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The difficult process of adopting a comprehensive energy retrofit in housing companies: Barriers posed by nascent markets and complicated calculability

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ABSTRACT

Comprehensive energy retrofits by households and housing companies have been recognised as important means for emission reductions. However, the diffusion of comprehensive energy retrofits has not been as fluent as expected. In this article, we study the Finnish energy retrofit market and comprehensive energy retrofit acquisition process through participant observation and interview methods in order to better understand the work that housing companies, as potential adopters, must carry out. The results of our study suggest that to operate in the current market, adopters must expend a considerable amount of effort in finding market actors, understanding the offerings and coming to grips with what kind of energy system would be ideal for their site. Only a handful of market actors are able to help adopters in this work and even these were difficult to locate due to their position in the energy retrofit market ecology. The study indicates that future policy should foster matchmaking between potential adopters and energy counselling services and support tighter collaboration between public and private energy sector actors.

1. Introduction

Much research and policy focus in recent years has been targeted to transitioning to sustainable energy production and use. In the European Union alone, residential energy use represents one quarter (25.7%) of total energy consumption (EU, 2018). Hence, households can play an important role in the energy transition by reducing energy consumption and implementing *energy retrofits*. Defined generally, energy retrofits in housing typically consist of 1) improvements in energy efficiency (e.g. insulation and waste heat recovery) and 2) the adoption of low carbon energy generation technologies (e.g. heat pumps and solar photovoltaic panels) (Hong et al., 2014; Owen et al., 2014; Heiskanen and Matschoss, 2017). In practice, the motives, content and scope of an energy retrofit and energy retrofitting can vary significantly based on household needs and the circumstances of different properties. An energy retrofit can consist of an individual technology installation and be motivated by personal interest in technology (Karjalainen and Ahvenniemi, 2019), but to maximise energy savings and emissions reductions, a *comprehensive whole house energy retrofit* (or simply, comprehensive energy retrofit) evaluating the applicability of multiple energy solutions has been presented as an ideal (Brown et al., 2017; Mahapatra et al., 2013). Such comprehensiveness is an attractive policy goal, but realising the potential of comprehensive energy retrofits can be difficult and conditioned by the market.

Indeed, energy retrofit diffusion has not been as smooth as expected. Previous studies have reported difficulties in market construction for energy retrofits due to a lack of suitable policy instruments (Matschoss et al., 2013) and demand in the marketplace (Kangas et al., 2018). In addition, the markets themselves may be nascent due to low installation volumes for some products, rapid and shifting price developments for newly emerged solutions (e.g. related to the rapid drop in PV panel installations during the last decade) and because the yield and suitability of solutions to particular buildings varies. For potential adopters and users, the energy retrofit market can be difficult to navigate due to a lack of suitable products (Hyysalo et al., 2013), piecemeal nature of energy retrofit offerings (de Wilde and Spaargaren, 2019), perceived product complexity (Drury et al., 2012; Karakaya and Sriwannawit, 2015) and associated product mechanisms, such as warranties (Davies, 2018). Hence, particularly in comprehensive energy retrofits which seek to integrate solutions, reliable, easily understandable and accessible solutions and information about them may be arduous to attain, and the intermediary actors that could support the adoption process in a complex marketplace may not be easily available either (Owen et al., 2014; Hyysalo et al., 2013, 2018; Brown et al., 2017).

Recognising the need to foster comprehensive whole house energy retrofits and the dynamics in market formation, we pursue the

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following two research questions:

1) How and to what extent does the marketplace serve comprehensive whole house retrofit projects in Finland?
2) What are the market characteristics and qualities of energy retrofits?

To clarify the role of the marketplace in facilitating or hindering energy retrofits, we adopted a user's perspective and conducted an energy retrofit acquisition process on behalf of two Finnish *housing companies,* taking the role of a housing company board member who is tasked broadly to explore means for improving the energy issues of the property. This active presence in the market place as a participant observer, akin to a mystery shopper, regarding how an energy retrofit can be acquired lasted for five months and was meticulously documented in terms of process, contacts and information content. The process was complemented by an interview study with members of housing companies which had successfully conducted energy retrofits in recent years.

Our focus on housing companies is motivated by the importance of this housing segment in Finland and similar *multi-owned housing* arrangements globally. There is considerable variance in the legal, terminological and practical aspects of multi-owned housing across national contexts (Lujanen, 2010; Blandy et al., 2010), but overall the Finnish housing company model is akin to housing cooperatives, condominiums and/or homeowner associations found in other countries (Matschoss et al., 2013; Lujanen, 2010; Weatherall et al., 2018). In Finland, 89,000 housing companies provide homes for 2.7 million people – approximately half of the Finnish population (Sitra, 2018). In Europe, approximately 40% of dwellings are multi-owned (Weatherall et al., 2018) and it is the dominant ownership form in, for example, Bulgaria, Czech Republic, Romania, Italy and Spain (Matschoss et al., 2013). Beyond Europe, multi-owned housing constitutes approximately 19% of housing in the United States (McKenzie, 2010) and has become increasingly common in the densifying cities of the Asia-Pacific region (Altmann and Gabriel, 2018), representing, for instance, 70% of housing in Hong Kong (Yip, 2010).

In multi-owned housing, major decisions regarding the property (including energy retrofitting) are commonly made collectively by the owners. A board typically formed of a limited group of the owners holds a major role in proposing and planning for coming renovation and maintenance projects (Matschoss et al., 2013; Lujanen, 2010). Thus, the board governs significant economic assets, must weigh different options carefully and is legally obliged to drive the economic interests of the owners. Whilst members of such boards seldom command expertise in real estate or technology, a successful energy transition will, nevertheless, depend strongly on their ability to successfully engage, negotiate and liaison with market actors and their ability to make informed decisions. Thus, multi-owned housing units and their board members are important and interesting actors, who naturally form a proxy for a calculative and rational market actor who would make informed decisions about energy systems. As we will show, the burden of making properly informed choices in a turbulent market plagues the attempts of multi-owned housing units to enter and navigate energy transitions. Hence, we contribute to the study of the nature of and obstacles for rational action by relatively small and lay actors in the nascent energy retrofit market.

