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# Series of configurational movements: User activities in technology generalization

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ABSTRACT

The detailed studies of adoption and user activities indicate that continuous alterations accompany the proliferation of new technology, yet diffusion theory and system change-oriented frameworks portray the spread of technologies across a social or sociotechnical system with relatively few changes. To better reconcile the two orientations, we introduce a *series of configurational movements (SCM)* as a conceptual register for the generalization of new technology in society. We elaborate on the SCM with an over-a-decade-long investigation into heat pumps in Finland, one of the globally furthest progressed energy transitions. The process has thus far involved nine configurational movements, each featuring a change in the character of the technology, the ecology of actors relevant to it, and the contexts in which the technology spreads. SCM analysis further surfaces eight user activity types that have shaped how the technology, its deployment, and its markets have evolved: Adoption and routine use, adaption and adjustment, championing, user innovation, community building, peer intermediation, market creation and production of legitimating discourse on heat pumps. In all, the generalization features significant shifts in user practices, the technology, and societal impact throughout the process, not only during its early phases, instilling energy system wide change.

## 1. Introduction

The new technologies that could spread quickly and widely enough to make a difference in climate change mitigation are already well past their early development phases (IEA, 2021). The mass uptake of solar, wind, and heat-pump technologies and other renewable technologies has progressed well (Peters et al., 2017) but at a slower rate and more unevenly than low-carbon scenarios require (IPCC, 2022). Their accelerated uptake is difficult to achieve by way of subsidies, regulation, and supply-end investments alone. The “demand side” of energy transition features importantly in, for example, financing, market creation, changing consumption patterns, and further innovation, and there is thus a heightened need to better understand it.

Academically, “a stability paradox” prevails between studies and frameworks that focus on the spread of new technologies in society and those that focus on how new technologies are adopted. Regardless of disciplinary origin, detailed studies of adoption consistently show how adoption requires the translation of technology to local settings, practices, instrumentations, and institutions, often resulting in greater or smaller alterations (see, e.g., Agarwal, 1983; De Laet and Mol, 2000; DeSanctis and Poole, 1994; Silverstone et al., 1992; for recent review see Kohtala et al., 2020). In contrast, the spread- and system change–oriented frameworks, such as diffusion and the multi-level perspective, portray a process where a technology spreads across a social or sociotechnical system with relatively few changes (Geels and Schot, 2007; Geels et al., 2016; Rogers, 2003). This discrepancy has not gone unnoticed. Over the years, concepts such as reinnovation, reconfiguration, social embedding, innofusion, and generification have been developed to bridge these positions, departing from “spread” and “adoption” oriented researchers alike (Fleck, 1993; Geels et al., 2016; Kohtala et al., 2020; Pollock and Williams, 2008; Rogers, 2003). Yet the recent increase in alternative terms used to discuss the proliferation of new technology—such as *upscaling* (Wigboldus et al., 2016), *roll-out* (Van Winden and Van Den Buuse, 2017), *distributed participation* (Ryghaug

*Abbreviations:* ASHP, Air source heat pump; ASWHP, Air Source to Water heat pump; BOAP, Biographies of artifacts and practices; DIY, Do-it-Yourself; EHP, Exhaust air heat pump; GSHP, Ground source heat pump; HVAC, Heating, Ventilation and Air Conditioning; SCM, Series of configurational movements; S-RET, Small scale renewable energy technology; S&TS, Science & Technology Studies.

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and Skjølsvold, 2021), and *generalization* (Robinson et al., 2022)—indicate that scholars do not see the challenge resolved.

One root problem underlying the paradox and the difficulties of resolving it lies in the study designs, the resulting empirical data, and the generalization styles of scholars whose primary orientation is either the days and months of adoption or the years and decades it takes for a technology to spread in society.[1] We thus argue that both theoretical and methodological renewal in the study of generalization processes is needed in order to arrive at more productive theory development.[2] Therefore, our first research question is: How can the generalization processes of new technologies in society be examined in a manner that attends to both the local translations and stabilities found during these processes?

To this end, we introduce a *series of configurational movements* (SCM) as an alternative conceptual register for the generalization process of a new technology in society. We elaborate how the SCM intertwines with the methodological approach of *biographies of artifacts and practices* developed within the social shaping of technology (Glaser et al., 2021; Hyysalo, 2010; Hyysalo et al., 2019; Pollock and Williams, 2008). This double renewal of generalization—how it can be researched more adequately and how it can be subsequently theorized—is exemplified by our over-a-decade-long investigation into the generalization of heat pumps in Finland. We trace the proliferation of heat pumps in Finland through nine configurational movements, each of which features a change in the character of the technology, the ecology of actors relevant to it and the contexts in which the technology spreads, and the contributions that users make. Thus, our second research question is: What does SCM analysis reveal about the generalization process and the user activities involved in the course of generalization?

Our argumentation proceeds as follows. In the next section we shall review the relevant literature in more detail. We then move on to elaborate our analytical approach, methodology, and data in Section 3. In Section 4 we present our materials and methods and in Section 5 we proceed to the empirical analysis of the heat-pump revolution in Finland. We then zoom in to discuss the user activities in this process in Section 6. The discussion, and conclusions and implications follow in Sections 7 and 8.

## 2. Technology generalization between spread and adaption perspectives

### 2.1. Users: Invisible agents in technological change

Users were long considered to be insignificant as agents in technological change, and their capacities and the extent of their engagement have been gradually discovered in innovation studies (von Hippel, 2017, 2005, 1976) design research (e.g., Kohtala et al., 2020), consumption studies (Silverstone et al., 1992), information systems (DeSanctis and Poole, 1994; Szymanski and Whalen, 2011), and science and technology studies (S&TS)(e.g., Oudshoorn and Pinch, 2003). A root cause for both the long neglect of users and the gradual realization of their importance lies in the *invisibility of many of their contributions*. Much of this invisibility can be captured by the notion of *invisible work* found in S&TS (Star and Strauss, 1999; Verhaegh and Oudshoorn, 2016): What users do is not recognized by themselves as being of importance; if it is, it is seldom recorded and thus it is gradually lost to memory and even if recorded by someone, the records are not known to the people who are typically studied in relation to technology development, such as industry experts, civil servants, or researchers (von Hippel, 2017). This invisibility has entailed a need to develop site-specific and arduous research designs to capture the contributions that users make, such as ethnographies and large representative surveys (De Jong et al., 2015; Suchman, n.d.; Szymanski and Whalen, 2011). The downside has been a difficulties to assess to what extent and how citizens affect sociotechnical change overall (Hyysalo, 2021).

This general condition holds also regarding renewables and energy transition on which we focus in this article. There are exemplary works on particular adopter activities related to transitions, such as on innovation (e.g., Nielsen, 2016; Ornetzeder and Rohracher, 2013, 2006; Truffer, 2003); on adoption, adaption, and consumption (Judson et al., 2015; Juntunen, 2014a; Nyborg, 2015); on social movements (Hess, 2016; Smith et al., 2014); and on energy communities (e.g., Herbes et al., 2017; Walker and Devine-Wright, 2008). Yet, these studies are from different eras, technologies, and countries, and they cluster strongly around the early phases of technological change, most likely because few sustainable alternatives have yet progressed to the late phases of societal uptake.

### 2.2. The ways in which users affect technology and its development

Studies of technology adoption reveal that taking goods into use often involves adaptions, such as resignifying, repurposing, adding on to, modifying, redesigning, and intertwining the good with other artifacts, physical contexts, and everyday practices (DeSanctis and Poole, 1994; Juntunen, 2014a; Kohtala et al., 2020; Silverstone et al., 1992). Studies of home consumption have revealed that instead of being passive adopters, ordinary consumers are active in adapting the materialities and meanings of technology in order to make it work for them (Lie and Sørensen, 1996; Silverstone et al., 1992). They have "domesticated" the technology into the moral economy of their households and contributed to the long-term taming of the new types of technology (Berker et al., 2006; Slater and Miller, 2007; Sørensen and Williams, 2002).

Studies of workplace technology adoption show that mutual adaption of technology and work practice is the norm (Leonard-Barton, 1995). The iterative loops between design and use could last as long as several product generations, forming an *innofusion* pattern (Fleck, 1993; Hyysalo, 2010; Pollock and Williams, 2008). This research has been taken furthest in information systems, which have identified over 30 different adoption moves that shape a technology and its effects on work practices (DeSanctis and Poole, 1994). In workplaces and in home consumption alike, selective appropriation, integration into other devices, the co-evolution of practices and new technology, add-on solutions, new uses, (re-)inventions, and efforts to market the technology have been found to be common (e.g., Johnson, 2013; Kohtala et al., 2020; McLaughlin, 1999; Szymanski and Whalen, 2011). Studies of homes and workplace equally show that more advanced peers, "local experts," second their help to others, helping them in appropriation and making adjustments as "user-side innovation intermediaries" (Stewart, 2007; Stewart and Hyysalo, 2008).

