews were recorded, transcribed and analysed by applying thematic content analysis (Anderson, 2007). Common themes of values concerning SHEMS and factors in the user experience of SHEMS were identified as the material was listened to and read.

In the data analysis, for the content analysis of audio and video recordings of the interviews, key themes were coded initially. For papers I and IV, the abstraction levels of laddering technique (attributes, consequences and values) were kept in mind during the analysis, as were the value schemes by (Schwartz S. H., 1992), (Rokeach, 1973) and (Ligtvoet, et al., 2015). The three most important values for each family are listed in Appendix 1. Second, the identified attributes, consequences and values were consolidated in the value matrix (see Figure 4 in findings). For paper II, the analysis of data and selection of relevant data for the description of sensory user experience was a heuristic process: returning to the video recordings, transliterations, home mind maps and notes. Sensory categories emerged from the material through repetitions and emphasis in several interviews. Quotations illustrating the most common themes and categories were selected from transliterations. Besides discussion, the interviews and observations included mental maps of home and re-enactment of daily routines during a home tour. The video- and audio-recorded interviews and observations were coded, and the data was consolidated thematically. For papers IV and V, the thematically coded interview and observation material was analysed with the equity analysis of technology (Bush, 2009), which focuses on possible benefits and risks in the contexts within which the technology operates. Besides the developmental and user contexts of technology, equity analysis expands on environmental and cultural contexts of technology (Bush, 2009). In addition to interview and observation data from 28 families, in paper V, interview data from telephone interviews with the energy community is briefly referred to.

5 Results

This chapter presents the findings and the answers to the research questions in each paper. In the end of the chapter the findings of this research are summarised. The research questions in the papers were the following:
RQ in article I: What are key user values of SHEMS?

RQ in article II: What does sensory user experience of home energy technologies consist of? This is further broken down to questions: What implications does the sensory experience of home and of practices entailing energy use give for the design of home energy technologies? How does sensory user experience influence SHEMS use, and how do the energy and SHEMS use influence the sensory user experience?

RQ in article III: What kinds of changes occur in the electricity consumption after the adoption of a SHEMS in terms of consumption volumes and the times of use, reviewed with the household values?

RQ in article IV: What are drivers and barriers to adoption of SHEMS?

RQ in article V: How does gender inclusiveness emerge in the adoption and use of SHEMS and in the interest in energy communities, and how could it be further fostered?

5.1 Key user values of SHEMS

Based on the VSD empirical investigation, the laddering interview technique and data analysis, the summarised findings concerning SHEMS user values are presented here. The types of SHEMS users and their value categories are based on the values and goals elicited in the interviews and observations using a sensory ethnography lens and on the life situation of the 28 studied households. The identified user types were full-nesters, empty-nesters and optimisers. Full-nesters are families living their rush years, constrained with time and trying to balance work and family life with routines and housework. These households seek savings in energy costs but they also cherish the comfort of all family members. Full-nesters would like to live sustainably, but they do not always have the means or time to do so. Comfort for full-nesters means not only pleasant indoors temperature but also easy control of energy consumption with one control application, and safety is particularly important with small children.

Empty-nesters are typically elderly couples whose adult children have left home. They have free time and unused spaces in their home, and they are not pressured by work or house mortgages. They can invest in new technologies such as SHEMS, solar panels and hybrid or electric cars. Empty-nesters have a simple and traditional lifestyle characterised by frugality and closeness with nature. As their lives are not busy and focused on children, they can be altruistic and emphasise ecologic sustainability. They may not expect significant savings in energy costs with SHEMS, but they do expect the system to pay itself back in a few years; they also want ease of use.

Optimisers are technology and energy savvy men, who discuss technologies and solutions to optimise home energy use with their friends, colleagues and neighbours. They would prefer a system with open hardware and software in order to modify the SHEMS to suit their own homes. Optimisers have development ideas for SHEMS, and they may propose ways to implement certain features in the system. For them, a SHEMS is an intellectual and practical endeavour, and they enjoy optimising all home technologies. Autonomy, exploration and self-direction are the values they prioritise in the adoption and use of SHEMS. Tuning the SHEMS or building a system themselves are further ways of distinguishing themselves among their peers. Economic savings are a driving motive for adoption of SHEMS, and they calculate an estimated return on investment before acquiring it. Optimisers are doubtful about the sustainability consequences of the system. For some optimisers, comfort of living is more important than savings in money or energy. Optimisers are early adopters of SHEMS and often acquire SHEMS because they know SHEMS developers and producers personally.

The consolidated value categories were frugality, sustainability, comfort, security and peace of mind, stimulation, exploration, self-realisation and distinguishing oneself. The most often elicited values in discussions with users about the motivations and goals for using SHEMS were frugality, sustainability, comfort and security and peace of mind, in that order. In Figure 4 the SHEMS user values categorised with the laddering technique are presented. On the bottom level are the important attributes of SHEMS, in the middle the expected consequences, and on the upper level are the values that these attributes and consequences represented for the SHEMS users.

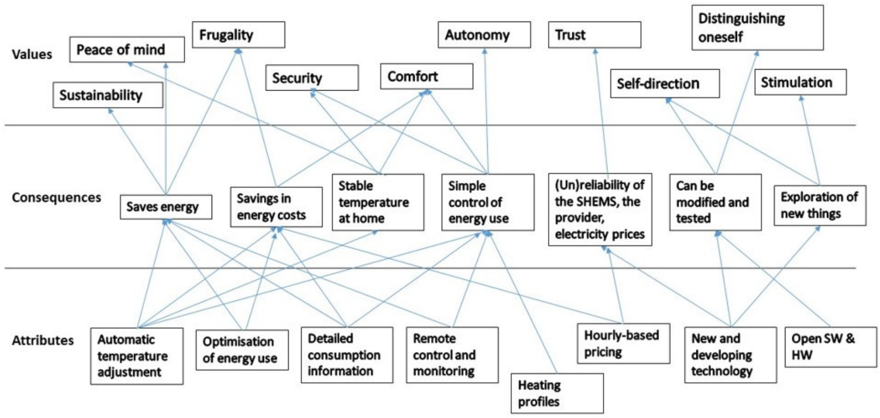


Fig. 4. SHEMS user values categorized with the laddering technique.

Frugality. The users expect primarily to save money and energy through SHEMS. Saving in energy is assumed to equal savings in costs. Half the interviewees said frugality was the most important value related to SHEMS, and most of the others ranked it as second or third in importance. Characteristic to the households in this research was that frugality meant a simple and modest lifestyle. Deliberate frugality (Evans, 2011) is an expression of a traditional Nordic way of living rather than a reaction against consumerism (e.g. (Aune, 2007), (Håkansson & Sengers, 2013)) or 'forced frugality' due to lack of resources (e.g. (Wilson, Hargreaves, & Hauxwell-Baldwin, 2015)).

Comfort, security and peace of mind. Comfort for the users meant that the room temperatures at home were stable, predictable and adjustable with one user interface, remotely. Given the harsh climate, the right home temperatures are not only about comfort but also security. Comfort means temperatures that are not too hot, particularly in the bedroom. Comfort was the most important SHEMS-related value for 21% of households and the second or third in importance for half of interviewees. One control interface for all heating settings frees users from walking from a room to another to adjust the thermostats, which again adds to security. In addition, remote monitoring with the SHEMS control application strengthens the sense of security. Comfort, security and peace of mind are related values. Increased security amounts to increased comfort and peace of mind. For most users, increased comfort means they can forget about adjusting the temperatures once the system has been programmed and the SHEMS has learnt to regulate the temperatures automatically. After the initial months, the users usually ‘forgot’ about the system. When it worked without notable problems, they did not change the settings.

Sustainability. ‘Sustainability’ here means ecologic sustainability. Both sustainability and frugality imply saving resources and consuming less. However, ecologic sustainability was the most important value only for 14% of households and second or third most important for a third of them. SHEMS may reduce the consumption of energy, especially during times of high prices, usually profiting from hour-based electricity prices and thereby decreasing the need for peak power generation. SHEMS applications also help to identify the places, appliances and practices at home that consume the most energy, thus helping people to focus their energy-saving efforts. However, SHEMS users were more concerned of their own home’s consumption and costs of energy than the impact of their energy consumption in the larger energy system. Most interviewees emphasised their sustainable lifestyle in other ways, like recycling, close relationship with nature and interest in EVs and solar panels. They did not mention the possibility to increase demand flexibility with SHEMS, allowing larger use of renewable energy. Three users said that besides saving money due to SHEMS, they also wanted to save energy because the menace of climate change requires us all to consume less energy. Yet the users had not considered or were not aware of how SHEMS relates to the use of renewable energy, or the possibility of the utility remotely controlling the consumption of electricity via SHEMS, for example at times of low supply and/or high demand of electricity.

Stimulation, exploration, self-realisation and distinguishing oneself. Although rarely the primary values of SHEMS users (7%), these values enforce the interest to adopt SHEMS. Particularly the optimisers were driven by curiosity, creativity and experimenting with new technologies. The users who demonstrated these strongly interlinked and individualistic values had a certain level of economic and social freedom as well as technical competence. Often, they considered SHEMS as their personal project rather than a family system.

5.2 Sensory user experience of SHEMS

By applying a sensory ethnography lens to the home interviews and observations, we identified the sensory categories in the homes. Through quotations and selected mental maps of homes, we demonstrate that the sensory user experience of SHEMS in homes consists of intertwined sensory and affective sensations in physical, material and technological settings. The selected anecdotes and mental maps illustrate the most often elicited themes among interviewees.

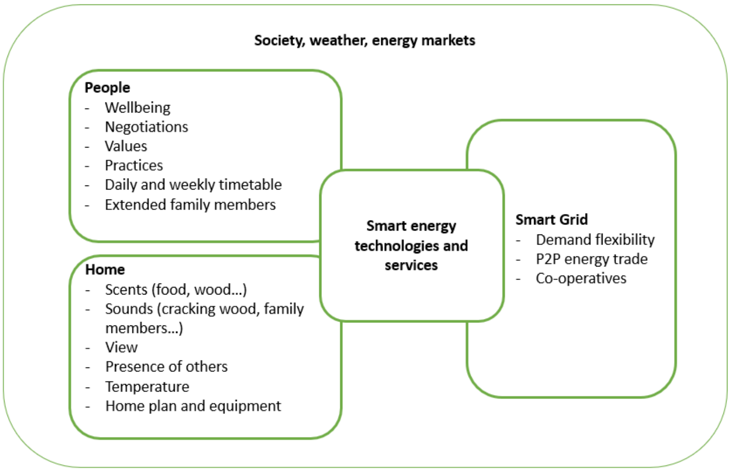


Fig. 5. Elements of the sensory user experience of SHEMS.

In Figure 5 different dimensions of sensory user experience of SHEMS are illustrated. SHEMS user experience is situated in a complex social and technological environment, with implications on many levels for the users, smart grid and society.

The presence of family makes the home. The sense of home is social rather than material, created together with other family members in the centre of the home, where family members see, hear and feel the presence of each other. The mental maps and discussions indicated that family life is centred in a kitchen or a kitchen–living room (if combined as a larger open space). In addition to the presence of family members, the kitchen is also a source of sensory stimulus (e.g., cooking and eating, fire in a wood stove). People also prefer to spend time at home in areas with a good view of both the outside and the main space in the home, which is typically a kitchen–living room. Men seem to prefer to sit on a couch or armchair and choose a place and direction where they can see both the outside, preferably a garden or riverside, and into the open kitchen or living room space. People do not want to compromise their comfort by – for example – lowering the temperature in spaces which carry most valuable meanings for them.

Figure 6 shows two mental maps of homes. The left map was drawn by the mother of a family, who symbolised the kitchen as a heart. The kitchen is a place where she enjoys cooking and socialising with family members; it is where other family members come to seek her and where she feels confident in what she does. The right-hand mental map was by a man who lived with his wife and an adult child. He described how he spends most of the time at home on the couch (green spot) because there he has good view to the garden outside. The open space in the centre of the house, in the company of other family members, is more attractive than other rooms, which are considered rather small, dark or isolated.

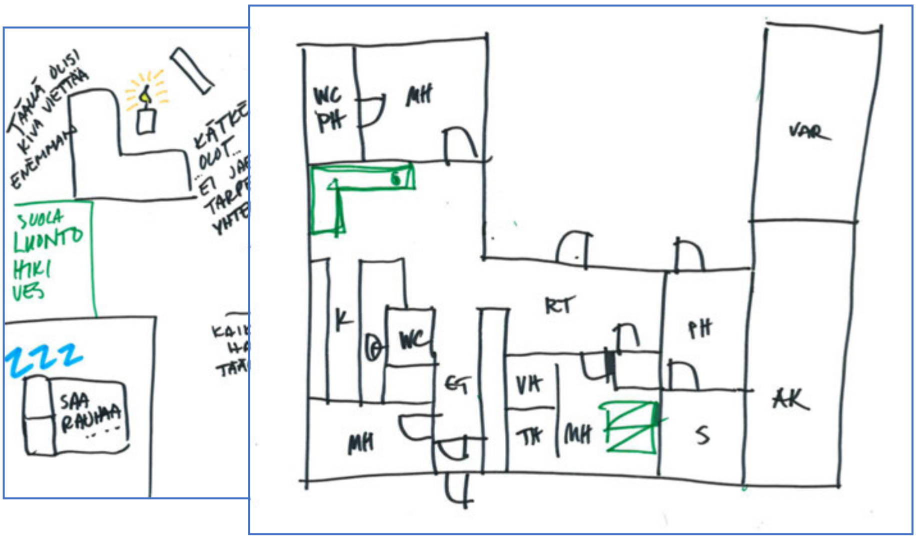


Fig. 6. Mental maps of home. Right: female, teacher, 42 years (P13F). Left: an engineer, male, 56 years (E19M).

Some spaces in the home are used very little. Often, the rooms which are not used much are described as lacking a particular sensory feeling. Spaces in the home are used according to the daily rhythms of family members: during the daytime, people are mostly in the kitchen and the living room, if next to the kitchen; the bedroom is used only for sleeping. One space often mentioned as a neutral or even unpleasant place in the home is the utility room. Some women described it in neutral or negative terms, e.g., there is ‘stuff I just have to do’, and it is a ‘technical place’. Men did not mention it at all.

Energy-efficient practices and technologies may cause unwanted changes in the home sensory environment. For example, the use of the washing machine could be more economic and environmentally friendly during the night hours, but the interviewees did not want to the hear noise of the washing machine during the night. Homes with air heat pumps or external radiators integrated with SHEMS made disturbing noises when SHEMS automatically sought the optimal temperature and adjusted the heating level, causing air heat pump and radiators to make clicking sounds.

The use of materials may carry specific meanings for householders. For example, the use of wood in a fireplace or a wood stove not only complements electric heating but also adds to the sensory effects of the home. The wood stove, usually placed in the kitchen–living room, gives out ‘soft’ heat, in contrast to dry electric heating. The sounds and scents of burning wood add to the ‘feeling of home’, and carrying and keeping logs indoors gives out the smell of wood.

A challenge in designing smart home technologies is the diversity of families. They have different situations and differ in the structure of their daily lives. Retired people and shift workers do not have highly regular times of absence from home, unlike families with regular working and school or day care hours. Family composition and the house plan, structure, materials, yard and buildings around the main building and numerous other house features largely determine what opportunities and limitations householders have for energy management and how their daily sensory paths are created. Home energy technologies are installed in a home with preconditions, ways of living and diverse needs.

Family wellbeing is one of the key values in the home. There are continuous negotiations between family members on how to guarantee wellbeing for every family member. The use of SHEMS and the practices entailing energy use are compromises of individual goals, needs and preferences. The sensory user experience of SHEMS is a shared user experience constituted by each person’s own experience and that of other family members. Typically, the main user of SHEMS was the man of the family; however, a couple often decided together on important acquisitions like SHEMS. The use of SHEMS was discussed mostly in terms of comfort. Usually the comfort of family members, even those who were not able to give direct verbal feedback – such as children and pets – was also considered in the sensory user experience of SHEMS. Moreover, extended family members influenced the use of SHEMS.

5.3 Impacts of SHEMS on energy consumption

The real-life experiment of installing SHEMS in 11 households gave the researchers an opportunity to collect unique data on changes in energy consumption volumes and profiles due to SHEMS. The quantitative findings were integrated with the qualitative findings about values concerning SHEMS in each household. The data from 10 households was used, since in one new user's home a previously not-heated attic was taken into use, rendering the consumption figures before and after the installation incomparable.

The results indicated that the SHEMS increased energy conservation, changed households' energy consumption profiles and shifted the times of consumption. In addition, the number of high-consumption hours decreased, thus flattening the consumption peaks. The extent of these changes depended on the users' preferences and the values they expressed about the use of the SHEMS. Users who valued comfort over ecological sustainability set the SHEMS at higher temperatures and did not seek as many savings on a consumption level. Nevertheless, even their energy consumption decreased and the consumption profiles changed. The peaks flattened, and the hours with less-than-average consumption increased.

Changes in consumption volumes and profiles. In Table 1, the total monthly electricity consumption in kWh is shown for the winter months of January, February and March 2018 and 2019. The total monthly consumption was weather-corrected using the formula in Appendix 2. The share of heating in the total electricity consumption was estimated based on the monthly summer consumption of each household, and the estimated heating proportion was weather-corrected with the HDD factors provided by the Finnish Meteorological Institute (Finnish Meteorological Institute, 2018-2019).

Table 1. Changes in total electricity consumption (weather-corrected) for the 10 households in the winter months of 2018 and 2019.

		January /kWh	February / kWh	March / kWh
	2018	3008.6	2661.4	2470.8
Household 1	**2019**	2955.1	2445.2	2471.1
	Energy saving %	**1.8**	**8.1**	**0.0**
	2018	3621.6	3577.7	3178.6
Household 2	**2019**	3684.5	3290.1	2838.8
	Energy saving %	**-1.7**	**8.0**	**10.7**
	2018	3092.4	2573.3	2108.2
Household 3	**2019**	2366.8	2179.3	1860.9

		January /kWh	February / kWh	March / kWh
	Energy saving %	**23.5**	**15.3**	**11.7**
	2018	3060.3	2751.0	2465.0
Household 4	**2019**	2990.1	2566.7	2379.2
	Energy saving %	**2.3**	**6.7**	**3.5**
	2018	2194	2042	2172
Household 5	**2019**	2365	1962	1889
	Energy saving %	**-7.8**	**3.9**	**13.0**
	2018	3339.6	2867.7	2622.0
Household 6	**2019**	2717.6	2498.9	1898.5
	Energy saving %	**18.6**	**12.9**	**27.6**
	2018	1886.3	1673.7	1629.9
Household 7	**2019**	2070.4	1875.8	1536.1
	Energy saving %	**-9.8**	**-12.1**	**5.8**
	2018	2827.7	2470.4	2297.3
Household 8	**2019**	2824.8	2142.9	1844.3
	Energy saving %	**0.1**	**13.3**	**19.7**
	2018	4411.8	3720.9	3243.9
Household 9	**2019**	3729.4	3245.0	2734.5
	Energy saving %	**15.5**	**12.8**	**15.7**
	2018	3749	3075	2649
Household 10	**2019**	2742	2232	1834
	Energy saving %	**26.9**	**27.4**	**30.8**

Most households obtained significant savings (up to 30%) in their electricity consumption. However, there were interesting differences in that some households increased their consumption for one or two months. This raised the question of what accounted for these differences and whether they were related to values and preferences.

Table 2 presents the changes in the mean (μ), skewness and kurtosis values for hourly consumption distributions of all 10 households in January, February and March 2018 and 2019. Daily weather corrections were not used in these figures, because HDD is not applicable on an hourly basis, as these figures do not affect timely variations in hourly settings. January 2019 was significantly colder than January 2018, therefore these figures were hard to compare from an energy-saving perspective, as almost all households increased their hourly average consumption. For February and March, the differences in the mean savings for all households were negative, with lower means in 2019 (negative difference). The skewness differences were positive for these months for most of the households, since the distributions became more skewed to the right as the number of low-consumption hours increased. In terms of distribution, there were mostly positive differences in the kurtosis values, with the right tail becoming relatively heavier. This was expected, because heavy consumption hours – for example, those relating to meal preparation and dish washing – are difficult to change. However, in general the peak consumption moved to lower consumption volume hours. As evident in Table 2, there were exceptions to the trend regarding these changes. For example, in household 3 (HH3), the average consumption decreased, the number of high-consumption hours decreased and the tail became less heavy. The householders wanted to use the SHEMS not only to flatten their peak-hour consumption and improve their overall energy conservation, but also to use the hourly based electricity prices to direct their consumption to hours with lower prices. They changed their electricity contract from a two-time electricity contract to a time-of-use tariff (spot price). Their high-consumption hours then took place late at night and in the early hours of the morning, when energy is cheaper. The household's overall energy conservation through adopting SHEMS was significant (11.7% – 23.5%). In HH6, the users said it took some time for them to adjust the SHEMS settings correctly. They used the SHEMS control application to monitor room-specific consumption and noticed that one room consumed an unexpectedly large share of the total heating consumption. They improved the insulation of the room and started to keep its door open to let in heat from the air heat pump.

Table 2. Differences in mean, skewness and kurtosis FOR hours of electricity consumption in the winter months of 2018 and 2019: all 10 households.