Next, we discuss the market development in energy transitions in the light of previous research. Then, after outlining the methods and data used in the study, we discuss the empirical results of our study and outline the energy retrofit market from the user-consumer perspective. Finally, we end the article with conclusions and the implications for energy policy.

2. Market development for energy transitions

2.1. Acquiring comprehensive energy retrofits: how adopters qualify energy technology

To acquire a comprehensive energy retrofit, the potential adopters need to understand, among other things, the relative advantage that new innovations or products offer over other alternatives and how compatible they are with their needs and existing solutions (Rogers, 2003). However, the qualities of products in the market are not self-explanatory. Here, research on the sociology of markets is useful for understanding how consumers interact with and make sense of goods in the marketplace. Goods in the marketplace are in a constant process of *qualification* (Callon et al., 2002), in which their characteristics are reworked, represented and brought forward interactively by suppliers, consumers and other market actors, such as intermediaries (Muniesa et al., 2007; Callon et al., 2002; Callon and Muniesa, 2005; Çalışkan and Callon, 2010).

Key processes in product qualification are objectification and singularisation. Through these processes, product properties are defined so that they can enter the world of the consumer and become attached to it (Callon et al., 2002; Callon and Muniesa, 2005). In objectification, the qualities of a product or good are determined (often with the aid of specific instrumentation) and made into a *thing* that can be detached from its maker or owner. In singularisation, the qualities of a product or good are made relevant for a consumer and her or his need to create an attachment to the product and enable it to enter her or his world. Product qualities can be anything that can be more or less legitimately attached to the product and considered relevant in making it stand out from the competition (e.g. material origin, measurements, usability, standardisation or performance). In this view it is important that market actors – including users and consumers – are able to make calculative decisions (Callon, 1998; Callon et al., 2002). At the heart of calculative decisions is the possibility and ability to identify different options or 'world states', compare and rank them with each other and identify how to reach them (Callon, 1998; Callon et al., 2002). In the energy retrofit context, we interpret this as a requirement for understanding, representing, comparing and ranking different renovation and technology options and who might implement these options at a given property. Given the broad scope, variety and unintended positive and negative side-effects of possible energy retrofit measures and technologies, it can be expected that identifying and finding comparable comprehensive energy retrofit offerings, or even alternatives that would constitute a suitable retrofit, can be specifically challenging for adopters. Yet, given the significance of the investments, adopters are likely to make attempts to calculate and compare non-uniform offerings.

Product qualification (and the associated calculation) is not a one-time effort but instead a constant process that involves requalification in the value chain and life cycle of the product. For instance, the qualities of a car in manufacturing are different from those that are outlined in brochures, highlighting the different perspectives of actors along the car value chain (Callon et al., 2002). The temporal scope of qualification and requalification may be large. For example, heat pumps were not considered a renewable energy source for decades because of their dependence on electricity, but later became a part of the renewable energy mix due to policy changes (Heiskanen et al., 2014; Nyborg and Røpke, 2015) – a qualification process quite apart from technical qualities. Qualifications like this gain significance and derive power from institutional arrangements and policy targets, and point to the arbitrary and indiscrete nature of the classifications that organise energy transitions.

A key group of actors involved in the qualification of products and goods is formed of various intermediaries who facilitate, configure and broker between supply and use, and different actors; in this capacity the group is centrally involved in the emergence of new markets and qualification processes (Hennion, 1989; Stewart and Hyysalo, 2008;

Geels and Deuten, 2006). For example, early adopters and online internet forums have played an important role in supporting heat pump adoption in Finland by providing peer support and configuring the pumps to the Finnish climate (Hyysalo et al., 2018). Research on intermediaries is useful for underscoring the importance of *who* performs qualification in a marketplace. Qualification processes and activities carried out by intermediaries do not neutrally or mechanically aim to match demand and supply or help suppliers and users meet each other, but are instead shaped and constructed by the actors performing them (Stewart and Hyysalo, 2008; Callon et al., 2002). Depending on its position in the ecology of intermediation, an intermediary may purposefully frame information, suggest valuation frames or act in certain ways for its own benefit or based on its capabilities (see e.g. Zarazua de Rubens et al., 2018). Furthermore, in the face of uncertainty in a market, different actors may interpret and frame the same piece of information in considerably different and even opposing ways (Beunza and Garud, 2007). On the other hand, Çalışkan and Callon (2010) claim that the facilitation of market formation and the work of intermediation requires calculation over and across different market positions (i.e. *cross calculation*).

Based on these insights, comprehensive energy retrofit adoption may potentially be complex for users and this ought to be empirically investigated more. Not only do users need to make sense of products and offerings in a market that is characterised by novelty, complexity and change (e.g. Davies, 2018; Juntunen, 2014), but they face ongoing requalifications which reshuffle the established product categories and rankings therein. Even if intermediaries exist, they may not be necessarily looking after the best interest of users in the process but merge logics and enact covert interests. In the multi-owned housing context, such barriers can become critical to decision-making which is impacted on by, for instance, different owner logics, cost-effectiveness uncertainties and a lack of information (Uihlein and Eder, 2009; Matschoss et al., 2013).