Users, both citizen users and organizational users, are also common sources of inventive new technologies in areas where extant products do not cater to their specific needs. Even though the further development often takes place in R&D companies, the lead-user designs spur on new product lines and improve earlier ones (von Hippel, 2017, 2005, 1976).

The rapid proliferation and sophistication of digital-sharing

[1] The difficulties are often compounded by the (willingly) oversimplified assumptions of research, such as it being either strictly deductive or inductive research.

[2] Note on the terminology: Because of the range of disciplinary terminologies that are relevant for understanding generalization processes, we use the terms involved in each tradition when possible, but once we have contrasted them, we resort to the following base terms. *Generalization* and *proliferation* are used as the umbrella terms to describe "the routes and processes that transform, normalize and embed the outcomes of innovation" (Robinson et al., 2022) all the way up until the point where the new technology has reached its maximal adoption extent. *Adopter* and *user* are used interchangeably to refer to a person, an organization, or a community who acts as the subject that acquires and localizes technology. We use *citizen user/adopter* and *organizational user/adopter* to differentiate between whether we talk of individual users/adopters or corporate bodies.

platforms in this millennium has underscored the importance of user innovation communities and user-configurable content communities beyond open source software (e.g., Benkler, 2006; Jeppesen and Molin, 2003). Living labs, web-based innovation areas, and user groups mark some of the widespread practices through which users are actively connected to each other and to producers in order to facilitate company research and development activities (Hyysalo and Hakkarainen, 2014; Johnson et al., 2014; Leminen et al., 2014; Mozaffar, 2016). Internet user forums, blogs, and discussion platforms have allowed users to pool their experiences and reveal their designs to other users. This has led to a "do-it-yourself renaissance," in which self-created and collectively created artifacts are gaining new impetus (see e.g., Grabher and Ibert, 2014; Kohtala, 2016; Kuznetsov and Paulos, 2010).

Some authors go as far as to insist that technology proliferation is always "translation" rather than "diffusion" (De Laet and Mol, 2000; Latour, 2005). Yet, the incidence and extent of the alterations is known to vary greatly between technologies, as well as between adopters. For instance, with respect to the empirical domain of this paper, small-scale renewables, the need to make adaptions to equipment appears to depend on region-specific variations in housing, climate, and regulation, as well as on the building location, housing type, and the homeowners' everyday practices (Judson et al., 2015; Juntunen, 2014b; Nyborg, 2015). Many users end up *championing* new installation types and novel ways to integrate the technology (Martiskainen and Kivimaa, 2018). Activist citizen groups have been important innovators, initiating niche developments in wind turbines, solar collectors, low energy housing, and alternative building types (Nielsen, 2016; Ornetzeder and Rohracher, 2013, 2006; Seyfang, 2010; Truffer, 2003). Some of these civil society initiatives have fueled mainstreamed development whilst others have remained local alternative endeavors (Hargreaves et al., 2013; Smith et al., 2016, 2014). Regarding peer intermediation and peer communities, research has concentrated on community groups and movements that are united by an ideological commitment to alternative technologies and are typically geographically local (e.g., Hargreaves et al., 2013; Seyfang et al., 2014; Walker and Devine-Wright, 2008). Yet, there are also increasingly important digital communities, such as the Internet discussion forums, that have emerged to mediate the knowledge, market, and technical needs of geographically separated peers (Grabher and Ibert, 2014; Hyysalo et al., 2013a; Meelen et al., 2019; von Hippel, 2017).

Research has further emphasized citizen advocacy and political participation in transitions (Hess, 2016; Jørgensen, 2012; Smith, 2012). Many energy- and mobility-related societal decisions are political in nature, either in regard to preserving the status quo or in deciding to favor alternatives that are typically initially more costly and uncertain. Citizen activism and the environmental movement have been crucial in the early development of low carbon solutions (Hess, 2016; Ornetzeder and Rohracher, 2013; Smith, 2012).

In all, the streams of research focused on users and adoption portray the generalization process as a continuous alteration of goods and the settings in which they are deployed. User alterations can increase the adoption of innovation by making it possible to adjust it to the cognitive, social, and material needs of the adopters (Agarwal, 1983; Kohtala et al., 2020; Rogers, 2003; von Hippel, 2005). How this translates into the overall proliferation process is, however, as yet less clear, both generally and with respect to renewables.

### *2.3. The spread of technology: Diffusion and transitions research focusing on the big picture of generalization*

To date, the largest and best-known body of research on how technology generalizes is still that related to the diffusion of innovation (Rogers, 2003). Diffusion studies have predominantly proceeded through surveying the adoption and non-adoption of novelties in a social system. Diffusion research has clarified the characteristics of goods that are conductive to or complicate diffusion, as well as the types of actors and characteristics of social systems that tend to be conductive to diffusion. It has distinguished the typical adopter segments of innovators, early adopters, the early majority, the late majority, and laggards in the course of the process of diffusion mapped onto S-curves and bell curves (Rogers, 2003). These are important contributions, yet diffusion theory has been severely critiqued for its assumption that a good spreads as is, for treating a social system as an undifferentiated vacuum, and for neglecting the organizational and institutional characteristics of adoption, including the shaping of innovation pursued by adopters in particular (see e.g., Attewell, 1992; Redmond, 2003; Wigboldus et al., 2016). Diffusion research has also overlooked the differences in the adoption process by typically competent and highly motivated early adopters and the rest of the adopter segments: the requisite signaling of availability, the social legitimacy of adoption, payback characteristics, observability, the availability of diffusion champions, the understandability of the new solution, and the ease of adoption all need to be at a higher level in order for the later adopters to adopt. The diffusing good and social system may thus both have to change substantially during diffusion if the good is to spread to yet new segments (Cockburn and Ormrod, 1993; Fleck, 1993; Williams et al., 2005). Whilst many of these critiques were acknowledged as caveats in sections of the last edition of *Diffusion of Innovations* (Rogers, 2003), they were never duly integrated into the diffusion of innovations' core constructs.

Social vacuum problems have been addressed in sustainability transitions research, which examines complex long-term sociotechnical change that requires thoroughgoing reorganization of the systems involved (Köhler et al., 2019). Transitions research posits that dynamic stability prevails in nested sociotechnical regimes that hold institutional and market dominance in a given sociotechnical domain (Fuenfschilling and Truffer, 2014; Köhler et al., 2019; Smith et al., 2005). This shaping of the selection environment affects how novelties are taken up or suppressed, and thus, the generalization of novelties is taken to involve change in the item that generalizes as well as in the regime(s) that it transform(s) (Geels and Schot, 2007; Köhler et al., 2019; Smith et al., 2005).

With respect to the novelty that generalizes, transitions research stresses the qualitative shifts in the adoption and make-up of innovation in the early exploration and take-off phases of a transition. It emphasizes experimentation and mutual shaping of technology and the expansion of alternative technology niches through mainstreaming, scaling up, or the formation of critical niches (see e.g., Dewald and Truffer, 2012, 2011; Meelen et al., 2019; Smith et al., 2014; Truffer, 2003). The transition process is then taken to involve gradual institutional, economic, and cultural changes that result in the social embedding of the novelty and the stabilization of its form and meanings among users; in all, it is seen to result in wide and accelerated adoption (Kanger et al., 2019; Schot et al., 2016).

The other side of transition, change in incumbent regimes, begins once a novelty has generalized to a point that it instills a reaction from regime actors. Here, different transition contexts have been identified with respect to the coordination of the regime response and the internal or external location of the change (Fuenfschilling and Truffer, 2014; Geels and Schot, 2007; Smith et al., 2005), resulting in different transition pathways ranging from, with varying terminology, substitution, transformation, reconfiguration, de-alignment and re-alignment, and mixed pathways (Geels and Schot, 2007; Geels et al., 2016; Smith et al., 2005).

In principle, transition research follows both novelty and regime change equally across a transition. In practice, a focal shift can be observed, shifting from often quite detailed studies on the coevolution of innovation and uses in early transition to more broadscale studies that also cover later phases and regime changes (Köhler et al., 2019; Smith et al., 2005). There have been less than a handful of literature review–based attempts to also connect the research on users and civil society in the later in transition phases. Smith (2012) reviewed civil society–influencing mechanisms for energy transitions. He viewed grassroots innovation, citizen science, and green consumption as early niche-supporting processes that can lead to the community-led upscaling of innovation; consumer boycotts, protests, lobbying, counter-expertise, and standard creation as regime-destabilizing forces; awareness raising and social pressure as landscape-level pressuring processes; community aspirations; and the emergence of plural visions in civil society. Schot et al. (2016) phrased their review in terms of users, proposing a sequence where "user-producers" and "user-legitimators" create technological and symbolic variety during the start-up phase, "user-consumers" integrate the solutions into their everyday lives together with "user-intermediaries" who align various actors during the acceleration phase while increasing the number of "user-citizens" who mobilize against the prevailing regime, causing ever more consumers to choose the emerging regime. In this schemata, the active civil society roles are clustered under the roles of user-citizens and user-legitimators, and direct engagement with technology falls under the roles of user-producers and user-consumers who are assumed to only play a key role in the early phases. Kanger and Schot (2016) and Martiskainen et al. (2021) have taken this model as a theory and sought to test it.