	January			February			March		
	μ	**skew.**	**kurt.**	**μ**	**skew.**	**kurt.**	**μ**	**skew.**	**kurt.**
HH1	+0.627	+0.12	+0.124	-1.008	+0.915	+1.873	-0.455	+1.149	+3.577
HH2	+1.04	-0.745	-2.335	-1.49	+0.614	+1.036	-1.124	+0.36	+1.22
HH3	-0.513	-0.542	-2.793	-1.093	-0.196	-1.534	-0.598	-0.878	-4.158
HH4	+0.527	-0.079	+0.643	-0.891	+0.196	+1.247	-0.494	+0.556	+1.899
HH5	+0.553	-0.087	-0.011	-0.389	+0.208	+0.399	-0.613	+0.085	+0.116
HH6	-0.188	-0.732	-1.608	-1.267	-0.097	-0.88	-1.447	+0.671	+0.771
HH7	+0.712	-0.206	-0.065	-0.137	+0.511	+1.333	-0.415	+0.344	+1.196
HH8	+0.663	-0.74	-1.179	-1.108	-0.169	-0.879	-1.026	+0.196	+0.105
HH9	+0.031	-0.078	-0.927	-1.704	+0.754	+0.561	-1.303	+0.266	-0.8

	January			February			March		
HH10	-0.589	-0.398	-1.149	-2.090	+0.658	+0.163	-1.639	+0.48	+0.229

Flexibility in consumption was marginal in HH8 because they had small children in home, and they did not want to lower the indoor temperature much. This point demonstrates how in addition to values, the householders' capacity to take full advantage of the SHEMS influenced the performance of the SHEMS.

Appendix 3 lists the characteristics of the 10 households (i.e., living space, heating system, number of residents, key values ascertained during interviews), the figures showing the daily consumption profiles for the analysed winter months and the distributions of the hourly volumes. Overall, the results show that the number of hours of electricity consumption skewed positively from high-consumption hours to an increased number of low-consumption hours. This is evident from the movement of the 2019 consumption distribution to the right in the graphs in Appendix 3, as it increasingly peaked around low-consumption hours.

Values underpinning electricity-related decisions. The key user values with SHEMS are economic gain, ecological sustainability, comfort, security and stimulation. Less often mentioned values were trust (reliability), privacy, ease of use and interoperability with other home technologies. As shown in Figures 7 and 8, the consumption profiles and their changes differed depending on a household's key values. Figure 7 presents the consumption of a household (HH4) that primarily sought to maintain comfortable temperatures throughout the day and did not consider energy conservation or demand flexibility to be important for ecological reasons. The first graph in the figure presents the daily consumption in kWh for March 2018 and March 2019. The bold blue line is the average for March 2018, and the bold red line is the corresponding hourly average consumption in March 2019. The second graph in the figure illustrates the distribution of hourly consumption in kWh on the horizontal axis and the number of hours on the vertical axi

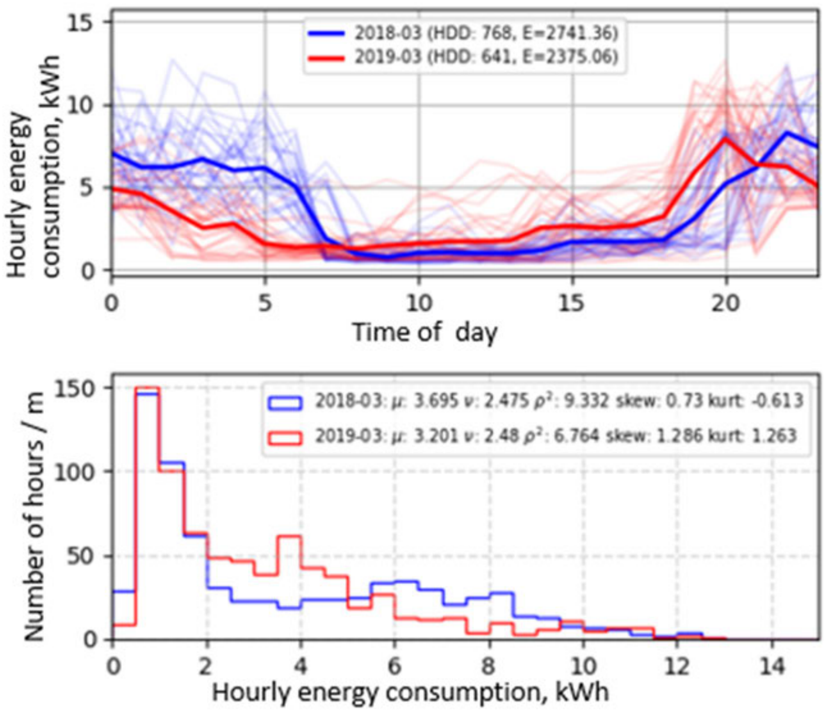


Fig. 7. March 2018 and 2019 daily profiles (bold lines indicate averages) and distribution of hourly electricity demands (second graph) in HH4 where avoidance of discomfort dominated the use of the SHEMS.

As demonstrated in Figure 7, the SHEMS alone could bring dramatic changes to the consumption profile of HH4. In this home, the users valued avoiding discomfort over other values (such as ecological sustainability and the use of RES) and they did not decrease the indoor temperatures during the day. They wanted to gain economic savings by shifting more consumption to the night hours and expected the hourly energy price of electricity (spot price) to result in savings. However, after installation of the SHEMS, their night-time consumption was lower than it was the year before (i.e., before SHEMS) and their consumption was slightly increased during the expensive daytime hours.

The corresponding results for the family in HH9 are presented in Figure 8. HH9 emphasised ecological sustainability as a SHEMS user value. The graph shows a shift in daytime hourly consumption and a notable increase in low-consumption hours.

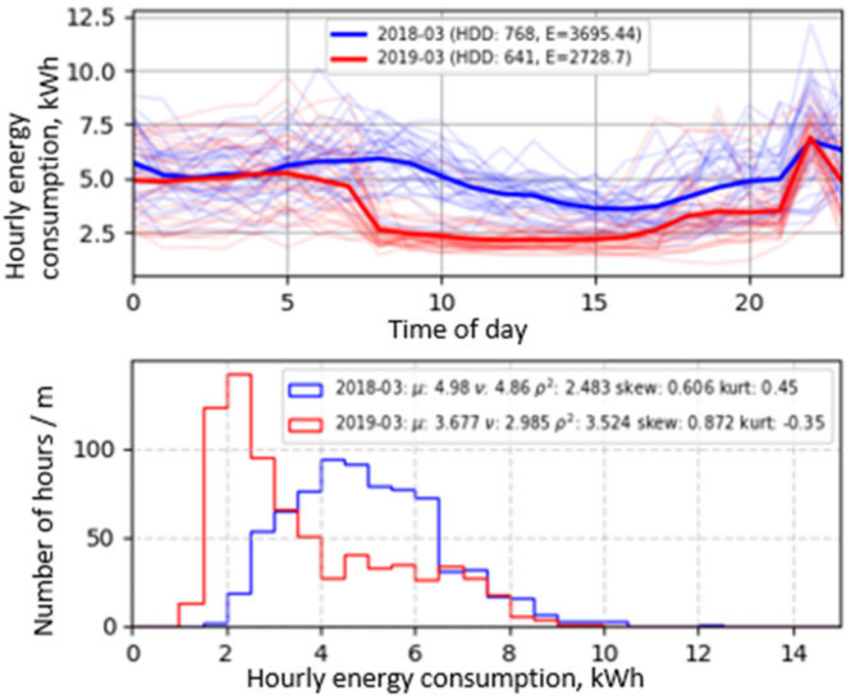


Fig. 8. March 2018 and 2019 daily profiles (top) and the distribution of the hourly electricity demand in the HH9, where the users sought primarily to realise their ecological values through the use of the HEMS.

Decay effects. In energy efficiency nudging experiments, the effects decay to some extent after the nudging ends. For example, Alcott (2011) found that while the two-year nudging experiment continued, the savings continued. As soon as there was a break in the delivery of nudging information letters, the savings diminished. It is not yet known whether decay effects will occur in the use of SHEMS. In this study, autumn 2018 was not a good choice for comparisons as the families may have been preparing for the experiment and applying various kinds of early adjustments; the interviews with the families confirmed this. However, the months of December in 2017, 2018 and 2019 could be compared, as the automation systems were assembled in November 2018. Figure 9 illustrates the data from December in these three consecutive years. In the first year with SHEMS (2018), the energy consumption among seven of the households was lower than in the following year (2019), indicating a possible decay effect. The consumption in December 2018 was however still similar to that at the beginning of the study; the lower consumption might have been associated with enthusiasm among households regarding their new systems. Increased awareness of their energy use due to the introduction of SHEMS and discussions around energy conservation with the researcher might also have played a role. Compared to December 2017, in December 2019 all households consumed less electricity, according to the weather-corrected data. However, from 2018 to 2019 the consumption decreased in only three households. While no firm conclusions on the decay effect can be made, our results point to the possibility that in the use of SHEMS, decay effects may emerge.

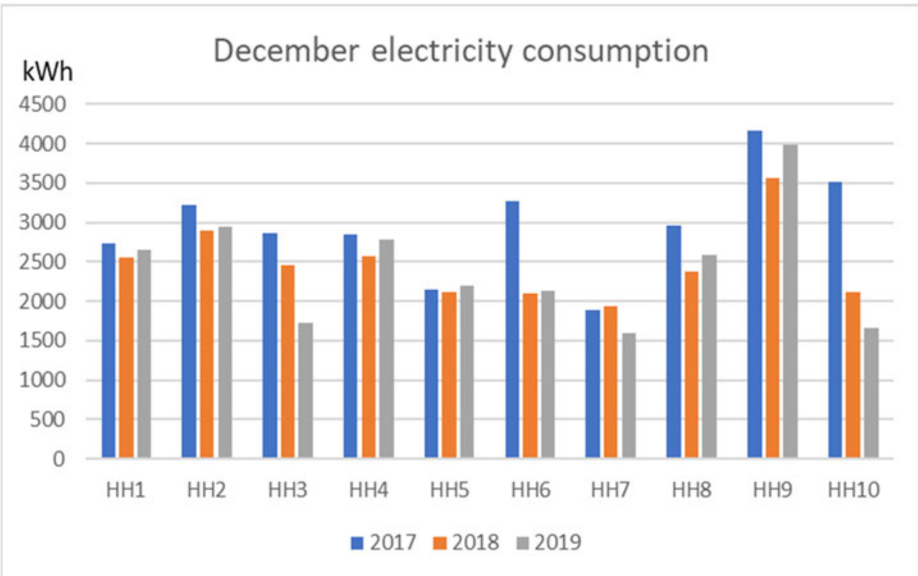


Fig. 9. Energy consumption (weather-corrected) in households 1-10 in December 2017, 2018 and 2019.

5.4 Drivers and barriers in adoption of SHEMS

Based on the interviews and observations in 28 households, we identified the drivers of and barriers to adoption of SHEMS for three user groups: new users, prospective users and experienced users. New users adopted SHEMS during the research project; prospective users were interested in acquiring SHEMS yet declined for the time being, and experienced users had used SHEMS for 2–4 years. The number of households in each user group is shown in Figures 10 (drivers) and 11 (barriers).

5.4.1 Drivers of adoption of SHEMS

Saving in energy bills. All 28 interviewed households expected SHEMS to yield savings in energy bills, although five new users doubted the savings would be noteworthy. They decided to adopt SHEMS because they expected SHEMS to bring other desirable consequences in addition to economic savings.

Environmental friendliness. Ten out of 11 new users thought energy conservation was important for not only economic but also ecological reasons. For two new users this was a primary driver and part of the ecological lifestyle they promoted; and for the others, although not a primary driver it was nevertheless a significant factor. However, only a few interviewees were aware of the significance of reducing energy production emissions through the demand flexibility enabled by SHEMS. Most users thought that optimising energy use and not wasting energy wherever possible were important and rational practices. Experienced users had not adopted SHEMS with ecological impacts in mind, but when asked, four of them said it may be one more driver for some others, whereas four doubted that SHEMS had a significant impact for the environment. The prospective users had divided views on the importance of environmental impact. About half of them (six) considered environmental friendliness as an important factor, whereas the others (five) did not mention it, and when asked, they said they doubted SHEMS had any impact.

Comfort of living and comfortable energy management. Increased levels of comfortable living was an observed and unexpected consequence of the use of SHEMS among experienced users, rather than an initial driver. They all said the indoor temperature was steadier and changed more smoothly with SHEMS. Comfort of living increased especially in homes with water-based underfloor heating. SHEMS learns how the house reacts to increases and decreases in indoor and outdoor temperatures; using sensor and weather data, the system adjusts thermostats even before the scheduled room temperatures are reached. Therefore, the temperature change of otherwise slowly reacting underfloor heating is smoother and temperatures are kept constant or as scheduled by the users. New and prospective users did not consider increased comfort of living as a driver, probably because of a lack of knowledge about peer experiences. Instead, they emphasised expectations of more comfortable energy management. The SHEMS control application can be used with a computer, a tablet or a mobile phone, and remotely. Having one user interface for controlling the energy use of the whole house was clearly an advantage compared to walking around the house for adjustments. In addition, automation was expected to save the effort of constantly thinking and changing the indoor temperatures, air conditioning, air heat pump settings or car heating. Two new users considered comfort of energy management more important than possible savings SHEMS would bring.

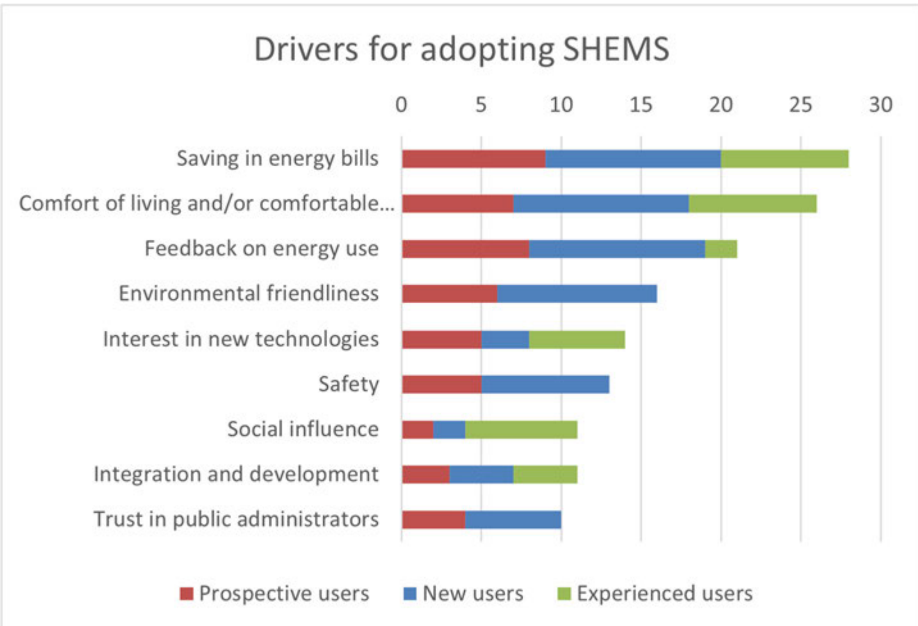


Fig. 10. Drivers for adopting SHEMS.

Feedback on energy use. Users wanted to monitor their energy use and gain detailed understanding of their energy consumption in different parts of home and how it changed during the day and in a year. Some new users had specific questions such as whether the insulation of a door was tight enough or how much energy the water boiler consumed. They hoped to identify ‘energy-eaters’ in the home to target home repairs and improvements. In addition, they expected to understand better how their behaviour in the home impacted energy use through the SHEMS user interface. New users considered the monitoring feature particularly important and were eager to follow their energy consumption with the control application. Only a few experienced users had continued to monitor their energy use. They returned to the control application only to change the settings in the turn of a heating season.

Safety. New users expected that the possibility to monitor home energy use, temperatures and humidity would increase their sense of safety. Experienced users did not mention safety and it seemed that few regularly checked the application. For an extra cost, users could add a leak control feature to their SHEMS, which five new users wanted to order.

Interest in new technologies. The second driver after saving money for some new (three) and prospective (five) users and for most experienced users (six) was curiosity about new technologies. Two new and two prospective users stated they had followed the development of HEMS or had planned to build one themselves. These people were ready to spend their time and effort in optimising their home with new technologies.

Social influence. All experienced users except one had adopted SHEMS after developers of SHEMS had proposed it. Prospective SHEMS providers wanted to test their systems with friends, neighbours and acquaintances before launching the systems into markets. Experienced users had not known of SHEMS before someone working on SHEMS development had talked about it and asked whether they would like to try it in their home. Only one experienced user had ordered SHEMS without knowing a developer. Prospective users were minimally influenced by other people in their adoption process; if they were, the influencers were family members or friends who doubted the benefits of SHEMS.

Trust in public administrators. Although not an initial driver, certainly a confirming one – especially for new users – was that the trust they had in their town and in the other project actors. As the level of awareness on SHEMS was low, their hometown’s participation in the project and financial support for the adoption of SHEMS increased not only knowledge about SHEMS but also the perceived reliability of the systems. The users believed SHEMS must be useful and a reasonable investment if it was supported by public administrators.

Integration and development. Users expected active and stable maintenance and development of SHEMS in the future. They looked forward to new SHEMS features and integration with other energy-intensive and security technologies in the home, e.g., optimising the production and consumption of home solar panel energy and an EV charging point. This expectation was, however, also a barrier for users who had doubts about SHEMS providers' financial stability and were afraid the investment could lose its value if the provider had to discontinue development and service.

5.4.2 Barriers for the adoption of SHEMS

Barriers usually mean issues that prevent people from doing something. Here, we additionally include doubts and uncertainties that some users had related to SHEMS even if they had adopted the system. Often, studying the barriers of prospective users for not adopting a technology can be challenging. In this study there was a unique opportunity to contact households who had participated in the information event about SHEMS and the related project. The prospective users had left their contact information, and many of them contacted the SHEMS providers to ask about the prices and other details. Yet they decided not to adopt SHEMS. Nine such households were interviewed and asked about the reasons why they were interested in SHEMS but then declined the acquisition. Some households had a clear and definite reason for not adopting SHEMS, but mostly people had considered acquisition from various perspectives and the decision was a sum of many factors. Hence, the barriers reflect not only the reasons why prospective users did not acquire SHEMS but also the doubts that many new users expressed even though they did adopt SHEMS.

Too low estimated return on investment. The users considered the price of the system high, despite the 50% support given by the project. Depending on the size of the house, the one-time investment cost about €1000–2500 above the support given by the project. The monthly service fee was between €6 and €10. Many prospective users calculated that the system would not yield enough savings to offer a reasonable payback time. However, some new users who had doubts SHEMS would pay itself back still wanted to adopt it. The users criticised the examples of savings presented by SHEMS providers as unrealistic.

High spot price of electricity. During the period of adoption decisions, the spot price was notably high and the variation during the day was low. This situation did not encourage people to invest in a system that was supposed to benefit from the variation of electricity prices to yield savings in electricity bills. Although it was acknowledged that high prices and low within-day variation may be temporary, the timing was poor for people to change their fixed-price electricity contracts to more risky variable prices. In addition, estimating how much could be saved by automatic load shifting was difficult due to the unpredictability of electricity market prices and the flexibility capacity of the residence.

Energy-saving lifestyle and house. Most new and prospective users had already implemented measures for energy conservation and minimised their electricity consumption and cost. If a house was not very large (< 150 m^2) and heating electricity consumption was reduced, such as with an air heat pump and/or wood heating, SHEMS was not thought to bring much savings in energy consumption.

Lack of knowledge. SHEMS are relatively new, and the market is not yet well-established. Smart home energy technologies are not widely diffused, and the lack of awareness and knowledge are barriers to SHEMS adoption. Only one new user and two prospective users (of 17 in total) were familiar with SHEMS before the project published an advertisement for the system and the related project. None of the new or prospective users had heard anybody discussing their experiences of SHEMS use.

Lack of trust. Because the SHEMS and the system providers were not yet established and known on the market, people did not trust them. Users were sceptical about the examples and saving rates SHEMS providers presented in the information event. The stability of the new and unknown companies was questioned, and the users were sceptical about their ability to maintain and develop the system in the long run.

The stage of technology. Some prospective users saw current SHEM systems as an early-stage technology, and they wanted to wait for more sophisticated systems. They believed that as the SHEMS market matures, the systems will become more efficient, more integrated into other home technologies and more economic. Users raised concerns about fast-changing technology soon becoming obsolete. They were unsure what would happen with the installed SHEMS if the provider fails or the technology development makes the current system obsolete. Updates to the software and the cloud service are included in the monthly service fee, but it is unclear what the use value or retail value of possibly soon obsolete technology is.

Too complex technology. Prospective and new users with technical skills criticised SHEMS for being too complicated and sophisticated, when less would have worked as well. Simpler system would cost less and could possibly be modified by users if needed. Users did not want ‘a full smart home’. They wanted to begin with a simple, reliable system for energy management, with an open interface for future integrations and add-ons.

Retrofitting problems. Although for most houses, SHEMS was relatively effortless to install, that was not always the case. In houses with water-circulating floor heating, a room-specific heating control can be difficult to implement. The capacity of fuses was too low in two houses. Changing fuses would have caused extra costs and required a different kind of electricity contract with higher monthly payments.

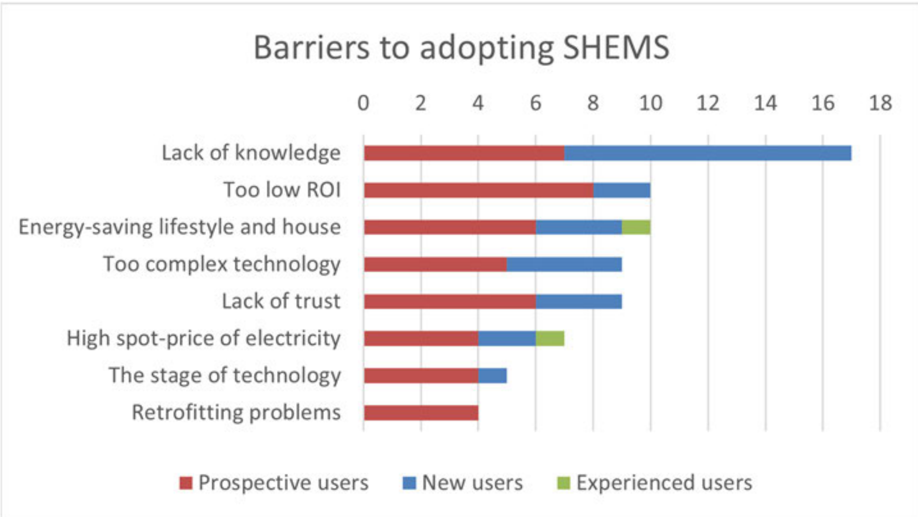


Fig. 11. Barriers to adopting SHEMS.