2.2. Energy transition literature and users

Issues of qualification, intermediation and what happens at the micro and ground level of adopting new transition-relevant technology (as users try to make sense of new energy opportunities) is an increasingly topical issue in transition research. In particular, energy users have become the recent focus of transition research (for reviews, see Köhler et al., 2019; Schot et al., 2016; Hyysalo et al., 2018; Silvast et al., 2018). Transition research has often been conducted from a macro perspective on how technological and societal change unfold over an extended time period (Geels, 2002; Kemp et al., 2001; Geels and Deuten, 2006). Typically building on theories of strategic niche management and a multi-level perspective (Kivimaa et al., 2019), transition literature frames transitions as interplay between technological niches, existing technological regimes and the overall landscape wherein technological change occurs. In these theories, a transition is characterised as an accumulation of niche developments which eventually take over (or fail to take over) the existing technological regime (e.g. Geels, 2002 on how steam ships replaced sailing ships; Kemp et al., 2001 on the relative merits of Californian and Danish wind power policies).

Against this helicopter view of systems change, understanding the human element in energy technology adoption is of key importance as technology itself cannot achieve resource-use reductions (Wade et al., 2016; Owen et al., 2014). Users indeed appear to play important roles in developing, advocating, adopting and disseminating new measures that support transitions, such as energy retrofits – user-consumers and their adoption decisions are key to both acceleration and stabilization of transitions (Heiskanen et al., 2014; Schot et al., 2016; Hyysalo et al., 2018). Multi-owned housing plays an important role as the final adopter of new technology and associated routines. Put differently, housing companies constitute demand for integrated, feasible, advanced and trusted or otherwise qualified energy solutions. Better understanding what it takes for housing companies to act competently in the emerging markets for comprehensive energy retrofits and if these markets serve such users thus also gives us a better understanding of broader user and intermediary roles within the transition processes (Kivimaa et al., 2019).

3. Methods and data

To understand the energy transition at the micro level, we used a two-track approach. First, to develop a picture of comprehensive energy retrofits from the adopter perspective, we collected data through ethnographic participant observation of housing companies initiating an energy retrofit acquisition process, which formed an extended five-month version of being a mystery shopper in the market research tradition (e.g. Wilson, 1998; Zarazua de Rubens et al., 2018). Second, to trace successful adoption processes, we made an interview study of 12 housing companies which have gone through the full energy retrofit process.

Participant observation provides a useful research strategy for uncovering what the market for energy retrofits is like for potential users. The first author (dubbed *John* in-text from here onwards) acted in the field on behalf of two housing companies which had contemplated improving their energy systems. The set-up was realistic in that John was a board member in one housing company and the third author was in the other. John had no previous energy research experience, and he thus represented well the perspective of a housing company board member interested in broadly exploring options for energy retrofitting and potentially initiating an energy retrofit project (without a detailed initial idea of what the energy retrofit could consist of).

Both housing companies were located in large Finnish cities. In terms of housing type, Site 1 (S1) was a small apartment block built in the 1950s while Site 2 (S2) was a terraced house built in the 1980s, split into four units. Both sites have district heating and natural ventilation.

Participant observation was initiated in February 2018, first in S1 and a few weeks later in S2. John entered the field by inquiring the current electricity network operators of the sites about their solar photovoltaic (PV) offerings, which seemed to be easily accessible low carbon energy generation technology that could suit both sites and represented a likely and possible starting point for a housing company board member. Thereafter, John proceeded without specific external guidance or a plan, following the information and recommendations provided regarding how to best accomplish an adequate proposal for the two housing companies. This resulted in a process of engaging with additional commercial actors, public energy advice centres and online peer-to-peer communities.

The main body of data consists of field notes made during the project, documenting actions, contacts, observations and reactions related to the sites. The final field notes comprises 145 entries across the two sites and general activities relating to the energy retrofit process (45 for S1, 45 for S2 and 54 in general). Additionally, documents provided by the contacted market actors have been used as data (unless labelled as *confidential*).

To uncover further insights from the data, it was tabulated in chronological order and each entry was assigned codes or labels, such as *contact type, contact status* and *the knowledge a contact yielded*. Additionally, various quantifications were performed, such as time usage and the cumulative amount of contacts. In the following description of the results, the coding and the quantifications are used to complement the narrative of how the investigation unfolded.

In addition to the participant observation, our data is drawn from an interview study of 12 housing companies where energy retrofits have been implemented in different scopes (identified as cases C1–C12). The case identification proceeded through public and social media sources, complemented by apartment sales portals to gain insights from less vocal energy retrofit adopters. The 12 semi-structured interviews with housing company members lasted from 44 to 82 min. The interview situations sometimes included visits to the housing company premises and included anything from one to four interviewees involved in the projects (total: 21 interviewees). The interviews were recorded and transcribed for analysis. The participant observation and interview study results are discussed separately below in Sections 4 and 5, and then discussed in terms of cross-validation in Section 6.

4. Results

In this section, we begin with a brief description of the participant observation study process, followed by an analytical assessment of how operating in the market played out and what challenges were discovered in qualifying and making sense of the products in the marketplace.

4.1. The process and time required for establishing the needed information

The market engagement performed in the study took place between February 2018 and June 2018. The first key result of the participant observation concerns the needed investment of time and the length of the process. It took 83 h of active time use, spread across 22 weeks, to figure out what energy systems would be suitable for the sites. The spread of time primarily resulted from waiting for answers to queries and managing the course of the investigation. John carried out two concurrent tasks: 1) the collection of general information about energy retrofits and 2) finding and contacting market actors. In total, John was in contact with 20 actors in each of the sites (see Table 1 for an overview of contacts, responses, response rates and queries left open in the study). Activities relating to S1 took just under 25 h of the total time, activities relating to S2 took 21 h and 37 h were spent on general knowledge gathering relevant for both sites as necessary background learning.