The assumption about increasing uniformity of a novelty and its adoption in later transition phases likely owes to the early social construction of technology and the history of technology works (see e.g., Bijker et al., 1987) and diffusion theory's adopter segment differences (Rogers, 2003). Yet, the accumulating findings since on the continued adaptions, variations, and reinnovations taking place in the proliferation process by now question whether this assumption holds (see e.g., Rosen, 2002; Sørensen and Williams, 2002; Williams et al., 2005), meriting further research on generalization processes (Robinson et al., 2022).

In all, the spread-oriented frameworks have their focal interest in the overall picture of technology proliferation and thus timespans of years and decades and include tens of thousands to millions of installations. In light of the adoption-focused studies, the spread-oriented studies have addressed adaption, variation, and other user influences in the studies of the early phases of transitions but have only begun to investigate and integrate them regarding the later phases of generalization.

## 3. Theory: The key concepts in the SCM analysis

The SCM directs us to identify what may be the "key biographic moments" (Glaser et al., 2021) in which the relationally constituted character of a technology, its material make-up, underlying principles and theories, designed artifacts, usages, and users' and other actors' practices are shifted. As noted, such shifts are well recognized by both adoption- and spread-oriented scholarship regarding an innovation moving from labs to trials and onto early pilots at user sites and finally onto transferring the technology to the next locations (Glaser et al., 2021; Hyysalo et al., 2019; Sengers et al., 2021; Wigboldus et al., 2016). These moments and movements may not end at the point of market entry or transfer, and the concepts of sociotechnical configuration and a series of configurational movements sensitize one to noticing and tracing them (Hyysalo et al., 2019).

By *sociotechnical configuration* we mean the intertwinement or "assemblage" of the technical and social elements that produce outcomes in an identifiable setting (e.g., Latour, 2005). An artifact is never the sole defining point of analysis as such but always exists in a "contexted" way in particular settings where the artifact is enacted and consequential, as Glaser et al. (2021) put it. The elements of configuration, be their form "technical" or "social," are bound to actors through the materials, designs, principles, theories, usage, and regulations that are enacted (Hyysalo, 2021) and imply other actors and actor behaviors.

The term *sociotechnical configuration* has been used for widely different scopes of phenomena. In adoption-oriented studies, it encompasses a technology installation in a particular context or a growing set of tens or hundreds of installations (Fleck, 1993; Voss, 2009). At the other extreme, transition studies have employed *socio-technical configuration* as term for describing large, relatively stable networks that constitute a "regime" (Fuenfschilling and Truffer, 2014; Smith et al., 2005), and recently, in further expanded use, the term is used to address the global reach of technology-related structures in "configurational analysis" (Heiberg et al., 2022). In these usages, *configuration* denotes a base technology, global or national context, and the few most important overall changes that happen to the configuration over decades (Fuenfschilling and Truffer, 2014; Geels et al., 2016; Heiberg et al., 2022).

Our use of *sociotechnical configuration* lies in between these registers, similarly to its use by, for example, Walker and Cass (2010), who used the term for roughly similar technology characteristics in roughly similar social, operating, ownership, and business arrangements, such as community-scale wind power in the UK (in contrast to "on-shore wind" or "Vestas 2MW systems") (Juntunen and Hyysalo, 2015). Such a "sociotechnical variant," is taken to be comprised of the commonalities across the competing makes and models, their installation localities, and the actions of their users, manufacturers, and installers. By *configurational movement* we mean a significant change in the configuration, which changes several relations between other elements in the configuration. New uses, technical advances, changes in regulations, new competencies, changed practices, and so on can result in such a movement if they become intertwined with (or replace) the previous relations.

To give a simplified example from our empirical section, the sociotechnical configuration of a ground source heat pump (GSHP) with a horizontal collector field implies (as a non-exhaustive list) the following: a heat-pump unit, a hot water tank, and plumbing integrating them with centralized water heating; the design choices made by the equipment manufacturer and its component providers; the sales arguments, pricing, delivery types, and resellers; the installation practices of installers and adopters; the adopter practices involved in running and maintenance; the management of heat intake and heating needs by the adopter, and other heating solutions of the adopter. Importantly, it implies that an adopter who has the possibility and willingness to lay hundreds of meters of coil in the close vicinity of their house without being disturbed by the effects upon their house surroundings, including the prospect of potentially having to dig the ground up anew to mend problems that may occur with the coil. A *configurational movement* started to happen once vertical bore-hole design and installation solutions were developed as they expanded the user base to new types of people, houses, and allotments, tied the drilling companies into the ecology of actors (replacing land-moving operations), and further changed the material make up of GSHP systems and their installation competencies, pricing and payback times, scaling principles, and estimated returns (Lauttamäki, 2018).

Thus, in our use of the term *sociotechnical configuration*, the "variant" is intertwined with an *ecology of actors,* patterned and mutually defining lines of action among several actor groups (Clarke and Star, 2003). Following ecological sociology in pragmatism and symbolic interactionism (see e.g., Abbott, 2005; Akera, 2007; Clarke and Star, 2003; Star, 1995; Strauss, 1978, 1993), we conceptualize ecologies of actors to feature differing socio-materially constituted entities, such as supplier organizations, citizen groups, professional and industry associations, science labs, start-up companies, families, and government agencies. Rather than forming a system, these actor groups have distinct characteristics and their ensuing different capacities for action, topologies of power, resources, skills, constituencies, and commitments. They enable, constrain and contest each others' actions rather than have mechanics and routine integration as in rule-governed systems or move in flexible homeostasis as in structural functionalism (Abbott, 2005, p. 248). Their ties are taken as considerably stronger than those between interacting rational actors of microeconomics, and many actors have interrelations that reach beyond a single event and arena in time and space, resulting in many-to-many interactions and translations that extend over time (Clarke and Star, 2003; Hyysalo, 2021; Star and Griesemer, 1989). The actors within an ecology are at least partially aware of each other, and the patterns of previous actions and their interrelations are layered and tied to materials and infrastructures (Akera, 2007; Hyysalo et al., 2022), which stands in contrast to, for example, the relevant social groups of social constructivism that are only defined by meanings related to the focal technology (Bijker et al., 1987).

In this context, *arenas* refer to socially and materially constituted sites (rather than simple geographic locations) wherein the current and renewed order between actors is negotiated (Clarke and Star, 2003). Arenas feature some measure of stability and recognizability for the actors involved in them. Arenas can be at various stages of formation, ranging from being emergent and fluid networks, similar to the "arenas of development" concept (Jørgensen, 2012), to established arenas that feature pre-existing sets of (bundled) issues and rules, and require certain skills, resources, and materials in order for there to be competent action (Hyysalo et al., 2022; Strauss, 1978).

In line with its starting points, in the social shaping of technology and ecological sociology, SCM analysis refrains from proposing a strong prefixed social topology (Akera, 2007; Clarke, 2005; Clarke and Star, 2003) in which sociotechnical change begins, proceeds, and ends (in contrast to, e.g., the multi-level perspective or diffusion of innovation); rather, it leaves the patterns to be discovered, conceptualized, and linked to the findings and constructs proposed by other research traditions. Similarly, interactions between supply- and demand-side actors in an ecology are of central interest in the SCM, but they are not prefixed. In all, SCM concepts *sensitize* empirically grounded *theorizing* (Clarke, 2005; Clarke and Star, 2003; Strauss, 1993) rather than form a fixed set of theory propositions that are cast in order to be verified or falsified. In this capacity, paired with the associated methodological guideposts that we elaborate next in Section 4, the SCM addresses a research scope that falls between adoption- and spread-oriented research on sociotechnical change.