5.4.3 Experienced, new and prospective users

Research on users of new energy technologies indicates that among the early users there are 'user-producers', who 'invent, experiment and tinker with radical technologies, creating new technical and organisational solutions, articulating new user preferences, and enabling new routines to emerge' (Schot, Kanger, & Verbong, 2016) as well as 'lead users', who are first adopters and experimenters of new technologies (Peacock, et al., 2017), (Hyysalo, 2021). In this research, these types were found in all three user groups, i.e., among experienced, new and prospective users. Similarly, in all user groups, user-consumers existed, who viewed SHEMS as a part of their daily lives and lifestyles but without having particular interest in new technologies. This heterogeneity of users in all phases of adoption should be addressed in SHEMS design, marketing, guidance and maintenance. Both new and experienced users adopted SHEMS into existing homes, i.e., retrofitting (Balta-Ozkan, Amerighi, & Boteler, 2014). In addition to SHEMS, they had considered and adopted various other ways to conserve energy. As we had expected, prospective users encountered stronger barriers to adoption than did new or experienced users. Some barriers outweighed the drivers altogether, for example if the retrofitting of SHEMS was not possible in their home for technical reasons.

5.5 Gender inclusiveness in adoption and use of smart home energy technologies

In the interviews, observations and telephone interviews concerning the energy community, it became evident that distinct gender roles exist regarding adoption and use of SHEMS. Applying equity analysis (Bush, 2009) to SHEMS interviews and observations and the REC interview data, I identified four contexts of technology adoption and use of SHEMS and REC that reinforced the gender gap: 1. The design or development context, which includes all the decisions, materials, personnel, processes and systems necessary to create SHEMS and REC. 2. The use context, which includes all the motivations, intentions, advantages, and adjustments called into play by using SHEMS and REC. 3. The environmental context, which describes the nonspecific physical surroundings in which SHEMS and REC are developed and used. 4. The cultural context, which includes all the norms, values, myths, aspirations, laws and interactions of the society of which SHEMS and REC are a part.

The research subjects in both studies were self-selected and as such they do not represent the whole population. However, the self-selection to participate in energy research is itself an interesting finding. With few exceptions, the participants in these two studies were men: in the SHEMS study of 28 households, 24 were represented by men, two were represented equally by both the man and the woman in the household, and two households were represented by women only (see Appendix 4). In the energy community phone interviews of 96 interviewees, only 10 were women, and among those 10, three women had solar panels in their houses. Of the 86 men participating in the interviews, 50 had solar panels in their homes. From these relatively small numbers, no statistical conclusions can be drawn, but they indicate an unequal level of interest in RECs among men and women.

SHEMS is also used predominantly by men. In 24 of 28 families interviewed and observed applying sensory ethnography, the main user of SHEMS is – or would have been in the case of prospective users – the adult man of the family. In three families both adults were equally using or planning to use the system. One prospective user was a single mother. New users of SHEMS were observed during the installation and take-in-use situation. For the buyers of home energy technologies, often the only touchpoint during the acquisition process is the person who comes to install the technologies (such as the SHEMS or solar panels). He also guides the user(s). In this research, 11 installation and guidance events were observed, and in 10 of these cases both the male and female adult of the family were present. In every case the male technician explained to the man of the household the installation and showed him how to use the control application. In one household, only the woman was present during the installation. Often, when the woman was present, she did not participate in the discussion, nor did the technician make eye contact with her or try to include her in the discussion. In one household, the man asked the woman to come and see how the control application was used 'as both of us will use this'. People living in the home are all influenced by SHEMS, but they are not equally users of the system.

Often, in families where the man was the only user, he commented about the wife's role in SHEMS adoption and use with comments such as the following: 'This is my thing, my wife has nothing to do with it', 'My wife is not interested in this at all', 'I did not have to discuss with anyone about buying SHEMS, with my money I can do what I want' and 'At work with other colleagues [men] we discuss about SHEMS, that way I got interested in it'. Some men even expressed surprise when asked about the adoption and use of SHEMS by other family members. For most men, and for most of the few women participating in the interviews, it was obvious that the man in the family was the one who 'knows about energy' and 'manages all things related to energy and home technology use'; one woman stated that 'I don't really understand these things'. In households with two adults, women were often either in the background or absent during the interviews and observations. From the background they may comment about the acquisition and use of SHEMS, but usually it is seen as a 'man's toy'.

The immediate environment for the use of SHEMS is the home, which may appear the same to all residents in the household. Yet the sensory ethnography observations revealed that men and women had different home practices and different values which they associated with spaces and other sensory dimensions of home. There were also differences in how men and women perceived and used energy in the home. Things related to energy management were considered a man's responsibility. Women used energy and they experienced the consequences of using SHEMS in the home. Examples were when the temperature changed in the rooms, or when SHEMS automatically changed the temperature to follow the settings entered into the system by the man, or when the air heat pump could no longer be used with a remote control as it had been integrated into the SHEMS. Women may become aware of the economic benefits of SHEMS. However, many women were indifferent to – or questioned the need for – SHEMS in their homes.

In the cultural context consisting of values, norms, attitudes and interactions, energy is defined as non-female topic. Some women in our study stated that energy is an important domain for everyone to know and manage. Yet, in the presence of their male partners, women withdrew from the discussion. Women themselves often made dismissive comments about their own knowledge about or capacity to plan the energy management at home. When the interviewees were asked about values behind adopting SHEMS, their responses did not differ by gender. Both the men and the few women who participated in the interviews sought mainly economic savings, increased level of comfort at home and environmental friendliness. For example, in the interviews I found that women did not discuss energy technologies or other energy-related subjects with their friends or other peers, as many men did. The man of the family was expected to know the household's energy consumption and how to manage it, but often the knowledge was not shared with other household members.

6 Discussion

This research presents multiple facets of users and use of SHEMS. User experience and values related to SHEMS have been studied to understand why and how the users adopt and use SHEMS and what consequences the use of SHEMS carries. In the five papers included in this thesis, I presented the key user values of SHEMS, sensory user experience of SHEMS, quantitative changes in energy consumption due to SHEMS, drivers and barriers to adoption of SHEMS and finally gender inclusiveness in the adoption and use of SHEMS. As far as I know, previous research had not addressed the values and user experience of three kinds of users in three phases of adoption and use of SHEMS. This study did so by including new users who adopted SHEMS during the research project; prospective users, who were interested in adopting SHEMS yet declined it; and experienced users with 2–4 years of experience with SHEMS. Interviews and observations with these three kinds of users provided the researcher with a cross-section of values, drivers, barriers and user experiences of SHEMS. In addition, quantitative data on energy consumption collected during the research provided a unique opportunity to analyse the changes in volume and consumption profiles due to SHEMS in a real-life experiment.

6.1 Summary of the results

In paper I, three user types were identified, based on the user values elicited through VSD empirical investigation concerning SHEMS and their life situations: full-nesters, empty-nesters and optimisers. Values were elicited in sensory ethnography interviews utilising the laddering technique. The most prevalent values among SHEMS users were frugality, sustainability, comfort and security; however, there was variety in values across the three user groups. Unlike the smart home technology optimisers profiled by Jensen et al. (2018), here the optimisers did not only want to optimise the energy use of their house but were also interested in optimising the technology. The primary value of SHEMS users was frugality: saving energy and saving money. The users were concerned about ecological sustainability and climate change, but they felt they lacked a clear understanding of the consequences of their own energy consumption practices and the impacts of their sustainability efforts. Householders yearned for personalised feedback and guidance for energy efficiency. This finding is consistent with (Moussaoui & Desrichard, 2016), who reported that people were more motivated regarding environmentally friendly behaviour when goals were concrete and related to daily life and when the required actions were small, with confirmed results. High-level abstract goals such as 'mitigate the climate change' were less effective. The results were also congruent with (Ligtvoet, et al., 2015) showing the users consider the individual and social values more important than the functional values of the technology. Furthermore, they were in agreement with (Easthope H. , 2004) emphasising the family as a user instead of the values of individuals. The users of SHEMS emphasised the values and consequences in their own homes rather than the community or society at large. SHEMS users valued concrete impacts of the system, such as comfort, savings and exploration of new technology and were not highly concerned about privacy, reliability or implications in the larger smart grid system (Ligtvoet, et al., 2015).

In paper II, I explored the sensory user experience of SHEMS. The data collected in the sensory ethnography interviews and observations highlighted the shared user experiences of SHEMS. This finding concurs with (Tsai, Chen, & Chuang, 2015). Different from the use of personal technologies, smart home technologies can influence the lives of several individuals and can be used by many people with differing goals and values. Established families usually have shared values which form the basis for decisions and everyday living. Yet individual preferences and priorities are discussed in the context of adoption and use of SHEMS. The potential SHEMS user population is heterogeneous, with varying technical competence. The users set their own goals and tasks, with no supervision or systematic feedback (Sauer, Schmeink, & Wastell, 2007) and this situation places certain demands on the 'smartness' requirements for SHEMS. I note that at present, SHEMS – like other smart home technologies – are predominantly adopted and used by tech-savvy affluent middle-aged men; the same point was noted by other researchers (Powells & Fell, 2019), (Aristondo & Onaindia, 2018), (Eurostat, 2021), (Strengers & Kennedy, 2020). As demonstrated in paper IV confirming the findings of (Strengers & Kennedy, 2020), women in our study had the pragmatic, 'the voice of reason' role in family, and the researcher testified the 'wife acceptance factor' (Strengers & Kennedy, 2020) in households where women were asked about their acceptance of the acquisition and adoption proposed by man. Even though SHEMS influences the energy use and sensory experience of all family members, other than the man in the family, additional adults were considered mostly passive background characters. They may have had a say concerning the adoption and use of SHEMS but they did not decide on the acquisition or how the SHEMS would be used at home. Furthermore, information and experiences on SHEMS were usually conveyed between male friends and colleagues.

In paper III it was demonstrated with consumption data that SHEMS may have a significant impact on energy consumption both in volume and in the consumption profile. As a result, the system makes energy consumption more sustainable by reducing total consumption and shifting consumption to off-peak hours. The study on the quantitative impacts of SHEMS on energy consumption responded to the lack of prior research involving real-life experiments regarding the changes in domestic electricity consumption resulting from SHEMS. The relationship between values and SHEMS use was also addressed; this connection between values and related quantitative energy consumption changes had not been previously studied. The results indicated that SHEMS may yield savings of up to 30% if householders value energy conservation and are willing to sacrifice some comfort. However, even families who valued comfort over other values gained in savings. This is in line with the findings of a SHEMS simulation study where the correlation between cost savings and degree of discomfort (DoD) was not linear; that is, savings increased to some extent without or with only a minor increase in DoD (Dittawit & Aagesen, 2014). Nonetheless, the results also showed that the level of energy conservation varied greatly between households and even in different months for the same household. Although from the energy system perspective, SHEMS connects homes to a smart grid (e.g., (Siano, 2014), (Shakeri & Amin, 2018)), with vast potential for systemic sustainability through demand response (Liu, Qiu, Fan, Zhu, & Han, 2016), this point seems unimportant for SHEMS users, or they were not aware of the potential connection. Concepts like 'demand flexibility' and 'smart grid' were rather distant and abstract ideas for the users, and they found it hard to make a connection between the use of SHEMS and the use of renewable energy resources. Darby & McKenna (2012) similarly noted energy users' lack of knowledge about demand response and smart grid. The results of this research highlight the users' lack of knowledge about the possibilities to increase the use of clean energy through SHEMS, and some participants had doubts concerning this aspect. However, most users considered environmental consequences an important factor in the adoption and use of SHEMS. This finding is in line with (Maibach, Leiserowitz, Roser-Renouf, Akerlof, & Nisbet, 2010) who found that a sense of morality, feeling good about oneself and complying with the wishes of another person were important second-tier motivators of energy efficiency actions, but are rarely the primary drivers. The SHEMS users interviewed in this research expected the system providers to inform them about the linkages between SHEMS use and the larger energy system and energy transition.

Paper IV explored the drivers and barriers to adoption and use of SHEMS. The research provides considerable insight into the multiple factors influencing such adoption and the complexity of the context of adoption and use of smart home energy technologies. New users balanced their expectations and doubts and did not quite know what to expect of SHEMS. Experienced users had been early adopters, who mainly identified drivers and indicated few barriers. However, only half of the experienced users regularly reviewed their electricity consumption or had estimated how much they saved through SHEMS. This is in line with the findings of (Hargreaves & Wilson, 2017 s. 50) that early adopters had weaker perceptions of the benefits and risks than did other users. Prospective users initially had an intention to adopt SHEMS but assessed the barriers as outweighing the drivers. The results partly confirm previous findings on the drivers of and barriers to the adoption of smart home technologies; despite strong drivers such as saving money and energy or increased comfort and safety, there are many barriers as well (e.g., (Karlin et al., 2015), (Hargreaves & Wilson, 2017), (Balta-Ozkan et al., 2013)). Awareness of SHEMS and other smart home technologies is low, and the impacts are difficult to measure. Users' fear of obsolescence of SHEM technologies may be valid; the stability and continuity of current smart home energy technologies may be unpredictable due to rapid changes in both the energy sector and technologies. Users ask for continuous development, expansion and integration of SHEMS with other home technologies. All new and prospective users had some doubts and potential or actual barriers to SHEMS adoption, whereas none of the experienced users remembered any doubts or did not mention them, possibly wanting to rationalise their decisions. Yet they had notably vague understanding of the benefits SHEMS had brought to their homes.

Paper V focused on the value of gender inclusiveness in the adoption and use of SHEMS and in the interest in participating REC. Gender inclusiveness in the adoption and use of SHEMS and RECs is built on several factors, such as power, democratic participation, economic possibilities and life management. The findings of this research are in good agreement with (Sefyrin, 2010), who pointed out that participation in the design and use of technologies is entangled with gender, power and knowledge. It is intertwined with socio-material practices which entail both possibilities and boundaries for actors. Normative gender roles, particularly those related to a heteronormative conception of 'the home', shape the way that men and women relate to home energy technologies. HCI can support a more gender inclusive approach to designing such technologies. Friedman (1999) identified three kinds of bias in information systems, which I recognised in the gendered adoption and use of SHEMS: pre-existing bias, technical bias and emergent bias. Pre-existing bias stems from social institutions, practices and attitudes. Technical bias arises from the resolution of issues in the technical design, e.g., not considering the limitations of technology or trying to make human constructs amenable to technology (Friedman B. , 1999). Emergent bias arises in the context of use of technology (Friedman B. , 1999). In the case of gender inclusiveness in SHEMS and RECs, all three kinds of bias can be identified. In particular, pre-existing and emergent bias exclude women as the users of home energy technologies. Social, economic and cultural factors as well as the context of use of SHEMS and RECs maintain the gender gap.

The findings confirm the usefulness of SHEMS in residential energy efficiency efforts. However, they underline the need for further research on the use context, user preferences and opportunities for new energy technologies that energy transitions require and push to households. In addition, the research findings provide support for practical steps in advancing smart energy solutions.

6.2 Research contributions and implications

The results contribute to smart home energy technology research and knowledge about the users of these technologies. It addresses several research gaps. There was a call for more research concerning the users of energy and smart home technologies (Sovacool, 2014), (Lennon, et al., 2019), particularly concerning the values of SHEMS users (Ligtvoet, et al., 2015) and real-life experiments on the impacts of SHEMS on energy consumption (McIlvennie, Sanguinetti, & Pritoni, 2020), (Karlin, et al., 2015). Furthermore, the sensory user experience of SHEMS or other smart home energy technologies had not been studied. In addition, the findings expand the understanding of several contextual (e.g., social and economic) factors influencing the use, adoption and user experience of such technologies. The findings have implications for research in several areas, notably sustainable HCI, ubiquitous technologies and smart living environments and studies on the users of smart energy systems and SHEMS.

The findings bear relevance for sustainable HCI research in several respects. There are opportunities for energy conservation, demand flexibility and energy exchange through smart home energy technologies, as shown by the data analysis regarding changes in real-life consumption. Understanding human–environment interaction in the home allows the resulting design to support and enhance the values and sensory user experience and increase the participation of homes in the energy transition. Seemingly mundane everyday practices, values and sensory meanings are pivotal for how the user experience of home technologies evolves (Aune, 2007), (Buswell, Webb and Mitchell, 2015). Also, this research has enhanced the understanding of end users of sustainable home technologies, including rarely reached experienced users as well as non-users with an interest in technology. Users identified several drivers for the adoption of SHEMS, but there were also barriers to overcome in order to improve energy conservation and demand flexibility through SHEMS.

It is fundamental to note that research on home energy technology users requires thinking about households as units in all their diverse forms. Instead of designing for the individual having a user experience, researchers must pay attention to the co-experience (Battarbee & Koskinen, 2005) that is created together with others. The current approaches to manage energy use and increase the use of renewable energy with SHEMS and other solutions tend to focus on technical and economic aspects. Yet a critical perspective on inclusiveness concerning the cultural and social conditions and social outcomes of the adoption and use of these technologies is needed to achieve the ambitious goals of energy citizen schemes. HCI has emphasised equality and inclusion in different senses and contexts thorough the years. Although gender equality in the adoption and use of energy technologies or in the energy sector has largely been ignored by HCI research, the topic of gender equality and inclusiveness is growing in importance (see e.g., (Stumpf, ym., 2020)).

The VSD provided the theoretical framework in this research. The VSD framework has many interesting and valuable applications (e.g., (Davis & Nathan, 2015), (Friedman & Kahn, 2000) and was originally intended for use in technology design. The approach has been criticised for failing to provide a systematic method for identifying stakeholders and involving them adequately in the design process (Manders-Huits, 2011), (Yetim, 2011). In this research, VSD was used as a theoretical framework, and sensory ethnography and laddering technique were chosen as methods to elicit SHEMS user values, to identify stakeholders and to reflect on the home energy technology adoption and use with a pre-selected value of gender inclusiveness. The values elicited in this research and value prioritisation may change – for example, with increased awareness of the impact of the technology. In line with Iversen et al. (Iversen & Leong, 2012), I consider values to be dynamic and open to negotiation and challenge through dialogue. However, some values – like wellbeing of family members – are probably more static and are always high in people's priorities. In this research, people's values sometimes changed when the users' knowledge about energy technologies and the dynamics and needs of the smart grid increased during the interviews and discussions with the researcher. Also, the experience of using SHEMS sometimes changed the values of new users as they found the system provided unexpected consequences.

From a systemic perspective, SHEMS is a part of a complex socio-energy system that contains tensions on the level of user values as well as differing and conflicting motivations and goals among stakeholders. Members of families and even indirect stakeholders of SHEMS – such as utilities, transmission service operators and SHEMS developers and resellers – hold diverse goals and values regarding the technology. In addition, there will be new stakeholders, such as aggregators and data hubs, whose roles and values in the system are still uncertain. For a more complete understanding of the opportunities to design a value-based SHEMS, indirect stakeholders' values should be mapped and analysed.

This research focused on exploring values related to SHEMS adoption and use and does not cover the phase of implementing the values in the design of smart home energy technologies. However, I acknowledge the challenging task of engaging with or embodying values in design (see e.g., (Friedman, Hendry, & Borning, 2017), (Manders-Huits, 2011). Also, I acknowledge that a straightforward list of prioritised values gives a simplified picture of the real values within homes. Values in families overlap and are linked in many ways, and the same values are differently interpreted and put into action in various ways. Family members have common values but also differing individual values and value prioritisations, goals and motivations, and they may have different roles in their interactions with the system. People in the home may compromise their own values to accommodate the values (or assumed values) of other family members. Sustainable HCI research on smart home energy technologies should focus on households as research units in all their diverse forms, or could identify diversity of roles in homes related to technologies and the co-experience (Battarbee & Koskinen, 2005) that is created together with others.

The sensory ethnography lens was applied in the interviews and observations to explore non-verbal dimensions of user experience and use context, i.e., the home. In paper II, I conceptualised and studied the sensory user experience of SHEMS and the feeling of 'home' to extrapolate implications for future research and the design of smart home energy technologies and services. This work enhances the research on sustainable digital practices in HCI with greater understanding of the condition of humans interacting with ubiquitous and pervasive technology, as stated by (Bødker, 2014) and (Yoo, 2010). Applying the sensory ethnography lens unveils often ignored yet valuable aspects of technology use. However, there are challenges involved with conducting sensory ethnography. For example, verbalising sensory and material aspects can be challenging not only for interviewees but also for the researcher. Sensory ethnography involves the researcher in sensory experiences together with interviewees, and the primary data includes text but goes beyond that. Recording, analysing and sharing multisensorial experience with a research community requires innovative communication techniques. Transcribing the interview material reduces the sensory experience to text, which raises the question of how to enrich the analysis of sensory ethnography interviews with sensory experience, gestures and even power relations in the situation. Different forms of transcription have been proposed to do that, e.g., formatting the text to express tones, pauses and gestures, or through multimodality (O'Dell & Willim, 2013). In addition, photos, pictures or cartoons can be used to illustrate and share the research data visually rather than textually; however, this approach would emphasise the already dominant visual aspect and leave much of the multisensory experience unattainable. Furthermore, analysing video recordings and other visual or sensory material is onerous and time-consuming. Nonetheless, the participation of researchers in the transcription and analysis of the data is worthwhile, since the analysis in effect begins from the first contact with participants.

6.3 Practical implications

The findings offer valuable input for the design of smart grid and smart home services and products. They inform designers about users' needs and provide an understanding of the context of use of these technologies. The values that people hold in relation to energy use and digital technologies, and specifically energy technologies, as well as knowledge about sensory user experiences can be applied in home energy technology design. Doing so can enable people to realise their values and increase their sustainability impact.