As a result of the process, a number of energy retrofit suggestions were made for the sites. In both sites, a ground source heat pump appeared as the most influential solution for improving the energy system (especially energy production economics). Various insulation and system adjustments were also evidently beneficial for both sites, and several renovation possibilities were deemed as unfitting. The main difference between the recommendations for the sites was in solar energy utilisation as S2 had less favourable orientation and location. However, despite the time expended, John still hesitated and was unsure whether the suggested solutions were optimal or solid enough to take forward in the housing companies. To understand this better, we take a deeper look at the issues faced during the process.

4.2. Prerequisites for entering the market: site and configuration specification

To enter the energy retrofit marketplace John needed to specify the site in question to the other market actors. This practically implied the provision of anything from a general statement of interest in energy retrofitting to a detailed breakdown of up to twenty pieces of site information (typically spatial volume, energy consumption, and the type of heat and ventilation system). Existing and standardised housing-related documentation, such as the property management certificate, was requested and used to convey some of the information.

The needed information about the sites and their characteristics proved to be more difficult to access and interpret than expected. Much of the site data requested by the market actors was not readily available for John and certainly not recognised *a priori* as relevant. Hence, acquiring, interpreting and calculating the necessary information required effort and time. For example, accessing and exporting energy consumption data required 3 h of active work in S1. In S2, John waited ten days for the property manager to deliver this data, and he had to forward the request to another person in the company because of the needed metric: 'don't we have [data on] heat, electricity, water consumption on a monthly level[?] What about daily consumption[?]'

At times, the correct interpretation of site information proved to be difficult. For example, the inexperience with heating control devices of John and the housing company boards made John repeatedly provide inaccurate information about the heating system of S1 in questions asked by internet forum members, who quickly noticed the error based on the figures. For instance, *'[i]sn't that the temperature of incoming district heat water? I've never seen such hot water being used in radiators'* and *'did you request these figures from someone who knows the planned water temperature when it is -26°C [outside temperature] or [did you get them from] the controller settings[?]'* A few of the market actors (two in S1 and five in S2) circumvented this problem by visiting the premises themselves and going through the details of the systems. Most market actors were comfortable with operating from a distance or their resources forced them to do so (i.e. they did not visit the sites), and a degree of uncertainty remained over the accuracy of site specifications throughout the process.

Specifying the site was but a step in identifying what the optimal or at least well-justified energy retrofits would be. Process-wise, John's and the housing boards' lack of knowledge about products on the market and uncertainty over site specifications made John redirect the focus of the process multiple times. The initial focus on solar PV soon became complemented by a focus on heating as John realised that it represented a far larger expense in both sites. Also, recommendations by energy counselling to approach energy issues from a systemic and energy efficiency perspective made John shift his focus to more comprehensive energy system solutions, including insulation and adjustment measures. However, these redirections were not always for the better as John sometimes shifted focus based on incorrect information and dropped the pursuit of well-suited configurations in preference for poor ones (one such redirection being the misreading of heating control devices discussed above). Overall, the entry to the market with the broad idea of carrying out a comprehensive energy retrofit left a significant scope for, and also factually resulted in, multiple further project specifications.

Table 1
A numeric summary of contacts and responses.

Actor type	S1					S2				
	Contacts	Responses to initial contact	Responses after a reminder	Response ratio	Open queries	Contacts	Responses to initial contact	Responses after reminder	Response ratio	Open queries
Commercial	15	4	4	53%	9	15	8	3	73%	7
Energy counselling	3	3	0	100%	1	1	0	1	100%	0
Internet forum/peer	2	2	0	100%	0	4	4	0	100%	0
Sum	20	9	4	65%	10	20	12	4	80%	7

Initial contact response ratio 53%.
Overall response ratio 73%.

4.3. Establishing information sufficiency for comprehensive energy retrofits under uncertainties and self-interested biases

In exchange for site information, John received recommendations and configurations outlining what kinds of energy retrofit measures would potentially be suitable for the sites (in total 59 measures or technologies – such as 'additional roof insulation', 'air source heat pump' or 'small-scale wind power' – were encountered during the investigation). The recommendations were framed varyingly as 'savings measures', 'offers', 'options' or 'advice' by the different actors. Additionally, John went through the materials put forward by the market actors, such as marketing materials and energy guidebooks to understand what configurations were available in the market and whether they would be suitable for the sites.

The position and operational logic of the contacted actors in the energy retrofit market shaped the ways in which they provided information and framed what is ideal for a given site (to the point of being strongly biased). Energy counsellors hesitated to recommend either technologies or installers (as the counsellors are public actors), approached energy issues as a whole and put forward more comprehensive retrofit recommendations (recommending combinations of up to 10 individual technologies or measures) compared to commercial actors or internet forums. General information about energy retrofits suffered from similar challenges and was too generic to have direct relevance for the sites. In contrast, commercial actors focused on a narrower set of technologies or combinations of technologies (recommending combinations of up to six measures or technologies), but they were able to tailor their configurations for the sites and provide detailed information on implementation, expected benefits and costs. The internet forums and peer support did not have similar limitations to counselling, but they were typically structured around certain technologies (recommending combinations of up to three measures or technologies). Some forums or their sections had wider interests, but John's posts in those forums failed to attract interest and tap into the potentially wider knowledge base.

Let us illustrate these biases in more detail with a few examples. While general information on energy retrofits suggested solar thermal collectors as a good complementary technology to ground source heat (following the comprehensive ideal), installers familiar with solar thermal energy favoured solar PV because it was useful for both electricity and heat generation and because less 'hassle' was involved without the required piping for solar thermal energy. Another telling example concerned ground source heat, which a small company representative discussed shying away from due to high investment requirements, while a utility company referred to pumps as small-scale solutions in comparison to their 'own thing', district heating and cooling. Over time, John understood that the offerings of the market actors were rarely ideal for the specific needs of the sites but rather reflected what each commercial party could deliver profitably to the site. Commercial actors rarely recommended or commented on measures that they did not provide (and had no more than general knowledge of such measures). For instance, in a discussion about the best ways to develop the energy system of S2, a solar thermal energy and PV installer suggested evaluating 'the possibility of a heat pump hybrid [system] with solar energy on the side', but did not provide specifics on pump types.