## 4. Materials and methods: The biographies of artifacts and practices approach

SCM concepts are anchored to the biographies of artifacts and practices (BOAP) approach developed within S&TS over the last two decades (Glaser et al., 2021; Hyysalo et al., 2019; Pollock and Williams, 2008). The approach is premised on long-term in-depth engagement with the evolving sociotechnical phenomena under study. This approach means studying settings in detail—such as studying users' everyday practices, innovations, and communities—in order to render the intricate and often otherwise invisible aspects visible. But it also means doing so across the several interlinked settings and times in which the focal technology and user practices have been shaped. The approach proceeds through stringing together both the ethnographic and historical sub-studies of different scales and sites with the phenomena studied (see e.g., Hyysalo, 2021; Hyysalo et al., 2019; Pollock and Williams, 2008). A set of eight methodological guideposts for research on long-term sociotechnical change have evolved (giving rise to and concretizing SCM conceptualization discussed in Section 3 above) (Glaser et al., 2021; Hyysalo, 2021; Hyysalo et al., 2019):

1. The spatial and temporal reach of study
2. Attention to ecologies of interconnected actors
3. Attention to interactions and interstices between these
4. The use of multiple temporal scales in data gathering and analysis
5. Treating contexts as multiple and enacted
6. Paying explicit attention to materialities and their influences;
7. The avoidance of asymmetric actor assumptions (e.g., the assumption that only designers design)
8. Caution over imposing generic theory constructs on substance findings regarding sociotechnical change

These BOAP guideposts are explicitly detached from social theory underpinnings, albeit they are natively compatible with ecological sociology in Science & Technology Studies (see Section 3) (Silvast and Virtanen, 2023).

In the present paper, we synthesize the findings from a BOAP investigation of Finnish heat pump users, conducted via a string of studies conducted over the years 2011–2022. This allows connecting the hitherto separate angles and data sets on the users involved in such long sociotechnical change (see Fig. 1, Table 1).

For the first-stage analysis, we relied on data on Internet ethnography (collected during 2011–2012 and in 2017) on Finnish small scale renewable (S-RET) forums, which moved from base-level characterization of the main forum subsections (by coverage of 10–20 discussion threads per category) and then fully covering over 1200 of the most important threads for content. The study also included 61 semi-structured interviews with 47 forum-active inventive consumers, five (5) with firms that had collaborated with inventive consumers, and nine (9) with users who had only adopted the S-RETs. Each interview was recorded and lasted for 30–120 min.

The posts and interviews were coded by one to three researchers. The initial coding focused on usage, procedures, and technology and design knowledge, which were constructed and shared inside the community. We analyzed practices related to heating equipment (for example, advice on purchasing, installation, daily use, maintenance, general instructions, problem solving, second-hand sales, and repurchasing). Procedural codes focused on forum activities and discussions around laws, status, and building an open-source community. Technology- and design-related coding analyzed the nature and make up of inventions, the types of technology featured in the forums, support given and received, and members' learning and development pathways. In the second stage of analysis, these first-level thematic codes were clustered under major themes relating to user activities in the heat-pump transition (Hyysalo et al., 2018, 2017, 2013b, 2013a).

Our second focus was on housing companies. We collected data through ethnographic participant observation of housing companies initiating an energy retrofit acquisition process during 2018–2019, which took the form of an extended five-month "mystery shopping" process in the market research tradition (e.g., Zarazua De Rubens et al., 2018). We complemented this with an interview study of twelve housing companies that have gone through the full energy retrofit process. This data was coded and tabulated for market actions, strategies for acting in the market, and the material and conceptual tools used in the projects, first outlined with descriptive labels, then thematically coded for commonalities across the cases and sites, and finally coded in comparison with theoretical literature (Murto et al., 2019a; Murto et al., 2019b). Further, we ran five expert and user interviews related to large building markets and industry-scale heap pumps in 2022 to complement our earlier data set.

We have contextualized the above ethnographic work in historical analyses of heat pumps in Finland 1978–2015 (Heiskanen et al., 2014a; Lauttamäki and Hyysalo, 2019) and further cross examined our analyses in light of historical studies by Heiskanen et al. (2014b) and Lauttamäki (2018) and other research into the field (Heiskanen et al., 2011; Martiskainen, 2014; Salmela, 2021). The present article bridges and cross-analyzes the published sub-studies on the generalization and related user activities of Finnish heat pumps.

## 5. Results: The configurational movements of heat pumps in Finnish space heating

### 5.1. Context: Small-scale renewables and space heating in Finland

The space heating in Finland has featured a varying mix of burning

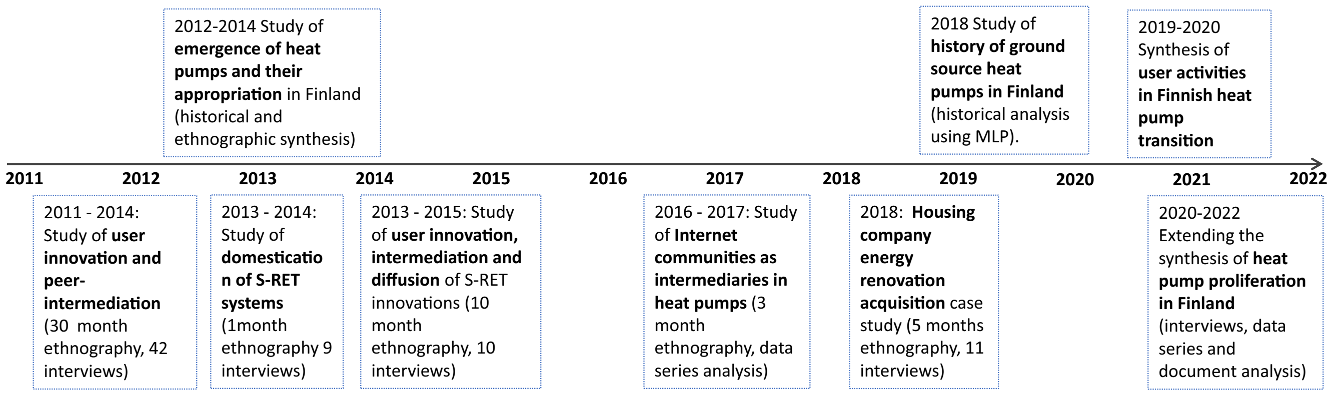


**Fig. 1.** Sub-studies on heat pumps in Finland.

**Table 1**
A summary of the data.

| Data type | The amount of data |
|---|---|
| Ethnographic observation | Approx. 48 months FTE |
| Interviews of users | 60 |
| Interviews with experts | 7 |
| Document materials | +10,000 pages of Internet forum discussions |

oil, solid wood, coal, gas, and peat; heating with direct electricity; and the recent rise of heat-pump produced additional energy. In the 1970s, the space heating was solely fossil- and wood-energy based, but gradually, fuel oil's dominance gave way to district heating with rapid urbanization.[3] For residential detached houses, which comprise an average of roughly 70 % of the present Finnish housing stock, these fifty years comprise a sustainability transition from fossil fuel's dominance of 1970 (accounting for 80 % of space heating energy, the remaining 20 % being covered by the small-scale combustion of wood) to the "remnant problem" of the remaining fossil fuel heating in 2020s amidst a more varied energy palette. The transition is ongoing but less advanced in larger buildings and district heating.

Currently 1.5 million heat pumps are in operation in Finland, both as primary and secondary heating sources in approximately 1.6 million applicable buildings, even though the heating retrofit cycles are slow and the transition will continue for some time to come. The development has mostly been market based, only minor household and energy renovation subsidies have been in place since the 2000s. In European comparison, Finland is among the countries where the relative household energy prices favor electricity and heat pumps over gas and oil and in which heat pumps have diffused widely. In contrast, in countries where gas, oil, or district heat prices have been consistently lower than electricity prices, and lower than the overall heat-pump produced energy price (Germany, UK, Belgium, Italy and Denmark), only a modest heat-pump uptake has taken place (EHPA, 2022; Hyysalo, 2021). These rough relative energy price levels are good to keep in mind regarding country comparability but do not alone explain heat pump proliferation.

If only viewed through aggregate cumulative unit sales and withdrawal numbers, the Finnish heat-pump proliferation has progressed through roughly linear growth since the market accelerated in the early 2000s. Thus, assuming the spread will slow down once the market becomes saturated, the diffusion would eventually form a S-curve (Rogers, 2003). However, once we view the heat-pump proliferation more closely, there are nine configurational movements that have significantly changed the shape of heat-pump technology within Finnish space heating during 1980–2022 (Fig. 2).

### 5.2. *Early market development: The first and second configurational movements*

The first key arenas and configurations for heat-pump systems were located outside of Finland in the 1970s, when the basic heat-pump designs gained their first commercial introductions and early markets. The ecologies of actors in these arenas typically featured experimentation by researchers, (typically modest) commercial producers, and users alike (see e.g., Dzebo and Nykvist, 2017; Heiskanen et al., 2014a; Lauttamäki, 2018). In Finland heat pumps were commercially adopted during the oil crises of the late 1970s and early 1980s (Heiskanen et al., 2014b, 2014a; Lauttamäki, 2018; Lauttamäki and Hyysalo, 2019). These installations were GSHPs with horizontal collector field systems on the land or in water reservoirs (the second configuration). The ecology of actors was comprised of small resellers and producers (or the small sub-units of larger companies) of plumbing and coolant companies that diversified into heat pumps and the adopters who proceeded to purchase and then run their installed systems. Some users acted as advocates of heat pumps in public media and many more championed the new technology in their own buildings in order to have the heat-pump systems implemented successfully. By 1985, roughly 12,000 units had been sold to house owners and to various small and medium-sized businesses (Lauttamäki, 2018; SULPU - Suomen Lämpöpumppuyhdistys, 2022). In the media, heat pumps were predominantly discussed positively, albeit they were also the target of attacks by incumbent energy and energy technology actors during the course of the 1980s (Heiskanen et al., 2014b). The nascent heat-pump arena featured little organizational or domestic research, and quality problems riddled many early installations. Yet the market developed positively until the oil price decreased dramatically in the mid-1980s and cost drivers disappeared. The final turning point was negative publicity on national television that claimed that heat pumps were inefficient and unhealthy. The sales stalled, companies withdrew, and the maintenance and customer problems were left unattended, leading to a tarnished reputation (Lauttamäki, 2018; Lauttamäki and Hyysalo, 2019).