This research could be a useful aid in business and policy strategy planning and execution. This study approaches the topic of energy consumption in homes, which has significant sustainability consequences. Clearly there is a gap between the vision of SHEMS as part of the energy transition versus the reality. The findings can help to bridge the gap between the vision of active energy citizens and actual household energy technology adoption. The research also identifies paths for future end user inclusion in the energy transition and for developing policy instruments and business strategies to foster the adoption of home energy technologies and participation in energy transition. To speed up the adoption of such technologies and the achievement of full benefits for users as well as the energy sector and the environment, simpler and cheaper versions of SHEMS should be designed and promoted and public awareness of the potential of SHEMS should be increased. Currently, the sustainability aspect of SHEMS is not well understood by most users. Our results point to the need for more targeted campaigns to inform users of smart energy technologies and demand flexibility with 'a clear and careful language', as described by (Darby S. J., 2018). The gap between the current knowledge of a typical energy user and the assumed user should be addressed by policy makers, the energy sector and home technology providers. For a democratic and impactful energy transition, all individuals – regardless of gender or age – need to be involved in the use of home energy technologies such as SHEMS, solar panels and energy communities.

In this research, the participants were perceived as users of SHEMS and other home technologies. However, it is crucial to understand that people have different roles concerning energy, which further increases the complexity of values and their constellations. People are consumers who make contracts and purchase energy and services. They are citizens who are informed and advised and who consent to public policy measures and support their implementation (Defila & Di Giulio, 2018). Also, they are part of a community, or rather many communities (city, neighbourhood, work or school, larger family, etc.). Increasingly, people are becoming prosumers, producing energy themselves. The value of sustainability is common to all stakeholders. However, the way this value is prioritised and implemented in the system is linked to other – sometimes conflicting – values of privacy and liberty of individual choices versus the common good in society, and autonomy and independence versus technologies being controlled from outside the home (Renström, 2019).

7 Conclusions

I have argued throughout this work that there are opportunities to increase energy efficiency and the use of renewable energy through smart home energy technology. SHEMS is a relatively affordable and easy-to-use system that could be the first home energy technology many households adopt. The consumption data show that SHEMS saves up to 30% of electricity consumption during the winter months in Finnish households. However, the use context of SHEMS is complex, with several stakeholders, not only householders but also the system provider, smart grid and other energy sector operators. In the home, the use of SHEMS is a shared experience with many impacts and interactions on sensory, social and economic levels. Values guide people to make choices, especially in new situations. Climate change and energy transition, specifically the current energy crisis, are forcing people globally to face new situations and choices and reflect on their underlying values. Although values are quite stable, prioritising them may change. Interestingly, the value of ecological sustainability is not strongly connected to energy use, and there is a lack of awareness concerning people's interactions with the larger energy system. It is important to note that most households prioritise the values that relate to family wellbeing and cherish the place that is the heart of home – even at the cost of paying more for heating it. Technology like SHEMS may open possibilities to realise values or hinder them. The user values presented in this research can inform the design of SHEMS and other home energy technologies. In addition, the study provides insight into the values and user experiences related to SHEMS, which have many interesting applications, e.g., in designing citizen energy communities, in policy making and in research. This study enhances our understanding of the SHEMS and its users in the home context. The same methods and techniques can be applied to other technologies or in other smart environments. This work highlights the importance of understanding the end users in energy transition and can offer a useful aid for decision-makers. The findings of this study might have important implications for solving the problem of involving people and empowering them to become 'energy citizens'.

I hope that my research will be constructive for building dialogue among energy technology stakeholders and in building awareness of energy transition and new technologies.

7.1 Summary of the results

This research has explained user values and sensory user experience related to smart home energy technologies. It has investigated the implications of the use of SHEMS in energy consumption and has given an account of gendered user roles and the drivers of and barriers to adoption of SHEMS. An innovative combination of methods was applied to gain thorough understanding of user experiences of SHEMS and draw implications for the design of smart home technologies. The study addressed the following research questions.

In paper I, the key user values of new, potential and experienced users of SHEMS were elicited through VSD and the laddering technique. Users seek economic savings with SHEMS, and environmental friendliness is an important second-tier value. Comfort was a common and often unexpectedly discovered value in the use of SHEMS. There was a group of users I called ‘optimisers’, who carried values distinct from other users, namely creativity, stimulation and autonomy. In the shared user experience of SHEMS, these values may conflict with other family members’ values.

In paper II, the sensory user experience of SHEMS was conceptualised based on findings gained in sensory ethnography interviews and observations in SHEMS users’ homes. The sensory user experience of intertwined sensory and affective factors and it is intermingled with energy consumption and daily practices in homes. Interviewees’ quotations and mental maps indicated that sensory user experiences are social, negotiated and shared experiences. Different parts of the home impose different requirements for sensory user experience, and sensations of warmth, view, scents, sounds and light contribute to that experience. The users of SHEMS cherish comfort in the ‘heart’ of the home i.e., the kitchen and the living room. Nonetheless, there are always opportunities for energy management in the home.

Paper III demonstrated the changes in electricity consumption due to SHEMS in daily consumption profiles and the number of low- and high-consumption households among 10 Finnish homes. The changes were examined in the context of household values. The data indicates that the SHEMS reduced the total consumption of electricity in the winter months by up to 30%, shifted the consumption to off-peak hours and decreased the number of high-consumption hours. These changes also occurred in homes that valued comfort over savings or ecological sustainability; however, the levels of energy conservation varied greatly among the households and among months in the same homes.

In paper IV, the drivers of and barriers to adoption of SHEMS were identified based on the observations of three user groups (new, prospective and experienced users) from 28 households. The key drivers to adopting SHEMS were saving energy for economic and environmental reasons, increased comfort of living, safety and curiosity. However, the users were unfamiliar with SHEMS and they lacked understanding about how it relates to the larger energy system or to the use of renewable energy. The price of SHEMS, estimated low savings, complexity of the systems and problems with retrofitting were further are barriers to adoption.

Paper V brought to light the identified gender imbalance in the adoption and use of SHEMS and a lack of the value of gender inclusiveness in the current energy technology design and current institutional context of energy technologies. In the sensory ethnography observations and interviews during the adoption and use of SHEMS, the technology itself was found useful and easy to use by both men and the few women who used it. However, gender inclusiveness is lacking in the context in which the adoption decisions are made, information about SHEMS is conveyed and SHEMS is adopted. When it comes to interest in REC, over 90% of interested interviewees were men. The findings underline the need to redefine the default user of SHEMS and other smart home technologies and the need for more inclusive energy technology design. Greater understanding is needed of the diversity of households, as is greater variety in the approaches for increasing the awareness of energy technologies and facilitating their adoption.

Taken together, these findings highlight a role for SHEMS in household energy conservation and people's participation in energy transition. The results suggest there is a lack of knowledge, trust and inclusiveness concerning home energy technologies, yet these systems may offer an opportunity for users to implement their values and improve their sensory experiences of the home. The study provides the basis for a new way to evaluate and design home energy technologies. The significance of this work lies in the potential energy conservation, increased renewable energy use and nascent energy citizenship through using SHEMS and other home energy technologies.

7.2 Limitations of the research

This research clearly has some limitations. The first and most important limitation lies in the fact that the study was conducted in single-family detached houses in a geographically limited area. Most households where interviews and observations were conducted and consumption data was collected were in Northern Finland.

Thus, the findings might not be representative of families living in other kinds of homes and areas. The participants in this research were a self-selected group of people who expressed interest in SHEMS, and most of them had already adopted the system into their homes. They were probably more interested in energy technology and more affluent than the average Finnish person. The values of other user groups should be studied to gain insights into how to develop energy-saving technologies for all kinds of users. However, our results are rather consistent with (Ligtvoet, et al., 2015), (Buswell & Webb, 2015), (Energy and Digital Living, 2010-2014) and (Haines, Mitchell, & Cooper, 2007). Given this broad agreement, the values of SHEMS users might not be culture-specific, although the ways the values are applied in practice may differ in diverse cultures and circumstances. In this research, many factors influencing energy consumption and related choices, such as the structure of the electricity markets, pricing and taxation, are not considered.

Second, the research comprised only two kinds of SHEMS with rather similar functionality. More variety in the home energy technologies might bring up additional findings. Larger number of users could also be recruited through quantitative studies.

Third, the user values of SHEMS, sensory user experiences and the drivers of and barriers to adoption are a result of interviews with householders who were interested, had decided to acquire or were already using SHEMS. In most cases the main user of SHEMS was (or would become) the male adult of the family. These men were also the most vocal in the interviews. In some cases, only the male adult participated in the interview and was the only user of SHEMS. Therefore, in most interviewed homes, the expressed values were associated with the male adult. Other roles in the family concerning energy use and related technologies should be recognised and studied further.

Fourth, the quantitative analysis of energy consumption changes presented in paper III is based on a small sample, which does not allow for the generalisation of results or the possibility of testing the results statistically. Hence, the correlation between a household's values (comfort, cost, sustainability, etc.) and consumption are described only in a qualitative way. In future studies, such corelations should be explored using quantitative indicators. Also, although the consumption was weather-corrected according to HDDs, it was not corrected for occupancy; hence, the extent to which differences in consumption pre- and post-SHEMS that were due to changes in occupancy was not assessed.

Fifth, in any sensory ethnography interview and observation, the age, gender and personal traits of the researcher can impact the discussions with users and the data collection and analysis. Since all interviews were conducted by one researcher, personal experiences and interests may have guided the focus on certain phenomena more than others.

Despite these limitations, this work provides a valuable basis for further research.

7.3 Further research

The findings of this research pave the way for studies on the user's role with future energy technologies and services. RECs were touched upon in this research, but further work concerning them is being carried out. I am currently in the process of investigating stakeholders' perceptions and preferences concerning energy communities. Also, I will work on the applications of 6G technology in enabling and supporting a sustainable society.

This research has raised many questions in need of further investigation. Examples are how stable or dynamic – or culturally dependent – the values related to energy technologies or energy use may be. An additional question is how to implement the elicited values in designing future energy technologies. The conceptualisation of sensory user experience can be further theorised and applied in other contexts. Diverse households should be included in energy user research. The results presented here should be validated by a larger sample size. Further work needs to be done on the values and user experience related to energy technologies, and on the concrete impacts these technologies have. I hope that further research will broaden my findings.

Bibliography

Abascal, J., & Azevedo, L. (2007). Fundamentals of Inclusive HCI Design. In S. C. (ed.), *Universal Acess in Human Computer Interaction. Coping with Diversity. UAHCI 2007* (Vol. 4554). Springer.

Abdmouleh, Z., Gastli, A., & Ben-Brahim, L. (2018). Survey about public perception regarding smart grid, energy efficiency & renewable energies applications in Qatar. *Renewable and Sustainable Energy Rev, 8*, 168-175.

Ahmad, A., Khan, A., Javaid, N., Hussain, H., Abdul, W., Almogren, A., . . . Azim Niaz, I. (2017). An Optimized Home Energy Management System with Integrated Renewable Energy and Storage Resources. *Energies, 10*, 549. doi:https://doi.org/10.3390/en10040549

Alan, A. T., Costanza, E., Ramchurn, S. D., Fischer, J., Rodden, T., & Jennings, N. R. (2016). Tariff Agent: Interacting with a Future Smart Energy System at Home. *ACM Transactions Computer-Human Interaction, 23*(4), Article 25. doi:https://doi.org/10.1145/2943770.

Alao, O. D., Joshua, J. V., & Akinsola, J. E. (2019). Human Computer Interaction (HCI) and Smart Home Applications. *IUP Journal of Information Technology, 15*(3), 7-21.

Albadi, M. H., & El-Saadany, E. F. (2008). A summary of demand response in electricity markets. *Electric Power Systems Research, 78*, pp. 1989-1996.

Albrechtslund, A. (2007). Ethics and technolocy design. *Ethics and Information Technology, 1*(9), 63-71.

Alcott, H. (2011). Social norms and energy conservation. *Journal of Public Economics , 95*(9–10), 1082–1095.

Almond, B., & Wilson, B. (1988). *Values: A symposium.* Humanities Press International Inc.

Amasyali, K., & El-Gohary, N. M. (2016). Energy-related values and satisfaction levels of residential and office building occupants. *Building and Environment, 95*, 251-263.

Anderson, R. (2007). Thematic content analysis (TCA). Descriptive presentation of qualitative data, 1-4. http://rosemarieanderson.com/wp-content/uploads/2014/08/ThematicContentAnalysis.pdf.

Anfinsen, M., & Heidenreich, S. (2017). *Energy & gender - a social sciences and humanities cross-cutting theme report.* Cambridge: SHAPE ENERGY.

Annala, S. (2015). *Households' willingness to engage in demand response in the Finnish retail electricity market: An empirical study.* Lappeenranta University of Technology. Yliopistopaino.

Appadurai, A. (1990). Disjuncture and Difference in the Global Cultural Economy. *Theory Culture Society, 7*, 295-310.

Ardito, C., Buono, P., Desolda, G., & Matera, M. (2018). From smart objects to smart experiences: An end-user development approach. *International Journal of Human-Computer Studies, 114*, 51-68. doi:doi.org/10.1016/j.ijhcs.2017.12.002.

Aristondo, O., & Onaindia, E. (2018). Inequality of energy poverty between groups in Spain. *Energy, 153*, 431-442. doi:doi:doi.org/10.1016/j.energy.2018.04.029

Aune, M. (2007). Energy comes home. *Energy Policy, 35*(11).

Balta-Ozkan, N., Amerighi, O., & Boteler, B. (2014). A comparison of consumer perceptions towards smart homes in the UK, Germany and Italy. *Technology Analysis & Strategic Management, 26*(10), 1176-1195.

Balta-Ozkan, N., Davidson, R., Bicket, M., & Whitmarsh, L. (2013). Social barriers to the adoption of smart homes. *Energy Policy, 63*, 363-374.

Bannon, L. (2011). Reimagining HCI: Toward a more human-centered perspective. *Interactions, 18*(4), 50–57. doi:doi:10.1145/1978822.1978833

Barcham, M. (2021). Towards a radically inclusive design – indigenous story-telling as codesign methodology. *CoDesign*. doi:10.1080/15710882.2021.1982989

Bardzell, J. (2013). Critical and Cultural Approaches to HCI. In C. J. Price, *The SAGE Handbook of Digital Technology Research* (pp. 130-143). SAGE Publications Ltd.

Barr, S. (2006). Environmental Action in the Home: Investigating the 'Value-Action' Gap. *Geography, 91*(1), 43-54.

Battarbee, K., & Koskinen, I. (2005). Co-experience: User experience as interaction. *CoDesign, 1*, 5–18.

Berglund, C., Hage, O., & Söderholm, P. (2010). Household recycling and the influence of norms and convenience. In P. S. (ed.)., *Environmental Policy and Household Behaviour: Sustainability and Everyday Life* (pp. 193-209). Earthscan.

Bjelica, M. Z. (2018). How much smart is too much? *IEEE Consumer Electronics Magazine* (November 2018), 23-28.

Borning, A., & Muller, M. (2012). Next steps for value sensitive design. *Proceedings of the 2012 ACM annual conference on human factors in computing systems* (pp. 1125-1134). ACM.

BP. (2021). *Diversity, equity and inclusion report 2020.* Retrieved from https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/sustainability/bp-diversity-equity-and-inclusion-report-2020.pdf

Breslin, P., & Huang, L. (2006). Human taste: Peripheral anatomy, taste transduction, and coding. In &. A.-L. T. Hummel, *Advances in Otorhinolaryngology* (Vol. 63, pp. 152-190). Karger.

Brocki, M. (2016). The problem of the universal values and intercultural space – new/old predicament of anthropology. *Politeja, 44*, 131-142.

Brown, D., Hall, S., & Davis, M. E. (2020). What is prosumerism for? Exploring the normative dimensions of decentralised energy transitions. *Energy Research & Social Science, 66*, 101475.

Buchanan, K., Banks, N., Preston, I., & Russo, R. (2016). The British public's perception of the UK smart metering initiative. *Energy Policy, 91*, 87-97.

Buchanan, K., Russo, R., & Anderson, B. (2014). Feeding back about eco-feedback: How do consumers use and respond to energy monitors? *Energy Policy, 73*, 138-146.

Bull, M., & Howes, D. (2016). Editorial: The Expanding Field of Sensory Studies. *The Senses and Society, 11*(1), 1-2. doi:doi:10.1080/17458927.2016.1194612

Burke, M. J., & Stephens, J. C. (2018). Political power and renewable energy futures: A critical review. *Energy Research & Social Science, 35*, 78-93.

Burnett, M. (2016). “Womenomics” and Gender-Inclusive Software: What Software Engineers Need to Know (Invited Talk). *Proceedings of the 2016 24th ACM SIGSOFT International Symposium on Foundations of Software Engineering (FSE 2016).* ACM.

Bush, C. G. (2009). Women and the Assessment of Technology: To Think, to Be; to Unthink, to Free. In D. M. Kaplan, *Readings in the Philosophy of Technology* (pp. 112-126). Littlefield Publishers.

Buswell, R. A., & Webb, L. M. (2015). *LEEDR Household recruitment: procedures, materials and methods.* Loughborough University. Retrieved from https://dspace.lboro.ac.uk/2134/16860

Byrne, D. S., & Bartiaux, F. (2017). Energy Systems and Energy-Related Practices. In N. (. Labanca, *Complex Systems and Social Practices in Energy Transitions, Green Energy and Technology* (pp. 305-320). Springer International Publishing Swizerland. doi:10.1007/978-3-319-33753-1_14

Bødker, M. (2014). Walking. Sensing. Participation: Three meditations for experiential computing. *Proceedings of the European Conference on Information Systems (ECIS) 2014.* Tel Aviv, Israel.

Carlsson-Kanyama, A., & Lindén, A.-L. (2007). Energy efficiency in residences—Challenges for women and men in the North. *Energy Policy, 35*(4), 2163-2172.

Carpendale, S., Bardzell, S., Burnett, M., Kumar, N., & Balaam, M. (2018). Panel: Extending Conversations about Gender and HCI. *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems (CHI EA '18).* ACM.

Castelli, N., Ogonowski, C., Jakobi, T., Stein, M., Stevens, G., & Wulf, V. (2017). What Happened in my home?: An End-User Development Approach for Smart Home Data Visualization. *CHI '17* (pp. 853–866). ACM.

CE Delft. (2016). *The potential of energy citizens in the European Union.* CE Delft. Retrieved from https://friendsoftheearth.eu/wp-content/uploads/2016/09/ce-delft-the-potential-of-energy-citizens-eu.pdf

Christensen, T., Gram-Hanssen, K., & Friis, F. (2012). *Households in the smart grid-existing knowledge and new approaches,.* Centre for Consumer Science. Gothenburg, Sweden: University of Gothenburg.

Clancy, J., & Roehr, U. (2003). Gender and energy: is there a Northern perspective? *Energy for Sustainable Development, 7*(3), 44-49. doi:https://doi.org/10.1016/S0973-0826(08)60364-6.l.

Clear, A. C., & Comber, R. (2017). Towards a social practice theory perspective on sustainable HCI research and design. In L. P. Mike Hazas, *Digital Technology and Sustainability: Engaging the Paradox* (pp. 31-43). Routledge.

Cleveland, C. J., & Morris, C. (2015). *The Dictionary of Energy, Second Edition.* Elsevier.

Cockton, G. (2009). Getting there: six meta-principles and interaction design. *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 2223-2232). ACM.

Connected Devices Alliance. (2018). *Intelligent Efficiency: A Case Study of Barriers and Solutions - Smart Homes. Energy Efficient End-Use Equipment Technology Collaboration Programme.*

Connor, P. M., Axon, C. J., Xenias, D., & Balta-Ozkan, N. (2018). Sources of risk and uncertainty in UK smart grid deployment: An expert stakeholder analysis. *Energy, 161*, 1-9.

Cooper, C. (1974/2014). House as Symbol of the Self. In J. W. Gieseking, *The People, Place, & Space Reader* (pp. 168-172). Routledge.

Correljé, A., Cuppen, E., Dignum, M., Pesch, U., & Taebi, B. (2015). Responsible Innovation in Energy Projects: Values in the Design of Technologies, Institutions and Stakeholder Interactions. In B.-J. Koops et al. (eds.), *Responsible Innovation 2:Concepts, Approaches, and Applications* (pp. 183-200). Springer International Publishing Switzerland. doi:10.1007/978-3-319-17308-5_10

Coughlan, T., Leder Mackley, K., Brown, M., Martindale, S. S., Mallaband, B., Arnott, J., . . . Hine, N. (2013). Current issues and future directions in methods for studying technology in the home. *PsychNology, 11 (2), pp. 159 - 184., 11*(2), 159-184.

Cozza, M., De Angeli, A., & Tonolli, L. (2017). Ubiquitous technologies for older people. *Personal and Ubiquitous Computing, 21*(3), 607-619. doi:doi.org/10.1007/s00779-017-1003-7.

Cozzi, L., & Goodson, T. (2020). IEA commentaries: Empowering electricity consumers to lower their carbon footprint. Retrieved from https://www.iea.org/commentaries/empowering-electricity-consumers-to-lower-their-carbon-footprint

Darby, S. (2006). *The Effectiveness of Feedback on Energy Consumption: A Review for Defra of the Literature on Metering.* Environmental Change Institute, University of Oxford .

Darby, S. J. (2018). Smart technology in the home: Time for more clarity. *Building Research & Information, 46*(1), 140-147. doi:10.1080/09613218.2017.1301707

Darby, S. J., & McKenna, E. (2012). Social implications of residential demand response in cool temperate climates. *Energy Policy, 49*, 759-769.

Davis, F. D. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly, 13*(3), 319-340.

Davis, J., & Nathan, L. P. (2015). Value Sensitive Design: Applications, Adaptations, and Critiques. In J. v. al. (Ed.), *Handbook of Ethics, Values, and Technological Design* (pp. 11-40). Dordrecht: Springer Science+Business Media.