Finally, in a few cases, information uncertainty was further influenced by mismatches between what a market actor seemed to provide or marketed, and what they actually provided. For example, a large energy company outlined the benefits of both solar thermal energy and PV in their marketing materials, but their actual offering turning out to be solar PV alone (with an option for an air-to-water-source heat pump).

4.4. Comparing options in the face of complexity and uncertainty

To compare and synthesise the received information, recommendations and configurations, John compiled spreadsheets that indicated the suitability of different measures for the sites on a rough scale (*negative, neutral, positive*). This task proved to be far more laborious than initially expected, consuming circa 13 h of active of work over three months and requiring intensive cognitive work from John.

The primary challenge in comparing different options in the marketplace was complexity and uncertainty caused by the different ways in which the market actors and information framed energy retrofit measures. In practice, the market actors often used different site characteristic sets (as input variables) in determining the feasibility of energy retrofit measures (as outputs) for the sites. For example, the two energy guidebooks used in the study outlined principally the same measures and technologies, but in different building-type contexts. The exposure to and communication with market actors resulted in a total of 52 input variables (see Appendix 1) which had implications for what energy retrofit measures are most suitable for a particular site and which kinds of configuration are feasible. Although none of the measures were dependent on all of the 52 input variables, the overall energy systems of the sites were. Hence, the competent market presence of John as a user-consumer required an understanding of all the variables, their interactions and how they influenced the feasibility of the different energy retrofit measures; John was plagued by the repeated need to reiterate his understanding of the planning context.

The challenge with the input variables and comparisons was threefold. First, coded retrospectively from the field notes, John had come into contact with over half (28 of 52) of the relevant input variables after only about nine days spent in the field and circa 11 h of making contacts and research (Fig. 1). However, it took a further 97 days to come into contact with all of the variables discovered during the five-month participant observation. Hence, John did not have a full overview of all the relevant variables and characteristics that can come to play in renovation until after 16 weeks of action – rendering old information and comparisons uncertain each time that a new variable was discovered. The gradual discovery of the input variables affected how John evaluated the offerings and approaches of the different market actors.

The relative importance of the input variables was the second major challenge. For instance, only after six encounters (spread over 83 days) regarding the heating system water temperature did John realise that it may be a dealbreaker in ground source heat utilisation, as a high temperature differential means a low coefficient of power or extra investment in larger radiators for all apartments. Such a late dawning of comprehension was due to a direct connection between the general information about the technology and site-specific information only being made in an internet forum discussion at this point (commercial actors had not flagged the variable as critical in their offers). In contrast, in situations where the input variables were clearly visible to John and where they could be combined with site information to generate configurations (e.g. online solar PV calculators), it was easy to understand the feasibility of a retrofit measure. Indeed, when compared with the offers which John received from the market actors and interpreted from available information, most of the input variables emerged alongside retrofit proposals (43 of 52 variables). Thus, the variables – and hence the complexity of comprehensive energy retrofits – were only understood when put into specific application contexts.

Third, the composition and dynamics of the input variables were not always self-evident, nor were the reasons why certain variables mattered in the first place. For instance, the building year of a site was often used as a proxy indicator for evaluating insulation levels and whether or not certain other technologies are in place in the site. Hence, the input variables or information requested from John were sometimes proxy indicators that both contained and 'black-boxed' other site aspects and specifications. While this can be considered beneficial from

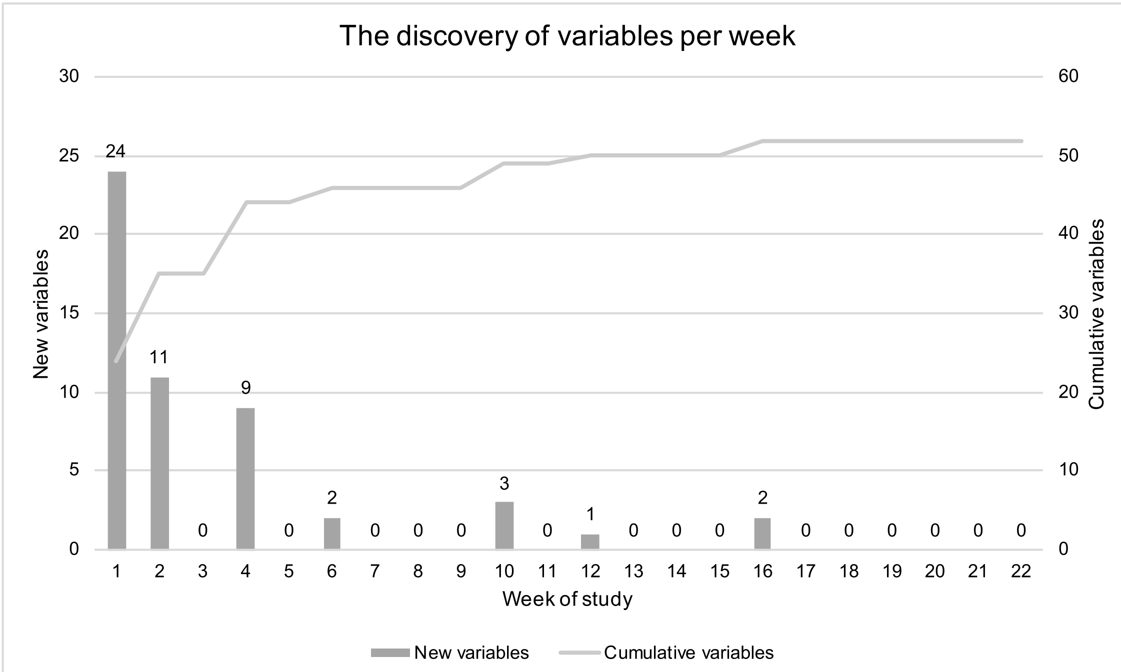

Fig. 1. The accumulation of input variables per week.