### 5.3. *The market reborn: The third and fourth configurational movements*

The Finnish heat-pump field arose from the ashes in the mid-1990s owing to a (third) configurational movement taking place in other countries, particularly in the neighboring country, Sweden (Dzebo and Nykvist, 2017). In GSHPs, the heat-exchanger equipment became more standardized and reliable, and the newly developed vertical borehole and collector technology made adoption possible for a far greater number of people and locations (Heiskanen et al., 2014b, 2014a; Lauttamäki, 2018). Air-source-heat-pumps (ASHPs) were also introduced as heating devices in the late 1990s, after being used for cooling in warm

[3] However, district heating was mostly produced with black coal until the 2010s, after which woodchips, gas, waste heat, and heat pumps begin to replace it.

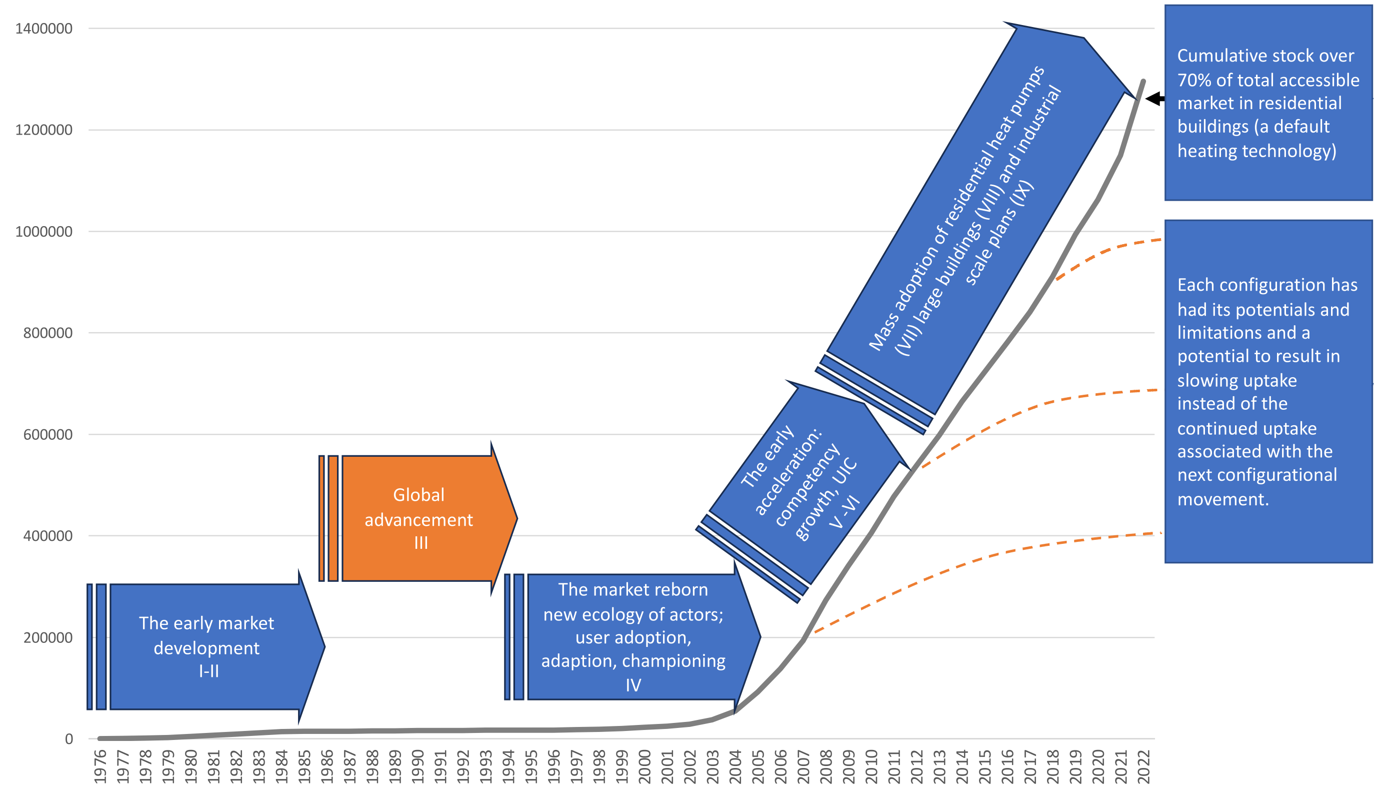


**Fig. 2.** The cumulative number of heat pumps in Finnish building stock and the configurational movements involved in the generalization process. Data corrected for replacements and multiple pumps in larger installations.

climates (Lundqvist, 2008). ASHPs were inexpensive, more straightforward to install, and had a quicker return on investment than GSHPs, even if there were doubts about the energy saving and their capacity mid-winter.

The ensuing restart of the heat-pump arena in Finland (the fourth configurational movement) was associated with a more organized ecology of actors that featured resellers, installers, and small manufacturers, users, and industry associations. The Finnish Heat Pump Association (SULPU) provided training, monitoring, public lobbying, and a voice in the energy field. GSHP installations started to re-emerge in the residential retrofits and new build markets after 1995. ASHP sales started a little later but rapidly increased to over 40,000 units being sold annually since 2005. Associated with steadily rising oil prices and environmental taxes on oil and electricity, the advances in both GSHP and ASHP systems had made them cost competitive. By the mid-2000s, there were 60,000 installations (6 %) of heat pumps in approx. 1 m Finnish detached houses (Hyysalo et al., 2018).

Yet, from the adopters' perspective, *adoption and the achievement of routine use* were still shrouded by uncertainties as to the technology yield, savings, pay-back times, and scaling, as well as in regard to vendor and installer trustworthiness. The adoptions required competencies in regard to understanding what the new technology is and how it works, its potential suitability, possible permit issues, cost–benefit calculations, comparisons between suitable makes and models, installation types, and the possibilities and requirements for routines, use, maintenance, and monitoring. All in all, the heat pumps in Finland proliferated against the grain of institutional rules, resale patterns, house valuations set for earlier heating forms, and technology tailored for other uses (e.g., drilling companies mainstay being boring wells and ASHPs being primarily produced for cooling in temperate climates) (Heiskanen et al., 2014a, 2014b, 2011; Lauttamäki, 2018; Lauttamäki and Hyysalo, 2019).

### 5.4. *The early market growth: The fifth and sixth configurational movements*

The fifth configurational movement was a qualitative shift within a subsection of the same arena and ecology of actors: not only sales and adoption were important, many users faced the need to alter the equipment or their social and technical contexts (physical houses, daily practices) and also their networks in regard to finding professionals to do non-standard installations, clarifying permits, et cetera. New competencies and materialities surfaced as the technology was no longer just bought and operated but it was tinkered with and adjusted, and users even produced well over one hundred innovations in their systems to make them work in their particular settings. This led to deeper engagement with the technology and the competencies required to deal with it, and the communication among peers changed heat pumps from being a novel and difficult-to-understand black-boxed technology to being malleable goods that can be adjusted and improved. These activities also signaled further design needs to resellers and manufacturers (Hyysalo, 2021; Hyysalo et al., 2017).

The sixth configurational movement took place through new market and intermediary actors entering the ecology of actors, namely large hardware retailers, and the build-up of *Internet-based user communities*. The initially modest peer-to-peer knowledge-sharing platforms rapidly grew into popular, diverse, and deep repositories of knowledge that came to feature 500,000 messages and had 150 m reads between 2004 and 2020, contributing to the peer-sharing of the user activities emerging in the fifth configurational movement and gradually also aiding market creation and the legitimacy of the new technology (Hyysalo et al., 2018).