De Giorgi, C., Lerma, B., Allione, C., & Buiatti, E. (2011). Sensory evolution: sensory and sustain-able design strategies. *Proceedings of the 2011 Conference on Designing Pleasurable Prod-ucts and Interfaces (DPPI '11).* ACM.

Dechesne, F., Warnier, M., & van den Hoven, J. (2013). Ethical requirements for reconfigurable sensor technology: a challenge for value sensitive design. *Ethics and Information Technology, 15*(3), 173-181.

Defila, R., & Di Giulio, A. R. (2018). Two souls are dwelling in my breast: Uncovering how individuals in their dual role as consumer-citizen perceive future energy policies. *Energy Research and Social Science, 35*, 152-162.

Delta-EE. (2020). *Accelerating the energy transition with Home Energy Management: Why the HEM market is at a tipping point in Europe.* Delta-EE.

Després, C. (1991). The meaning of home: Literature review and directions for future research and theoretical development. *The Journal of Architectural and Planning Research, 8*(2), 96-115.

DiSalvo, C., Sengers, P., & Brynjarsdóttir, H. (2010). Mapping the Landscape of Sustainable HCI. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (Atlanta, Georgia, USA)* (pp. 1975–1984). ACM. doi:https://doi.org/10.1145/1753326.1753625

Dittawit, K., & Aagesen, F. A. (2014). Home energy management system for electricity cost savings and comfort preservation. *2014 IEEE Fourth International Conference on Consumer Electronics Berlin (ICCE-Berlin)* (pp. 309-313). IEEE.

Dóci, G., Vasileiadou, E., & Petersen, A. C. (2015). Exploring the transition potential of renewable energy communities. *Futures, 66*, 85-95.

Dütschke, E., & Paetz, A.-G. (2013). Dynamic electricity pricing – Which programs do consumers prefer? *Energy Policy, 59*, 226-234.

Easthope, H. (2004). A place called home. *Housing, Theory and Society, 21*(3), 128-138.

Eid, C., Koliou, E., Valles, M., Reneses, J., & Hakvoort, R. (2016). Time-based pricing and electricity demand response: Existing barriers and next steps. *Utilities Policy, 40*, 15-25.

Elkhorchani, H., & Grayaa, K. (2016). Novel home energy management system using wireless communication technologies for carbon emission reduction within a smart grid. *Journal of Cleaner Production*, *135*, 950-962.

Energy and Digital Living. (2010-2014). LEEDR: University of Loughborough. Retrieved from http://energyanddigitalliving.com/

Entwistle, J. M., Rasmussen, M. K., Verdezoto, N., Brewer, R. S., & Andersen, M. S. (2015). Beyond the Individual: The Contextual Wheel of Practice as a Research Framework for Sustainable HCI. *Proceedings of the 33rd Annual ACM Co Annual ACM Conference on Human Factors in Computing Systems (CHI '15)* (pp. 1125–1134). ACM. doi:10.1145/2702123.2702232

Espe, E., Potdar, V., & Chang, E. (2018). Prosumer Communities and Relationships in Smart Grids: A Literature Review, Evolution and Future Directions. *Energies, 11*(2528). doi:10.3390/en11102528

European Commission. (2019). *Clean energy for all Europeans.* Directorate-General for Energy. Publications Office. Retrieved from https://data.europa.eu/doi/10.2833/21366

European Commission. (2019). *Directive (EU) 2019/944 on common rules for the internal market for electricity and amending Directive 2012/27/EU (recast).* European Commission. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019L0944

European Commission. (2019). *Eurostat: Energy consumption in households.* Retrieved from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households

European Commission. (2020). *European performance of buildings directive*. Retrieved from Energy - European Commission: https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-performance-of-buildings/energy-performance-buildings-directive

European Commission. (2021). *Smart Readiness Indicator*. Retrieved from European Commission: Energy: https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/smart-readiness-indicator_en

European Commission, Directorate-General for Energy. (2020). *Assessment and roadmap for the digital transformation of the energy sector towards an innovative internal market: final report.* Publications Office. Retrieved from https://data.europa.eu/doi/10.2833/36433

European Union. (2017). Gender Perspective on Access to Energy in the EU. Retrieved from http://www.europarl.europa.eu/RegData/etudes/STUD/2017/596816/IPOL_STU(2017)596816_EN.pdf

European Union. (2018). Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. Retrieved from http://data.europa.eu/eli/dir/2018/2001/oj

European Union. (2019). *Clean energy for all Europeans.* Publications office of the European Union.

Eurostat. (2020). Household composition statistics, 2019.

Eurostat. (2021). *People at risk of poverty or social exclusion by age and sex in EU27, 2019.*

Evans, D. (2011). Thrifty, green or frugal: reflections of sustainable consumption in a changing economic climate. *Geoforum, 42*, 550-557.

Faruqui, A., Sergici, S., & Sharif, A. (2010). The impact of informational feedback on energy consumption—a survey of the experimental evidence. *Energy, 35*(4), 1598-1608.

Fathallah, J., & Pyakurel, P. (2020). Addressing gender in energy studies. *Energy Research & Social Science, 65*, 101461.

Feenstra, M., & Özerol, G. (2018). Using energy justice as a search light for gender and energy policy research: a systematic review. *Proceedings of the 12th ECPR General Conference, Hamburg, Germany.*

Finnish Meteorological Institute. (2018-2019). *Lämmitystarveluku eli astepäiväluku*. Retrieved from Finnish Meteorological Institute: : https://ilmatieteenlaitos.fi/lammitystarveluvut

Flanagan M, & Nissenbaum, H. (2007). A game design methodology to incorporate social activist themes. *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 181-190). ACM.

Flanagan, M., Howe, D., & Nissenbaum, H. (2005). Values at play. *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 751–760). ACM.

Flynn, R., Bellaby, P., & Ricci, M. (2009). The 'Value-Action Gap' in Public Attitudes towards Sustainable Energy: The Case of Hydrogen Energy. *The Sociological Review, 57*(2), 159-180.

Ford, R., Stephenson, J., Brown, N., & Stiehler, W. (2014). *Energy Transitions: Home Energy Management Systems (HEMS).* Centre for Sustainability. University of Otago. Retrieved from http://hdl.handle.net/10523/4788

Fornara, F., Pattitoni, P., Mura, M., & Strazzera, E. (2016). Predicting intention to improve household energy efficiency: The role of value-belief-norm theory, normative and informational influence, and specific attitude. *Journal of Environmental Psychology, 45*, 1-10. doi:doi:doi.org/10.1016/j.jenvp.2015.11.001

Fraune, G. (2015). Gender matters: Women, renewable energy, and citizen participation. *Energy Research & Social Science, 7*, 55-65. doi:doi:http://dx.doi.org/10.1016/j.erss.2015.02.005

Frederiks, E. R., Stenner, K., & Hobman, E. V. (2015). Household energy use: Applying behavioural economics to understand consumer decision-making and behaviour. *Renewable and Sustainable Energy Reviews, 41*, 1385-1394.

Friedman, B. (1996). Value-sensitive design. interactions. *interactions, 3*(6), 16-23.

Friedman, B. (1999). *Value-sensitive design: a research agenda for information technology. Report for value sensitive design workshop.* National Science Foundation.

Friedman, B. (2012). Something of value [social impact award talk]. *SIGCHI conference on human factors in computing systems.* Austin, 9 May 2012.

Friedman, B., & Hendry, D. G. (2019). *Value Sensitive Design: Shaping Technology with Moral Imagination.* The MIT Press.

Friedman, B., & Kahn, P. H. (2000). New Directions:A Value-Sensitive Design Approach to Augmented Reality. *DARE 2000 April, 2000.* ACM.

Friedman, B., & Kahn, P. J. (2002). Human values, ethics, and designed. In *The human-computer interaction handbook* (pp. 1177–1201). L. Erlbaum Associates Inc.

Friedman, B., Hendry, D. G., & Borning, A. (2017). *A Survey of Value Sensitive Design Methods.* Now Publishers Inc.

Friedman, B., Kahn, P. H., & Borning, A. (2002). *Value Sensitive Design: Theory and Methods.* University of Washington.

Friedman, B., Kahn, P. J., & Borning, A. (2006). Value sensitive design and information systems. In *Zhang P, Galletta D (eds) Human-computer interaction in management information systems* (pp. 348–372). M.E. Sharpe.

Frontiers, I. S. (2008). Brown, S.Household technology adoption, use, and impacts: Past, present, and future. *Information Systems Frontiers*, 397.

Gieseking, J. J., & Mangold, W. (2014). Diverse conceptions between people, place, and space. In J. J. Gieseking, & W. E. Mangold, *The people, place, and space reader* (pp. 3-6). Routledge.

Goncalves Da Silva, P., Karnouskos, S., & Ilic, D. (2012). A Survey Towards Understanding Residential Prosumers in Smart Grid Neighbourhoods. *2012 3rd IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe), Berlin.*

Goulden, M., Bedwell, B., Rennick-Egglestone, S., Rodden, T., & Spence, A. (2014). Smart grids, smart users? The role of the user in demand side management. *Energy Research & Social Science, 2*, 21-29.

Grimes, S. M., & Feenberg, A. (2013). Critical Theory of Technology. In C. J. Price, *The SAGE Handbook of Digital Technology Research.* SAGE.

Gromet, D. M., Kunreuther, H., & Larrick, R. P. (2013). Political ideology affects energy-efficiency attitudes and choices. *Proceedings of the National Academy of Sciences of the United States of America, 110*(23), 9314-9319.

Grünewald, P., & Diakonova, M. (2020). Societal differences, activities, and performance: Examining the role of gender in electricity demand in the United Kingdom. *Energy Research & Social Science, 69*, 101719. doi:doi.org/10.1016/j.erss.2020.101719

Gui, E. M., & MacGill, I. (2018). Typology of future clean energy communities: An exploratory structure, opportunities, and challenges. *Energy Research & Social Science, 35*, 94-107.

Hahnel, U., Ortmann, C., Korcaj, L., & Spada, H. (2014). What is green worth to you? Activating environmental values lowers price sensitivity towards electric vehicles. *Journal of Environmental Psychology, 40*, 306-319.

Haines, V., Mitchell, V., & Cooper, C. M. (2007). Probing user values in the home environment within a technology driven Smart Home project. *Personal and Ubiquitous Computing, 11*(5), 349-359. Retrieved from https://dspace.lboro.ac.uk/dspace-jspui/bitstream/2134/2288/1/PUB455.pdf

Haines, V., Mitchell, V., & Ross, T. (2015). User Centred Design As An Enabler of Sustainable HCI. *British HCI 2015, 13th-17th July 2015.* UK.

Hall, E. T. (1966). *The Hidden Dimension.* Doubleday.

Halloran, J., Hornecker, E., Stringer, M., Harris, E., & Fitzpatrick, G. (2009). The value of values: Resourcing co-design of ubiquitous computing. *CoDesign, 5*(4), 245-273.

Hanke, F., Guyet, R., & Feenstra, M. (2021). Do renewable energy communities deliver energy justice? Exploring insights from 71 European cases. *Energy Research & Social Science, 80*, 102244. doi:doi.org/10.1016/j.erss.2021.102244

Hansen, A., Madsen, L., Knudsen, H., & Gram-Hanssen, K. (2019). Gender, age, and educational differences in the importance of homely comfort in Denmark. *Energy Research and Social Science, 54*, 157-165.

Hansson, L. Å., Pargman, T. C., & Pargman, D. S. (2021). A Decade of Sustainable HCI: Connecting SHCI to the Sustainable Development Goals. *CHI Conference on Human Factors in Computing Systems* (pp. Article 300, 1–19). ACM. doi:https://doi.org/10.1145/3411764.3445069

Haque, U. (2004). Haque, U. (2004)Scents of Space: An interactive smell system. *Proceedings of ACM SIG-GRAPH 2004 Sketches.* ACM.

Hards, S. (2011). Social Practice and the Evolution of Personal Environmental Values. *Environmental Values, 20*(1), 23-42. doi:doi.org/10.3197/096327111X12922350165996

Hargreaves, T., & Wilson, C. (2017). *Smart Homes and Their Users.* Springer.

Harrison, S., & Dourish, P. (1996). Re-place-ing space: the roles of place and space in collaborative systems. *Proceedings of the 1996 ACM conference on Computer supported cooperative work* (pp. 67-76). ACM.

Hasselqvist, H., & Eriksson, E. (2018). Designing for Diverse Stakeholder Engagement in Resource-Intensive Practices. *NordiCHI'18, September 29-October 3, 2018.* Oslo, Norway: ACM. doi:https://doi.org/10.1145/3240167.3240193

Hawley, M. (2009). Laddering: A Research Interview Technique for Uncovering Core Values. *UX matters*. Retrieved from https://www.uxmatters.com/mt/archives/2009/07/laddering-a-research-interview-technique-for-uncovering-core-values.php

Heinonen, J., Jalas, M., Juntunen, J. K., Ala-Mantila, S., & Junnila, S. (2013). Situated lifestyles: I. How lifestyles change along with the level of urbanization and what the greenhouse gas implications are—a study of Finland. *Environ. Res. Lett., 8*(2), 1-13.

Heitlinger, S., Bryan-Kinns, N., & Jefferies, J. (2013). Sustainable HCI for Grassroots Urban Food-Growing Communities. *Proceedings of the 25th Australian Computer-Human Interaction Conference: Augmentation, Application, Innovation, Collaboration (Adelaide, Australia) (OzCHI '13)* (pp. 255–264). ACM.

Heldeweg, M. A., & Séverine Saintier, S. (2020). Renewable energy communities as 'socio-legal institutions': A normative frame for energy decentralization. *Renewable and Sustainable Energy Reviews, 119*, 109518. doi:10.1016/j.rser.2019.109518

Holl, S., Pallasmaa, J., & Pérez-Gómez, A. (1994). Questions of Perception, Phenomenology of Architecture. *Architecture and Urbanism* (Special issue 94:07).

Hornecker, E., & Buur, J. (2006). Getting a grip on tangible interaction: a framework on physical space and social interaction. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '06)* (pp. 437-446). ACM.

Howes, D. (2003). *Sensual Relations: Engaging the Senses in Culture and Social Theory.* Michigan University Press.

Howes, D. (2005). Architecture of the Senses. *Sense of the City Exhibition Catalogue*. Montreal: Canadian Centre for Architecture.

Huddart-Kennedy, E., Beckley, T., McFarlane, B., & Nadeau, S. (2009). Why we don't walk the talk: understanding the environmental values/behaviour gap in Canada. *Human Ecology Review, 16*, 151-160.

Huizenga, J., Piccolo, L. S., Wippoo, M., Meili, C., & Bullen, A. (2015). Shedding Lights on Human Values: An Approach to Engage Families with Energy Conservation. In B. S. Abascal J., *Human-Computer Interaction – INTERACT 2015. INTERACT 2015. Lecture Notes in Computer Science, vol 9296.* (pp. 210-218). Springer. doi:https://doi.org/10.1007/978-3-319-22701-6_15

Hyysalo, S. (2021). Introduction. In S. &. Hyysalo, *Citizen Activities in Energy Transition: User Innovation, New Communities, and the Shaping of a Sustainable Future* (pp. 1-14). Routledge.

Håkansson, M., & Sengers, P. (2013). Beyond Being Green: Simple Living Families and ICT. *CHI 2013, April 27–May 2, 2013,*. France.

IEA. (2019). *Global Energy & CO2 Status Report 2019.* Retrieved from https://www.iea.org/reports/global-energy-co2-status-report-2019

Iivari, N., & Kuutti, K. (2017). Critical Design Research and Information Technology: Searching for Empowering Design. *Proceedings of the 2017 Conference on Designing Interactive Systems (DIS '17)* (pp. 983–993). ACM. doi:doi.org/10.1145/3064663.3064747

Ingeborgrud, L. H., Ryghaug, M., Moe Skjølsvold, T., Foulds, C., Robison, R., & . . . Mourik, R. (2020). Expanding the scope and implications of energy research: A guide to key themes and concepts from the Social Sciences and Humanities. *Energy Research & Social Science, 63*. doi:doi:https://doi.org/10.1016/j.erss.2019.101398

Ingold, T. (2012). Introduction: the perception of the user-producer. In W. G. (Eds), *Design and Anthropology.* Ashgate.

International Energy Agency. (2020). *Energy Technology Perspectives 2020.* Paris: IEA. Retrieved from https://www.iea.org/reports/energy-technology-perspectives-2020

Iversen, O. S., & Leong, T. W. (2012). Values-led Participatory Design - Mediating the Emergence of Values. *NordicCHI'12, October 14-17, 2012, Copenhagen, Denmark* (pp. 468-477). ACM.

Iversen, O. S., Halskov, K., & Leong, T. W. (2010). Rekindling values in participatory design. *Proceedings of the 11th Biennial Participatory Design Conference (PDC '10)* (pp. 91–100). ACM. doi:doi.org/10.1145/1900441.1900455

Iversen, O. S., Halskov, K., & Leong, T. W. (2012). Values-led participatory design. *CoDesign, 8*(2-3), 87-103.

JafariNaimi, N., Nathan, L., & Hargreaves, I. (2015). Values as hypotheses: design, inquiry, and the service of values. *Design issues, 31*(4), 91-104.

Jensen, R., Strengers, Y., Kjeldskov, J., Nicholls, L., & Skov, M. (2018). Designing the Desirable Smart Home: A Study of Household Experiences and Energy Consumption Impacts. *CHI 2018, April 21–26, 2018.* ACM.

Jin, X., Baker, K., Christensen, D., & Isley, S. (2017). Foresee: A user-centric home energy management system for energy efficiency and demand response. *Applied Energy*, 1583-1595. doi:doi.org/10.1016/j.apenergy.2017.08.166.

Jin, X., Baker, K., Christensen, D., & Isley, S. (2017). Foresee: A user-centric home energy management system for energy efficiency and demand response. *Applied Energy*, 1583–1595. doi:10.1016/j.apenergy.2017.08.166

Johansson, M., Gentile, N., & Neij, L. (2021). Energy efficiency behaviour in the built environment—an assessment of current evaluation practices in the Nordic countries. *Energy Efficiency, 14*(27).

Kampman, B., Blommerde, J., & Afman, M. (2016). *The Potential of Energy Citizens in the European Union.* CE Delft.

Kapoor, A., & Picard, R. W. (2005). Multimodal affect recognition in learning environments. *Proceedings of the 13th annual ACM international conference on Multimedia (MULTIMEDIA '05)* (pp. 677-682). ACM. doi:https://doi.org/10.1145/11

Karjalainen, S. (2012). Thermal comfort and gender: a literature review. *Indoor Air, 22*(2), 96-109.

Karlin, B., Ford, R., Sanguinetti, A., Squiers, C., Gannon, J., Rajukumar, M., & Donnelly, K. A. (2015). *Characterization and Potential of Home Energy Management (HEM) Technology.* Pacific Gas and Electric Company.

Kashar, R. (2019). The psychology of socio-technical systems: Professionalism, power, and personality in the electricity sector. *Energy Research & Social Science, 53*, 121-125.

Katzeff, C., & Wangel, J. (2015). Social Practices, Households, and Design in the Smart Grid. In &. B. L. Hilty, *ICT Innovations for Sustainability* (pp. 351-367). Springer International Publishing Switzerland. doi:10.1007/978-3-319-09228-7_

Keates, S. (2015). Design for the Value of Inclusiveness. In V. P. J., *Handbook of Ethics, Values, and Technological Design* (pp. 383-402). Springer.

King, J. (2018). *Energy Impacts of Smart Home Technologies. Report A1801.* ACEE.

Kinnula, M., Iivari, N., Isomursu, M., & Laari-Salmela, S. (2018). 'Worksome but Rewarding'–Stakeholder Perceptions on Value in Collaborative Design Work. *Computer Supported Cooperative Work (CSCW)*, 1-32.

Klaassen, E., & Van der Laan, M. (2019). *Energy and flexibility services for citizens energy communities.* USEF Foundation. Retrieved from https://www.usef.energy/new-white-paper-energy-flexibility-services-for-citizens-energy-communities/

Kotilainen, K., Sommarberg, M., Järventausta, P., & Aalto, A. (2016). Prosumer centric digital energy ecosystem framework. *MEDES'16, November 01-04* (pp. 47-50). Biarriz, France: ACM. doi:doi:http://dx.doi.org/10.1145/3012071.3012080

Kuijer, L., & Bakker, C. (2015). Of chalk and cheese: behaviour change and practice theory in sustainable design. *International Journal of Sustainable Engineering, 8*(3). doi:http://dx.doi.org/10.1080/19397038.2015.1011729

Kujala, S., & Väänänen-Vainio-Mattila, K. (2009). Value of Information Systems and Products: Understanding the Users' Perspective and Values. *J Inf Tech Theory and Application (JITTA), 9*(4), 23–39.

Kuutti, K., & Bannon, L. J. (2014). The Turn to Practice in HCI: Towards a Research Agenda. *CHI 2014, April 26 - May 01 2014, Toronto, ON, Canada* (pp. 3543-3552). ACM.

Käkönen, M.-N. E., & Kaisti, H. (2012). Actors, Interests and Forces Shaping the Energyscape of the Mekong Region. *Forum for Development Studies, 39*(2), 147-158.

Labanca, N., & Bertoldi, P. (2018). Beyond energy efficiency and individual behaviours: policy insights from social practice theories. *Energy Policy, 115*, 494-502.

Lai, A. (1995). Consumer values, product benefits and customer value: a consumption behavior approach. *Advances in Consumer Research Volume, 22*, 381-388.

Le Dantec, C. A., Poole, E. S., & Wyche, S. (2009). Values as lived experience: evolving value sensitive design in support of value discovery. *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 1141-1150). ACM.

Leder Mackley, K., Mitchell, V., Pink, S., Escobar-Tello, M., & Bhamra, T. (2013). Understanding technology in the home: sensory ethnography and HCI. *Mackay, W.E., Brewster, S. and Bødker, S. (eds.) Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Paris, France, 4pp.*

Leitner, M., Wolkerstorfer, P., Sefelin, R., & Tscheligi, M. (2008). Mobile Multimedia: Identifying User Values Using the Means-End Theory. *MobileHCI 2008, September 2–5, 2008.* ACM.