the perspective of the energy retrofit providers, it made comparisons more difficult for John as it increased the uncertainty and complexity of the investigation regarding what had or had not been considered by the information provider, and how reliably they had considered them. In addition, while some of the input variables (such as location, orientation and site soil type) are practically fixed, there are many input variables that may change – and are intended to change – during comprehensive energy retrofit projects. For example, changes in heating system type may shift expenses from heating to electricity (e.g. in heat pump adoption), which influences the overall feasibility of other technologies (e.g. increased electricity consumption can make solar PV more desirable). Thus, the complexity and uncertainty faced during the study related to handling the input variables at the present stage and considering changes in the variables and, hence, other possible energy retrofit configurations.

In sum, the difficulty of comparison was greatly increased by the uncertainty of whether all input variables, their relations and changes had been correctly understood, whether further information needed to be sought and, if so, what information. Added to this were constant needs to make scalar and unit conversions, which easily yield errors of magnitude. The resulting level and length of uncertainty made market action strenuous, if not outright overwhelming, for John and arguably will do so for any housing company board member needing to establish the grounds for an informed decision in a housing company general assembly. While John was at one point recommended to use acquisition consultants and pay specific attention to good planning of energy retrofits in order to deal with such difficulties, he did not encounter actors in the market who could do so. For example, the recommendations of commercial actors seemingly capable of planning comprehensive energy retrofits were limited to individual technical solutions and sometimes John failed to attract the interest of the actors altogether: one actor with a wide energy product and service portfolio responded, ‘we are not able to offer a contract on this’ – without further responding to queries. In an internet forum, one user highlighted the importance of good planning but was sceptical about who would do such planning.

5. Implemented energy retrofits

Echoing the difficulties encountered in the markets, we extended the study and made an interview study of 12 housing companies which had successfully gone through the energy retrofit process. In the following, we trace back their acquisition processes and present the results from the interviews carried out with housing company representatives.

The sample includes housing companies that have installed a ground source heat pump system (despite being located within district heating network) or a hybrid system which has other energy efficiency and/or energy technologies in addition to a ground source heat pump (Table 2). The energy retrofitting process is practically similar regardless of housing company size, following general housing company regulation. Also, while larger housing companies can access larger amounts of capital, they also need to make larger energy retrofit investments to cover for their consumption (e.g. the amount of boreholes for a GSHP system).

The interview study findings are largely compatible with the participant observation findings. First, most interviewees reported spending considerable time and effort in the projects, similarly to what the participant observation results suggest. This was especially the case in comprehensive energy retrofits, which are often considered as the ideal type, but also in some of the simpler projects. As worded by a retired representative of the housing company C10, ‘if I had been in working life during this time, the project would not have been realised’ and another from C4 mentioned spending ‘a hell of a lot of time’ on the project.

Second, these housing companies typically possessed the strong technical competences or experience to manage the project. For example, in C8, one of the housing company board members was a housing automation specialist while another member mentioned, among other things, having reverse engineered ground source heat feasibility calculation formulas from the results and having plugged old heat pump logic control units into his computer to see how they work. In C1, the interviewee had made a career in energy engineering and hence had excellent knowledge of the area and access to supplier networks. In C2, the interviewee mentioned lacking a technical background, but was still skilled enough to take part in tweaking the

Table 2
Summary of implemented energy retrofits.

Identifier	Building type	Amount of apartments	Measures undertaken	Energy consultant involved	Development of average price per square meter 2010–2017[a]
C1	Detached houses	5	GSHP		4.8%
C2	Terraced house	11	GSHP		−5.0%
C3	Detached and semi-detached houses	22	GSHP	X	1.7%
C4	Apartment block	36	GSHP + EAHR	X	14.6%
C5	Apartment block	64	GSHP + EAHR	X	8.5%
C6	Apartment block	24	GSHP + MAE	X	22.3%
C7	Apartment block	36	GSHP + EAHR	X	9.3%
C8	Apartment block	105	GSHP + EAHR + PV		6.5%
C9	Apartment block	19	GSHP		28.6%
C10	Apartment block	54	GSHP + EAHR + PV + ST + WWHR + insulation (various)	X	21.0%
C11	Apartment block	23	GSHP + GSC	X	N/A
C12	Apartment block	55	GSHP	X	24.6%

Abbreviations: PV = solar photovoltaics; GSC = ground source cooling; GSHP = ground source heat pump; MAE = machine exhaust ventilation; WWHR = waste water heat recovery; EAHR = exhaust air heat recovery; ST = solar thermal energy.
[a] Prices based on average prices in the postal code area (Statistics Finland, 2018).

technology as the supplier failed to make it work properly. Additionally, in over a half of the cases, the interviewees had a background in engineering or a related field (in some cases engineering expertise was also possessed by other housing company board members). Although this background did not always directly help them with the energy retrofit project, it does indicate that they were comfortable with new technology and far more competent than John (whose market activities we reported in the previous section).

Third, eight out of the 12 of the completed projects had found an energy consultancy company to aid them. These were identified through personal networks, happenstance or through their property management service company. The consultants were key in mediating between the housing company and the suppliers, especially by making offer comparisons, coordinating the overall system integration and managing the installation. In C7, the housing company board actually described the process as fluent and easy as the energy consultant had taken care of project management and technology installation. In some cases, the consultants also had a role in selecting contractors who were economically healthy in order to avoid situations where the system warranty and maintenance would come to an end due to bankruptcy.