### 5.5. *Mass adoption: The seventh configurational movement*

The seventh configurational movement is the *mass adoption* associated with the maturation of both the Finnish residential heat-pump arena and the stabilization of its ecology of actors, leading to the increasing normalcy of residential heat pumps in resales, regulations, and public and professional media, as well as in adopter choices. The 2010s featured steady yearly sales whilst moving from early adopter segments to a wider adopter base, made possible by the earlier configurational movements that had structured the market, improved information, and the intermediation of knowledge and technology characteristics to make adoption easier (Hyysalo et al., 2022). Heat pumps also gained support from neighboring technologies, from generally improved insulation levels, and from the increasing adoption of underfloor heating that supported GSHPs' and ASWHPs' as well as ASHPs' and EHPs' capacity to act in conjunction with existing heating technologies and other S-RETs in residential houses, often forming hybrid heating arrangements (Lauttamäki and Hyysalo, 2019; Numminen et al., 2023). During this decade, the technology characteristics also improved. A positive energy yield in the best ASHPs was retained with temperatures under −25 °C, in contrast to the early days −10 °C. Regarding GSHPs, the drilling technology advanced so that boreholes could be cost-effectively extended to 300 m, compared with the initial 60–80 m levels that left uncertainties over yield and sufficiency. By the end 2022 an estimated 74 % of Finnish detached houses had one or several heat pumps installed and their sales remained record high, indicating that their market penetration likely becomes unusually high for any energy technology already during the next few years.

### 5.6. *Expansion to large-scale heat pumps: The eighth and ninth configurational movements*

The eighth configurational movement concerns the shift of heat pumps from the detached housing market to larger buildings, owing to advances in heat-pump systems and drilling techniques (see the seventh configurational movement). The apartment buildings and other mid-sized installations became served by GSHP companies that had grown with the detached housing market, whereas shopping malls and large office buildings attracted a different ecology of building automation and HVAC suppliers and planners. Both markets were facilitated by the modeling the ground-source heat potential across the country by the Geological Research Centre of Finland (Lauttamäki, 2018). By 2023 a considerable number of apartment buildings, shopping malls, and office buildings had built with or converted to heat-pump use, associated with a continued market growth and new technical advances, such as over one-kilometer-deep heat wells. This development has faced mild resistance from incumbent district heating companies through, for example, raising the proportional share of the fixed power fee, not offering bidirectional district heating, and lobbying against drilling GSHP holes in downtown areas, but some incumbents have also joined it.

The ninth configurational movement took place within Finnish district heating networks, which deployed industrial-scale heat pumps using yet another ecology of actors in which the customers were district heating companies and the suppliers were industrial plant contractors. Initiated in 2006, the market grew slowly for a decade, but presently, the high-power units' growth is the most rapid in the market, reaching an over three fold annual increase from 2020 to 2022. Initial installations have utilized waste heat from wastewater treatment plants. Because of the limited availability of large waste-heat sources and the need to increase the resilience of the technology, users are increasingly piloting and installing technology based on modular air-to-water heat pumps. Industrial users have created user innovations in surrounding systems related to heat exchanger improvements, ease-of-use of maintenance, and automation in order to combine different heat sources and storage. Legitimacy for industrial-scale solutions has been good from the start and there has been minimal need for legitimacy building from industry actors' perspective.

By 2023, the technology that was consistently belittled in the last millennium has become the legitimate backbone heating technology for the Finnish energy transition across the scales (from detached houses to various large buildings and onto industrial-scale district heat production). Paired with the rapid increase in onshore wind power, it presently marks the most important technology base for decarbonizing the energy system.

## 6. Zooming in: User activities in the configurational movements

We now zoom in to more clearly elaborate the user activities involved in the SCMs, departing from adoption and routine use, and then we discuss a range of activities that have facilitated the spread of heat pumps beyond early adopters.

**The adoption and routine use** of heat pumps have been the most common and most important contributions by users in regard to the proliferation of heat pumps. The over-one-million purchase decisions and eventual routine use have created the volume and continuity that incentivized the resellers, manufacturers, industry associations, and vocational training institutes to invest in heat pumps. The routine use actions by users range from sizing, comparing, selecting, planning, overseeing installation, and learning to use the technology. The usage patterns blend with monitoring, maintenance, and troubleshooting the new heating equipment, and learning to live with the new type of heating (for example, learning to live with the warm air flow of an ASHP instead of radiating heat). Importantly, some aspects of purchasing and using heat pumps long required such effort and knowledge that it repelled the bulk of the adopter base (e.g., Hyysalo et al., 2018; Lauttamäki, 2018; Motiva, 2012).

**Adjustment and adaptation** have been common in getting routine use going. Users have had to make some changes to their daily habits, regarding, for instance, keeping the doors of rooms open, changing furniture layout, or changing routines related to emptying iced-up meltwater from the heat pump. Installing a heat pump in a particular house is also typically a process where adaptations and compromises have to be made regarding the aesthetics of indoor space and outdoor appearance, and the effectiveness of the heat emanating from the convector unit (Hyysalo et al., 2013a; Jalas et al., 2017; Heiskanen et al., 2014a). Notable discrepancies in different temperatures between factory values and the site-specific use have prompted many users to monitor their equipment and change the settings or make small hacks (Hyysalo et al., 2018, 2013a). Evidence of adjustment and adaptation can be found across the proliferation process (see e.g., Hyysalo et al., 2018; Lauttamäki, 2018; Motiva, 2012).

**Championing** has happened regarding ambitious projects, community building, and the dissemination of information. This took place in early pioneering projects that were novel and demanded effort from the adopters (Lauttamäki, 2018). In later phases, project championing is seen in efforts to introduce heat pumps into new installation types, in the efforts of users to assess the yield and payback times of both ASHP and GSHP systems, and in running joint-purchase projects (Heiskanen et al., 2011; Hyysalo, 2021; Hyysalo et al., 2018, 2013a). Championing also took place in the Internet communities, where a group of roughly 500 people has provided thousands of responses to various queries from others.

**Innovation by users** has happened among the hundreds of DIY projects the users have pursued. When verified for novelty and benefits by domain experts, 113 of these projects carried out between 2003 and 2017 turned out to be globally new innovations (Hyysalo et al., 2017, 2013b, 2013a; Mattinen et al., 2015). These innovations mostly emerged as responses to local particularities, which were poorly catered for by commercial models. These user innovations introduced solution variety to both technological offerings and new uses, but their uptake has been modest: Less than 10 % were commercialized or spread among peers, whilst 34 % were adopted in further DIY projects (Hyysalo et al., 2017). Importantly, the innovation and DIY projects and the related peer-to-peer knowledge exchanges build in-depth technical competence among this set of enthusiasts, forming a major component of peer communities and peer intermediation (Hyysalo, 2021; Hyysalo et al., 2013a).

**Communities** of citizens first emerged as sporadic local communities and joint purchase projects (Heiskanen et al., 2011, 2014a), but the major issue was the Internet communities that emerged in the early 2000s and gradually grew to have over 500,000 messages that have been read over 150 million times, becoming major catalysts for information and advice sharing among peers that provide connections between otherwise geographically separated people (cf. Grabher and Ibert, 2014; Hyysalo et al., 2018, 2017; cf. von Hippel, 2005). The critical mass of community members and accumulated information allowed the Internet communities to serve the varying needs of prospective adopters and existing users (Hyysalo, 2021; Hyysalo et al., 2018).

**Intermediation** by peers comprises not only facilitation but also the configuration of equipment and brokering of connections (Hyysalo et al., 2018, 2013a). Some intermediation has happened in local sites from the onset of heat-pump proliferation (Heiskanen et al., 2017, 2011; Lauttamäki, 2018), but the Internet communities made it bloom: Exchanges about installations, use experiences, real-time monitoring, technology concerns, cold-climate specifics, and DIY solutions (and so on) created a rich many-to-many mediation that helped citizens to grapple with the technology, its use, and its markets. Direct technical configuring was rarer as the distances between users prevented visiting