Lennon, B., Dunphy, N., Gaffney, C., Revez, A., Mullally, G., & O'Connor, P. (2019). Citizen or consumer? Reconsidering energy citizenship. *Journal of Environmental Policy & Planning*, 1-14. doi:10.1080/1523908X.2019.1680277

Leong, T. W., & Iversen, O. S. (2015). Values-led Participatory Design as a Pursuit of Meaningful Alternatives. *The Australian Special Interest Group for Computer Human Interaction (OzCHI '15)* (pp. 314 -323). ACM.

Levold, N., & Aune, M. (2003). "Cooking Gender": Hjem, kjønn og teknologi. *Sosiologisk Tidsskrift, 11*(03).

Lewis, S. C. (2011). Energy in the Smart Home. In R. (. Harper, *The Connected Home: The Future of Domestic Life* (pp. 281-300). Springer.

Ligtvoet, A., van de Kaa, G., Fens, T., van Beers, C., Herder, P., & van den Hoven, J. (2015). Value Sensitive Design of Complex Product Systems. In W. M. Janssen M., *Policy Practice and Digital Science. Public Administration and Information Technology* (Vol. 10, pp. 157-176). Cham: Springer. doi:https://doi.org/10.1007/978-3-319-12784-2_8

Lindenberg, S., Steg, L., Milovanovic, M., & Schipper, A. (2018). Moral hypocrisy and the hedonic shift: A goal-framing approach. *Rationality and Society*, 1-7. doi:10.1177/1043463118795719

Liu, Y., Qiu, B., Fan, X., Zhu, H., & Han, B. (2016). Review of Smart Home Energy Management Systems. *Energy Procedia, 104*, 504-508.

Lobaccaro, G., Carlucci, S., & Löfström, E. (2016). A Review of Systems and Technologies for Smart Homes and Smart Grids. *Energies, 9*, 348. doi:10.3390/en9050348

Looms, P. (2011). *Making television accessible.* International Telecommunication Union.

Luck, R. (2016). What Is It About Space That Is Important in Interaction? … Let's Take the World from a Situated Point of View. In H. S. N. Dalton, *Architecture and Interaction* (pp. 37-52). Springer, Cham. doi:https://doi.org/10.1007/978-3-319-30028-3_1

Lund, P., Lindgren, J., Mikkola, J., & Salpakari, J. (2015). Review of energy system flexibility measures to enable high levels of variable renewable electricity. *Renewable and Sustainable Energy Review*, 785-807.

Lynham, J., Nitta, K., Saijo, T., & Tarui, N. (2016). Why does real-time information reduce energy consumption? *Energy Economy, 54*, 173-181.

M. SilbeNathan, L., Knowles, B., Bendor, R., Clear, A., Håkansson, M., Dillahunt, T., & Mankoff, J. (2014, September-October). Next Steps in Sustainable HCI. *INTERACTIONS*, 66-69.

MacGregor, S. (2016, January 5). Go Ask 'Gladys': Why Gender Matters in Energy Consumption Research. Discover Society. *28*. Retrieved from https://discoversociety.org/2016/01/05/go-ask-gladys-why-gender-matters-in-energy-consumption-research/

Mack, B., Tampe-Mai, K., Kouros, J., Roth, F., & Taube, O. D. (2019). Bridging the electricity saving intention-behavior gap: A German field experiment with a smart meter website. *Energy Research & Social Science, 53*, 34-46.

Mackay, H., & Gillespie, G. (1992). Extending the social shaping of technology approach: ideology and appropriation. *Social Studies of Science, 22*, 685-716.

Maibach, E., Leiserowitz, A., Roser-Renouf, C., Akerlof, K., & Nisbet, M. (2010). Saving energy is a value shared by all americans: Results of a global warming audience segmentation analysis. In K. E.-M. (Ed.), *Human resources for climate solutions: Energy smart behaviors, people centered policies, and public engagement* (pp. 8-14). American Council for an Energy-Efficient Economy.

Manders-Huits, N. (2011). What values in design? The challenge of incorporating moral values into design. *Science and Engineering Ethics, 17*, 271–287.

Mankoff, J., Blevis, E., Borning, A., Friedman, B., Fussell, S., Hasbrouck, J., . . . Sengers, P. (2007). Environmental sustainability and interaction. *CHI '07 Extended Abstracts on Human Factors in Computing Systems, April 28-May 03.* ACM.

Maréchal, K., & Holzemer, L. (n.d.). Unravelling the 'ingredients' of energy consumption: Exploring home-related practices in belgium. *Energy Research & Social Science, 39*, 19-28. doi:doi://doi.org/10.1016/j.erss.2017.10.025

Marikyan, D., Papagiannidis, S., & Alamanos, E. (2019). A systematic review of the smart home literature: A user perspective. *Technol. Forecasting Social Change, 138*, 139–154.

Matschoss, K., Repo, P., & Timonen, P. (2019). Embedding European citizen visions in sustainability transition: Comparative analysis across 30 European countries. *Futures, 112*. doi:doi:https://doi.org/10.1016/j.futures.2019.102437

McIlvennie, C., Sanguinetti, A., & Pritoni, M. (2020). Of impacts, agents, and functions: An interdisciplinary meta-review of smart home energy management systems research. *Energy Research & Social Science, 68*, 101555. doi:doi:https://doi.org/10.1016/j.erss.

Mennicken, S., & Huang, E. M. (2012). Hacking the Natural Habitat: An In-the-Wild Study of Smart Homes, Their Development, and the People Who Live in Them. In L. P. Kay J., *Pervasive Computing. Lecture Notes in Computer Science* (pp. 143-160). Springer.

Merleau-Ponty, M. (1964). *The Primacy of perception and other essays on phenomenological psychology, the philosophy of art, history and politics.* Northwestern University Press.

Mesthene, E. G. (1997). The Role of Technology in Society. In K. S.-F. (Eds.), *Technology and Values* (pp. 71-85). Rowman & Littlefield Publishers.

Metaxa-Kakavouli, D., Wang, K., Landay, J. A., & Hancock, J. (2018). Gender-Inclusive Design: Sense of Belonging and Bias in Web Interfaces. *Proceedings of CHI '18: Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems.* ACM.

Miller, J. K., Friedman, B., Jancke, G., & Gill, B. (2007). Value tensions in design: the value sensitive design, development, and appropriation of a corporation's groupware system. *Proc. Supporting group work*, 281-290.

Mills, B., & Schleich, J. (2012). Residential energy-efficient technology adoption, energy conservation, knowledge, and attitudes: An analysis of European countries. *Energy Policy, 49*, 616-628.

Mitchell, V., Mackley, K. L., Pink, S., Escobar-Tello, C., Wilson, G. T., & Bhamra, T. (2014). Situating Digital Interventions: Mixed Methods for HCI Research in the Home. *Interacting with Computers, 27*(1), 3-12.

Mo, L., He, Y., Liu, Y., Zhao, J., Tang, S.-J., Li, X.-Y., & Dai, G. (2009). (2009). "Canopy closure estimates with GreenOrbs: sustainable sensing in the forest. *Proceedings of the 7th ACM Conference on Embedded Networked Sensor Systems (SenSys '09).* ACM.

Mok, L., & Hyysalo, S. (2018). Designing for energy transition through Value Sensitive Design. *Design Studies, 54*, 162-183. doi:https://doi.org/10.1016/j.destud.2017.09.006

Morley, J. (2017). Sustainability within HCI within society . In L. P. Mike Hazas, *Digital Technology and Sustainability: Engaging the Paradox* (pp. 63-66). Routledge.

Moussaoui, L. S., & Desrichard, O. (2016). Act local but don't think too global: The impact of ecological goal level on behavior. *The Journal of Social Psychology, 156*(5), 536-552.

Nathan, L. P., Friedman, B., Kasnja, P., Kane, S. K., & Miller, J. K. (2008). Envisioning Systemic Effects on Persons and Society Throughout Interactive System Design. *DIS 2008* (pp. 1-10). ACM.

Neustaedter, C., Bartram, L., & Mah, A. (2013). Everyday Activities and Energy Consumption: How Families Understand the Relationship. *CHI 2013: Changing perspectives.* ACM.

Nurkka, P., & Kujala, S. (2008). What matters - User Values or Value to the End User? *CHI 2008, April 5 – April 10, 2008.* ACM.

NYSERDA. (2017). *Home Energy Management System Savings Validation Pilot.* NYSERDA (New York State Energy Research and Development Authority). Retrieved from https://www.nyserda.ny.gov/-/media/Files/Publications/Energy-Analysis/Home-Energy-Management-System-Savings-Validation-Pilot.pdf.

O'Dell, T., & Willim, R. (2013). Transcription and the Senses: Cultural Analysis When It Entails More Than Words. *Senses and society, 8*(3), 314-334.

Obrist, M., & Fuchs, C. (2010). Broadening the View: Human-Computer Interaction & Critical Theory. *Proceedings of CHI 2010, April 10 – 15, 2009, Atlanta, GA, USA.* ACM.

OECD. (2020). *Gender and environmental statistics: Exploring available data and developing new evidence.* Paris: OECD Publishing.

Ortiz, M. A., Kurvers, S. R., & Bluyssen, P. M. (2017). A review of comfort, health, and energy use: Understanding daily energy use and wellbeing for the development of a new approach to study comfort. *Energy and Buildings, 15*, 323-335.

Paetz, A. D., Dütschke, E., & Fichtner, W. (2012). Smart Homes as a Means to Sustainable Energy Consumption: A Study of Consumer Perceptions. *Journal of Consumer Policy, 35*, 23-41.

Pahkala, T., Uimonen, H., & Väre, V. (2018). *Joustava ja asiakaskeskeinen sähköjärjestelmä; Älyverkkotyöryhmän loppuraportti.* TEM. doi:https://urn.fi/URN:ISBN:978-952-327-346-7

Pallasmaa, J. (2005). *The Eyes of The Skin- Architecture and the Senses.* Etobicoke, ON: John Wiley & Sons.

Palm, J., & Darby, S. J. (2014). The meanings of practices for energy consumption - A comparison of homes and workplaces. *Science and Technology Studies, 72*(2), 72-92.

Parag, Y., & Butbul, G. (2018). Flexiwatts and seamless technology: Public perceptions of demand flexibiity through smart home technology. *Energy Research & Social Science*, 177-191.

Peacock, A., Chaney, J., Goldbach, K., Walker, G., Tuohy, P., Santonja Climent, S., . . . Owens, E. (2017). Co-designing the next generation of home energy management systems with lead-users. *Applied Ergonomics, 60*, 194-206.

Pearl-Martinez, R., & Stephens, J. C. (2016). Toward a gender diverse workforce in the renewable energy transition. *Sustainability: Science, Practice and Policy, 12*(1), 8-15. doi:doi:10.1080/15487733.2016.11908149

Pellicer-Sifres, V. (2020). Transformative energy transition from the bottom-up: Exploring the contribution of grassroots innovations in the spanish context. *Null, 33*(2), 124-139. doi:doi:10.1080/13511610.2019.1705146

Pereira, R., Baranauskas, M. C., & Liu, K. (2015). The value of values for HCI: An informed discussion beyond philosophy. *Proceedings of the 14th Brazilian Symposium on Human Factors in Computing Systems.*

Pereira, R., Baranauskas, M. C., & Liu, K. (2018). An Essay on Human Values in HCI. *SBC Journal on Interactive Systems, 9*(1).

Perlaviciute, G., Steg, L., Contzen, N., Roeser, S., & Huijts, N. (2018). Emotional Responses to Energy Projects: Insights for Responsible Decision Making in a Sustainable Energy Transition. *Sustainability*, 2526.

Petkov, P., Köbler, F., Foth, M., Medland, R., & Krcmar, H. (2011). Engaging energy saving through motivation-specific social comparison. *CHI EA '11* (pp. 1945–1950). ACM.

Pettersen, I. N. (2015). Towards practice-oriented design for sustainability: the compatibility with selected design fields. *International journal of Sustainable Engineering, 8*(3), 206-218. doi:https://doi.org/10.1080/19397038.2014.1001468

Pierce, J., & Paulos, E. (2012). Beyond Energy Monitors: Interaction, Energy, and Emerging Energy Systems. *CHI 2012, May 5–10, 2012* (pp. 665-674). ACM.

Pierce, J., Strengers, Y., Sengers, P., & Bødker, S. (2013). Introduction to the special issue on practice-oriented approaches to sustainable HC. *ACM Trans. Comput.-Hum. Interact, 20*(4), Article 20. doi:DOI: http://dx.doi.org/10.1145/2494260

Pink, S. (2012). Ethnography of the Invisible: Energy in the Multisensory Home. *Ethnologia Europaea: Journal of European Ethnology*, 117-128.

Pink, S. (2013). Engaging the Senses in Ethnographic Practice. *The Senses and the Society, 8*(3), 261-267. doi:10.2752/174589313X13712175020433

Pink, S. (2015). *Doing sensory ethnography, 2nd edition.* Sage.

Pink, S., & Leder Makley, K. (2014). Flow and intervention in everyday life. In C. M. Yolande Strengers, *Social Practices, Intervention and Sustainability: Beyond behaviour change* (pp. 163-178). Routledge. doi:https://doi.org/10.4324/9781315816494

Pink, S., Leder Mackley, K., Mitchell, V., Hanratty, M., Escobar-Tello, C., Bhamra, T., & Morosanu, R. (2013). Applying the lens of sensory ethnography to sustainable HCI. *ACM Transactions on Computer-Human Interaction, 20*(4), 22. doi:doi:http://dx.doi.org/10.1145/2494261

Pink, S., Strengers, Y., Fernandez, M., & Sabiescu, A. (2016). Understanding energy futures through everyday life observation following an ethnographic approach. *41st IAHS WORLD CONGRESS: Sustainability and Innovation for the Future.*

Poier, S. (2021). Towards a psychology of solar energy: Analyzing the effects of the Big Five personality traits on household solar energy adoption in Germany. *Energy Research & Social Science, 77*, 102087. doi:doi:https://doi.org/10.1016/j.erss.2021.102087.

Powells, G., & Fell, M. J. (2019). Flexibility capital and flexibility justice in smart energy systems. *Energy Research & Social Science, 54*, 56-59.

Preist, C. (2017). Sustainable HCI: From individual to system. In L. P. Mike Hazas, *Digital Technology and Sustainability: Engaging the Paradox* (pp. 61-62). Routledge.

Public Interest Research Centre. (2011). P. I. R. Centre. The common cause handbook, 2011.

Pueyo, A., & Maestre, M. (2019). Linking energy access, gender and poverty: A review of the literature on productive uses of energy. *Energy Research & Social Science, 53*, 170-181.

Ram, S., & Jung, H.-S. (1991). "Forced" adoption of innovations in organizations: Consequences and implications. *Journal of Product Innovation Management, 8*(3), 117-126.

Rasheed, M., Javaid, N., Ahmad, A., Jamil, M., Khan, Z., Qasim, U., & Alrajeh, N. (2016). Energy Optimization in Smart Homes Using Customer Preference and Dynamic Pricing. *Energies, 9*(593). doi:https://doi.org/10.3390/en9080593

Rathnayaka, A., Potdar, V., Dillon, T., Hussain, O., & Chang, E. (2014). A Methodology to Find Influential Prosumers in Prosumer Community Groups. *IEEE Trans. Ind. Inform., 10*, 706–713.

Reckwitz, A. (2002). Toward a Theory of Social Practices: A Development in cultural Theorizing. *European Journal of Social Theory, 5*(2), 243-263.

Renström, S. (2019). Supporting diverse roles for people in smart energy systems. *Energy Research & Social Science, 53*, 98-109.

Reynolds, T., & Gutman, J. (1998). Laddering theory, method, analysis, and interpretation. *Journal of Advertising Research, 28*(1), 11-31.

Roberts, S., & Baker, W. (2003). *Towards effective energy information: Improving consumer feedback on energy consumption.* Centre for Sustainable Energy .

Rodden, T. A., Fischer, J. E., Pantidi, N., Bachour, K., & Moran, S. (2013). At home with agents: exploring attitudes towards future smart energy infrastructures. *CHI '13* (pp. 1173–1182). ACM.

Rode, J. A. (2011). A Theoretical Agenda for Feminist HCI. *Interacting with Computers, 23*(5), 393–400.

Rohracher, H. (2003). The Role of Users in the Social Shaping of Environmental Technologies. *Innovation, 16*(2), 177-192.

Rokeach, M. (1973). *The nature of human values.* Free Press.

Rose, D. A. (2001). Reconceptualizing the user(s) of – and in – technological innovation: the case of vaccines in the United States. In R. e. Coombs, *Technology and the Market. Demand, Users and Innovation* (pp. 68-88). Edward Elgar.

Ruokamo, E., Kopsakangas-Savolainen, M., Meriläinen, T., & Svento, R. (2019). Towards flexible energy demand – Preferences for dynamic contracts, services and emissions reductions. *Energy Economics, 84*.

Rybczynski, W. (1986 / 2014). Domesticity. In J. J. Gieseking, S. Low, S. Saegert, W. Mangold, & C. (. Katz, *The People, Place, & Space Reader* (pp. 150-155). Routledge.

Räty, R., & Carlsson-Kanyama, A. (2010). Energy consumption by gender in some European countries. *Energy Policy, 38*(1), 646-649.

Sanchez Guzman, S., Giffinger, R., Parra-Agudelo, L., & Bogadi, A. (2020). Open Participatory Design and Digital Tools for Inclusive & Resilient Development: Full-Day Workshop. *Proceedings of the 16th Participatory Design Conference 2020 - Participation(s) Otherwise. 2*, pp. 185–187. ACM. doi:doi.org/10.1145/3384772.3385164

Sandström, G. (2007). *Smart Homes & User Values.* Open House International Association.

Sanguinetti, A., Dombrovski, K., & Sikand, S. (2018). Information, timing, and display: A design-behavior framework for improving the effectiveness of eco-feedback. *Energy Research & Social Science, 39*, 55-68. doi:doi.org/10.1016/j.erss.2017.10.001.

Sanguinetti, A., Karlin, B., Ford, R., Salmon, K., & Dombrovski, K. (2018). What's energy management got to do with it? Exploring the role of energy management in the smart home adoption process. *Energy Efficiency, 11*, 1897-1911.

Sauer, J., Schmeink, C., & Wastell, D. (2007). Feedback quality and environmentally friendly use of domestic central heating systems. *Ergonomics, 50*(6), 795-813.

Schatzki, T. (1996). *Social Practices: A Wittgensteinian Approach to Human Activity and the Social.* Cambridge University Press.

Schatzki, T. (2015). Practices, governance and sustainability. In Y. a. Strengers, *Social Practices, Intervention and Sustainability - Beyond Behaviour Change.* Routledge.

Schatzki, T., & Knorr-Cetina, K. (2001). *The Practice Turn in Contemporary Theory.* Routledge.

Schick, L., & Gad, C. (2015). Flexible and inflexible energy engagements - A study of the Danish Smart Grid Strategy. *Energy Research & Social Science, 9*, 51-59. doi:https://doi.org/10.1016/j.erss.2015.08.013

Schot, J., Kanger, L., & Verbong, G. (2016). The roles of users in shaping transitions to new energy systems. *Nature Energy, 1*(5), 1-7.

Schwartz, S. H. (1992). Universals in the content and structure of values: Theoretical Advances and Empirical Tests in 20 Countries. In M. Z. (ed.), *Advances in experimental social psychology* (Vol. 25). Academic.

Schwartz, T., Denef, S., Stevens, G., Ramirez, L., & Wulf, V. (2013). Cultivating energy literacy: results from a longitudinal living lab study of a home energy management system. *CHI '13* (pp. 1193–1202). ACM.

Sefyrin, J. (2010). Entanglements of participation, gender, power and knowledge in IT design. *Proceedings of the 11th Biennial Participatory Design Conference (PDC '10)* (pp. 111–120). ACM.

Sellen, A., Rogers, Y., Harper, R., & Rodden, T. (2009). Reflecting Human Values in the Digital Age. *Commun ACM, 52*(3), 58–66.

Seyfang, G., J., P. J., & Smith, A. (2013). A thousand flowers blooming? An examination of community energy in the UK. *Energy Policy, 61*, 977-989.

Shakeri, M., & Amin, N. (2018). Transformation of Conventional Houses to Smart Homes by Adopting Demand Response Program in Smart Grid. In E. W. Majid Nayeripour, *Smart Microgrids.* IntechOpen.

Shakeri, M., Shayestegan, M., Abunima, H., Salim Reza, S., Akhtaruzzaman, M., Alamoud, A., . . . Amin, N. (2017). An intelligent system architecture in home energy management systems (HEMS) for efficient demand response in smart grid. *Energy and Buildings, 138*, 154–164.

Shove, E. (2017). Energy and Social Practice: From Abstractions to Dynamic Processes. In L. N. (eds), *Complex Systems and Social Practices in Energy Transitions. Green Energy and Technology.* Springer. doi:doi.org/10.1007/978-3-319-33753-1_9

Shove, E., & Walker, G. (2014). What Is Energy For? Social Practice and Energy Demand. *Theory, Culture & Society, 31*(7), 41-58.

Shove, E., Pantzar, M., & Watson, M. .. (2012). *The dynamics of social practice: Everyday life and how it changes.* Sage. doi:10.4135/9781446250655

Siano, P. (2014). Demand response and smart grids. *Renewable and Sustainable Energy Reviews, 30*, 461-478.

Slater, M., Usoh, M., & Steed, A. (1995). Taking steps: the influence of a walking technique on presence in virtual reality. *ACM Transactions of Computer-Human Interaction, 2*(3), 201-219. doi:http://dx.doi.org/10.1145/210079.210084

Sovacool, B. K. (2014). What are we doing here? Analyzing fifteen years of energy scholarship and proposing a social science research agenda. *Energy Research & Social Science, 1*, 1-29.