While the above observations all verify participant observation results, the importance of energy consultants in successful cases is an additional and important finding. It is however important that whilst such intermediary actors were recommended to John and sought in the participant observation as well, none were identified. Indirect discovery (through e.g. property management) did not take place as S1 does not use a property management company, while at S2 the property manager did not have experience of energy consultants (or at least did not share the information with John). Based on a cross-examination of the participant observation and interview data, it seems that these are not easy actors to find. When searching for the energy consultants named in the interviews using 41 saved internet searches made during participant observation (each containing 100 search items), only three matches surfaced, two of which no longer offered the service. Additionally, a search of the consultants from a certified installer portal put together by an energy consultancy body yielded zero matches. The consultant in C6 further explained that they operate through property managers or 'through the grapevine'. In other words, the market availability of energy consultants to housing companies is limited and down to chance.

6. Discussion

A user perspective on energy retrofit markets underscores the challenges of adopting new energy technologies that are – in principle – available on the market. In regard to our first research question concerning how and to what extent comprehensive energy retrofit projects are served by the Finnish marketplace, our results display that demand for an open ended and comprehensive energy retrofit found little resonance in the marketplace. In the terms of the sociology of markets, there was a lack of singularisation around the concept of comprehensive energy retrofits. Although energy counselling and general information sources provided valuable information about comprehensive energy retrofitting, it was not specific enough for informed decisions. Neither did it help to find suitable commercial actors. At the same time, the business logic of the contacted commercial actors was focused on technologically limited solutions, which would have not been optimal, or even well suited, solutions for a housing company. Whilst the internet forums could alleviate such problems, as they largely have done in relation to heat pumps (see Hyysalo et al., 2018), for larger and more encompassing energy retrofits, peer help was less useful. Indeed, given the amount of work involved in specifying a comprehensive energy retrofit, it may be unrealistic to assume that the individuals who post on the forums would engage in such complex energy system integration on sites outside their own context. Support for comprehensive energy retrofits was therefore primarily informational, and did not extend to offerings in the market.

As Callon et al. (2002) point out, singularisation and product choice are premised on the ability of consumers to differentiate between products and compare them. A local configuration of energy solutions is essential for overcoming cost and effect uncertainties (Matschoss et al., 2013; Owen et al., 2014). In this study, comparative sets were hard to form and quality remained ambiguous, thus valuation could not be properly performed and understanding the opportunity costs of different alternatives was difficult. Following Callon (1998), we can note that the fieldworker faced difficulties in practically all of the antecedents required for being 'calculative' and thus a 'market actor': listing different options or world states, comparing them and acting upon them. One could claim that the result is dependent on the open-endedness of the initial request for comprehensive energy retrofits. Yet, given the portrayal of comprehensive energy retrofits as the ideal type, it is obvious that consumers and other end users will call for solutions for energy retrofits rather than merely order standard components of domestic energy systems. This requires work in the marketplace in defining and articulating the content and scope of comprehensive energy retrofits.

In regard to our second research question concerning the market characteristics and qualities of energy retrofits, the results of our participant observation show that energy retrofits are complex offerings that are difficult to define as they can consist of multiple and varying measures of different kinds. Hence, energy retrofitting requires knowledge that is specific, demanding and arduous to acquire (cf. Kastner and Stern, 2015). What seems particularly challenging for the user-consumers is to discover and master the particularities of their building regarding energy retrofits and to come to terms with and evaluate technological solutions that compete and only partially overlap. Moreover, the hurdles for potential adopters do not only start when they are faced with the technologies or information about them, but already begin when they are seeking to enter the market. The participant observation especially indicated difficulties in acquiring basic information of one's own site. This had little to do with attitudes, dispositions and expectations towards energy retrofits or individual energy technologies (cf. Kastner and Stern, 2015; Nair et al., 2010) and was more concerned with seemingly trivial bundles of issues regarding how easily the site information could be accessed and made use of, and how well a housing company board member understands the site (see also Matschoss et al., 2013). Thus, energy retrofit markets are difficult for users to enter and their ability to participate in the qualification process and become a competent user-consumer is far from a given.

Further, our results display that the retrofit market is characterised by a systemic gap as there seemed to be a lack of systems integration expertise to serve the user-consumers (see also Mahapatra et al., 2013; Brown, 2018). Supply-side offerings were scattered and plagued with uncertainties to the extent that steps towards energy retrofit transactions were not taken. In the terms of Çalışkan and Callon (2010), the participant observation seemed to reveal a lack of cross-calculating market actors. In the implemented cases we studied, comparisons and calculation were primarily performed by energy consultants who operated in between the housing companies and commercial actors. Thus, the interview data shows that cross-calculating actors that serve housing companies do exist, but they were hard to find as do not necessarily consider housing companies to be their primary customers. Moreover, even when such actors were present, implementing energy retrofits still required extensive effort and investment from the housing company members.

The complexity of comprehensive energy retrofits calls to question how feasible comprehensive whole house retrofits are in practice and to which degree effective qualification can be performed in such a market in the first place. A certain level uncertainty and difficulty of qualification is likely to persist as a characteristic of energy retrofits, especially comprehensive ones. Yet, as our data suggests, energy retrofits are purchased *regardless* of difficulties in qualifying and singularising them. Thus, qualification in the energy retrofit market may be more concerned with ensuring that sufficient thresholds of certainty and qualification – both for market intermediaries and users – are reached to support wider diffusion.