**Table 2**
User activities within each configurational movement.

| Configural movement | 1 | 2 | 3 | 4 | 5 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| | *The early market development.* | | *The market reborn.* | | *The early acceleration phase of the market.* | *Mass adoption of heat pumps.* | *Large buildings.* | *Industrial-scale plants.* |
| Time period | 1970s | 1980–1990 | 1995–2000 | 2000–2005 | 2005–2013 | 2013- | 2010 to present | 2010 to present |
| Adoption and routine use | Users as early adopters of a new GSHP technology. | | Users as a early adopters of cost-competitive ASHP technology. | Users were actively installing but routuine use was shrouded by uncertainties. | An increasig number of users can just adopt and use technology routinely, albeit many need to make changes to their daily habits in order to “domesticate” the technology to their daily life. | Standardized technology that fits to most of the contexts well. Users have emerged practices to use and maintain the technology. | Early adopters of mid-sized GSHP and ASWHP systems. | Early adopters of industrial-scale units using waste heat and ambient air. |
| Adjustments, adaptation | Many users faced the need to alter the equipment or their social and their technical context. | | | | | | New integration between different heating forms at planning stage. | Optimization in ASWHP heat levels, melting cycles. Adjustements to surrounding systems. |
| Championing | Championing the new technology in users’ buildings. | | | Users championing non-standard installations, clarifying permits, making internet communities run etc. | | | Championing planning and calculations for company and office buildings. | Championing new DH plants and heat sources. |
| Innovation by users | | | Isolated user innovations to improved technology suitability for the local context. | | User innovations improve technology in local contexts, create competency and are shared in internet communities. | | | User innovations in several system areas. |
| Communities | | | | | Internet-based user communities emerge resulting in wide many-to-many intermediation. | Internet-based user communities widely used, wide intermediation. | Visits to earlier adopters. | Visits to earlier adopters. |
| Intermediation | Peer intermediation at local sites. | | Peer intermediation at local sites. | | | | Visits and intermediary unofficial market for spare parts. | |
| Market creation | | | Adopters provide an example and testimonials about the heat pumps to peers. | | Examples, testimonials, and comparisons as to the value of the goods accumulate in the Internet forums. Users engage in joint purchase projects. | Accumulated value evidence in internet forums. | Value evidence for later adopters. | Users actively expand the market. |
| Legitimacy building | User as advocates of heat-pump technology in public media. | | | | The Internet communities around heat-pumps fostered and made visible a neutrally legitimating discourse about heat pump technology. | | Projects featured in public media increased legitimacy. | Good legitimacy, minimal user action. |

peers on-site, but help in configuring equipment was abundant, as was help in the brokering of contacts (Hyysalo et al., 2018).

**Market creation** activities are not unidirectional supply-led initiatives that spur demand—they form an interactive process in which adopters take part. In order to act in the market, potential adopters need to be able to make sense of the qualities of products, compare them, and establish an understanding of what consequences different choices hold for them (Callon et al., 2002; Hyysalo et al., 2022). The heat-pump Internet communities were key in providing this market-related intermediation (Hyysalo et al., 2022, 2018), particularly through storing and updating the technology, product, and market information in the rapidly changing field. The third market-shaping activity that the Internet communities affected was the indirect policing of supply and retail actors through fostering brand- and make-specific discussions that surfaced problems, such as erroneous supplier claims or substandard installation services (Hyysalo et al., 2018).

**Legitimation** is a key process in how a new technology becomes intertwined in the fabric of society. The early stages of a new technology are characterized by uncertainties, doubts, and counterclaims to its proponents' narratives. Such "technological drama" is the overtly politicized side of sociotechnical change, wherein citizens and citizen movements often play an active role (Pfaffenberger, 1992; Smith, 2012). Adopters can, however, also play a key role in the regularization of technology with less sound and fury. The 500,000 messages in the Internet communities made available a public peer discourse about heat-pump technology as an understandable and trustworthy heating solution in the everyday contexts of fellow citizens. Whilst forum discussions feature plenty of critique, there is a conspicuous absence of wholesale doubts or dismissals of heat pumps, generic technology critique, or even sustainability-related ideological discourse (Hyysalo, 2021; Salmela, 2021). The net effect has been a discourse that connects technology to its social, cultural and economic contexts, and produces a matter-of-factness about its suitability (Hyysalo et al., 2018).

**Interactive and mediated changes** between these user activities and other actors in the heat-pump arena can be observed throughout the period. Knowledge of user problems and their adaptations of heat-pump models and installations have circulated among building inspectors, energy counselors, members of the professional media, and resellers (Heiskanen et al., 2014b).

These users' activities spread across the proliferation process, albeit intensifying the most in the acceleration and early mass adoption phases (in configurational movements 5–7), significantly catalyzing the proliferation of heat pumps (see Table 2).

## 7. Discussion

### *7.1. Generalization as a series of configurational movements*

The ability to better anticipate how technology generalization processes are patterned is central to green transitions and to reaching the UN's sustainable development goals. Configurational movements in the make-up, criteria, and actors related to technology do not end after the much-rehearsed shifts from labs to field trials, from experiments to products, or from early niches to wider markets but may continue long after the initial scaling up and scaling out (cf. Sengers et al., 2021; Wigboldus et al., 2016). This has equal theoretical import for adoption- and spread-oriented research on technological change. Our findings question whether the later "phases" of proliferation are duly depicted to be proceeding with just a few globally significant reconfigurations, let alone via the smooth diffusion of a matured technology. Neither are they are well covered with the handful of detailed adoption studies assumed to reveal the reality of adoption.

The SCM provides a relatively neutral or "agnostic" register with which to discuss the generalization process and sensitize spread- and adoption-oriented lines of research. Regarding the nature of change, the SCM assumes that both open confrontation and smoothly accumulating changes can result in a configurational movement; that generalization can happen within one ecology of actors or it can shift to other ecologies and arenas; that generalization may be driven by either global or local process; that the nature of technology configurations can be more or less fluid or relatively discreet and stable; and most importantly, in so doing, it sensitizes us to empirically attend to the likely mix of these characteristics that particular generalization processes have in the course of their often decades-long span.

Heat pumps in Nordic countries are a good example of where such descriptive versatility is needed. Their proliferation has been aptly characterized as a "silent revolution" (Johansson, 2017) featuring little open confrontation or discursive struggle between proponents and opponents, yet as we detail in Section 5, their generalization in Finland has been far from a smooth harmonious diffusion (Rogers, 2003). The possibility to install heat pumps as a direct substitution for heating in detached houses (GSHPs, ASWHPs) or as an addition to heating in detached houses (ASHPs, EHPs) has made their proliferation possible without requiring wide changes in electricity or heating fields. Yet the process is not well characterized by "logical" trajectories—such as fit-and-conform trajectories or stretch and transform trajectories (Smith, 2012)—as heat-pumps have at once *fitted* but *instilled* wide systems change: first in houses, then in larger buildings and in district heating. The incumbent reaction has also varied from indifference to detached house development, resistance towards substituting district heating to heat pumps in large buildings, and being gradually adopted for endogenous renewal in industrial-scope heat pumps. The patterning of change is thus more fine-grained and partial to be adequately fitted in any one ideal typical systems change–wide trajectory or a mix of ideal typical systems change–wide trajectories (cf. Geels et al., 2016; Smith et al., 2005).

Such complex change patterns merit attention as most renewable energy technologies (e.g., solar heat, solar photovoltaics, pellet and woodchip, and micro-hydro technologies) can be deployed on different scales (Juntunen and Hyysalo, 2015). Consequently, the patterns of their proliferation in different geographic and national contexts (and relative to their global development) can form different biographies that range from confrontational to amicable biographies; from being large scale to being small scale, and vice versa; from being procured to being subsidized and onto being market based; and from being culturally familiar to being alien energies.

Without discrediting the need to capture also the global overall contours of technological change and to do country comparisons (see e.g., Heiberg et al., 2022; Miörner et al., 2022), SCM analysis can reveal finer-granular global–local patterning in both adoption and proliferation, which is arguably crucial for policy and managerial actions in specific country and regional contexts. In contrast to early development contexts and overall transition, later adoption contexts tend to feature characteristics that have barred the early proliferation in the first place yet then interface with more developed technology solutions, manufacturing processes, business models, et cetera. The relative position amidst the global development results in somewhat different patterns, for instance, patterns in the speed of the mass adoption, the nature of institutional development in public discourse, and in the user activities involved in the transition. SCM analysis can be used, for instance, to trace the loci of action between global and local development and suppliers, users, and intermediaries in the course of the generalization process, and in so doing, they can help to anticipate what may be missing if, for instance, mass markets do not seem to have been formed despite an actor group seeking to bring them into existence (for policy and managerial implications, see Section 8). Fig. 3 represents how the SCMs in Finnish heat pumps map with global and nationally specific developments, as well as with the actions involved in supply and use.