Sovacool, B. K., & Furszyfer Del Rio, D. D. (2020). Smart home technologies in Europe: A critical review of concepts, benefits, risks and policies. *Renewable and Sustainable Energy Reviews, 120*, 109663.

Sovacool, B. K., Kester, J., Noel, L., & Zarazua de Rubens, G. (2019). Are electric vehicles masculinized? Gender, identity, and environmental values in Nordic transport practices and vehicle-to-grid (V2G) preferences. *Transportation Research Part D: Transport and Environment,, 72*, 187-202. doi:https://doi.org/10.1016/j.trd.2019.04.013

Spigel, L. (2005). Designing the Smart House: Posthuman Domesticity and Conspicuous Production. *European Journal of Cultural Studies, 8*(4).

Standal, K., Talevi, M., & Westskog, H. (2020). Engaging men and women in energy production in Norway and the United Kingdom: The significance of social practices and gender relations. *Energy Research & Social Science, 60*, 101338. doi:https://doi.org/10.1016/j.ers

Steg, L., Perlaviciute, G., & van der Werff, E. (2015, June 17). Understanding the human dimensions of a sustainable energy transition. *Frontiers in Psychology, 6*, Article number 805. doi:10.3389/fpsyg.2015.00805

Strauss, S., Rupp, S., & Love, T. (2013). *Cultures of Energy: Power, Practices, Technologies.* Left Coast Press.

Strengers, Y. (2012). Peak electricity demand and social practice theories: Reframing the role of change agents in the energy sector. *Energy Policy, 44*, 226-234.

Strengers, Y. (2013). *Smart Energy Technologies in Everyday Life: Smart Utopia?* Palgrave Macmillan.

Strengers, Y., & Kennedy, J. (2020). *The Smart Wife : Why Siri, Alexa, and Other Smart Home Devices Need a Feminist Reboot.* The MIT Press.

Stumpf, S., Peters, A., Bardzell, S., Burnett, M., Busse, D., Cauchard, J., & Churchill, E. (2020). Gender-Inclusive HCI Research and Design: A Conceptual Review. *Foundations and Trends in Human–Computer Interaction, 13*(1), 1-69.

Sugarman, V. &. (2015). Designing Persuasive Technology to Manage Peak Electricity Demand in Ontario Homes. *CHI 2015, Crossings.* ACM.

Taebi, B., & Kloosterman, J. (2014). Design for values in nuclear technology. In P. V. J. Van den Hoven, *Handbook of ethics, values, and technological design: Sources, Theory, Values and Application Domains.* Springer.

Thévenot, L. (2001). Pragmatic regimes governing the engagement with the world. In K.-C. K. Schatzki T, *The practice turn incontemporary theory* (pp. 56–73). London: Routledge.

Tilastokeskus. (2018). *Consumption of energy in living and housing in 2010-2017.* Helsinki: Tilastokeskus. Retrieved from http://www.stat.fi/til/asen/2017/asen_2017_2018-11-22_tau_001_fi.html

Tilastokeskus and LUKE. (2018). *Pientalojen polttopuun käyttö 2016/2017.* Helsinki: LUKE. Retrieved from http://stat.luke.fi/pientalojen-polttopuun-kaytto.

Tjørring, L. (2016). We forgot half of the population! The significance of gender in Danish energy renovation projects. *Energy Research & Social Science, 22*, 115-124. doi:https://doi.org/10.1016/j.erss.2016.08.008.

Tsai, W.-C., Chen, L.-L., & Chuang, Y. (2015). Balancing Between Conflicting Values for Designing Subjective Well-Beings for the Digital Home. *Proceedings of APCHIUX 2015.* Melbourne, VIC, Australia.

Ueno, T., Inada, R., Saeki, O., & Tsuji, K. (2006). Effectiveness of an energy-consumption information system for residential buildings. *Applied Energy*, 868–883. doi:http://dx.doi.org/10.1016/j.apenergy.2005.09.004

Umbrello, S. (2018). The moral psychology of value sensitive design:the methodological issues of moral intuitions for responsible innovation. *Journal of Responsible Innovation, 5*(2), 186-200. doi:10.1080/23299460.2018.1457401

UNESCO and EQUALS Skills Coalition. (2019). *I'd Blush If I Could: Closing Gender Divides in Digital Skills through Education.* UNESCO.

United Nations Development Programme. (2012). *Gender and Energy.* Retrieved from https://www.undp.org/content/dam/undp/library/gender/Gender%20and%20Environment/PB3_Africa_Gender-and-Energy.pdf

United Nations sustainable Development Group. (2021). *Universal Values Principle Three: Gender Equality and Women's Empowerment.* Retrieved from https://unsdg.un.org/2030-agenda/universal-values/gender-equality-and-womens-empowerment

Valtonen, A., Markuksela, V., & Moisander, J. (2010). Doing sensory ethnography in consumer research. *International Journal of Consumer Studies, 34*, 375-380.

Van De Poel, I. (2009). Values in engineering design. In e. A. Meijer, *Philosophy of technology and engineering sciences* (pp. 973–1006). Elsevier.

van den Broek, K., Bolderdijk, J. W., & Steg, L. (2017). Individual differences in values determine the relative persuasiveness of biospheric, economic and combined appeals. *J Environ Psychol, 53*, 145-156.

Van den Hoven, J., Vermaas, P. E., & Van de Poel, I. (2015). Design for values: Introduction. In P. E. Jeroen van den Hoven, *Handbook of Ethics, Values and Technological design* (pp. 1-7). Springer Science+Business Media.

Van Deth, J. W., & Scarbrough, E. (1995). *The Impact of Values.* OUP.

Van Summeren, L. F., Wieczorek, A. J., & Verbong, G. P. (2021). The merits of becoming smart: How Flemish and Dutch energy communities mobilise digital technology to enhance their agency in the energy transition. *Energy Research & Social Science*, 102160. doi:https://doi.org/10.1016/j.erss.2021.102160.

van Summeren, L. F., Wieczorek, A. J., Bombaerts, G. J., & Verbong, G. P. (2020). Community energy meets smart grids: Reviewing goals, structure, and roles in Virtual Power Plants in Ireland, Belgium and the Netherlands. *Energy Research & Social Science, 63*. doi:https://doi.org/10.1016/j.erss.2019.101415

Venkatesh, V., & Bala, H. (2008). Technology acceptance model 3 and a research agenda on interventions. *Decision Sciences, 39*(2), 273-315.

Venkatesh, V., & Davis, F. (2000). A theoretical extension of the technology acceptance model: four longitudinal field studies. *Management Science, 46*(2), 186-204.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User Acceptance of Information Technology: Toward a Unified View. *MIS Quarterly, 27*(3), 425–478.

Verkade, N., & Höffken, J. (2019). Collective Energy Practices: a practice-based approac to civic energy communities and the energy system. *Sustainability, 11*. doi:https://doi.org/10.3390/su11113230

Vermaas, P., Hekkert, P., Manders-Huits, N., & Tromp, N. (2015). Design Methods in Design for Values. In V. P. van den Hoven J., *Handbook of Ethics, Values, and Technological Design.* Springer. doi:doi.org/10.1007/978-94-007-6970-0_10

Walker, G. (2013). Inequality, sustainability and capability: Locating justice in social practice. In E. a. Shove, *Sustainable Practices: Social theory and climate change* (pp. 181-196). Routledge.

Wallenborg, G., & Wilhite, H. (2014). Rethinking embodied knowledge and household consumption. *Energy Research & Social Science, 1*, 56-64. doi:http://dx.doi.org/10.1016/j.erss.2014.03.009

Werff, E. v., & Steg, L. 2. (2016). The psychology of participation and interest in smart energy systems: Comparing the value-belief-norm theory and the value-identity-personal norm model. *Energy Research & Social Science, 22*, 107-114.

West, C., & Zimmerman, D. H. (1987). Doing Gender. *Gender & Society, 1*(2), 125-151. doi:10.1177/0891243287001002002.

Wilson, C., Hargreaves, T., & Hauxwell-Baldwin, R. (2015). Smart homes and their users: a systematic analysis and key challenges. *Pers Ubiquit Comput, 19*(2), 463–476.

Wilson, C., Hargreaves, T., & Hauxwell-Baldwin, R. (2017). Benefits and risks of smart home technologies. *Energy Policy, 103*, 72-83.

Winter, E., Forshaw, S., & Ferrario, M. A. (2018). Measuring Human Values in Software Engineering. *ESEM '18, October 11–12, 2018.* Oulu, Finland: ACM.

Wood, G., Day, R., Creamer, E., van der Horst, D., Hussain, A., Liu, S., . . . Brown, V. (2019). Sensors, sense-making and sensitivities: UK household experiences with a feedback display on energy consumption and indoor environmental conditions. *Energy Research & Social Science, 55*, 93-105. doi:doi.org/10.1016/j.erss.2019.04.013.

Yetim, F. (2011). Bringing discourse ethics to value sensitive design: pathways to toward a deliberative future. *AIS Trans Hum Comp Interact, 3*(2), 133–155.

Yildiz, Ö., Rommel, J., Debor, S., Holstenkamp, L., Mey, F., Müller, J. R., Radtke, J. & Rognli, J. (2015). Renewable energy cooperatives as gatekeepers or facilitators? Recent developments in Germany and a multidisciplinary research agenda. *Energy Research & Social Science, 7*, 55-65. doi:doi:http://dx.doi.org/10.1016/j.erss.2015.02.005

Yoo, Y. (2010). Computing in Everyday Life: A Call for Research on Experiential Computing. *MIS Quarterly, 34*(2), 213-231.

Yousefi, M., Hajizadeh, A., Soltani, M. N., Hredzak, B., & Kianpoor, N. (2020). Profit assessment of home energy management system for buildings with A-G energy labels. *Applied Energy*, 115618. doi:10.1016/j.apenergy.2020.115618

Zaman, B., & Abeele, V. (2010). Laddering with young children in User eXperience evaluations: theoretical groundings and a practical case. *Proceedings of the 9th International Conference on Interaction Design and Children (IDC '10)* (pp. 156-165). ACM. doi:10.1145/1810543.1810561

Zhao, Y., Zhang, X., & Crabtree, J. (2016). Human-computer interaction and user experience in smart home research: A critical analysis. *Issues in Information Systems, 17*(III), 11-19.

Zhou, B., Li, W., Chan, K. W., Cao, Y., Kuang, Y., Liu, X., & Wang, X. (2016). Smart home energy management systems: Concept, configurations, and scheduling strategies. *Renewable and Sustainable Energy Reviews, 61*, 30-40. doi:doi://doi.org/10.1016/j.rser.2016.03.047

Zvingilaiteand, E., & Togeby, M. (2015). *Impact of Feedback about energy consumption.* EA Energy Analyses.

Appendices

Appendix 1. Participating households and their key values

N=new users, E=experienced, or 1-4 years with SHEMS, P=prospective users, who are interested but have not acquired SHEMS yet.

Home	Householders	Value
N1	Technical project manager 46-50 Social worker, 41-45 3 children under 18	Frugality Self-direction, stimulation, autonomy Comfort
N2	Social worker, 31-35 HVAC engineer, 31-35 3 children under 18	Frugality Ecologic sustainability Autonomy
N3	Medical doctor, 31-35 Medical doctor 31-35 2 children under 18	Ecologic sustainability Comfort Security
N4	Work coach, 56-60 School headmaster, 61-65	Ecologic sustainability Frugality Security
N5	Entrepreneur, 41-45 Entrepreneur, 41-45 Student 18-20 3 children under 18	Comfort Frugality Ecologic sustainability
N6	Teacher, retired, 71-75 Teacher, retired, 71-75	Comfort Frugality Security
N7	Entrepreneur, 56-60 Entrepreneur, retired, 56-60	Frugality Comfort Security
N8	Nurse, 50-55 Nurse, 56-60	Comfort, Frugality Security
N9	Nurse, 36-40 Project manager, 50-55 2 children under 18	Frugality Comfort Security
N10	Entrepreneur, retired, 50-55 Entrepreneur, sick-leave, 50-55	Frugality Comfort Ecologic sustainability
N11	Accountant, 60-65 Nurse, 46-50	Frugality Ecologic sustainability Security
P12	Technical product manager, 40-45 Physiotherapist, 40-45	Frugality Self-direction, stimulation

	2 children under 18	Comfort
P13	Civil engineering, 40-45, Nurse, 40-45 4 children under 18	Autonomy Frugality Distinguishing oneself
P14	Teacher, 40-45 Civil engineer, 40-45 3 children under 18	Comfort Autonomy Frugality
P15	Teacher, 60-65 Pre-school teacher, 60-65	Ecology Frugality Security
P16	Project manager, 40-45 Teacher, 40-45 2 children under 18	Frugality Ecologic sustainability Comfort
P17	Sales representative, 62	Self-realization, exploration Frugality Comfort
P18	Finance manager, 35-44, 2 children under 18	Ecologic sustainability Frugality Security
P19	Nurse, engineer 40-45, Student, engineer 40-45 2 children under 18	Frugality, ecologic sustainability Exploration, stimulation Comfort
P20	House wife, 36-44 Mechanic, 36-40 10 children under 18	Frugality Comfort Ecologic sustainability
E21	Telecom technician, 56-60	Comfort Frugality Ecologic sustainability
E22	IT engineer, 51-55 Entrepreneur, 51-55	Comfort Frugality Security
E23	Construction worker, 51-55 Social worker, 51-55	Frugality Comfort Exploration, self-realization
E24	HVAC designer, 56-60 Director, 56-60	Frugality Comfort Autonomy
E25	Project manager, 51-55	Frugality Self-realization, exploration Security
E26	Real estate manager, 56-60 Public officer, 56-60	Frugality Comfort

		Security
E27	Executive director, 56-60 Entrepreneur, 56-60	Stimulation, exploration Frugality Ecologic sustainability
E28	Sales director Sales administrator 2 children under 18	Frugality Comfort Security

Appendix 2. The formula used for weather-corrected electricity consumption.

1. The electricity consumption of heating = total electricity consumption in a winter month − average consumption of electricity in summer months (June, July and August in the two most recent years).
2. The electricity consumption of heating was normalized using the formula below for every winter month, and the reduced summer average was added to obtain the total, normalised consumption of the winter months.
3. The reduction percentage in electricity consumption was calculated using the normalised electricity consumption figures for the winter months before and after the installation of the HEMS.

The weather-corrected electricity consumption in was calculated using heating degree days (HDDs) over the winter months (January - March) for the years 2018 and 2019. The HDDs were provided by the Finnish Meteorological Institute (Finnish Meteorological Institute, 2018-2019).

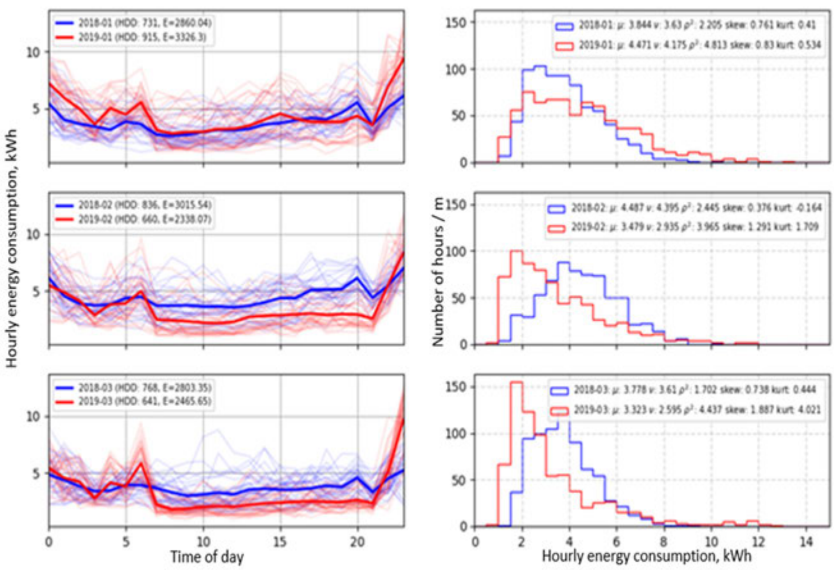
$$Q_{norm} = k_1 \text{ x } \frac{S_{n\ ref\ loc}}{S_{realised\ \ ref\ loc}} \text{ x } (Q_{realised} - \chi) + \chi$$

k_1	Municipality-specific factor (the municipality of Ii = 0.95)
$S_{n\ ref\ loc}$	Normal monthly (1981 - 2010) heating degree days in the reference locality (Oulu)
$S_{realised\ ref\ loc}$	Realised monthly heating degree days in the reference locality (Oulu)
$Q_{realised}$	Realised monthly electricity consumption in a household
χ	Mean of the monthly electricity consumption in the summer months (VI-VIII) in 2017 and 2018.

Appendix 3. Household features, daily and hourly consumption profiles before and after the SHEMS installation

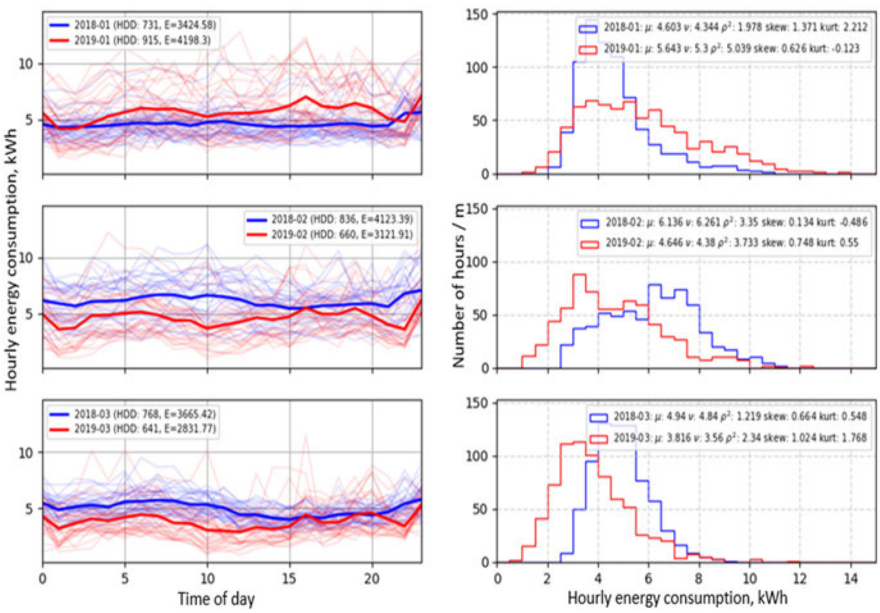
Household 1

<table>
<tr><td rowspan="5">A family of 2 working adults and 3 school-aged children. The house was empty during the office & school hours. The temperature was kept the same as before the SHEMS installation: lower in the daytime and higher from late afternoon till morning. The family expected the SHEMS to bring savings by shifting the consumption to the nighttime.</td><td>Total living space m²</td><td>199</td></tr>
<tr><td>Number of residents</td><td>2+3</td></tr>
<tr><td>SHEMS installed</td><td>8/18</td></tr>
<tr><td>Heating system</td><td>Partly reserving floor heating, wood stove, air heat pump</td></tr>
<tr><td>Key values</td><td>Economic gains, comfort, stimulation</td></tr>
</table>



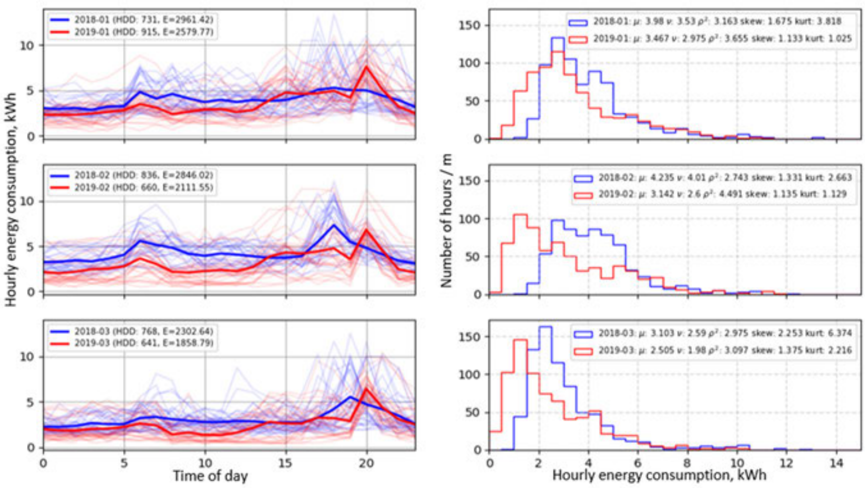
Household 2

A family of 2 adults and 3 children. The temperature was lowered in the daytime, but because of the small child, it was not kept very low when the family was at home. They valued ecological sustainability, thus energy conservation and shifting the time of use, but did not want to compromise comfort of living.	Total living space m^2	200
	Number of residents	2+3
	SHEMS installed	08/18
	Heating system	Direct electric, wood stove, air heat pump
	Key values	Sustainability, security, comfort