From a methodological perspective, our findings emphasise the yield from taking a micro view on transitions and market construction. A proper report on the work and experience of being a user highlights the critical bottlenecks of diffusion. The selected method may have contributed to an overtly complicated and cumbersome view of the market for energy retrofits. Had not John been a researcher interested in how the market caters for different energy retrofits, he might have cut corners, bracketed out options and recommended a feasible investment. Yet, the set-up of this study was a very ‘live case’ in which both of the housing companies had discussed energy retrofit needs and were expecting real outcomes from John's work; John was required to not only test the market but also to come back with solutions for the housing companies.

The findings are particularly pertinent to housing companies and multi-owned housing arrangements. These organisations manage a major share of energy demand and energy investments in countries such as Finland with a high level of multi-owned housing. Multi-owned housing organisations are not user-consumers in the traditional sense of being a single person or household. Whereas the decisions of individual user-consumers studied in the early stages of new energy technology diffusion are impacted on by social networks, proximate peers and local champions (Heiskanen et al., 2014; Neij et al., 2017; Simpson, 2018; Curtius et al., 2018) and may downplay financial considerations (Karjalainen and Ahvenniemi, 2019), multi-owned housing boards are liable for making decisions on more formalised economic principles. What counts as relevant and sufficient may differ between individual consumers and multi-owned housing board members. Yet, many multi-owned properties may be too small to be served by energy consultants proper and thus find it difficult to obtain sufficient and relevant information to back up energy-related decisions. To say the least, this organisational form indicates that board members need to do significant integration work and formulate demand. Moreover, there are further differences between these different kinds of user-consumers in terms of, for instance, the speed and basis of decision-making (e.g. the role of personal dispositions, access to capital). Hence, we see much further research needs to be done in understanding the ground level of energy transitions from the perspective of different kinds of user-consumers and other user roles, and the deployment of the corresponding new methodologies to do so.

As suggested by MacKenzie (2009) and Callon et al. (2007), the material artefacts that are involved in markets may have an important role in defining market construction and functioning. In this vein, our findings calls for a focus on the physical and conceptual tools of comparison and calculus that structure the interactions between the users and other market actors. These are further linked to the important role that intermediaries hold in brokering technologies and integrating them in the energy retrofit context – issues we discuss next in the implications section.

7. Conclusions and policy implications

The user perspective on energy retrofits revealed that reaching satisfactory solutions for housing companies required the integration and interlinked assessment of energy efficiency and energy generation technology. The markets did not match this demand but are dominated by suppliers of narrow solutions and lack actors who adequately mediate between available solutions and users. This holds even for relative isolated solutions and is greatly amplified for attempts to acquire comprehensive energy retrofits. In overall, users face high uncertainty regarding what are the relevant variables and their interrelations – information that is required to initiate and assess an energy retrofit.

Users’ difficulties to act in the market are visible both in our participant observation study and in analysis of successful cases. In most successful cases, the capacity to act in the market had required high expenditure of user time, a technical background and/or a relatively well-off housing company that could invest in the upgrades to their building. Most success cases additionally relied on the availability of an intermediary versed in energy retrofits. In this study, the focus was on housing companies, but the results also have implications for private house owners who face similar issues with even less resources and competences at hand. It is evident that *the often-claimed adoption barrier of technology is, to an important extent, a barrier formed by the complicated and developing energy retrofit market.*

There are four further policy implications for improving the energy retrofit market for users. First, housing companies need wider availability of *energy counselling and integrator services that can act in the market on housing company's behalf to determine well-suited energy efficiency and low carbon energy generation technology mixes.* The importance of such services has been recognised in the policy support for energy service companies. Yet, this discussion has often presumed that finance and uncertainty over the savings are in key roles. Housing companies appear to need specific front-end project counselling and implementation support (e.g. integration), even if they are not ready to sign up for energy performance contracts. Moreover, service providers currently focus on large projects in commercial and industrial buildings. Their services are not available to housing companies and private house owners as their demand is latent and geographically dispersed. *Public* support *systems targeted to users acquiring such services would signal to energy planning consultants the opportunity to move into this market and* support *users to acquire these services.*

Second, a gap exists between public energy counselling and private service providers. Public energy counselling remains too generic to be truly helpful for users due to its remit of remaining neutral. *The connection between public energy counselling and private integrator services needs to become tighter.* For instance, to improve the build-up of functioning markets, public energy counselling should include reference sites and be given a remit to provide lists of certified private energy integrator consultants. Public counselling could also host rating websites for private energy retrofit consultants or fund volunteer-based discussion forums to do so (cf. Hyysalo et al., 2018).

Third, other relevant *intermediaries, such as property managers, should be steered to engage in energy retrofits through training and potentially also through introducing early incentives and/or mandatory statutes*. These actors have a close ongoing relationship with housing companies (especially in the Finnish context), who are accustomed to seeking their council in the more established renovations of roofing, façades, plumbing etc. These are thus also 'natural' intermediaries to users for energy retrofits and they will either promote or belittle such needs, yet property management companies appear inactive and poorly equipped to act in this market.

Fourth, *users can be helped by emerging digital platforms, particularly in the initiation stages of energy retrofits*. Open building registry data has already been used to create digital platforms that allow identifying which forms of energy retrofits are possible at a given street address (e.g. http://energiavalinta.fi, https://www.google.com/get/sunroof). Such digital services provide further links to digital services for single technology acquisition sites such PV scaling and purchase sites. They also provide procedural guidance for how to proceed with a more complex and comprehensive energy retrofit and could include links not only to public energy counselling, but also to the certified providers of integrated solutions.

Taken together, the disparity between the particular contexts of energy retrofits and the market supply of singular solutions hinders the deployment of low carbon technology and presents an important policy concern. This gap is unlikely to be filled by users only and rather requires policy intervention, experimentation and further research on how to affect the maturing of the energy retrofit market.

Declarations of interest

None.

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Appendix A. Supplementary data

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