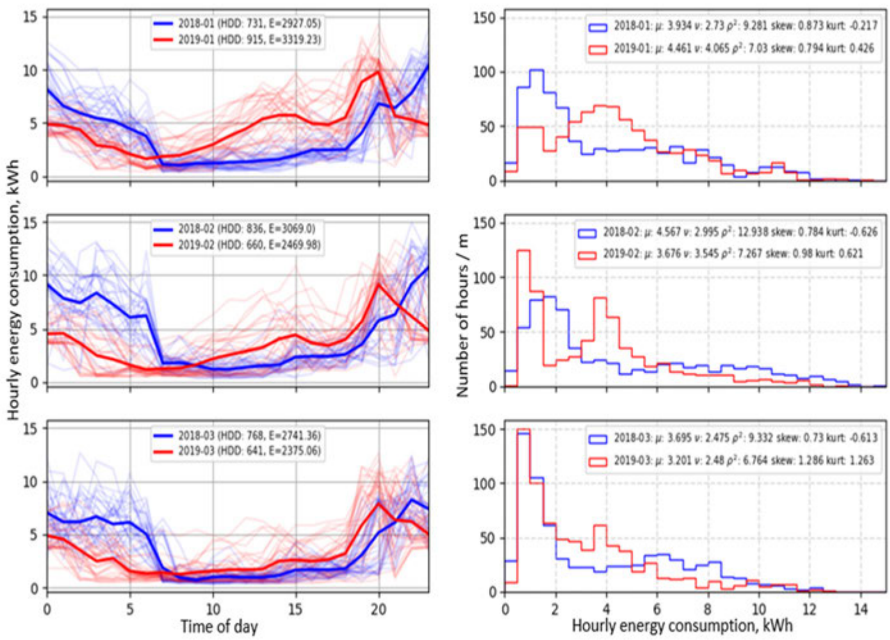
Household 3

Empty-nester couple, both working during the day. The wood stove was used frequently for heating during winter. Temperatures were lowered on weekdays when both the householders were absent. The less-used rooms were kept cooler all the time. The users thought part of their energy conservation was due to their changed energy usage behaviour based on increased attention to energy use, yet, they did not want to compromise much on comfort.	Total living space m^2	136 + 20
	Number of residents	2
	SHEMS installed	09/18
	Heating system	Direct electric, wood stove
	Key values	Sustainability, comfort, security



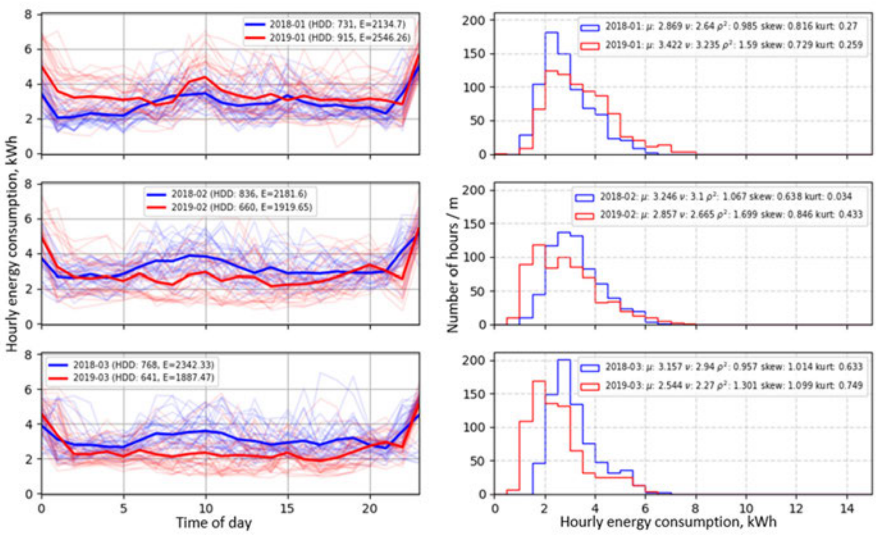
Household 4

Family of 2 adults and 4 school-aged children who did not want to compromise comfort. The temperature was high (23°C in some rooms). They expected to gain economic savings with the SHEMS via the automatic shifting of consumption to night-time, when the price of electricity is lower.	Total living space m^2	140
	Number of residents	3+3
	SHEMS installed	10/18
	Heating system	Direct electric, air heat pump
	Key values	Comfort, economic gains, stimulation



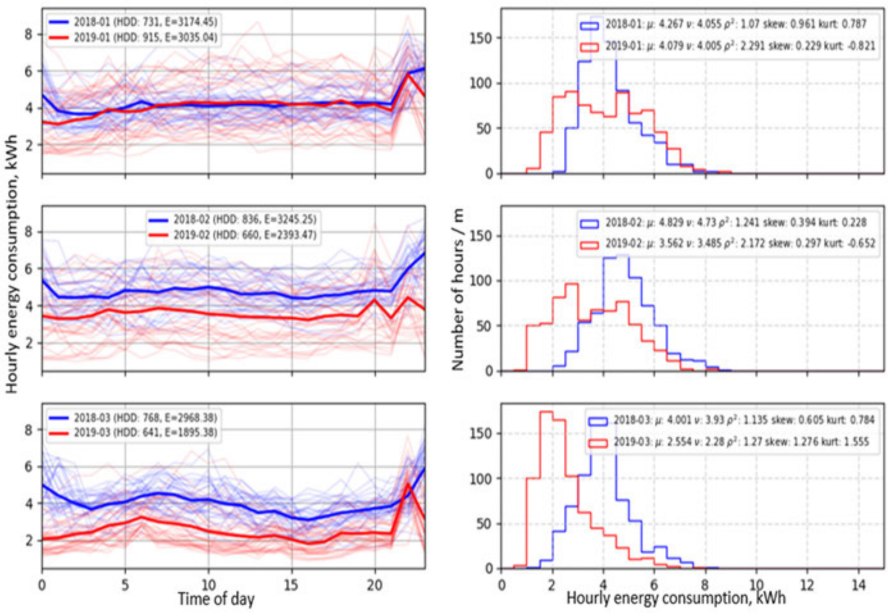
Household 5

Retired couple, who stayed at home all the time. The temperatures were kept the same all the time downstairs, where the couple spent most of the daytime. The female adult was sensitive to cold, so the temperature was kept relatively high. The less-used rooms and upstairs areas were kept cooler. The temperature was increased before going to bed and in the morning.	Total living space m^2	130
	Number of residents	2
	SHEMS installed	10/18
	Heating system	Direct electric, wood stove, air heat pump
	Key values	Economic gains, comfort, security



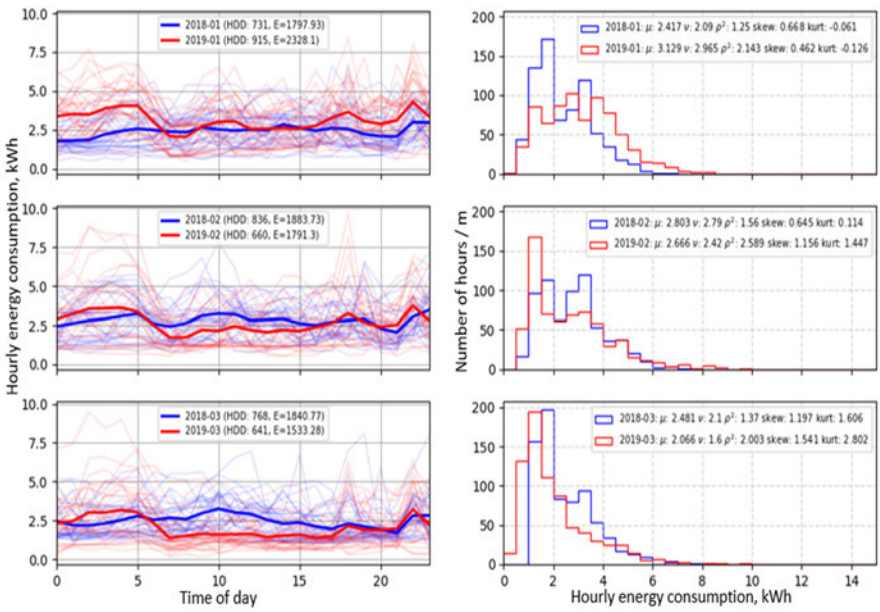
Household 6

Empty-nesters, one of whom one was retired and other worked as an entrepreneur close to home, so the house was occupied during the day. The temperatures were decreased in the less-used rooms and upstairs areas.	Total living space m^2	170
	Number of residents	2
	SHEMS installed	10/18
	Heating system	Direct electric, wood stove, air heat pump
	Key values	Economic gains, comfort, security



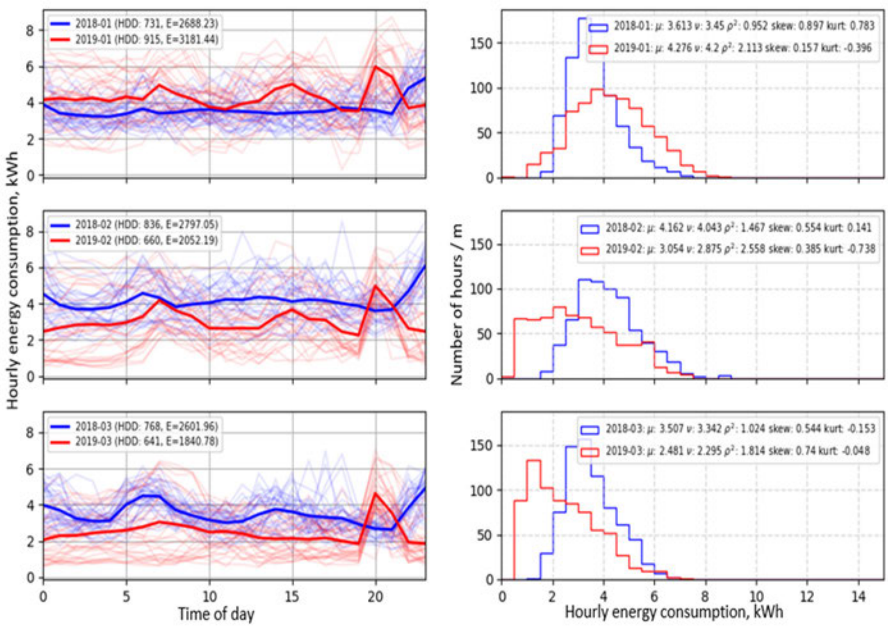
Household 7

Two working adults. The temperatures were decreased during the day when the householders were at work. With the SHEMS, the couple noticed the garage heating consumed energy disproportionally, until they lowered the temperature for the garage. A poorly insulated garage can increase heating costs even with a slight increase in temperature.	Total living space m^2	130+42
	Number of residents	2
	SHEMS installed	10/18
	Heating system	Direct electric, wood stove
	Key values	Comfort, economic gains, security



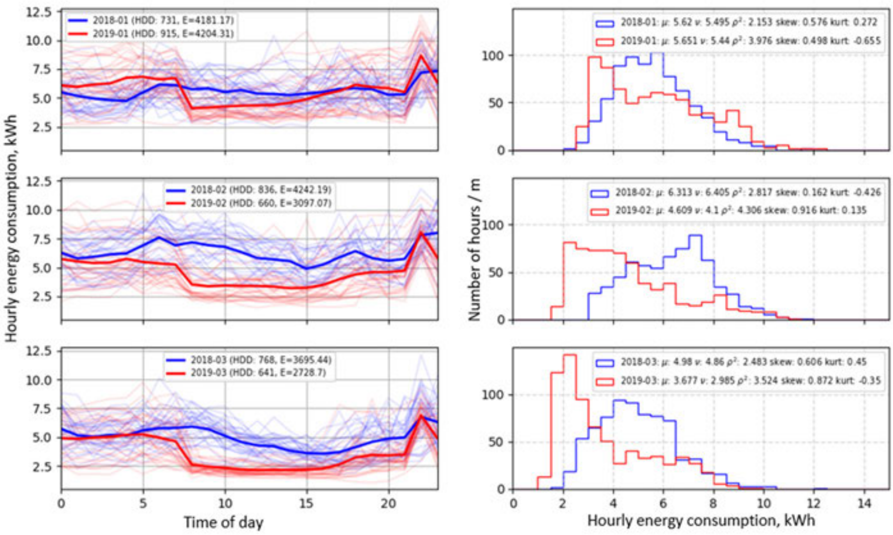
Household 8

Family of 2 parents and 2 small children. The mother stayed at home with the children, and the father worked remotely at home. House was always occupied. Because of the baby, the temperatures were not lowered much in the rooms in which they spent most of their time. The temperatures were lowered in the day-time in the bedrooms.	Total living space m^2	152
	Number of residents	2+2
	SHEMS installed	10/18
	Heating system	Direct electric, wood stove
	Key values	Economic gains, comfort, security



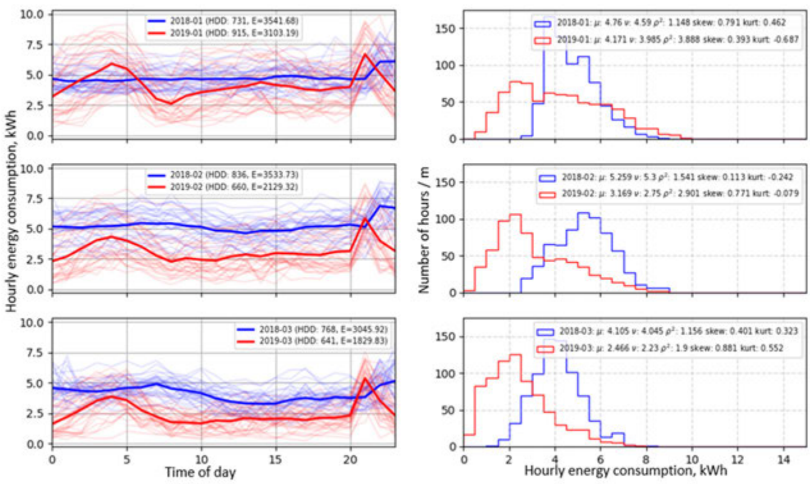
Household 9

Elderly couple, empty-nesters, who lived in a large two-floor house. Since they were both retired, the couple stayed at home during the day. The temperatures were lowered at night, and the wood stove was used regularly for heating to reduce the need for electric heating.	Total living space m^2	200
	Number of residents	2
	SHEMS installed	10/18
	Heating system	Direct electric, wood stove, air heat pump
	Key values	Economic gains, comfort, sustainability



Household 10

2 working adults, one of whom works in shifts. They kept the temperatures low and increased them only for some hours of ’active time’ in the evenings and the mornings. The less-used rooms and bathroom were heated in the mornings.	Total living space m²	120
	Number of residents	2
	SHEMS installed	11/18
	Heating system	Direct electric, partly floor and partly ceiling heating
	Key values	Economic gains, sustainability, security



APPENDIX 4. Participating households and gendered activity in the SHEMS adoption and use study.

N=new users, E=experienced, or 1-4 years with SHEMS, P=prospective users, who are interested but have not acquired SHEMS yet.

HH	Family members	Gender activity in SHEMS interviews and observations and in SHEMS use
New users, who participated sensory ethnography observational interviews before acquisition, during the take-into-use and after 4-6 months of use of the SHEMS		
N1	Technical project manager 46-50, Social worker, 41-45, 3 children under 18	Only man participated in the interviews. He had decided the purchase alone, and he told the wife is not interested in the SHEMS, it is 'his personal project'. He was the only user of the SHEMS in the household.
N2	Social worker (in maternity leave), 31-35, HVAC engineer, 31-35, 3 children under 18	Both woman and man participated in the interviews. The woman was the first to be in contact with project coordinator and express the interest to purchase SHEMS. Both agreed the man will be the main user of SHEMS. After the first 6 months they both had used SHEMS.
N3	Medical doctor, 31-35, Medical doctor 31-35, 2 children under 18	Man was active in the interviews; woman was present but did not participate in the discussion apart from few brief comments. They had discussed and decided the purchase of SHEMS together, but they both assume the man will be the main user. After the first 6 months only man had used SHEMS, and was the only one who knew how to use SHEMS.
N4	Work coach, 56-60, School headmaster, 61-65	Both man and woman participated actively in the interviews. They had decided the purchase together and intended both use the system. After the first 6 months they both had used SHEMS and were both excited about it.
N5	Entrepreneur, 41-45, Entrepreneur, 41-45, Student 18-20, 3 children under 18	Only man participated in the interviews. He had decided the purchase and was going to be the only user of SHEMS. After the first 5 months he was the only user of SHEMS in the family.
N6	Teacher, retired, 71-75, Teacher, retired, 71-75	Both man and woman participated in the interviews, though the man was more active, and the woman did homework on the background. Man had decided the purchase of SHEMS and was going to be the main user of SHEMS. Woman was against the purchase, and she was reluctant to use it. After the first 5 months, only the man had used SHEMS, and the woman still was against it considering it useless and complicating previously simple tasks (e.g., controlling the air heat pump and thermostats).
N7	Entrepreneur, 56-60, Entrepreneur, retired, 56-60	Both man and woman participated in the interviews, though the man sat down with the interviewee, and woman continued housework and commented occasionally. They had decided the purchase together, and both were going to use SHEMS. After the first 6 months, only the man had used SHEMS.
N8	Nurse, 51-55, Nurse, 56-60	Only the woman participated in the interviews. She had decided the purchase together with her husband, but she was going to be the main user of SHEMS. After the first 4 months, only she had used SHEMS.

N9	Nurse, 36-40, Project manager, 51-55, 2 children under 18	Only the man participated in the interviews. The woman was at home but continued to do housework during the interviews. The man had decided the purchase and was going to be the only user of SHEMS. After 5 months only the man had used SHEMS.
N10	Entrepreneur, retired, 51-55, Entrepreneur, sick-leave, 51-55	Only the man participated in the interviews. He had decided the purchase alone and was going to be the only user of SHEMS. After the first 5 months, only he had used SHEMS, and he was the only one who knew how to use SHEMS.
N11	Accountant, 61-65, Nurse, 46-50	Only the man participated in the interviews. He had decided the purchase alone and was going to be the only user of SHEMS. After 4 months only he had used SHEMS, and he was the only one who knew how to use SHEMS.
Potential users, who expressed interest but declined acquisition of SHEMS and participated one interview		
P12	Technical product manager, 41-45, Physiotherapist, 41-45, 2 children under 18	Only the man participated in the interview.
P13	Civil engineering, 41-45, Nurse, 41-45, 4 children under 18	Only the man participated in the interview.
P14	Teacher, 41-45, Civil engineer, 41-45, 3 children under 18	Both the man and the woman participated in the interview.
P15	Teacher, 61-65, Pre-school teacher, 61-65	Only the man participated in the interview.
P16	Project manager, 41-45, Teacher, 41-45, 2 children under 18	Only the man participated in the interview.
P17	Sales representative, 61-65	Only the man participated in the interview.
P18	Finance manager, 36-40, 2 children under 18	Only woman in the interview. (single adult family)
P19	Nurse, engineer 41-45, Student, engineer 41-45, 2 children under 18	Both the man and the woman participated in the interview.
P20	Housewife, 36-40, Mechanic, 36-40, 10 children under 18	Only woman participated in the interview. She was interested in SHEMS because the municipality was a behind the project, which increased her confidence and trust in SHEMS.
Experienced users of SHEMS, 2-4 years of experience, participated one interview and observation of use of SHEMS		
E21	Telecom technician, 56-60	Only the man participated in the interview. Lives alone. Purchase and interest, as well as use only the man (recruited as a test user by a neighbor/friend).
E22	IT engineer, 51-55, Entrepreneur, 51-55	Only the man participated in the interview. Purchase and interest, as well as use only the man (recruited as a test user by a neighbor/friend).
E23	Construction worker, 51-55, Social worker, 51-55	Only the man participated in the interview. Purchase and interest, as well as use only the man (recruited as a test user by a neighbor/friend).

E24	HVAC designer, 56-60, Director, 56-60	Only the man participated in the interview. Purchase and interest, as well as use only the man (recruited as a test user by a neighbor/friend).
E25	Project manager, 51-55	Only the man participated in the interview. Lives alone. Purchase and interest, as well as use only the man.
E26	Real estate manager, 56-60, Public officer, 56-60	Only the man participated in the interview. Purchase and interest, as well as use only the man (recruited as a test user by a neighbor/friend).
E27	Executive director, 56-60, Entrepreneur, 56-60	Only the man participated in the interview. Purchase and interest, as well as use only the man (recruited as a test user by a neighbor/friend).
E28	Sales director, 46-60, Sales administrator, 41-45, 2 children under 18	Only the man participated in the interview. Purchase and interest, as well as use only the man (recruited as a test user by a neighbor/friend).

Original publications

I Tuomela, S., Iivari, N. and Svento, R. (2019). User values of smart home energy management system: sensory ethnography in VSD empirical investigation. In *Proceedings of the 18th International Conference on Mobile and Ubiquitous Multimedia (MUM '19)*. Association for Computing Machinery, New York, NY, USA, Article 32, 1–12. https://doi.org/10.1145/3365610.3365641.

II Tuomela, S. Iivari, N. and Svento, R. (2020). Warmth is more than temperature, it is a feeling: Sensory user experience of smart home energy technologies. In *Proceedings of the 28th European Conference on Information Systems (ECIS)*, An Online AIS Conference, June 15-17, 2020. https://aisel.aisnet.org/ecis2020_rp/24.

III Tuomela, S., de Castro Tomé, M., Iivari, N. and Svento, R. (2021) Impacts of home energy management systems on electricity consumption. *Applied Energy*, 299, 117310. https://doi.org/10.1016/j.apenergy.2021.117310.

IV Tuomela, S., Iivari, N. and Svento, R. (2021). Drivers and Barriers to the Adoption of Smart Home Energy Management Systems – Users' Perspective. *In Proceedings of the Australasian Conference on Information Systems, 2021, Sydney.*

V Tuomela, S., Iivari, N. and Svento, R. (2022). Gender inclusiveness in adoption and use of home energy technologies. Manuscript.

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Original publications are not included in the electronic version of the dissertation.

760. Pyy, Johanna (2021) Forest management optimization according to nonlinear partial differential equation (PDE) and gradient based optimization algorithm
761. Mendes, Fabiana (2021) Insights from personality and decision-making in software engineering context
762. Karampela, Maria (2021) Recommendations to enable and sustain personal health data access and sharing : an empirical approach
763. Lämsä, Juho (2021) Behavioural mechanisms underlying food-deceptive pollination and neonicotinoid exposure of bumblebees
764. Mian, Salman Qayyum (2021) The social web as an ecosystem of networked improvement communities (NICS) : an interplay of user engagement, technology improvement, and the business opportunities as enablers
765. Kuutila, Miikka (2021) Time pressure and well-being in software engineering : evidence from software repositories, experience sampling, and prior literature
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771. Palkki, Riikka (2022) Vertailutehtävät ja tarkoitukselliset virheet – erilaisia ratkaisutapoja tarkastelemalla kohti joustavaa matematiikan osaamista
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