Regarding Fig. 3, we note that global–local dynamics are initially one way in that the basic solutions and earliest market experiments result in the initial domestic introduction and the formation of a nascent ecology of actors (SCM 1 and 2). The domestic market then grows through efforts

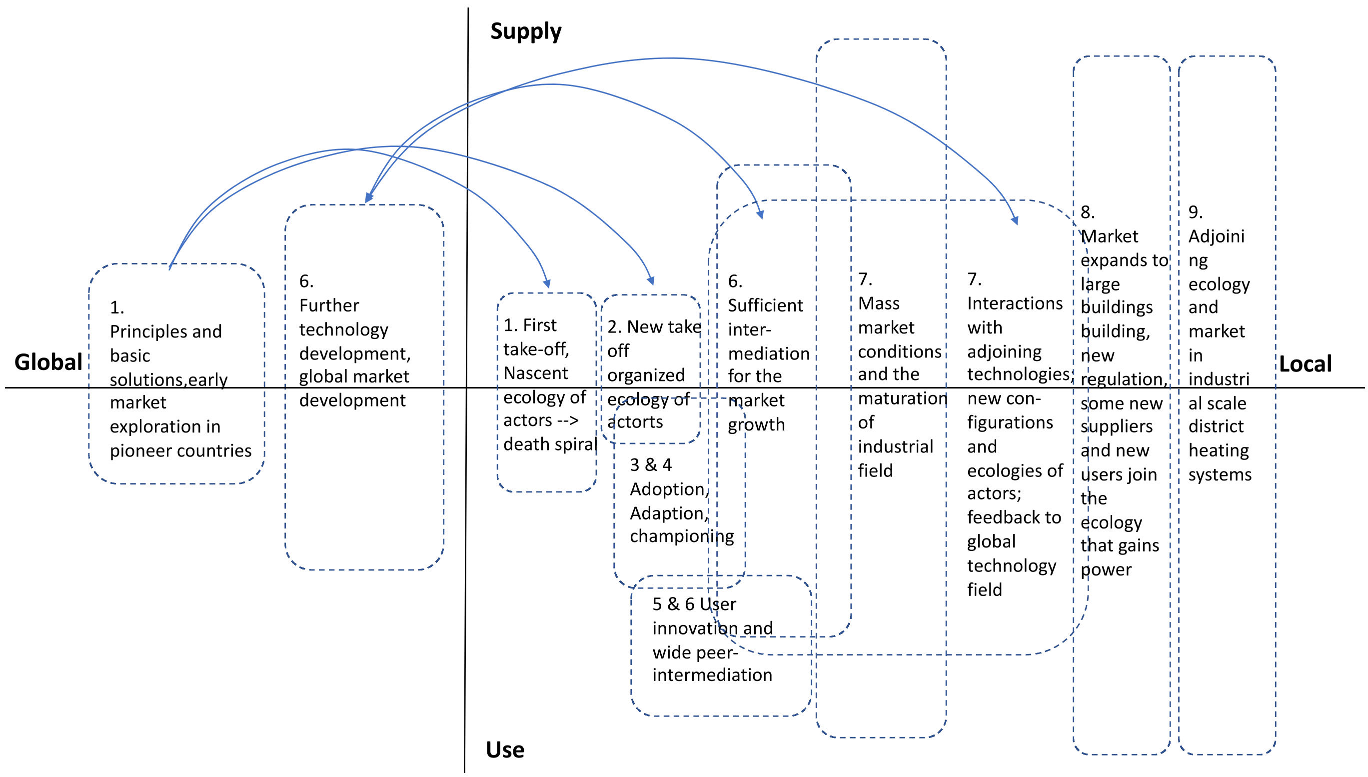


**Fig. 3.** The technology generalization SCM dynamics of Finnish heat-pump followers, plotted between global-local and supply side - use side axes.

by supply- and use-side actors alike. On the use side, adaption, championing, and peer intermediation must better suit the technology to the consumer specificities in the country (SCM 3 and 4), gaining further impetus through user innovation and wide intermediation (SCM 5 and 6). Together with the supply side of the ecology, interactive global technology improvements, and price reductions, these coalesce into sufficient intermediation for market growth (SCM 6). Only at this point, relatively late in the proliferation process (with approx. 20–25 % of the theoretical maximum market penetration; Hyysalo et al., 2022), mass market conditions emerge (SCM 7), further supported by interlinkages to adjoining technology solutions that support the technology. The now considerably more powerful and stable ecology of actors then initiates new domestic markets with which it previously could not compete (SCM 8) and the field is joined by another ecology of actors in industrial-scope installations (SCM 9). In terms of generalizing about sociotechnical change, we can conjecture the following:

a) There are necessarily locality- and country-specific developments, particularly with respect to use-side appropriation and intermediation.
b) Global–local interaction is central but subject to considerable contingencies that will shape how the patterning of sociotechnical change will take place in a given country (see the below points "e" and "f").
c) Mass-market conditions can be a major (and late) achievement, even in successful generalization processes, and by no means can they be assumed to take place or "fix" generalization.
d) The important shifts in the generalization process do not stop at mass-market take-up but may expand into further new markets and ecologies of actors, as well as lending (mutual) support to adjoining technology solutions.
e) Contingent hindering and promoting events are likely to take place during the generalization process, affecting its direction and speed.
f) Price and market characteristics will change throughout the generalization process for both field-internal developments and external developments. The improved cost-efficiency in mature and longer manufacturing runs can be curbed or boosted by taxation and other regulatory measures, adding shifts to the process.
g) The cultural image and acquaintance with the novel technology will change as the technology generalizes. Whilst the default change might be towards increasing normalcy, the cultural image may also lead to association with a specific populi and hinder generalization beyond them.

In sum, the SCM analysis underscores the need to extend technology analysis and respective policies beyond innovation, initial technology introduction, and transfer into demand- and field-shaping measures (see the conclusions and implications).

### 7.2. *User activities in technology generalization*

Several configurational movements resulted from, or were preconditioned by, the users' active engagement with the new technology, and it is thus of importance to attend to this *often-invisible work by users,* as well as to track them across the proliferation process. In our analysis, *adoption* and the consequently growing market are the prime mechanisms that signal user activities to other actors, both within the emerging field and outside it. However, adoption, particularly by later adopter segments, is importantly facilitated by a range of other engagements with the new technology. *Adaptation* and *championing* ensue when subsets of users face the need to alter the equipment or their social and technical contexts (physical houses, daily practices), and also their networks (for instance, networks related to finding professionals to do non-standard installations, clarifying permit issues, et cetera). Small subsets of people further turn to improving equipment (or saving costs) through DIY projects and *user innovations*. These activities affect other users through adding to the solution variety available to adapters, signaling further design needs to resellers and manufacturers, and by providing deep-level competence for *intermediation,* both locally in *wider user communities*, allowing these to build up into major repositories of knowledge and hotbeds of peer encouragement. User communities also affect *market creation*, may provide easily accessible and *wide intermediation* among peers, and contribute to enhancing the *legitimacy* of a novel technology. It is important to note that wide intermediation, market creation, and legitimacy are often the aggregate effects of community action rather than a "role" users play or even their purposeful activity (see Fig. 4).

These findings support examining the import of the manifold contributions that users make throughout the transition process without the findings being siloed into different disciplinary discourses (Smith, 2012). Our empirical findings surface eight user activity types, which stands in contrast to, for instance, the five user roles proposed by Schot et al. (2016) and indicates to us that it is too early to synthesize and close the list of relevant user contributions to transitions and generalization more broadly. This is particularly so as there are additional forms of citizen activism and peer finance that have been observed in other generalization process (cf. Nielsen et al., 2016; Smith, 2012). The extended time frame of the study also questions some assumptions made in other fields studying users. Even though user innovation has elsewhere been found to be concentrated in the early development phases of new technology types (Franke et al., 2006; von Hippel, 2005), in Finnish heat pumps, it continued long into the generalization process (Hyysalo, 2021; Hyysalo et al., 2022, 2017, 2013b)—this may well have happened in other small-scale energy technologies yet escaped attention as only the emblematic early stages have hitherto been systematically studied (Nielsen et al., 2016; Ornetzeder and Rohracher, 2013, 2006). Similarly, peer intermediation has been assumed to be foremost a local phenomenon (Kivimaa and Martiskainen, 2018; Stewart, 2007), but our findings show it can also have a widely distributed character.

### 7.3. Recalibrating research on generalization methodologically

We associate the SCM with a novel way of researching and theorizing about sociotechnical change that has import for both adoption- and spread-oriented research. The SCM's generalization-oriented yet empirically close-up research makes evident the need to move beyond single or small-number case research on adoption—as long argued by the proponents of the BOAP approach (Glaser et al., 2021; Hyysalo et al., 2019; Pollock and Williams, 2008).

The methodological yield of BOAP and SCM analysis towards spread-oriented research has been less elaborated but is no less important. SCM analysis shows the shortcomings of "testing" aggregate-level spread models regarding high invisibility topics, such as users' contributions to sociotechnical change. The literature synthesis model of Schot et al. (2016) has been taken as a theory to be tested by Kanger and Schot (2016) and Martiskainen et al. (2021), the latter using published work on Finnish heat pumps with interview study additions and comparing it with data from the UK. Martiskainen et al. (2021) found support for user-adopters, user-producers, and user-intermediaries in the Finnish heat-pump transition, but not for user-citizens and user-legitimators. Our analysis agrees that these are not roles that users hold in the relatively depoliticized Finnish heat-pump transition. But this is not to say that users would not have contributed to the areas of the generalization process that the constructs of Schot et al. (2016) implicate. With respect to legitimacy, the half a million moderated posts and 150 million reads in Internet communities aggregate into a legitimating discourse, whilst remarkably few of the discussants actively pursue legitimation. With respect to advocacy by citizens directed to non-users, our findings show that users champion, publicly intermediate, and contribute to market

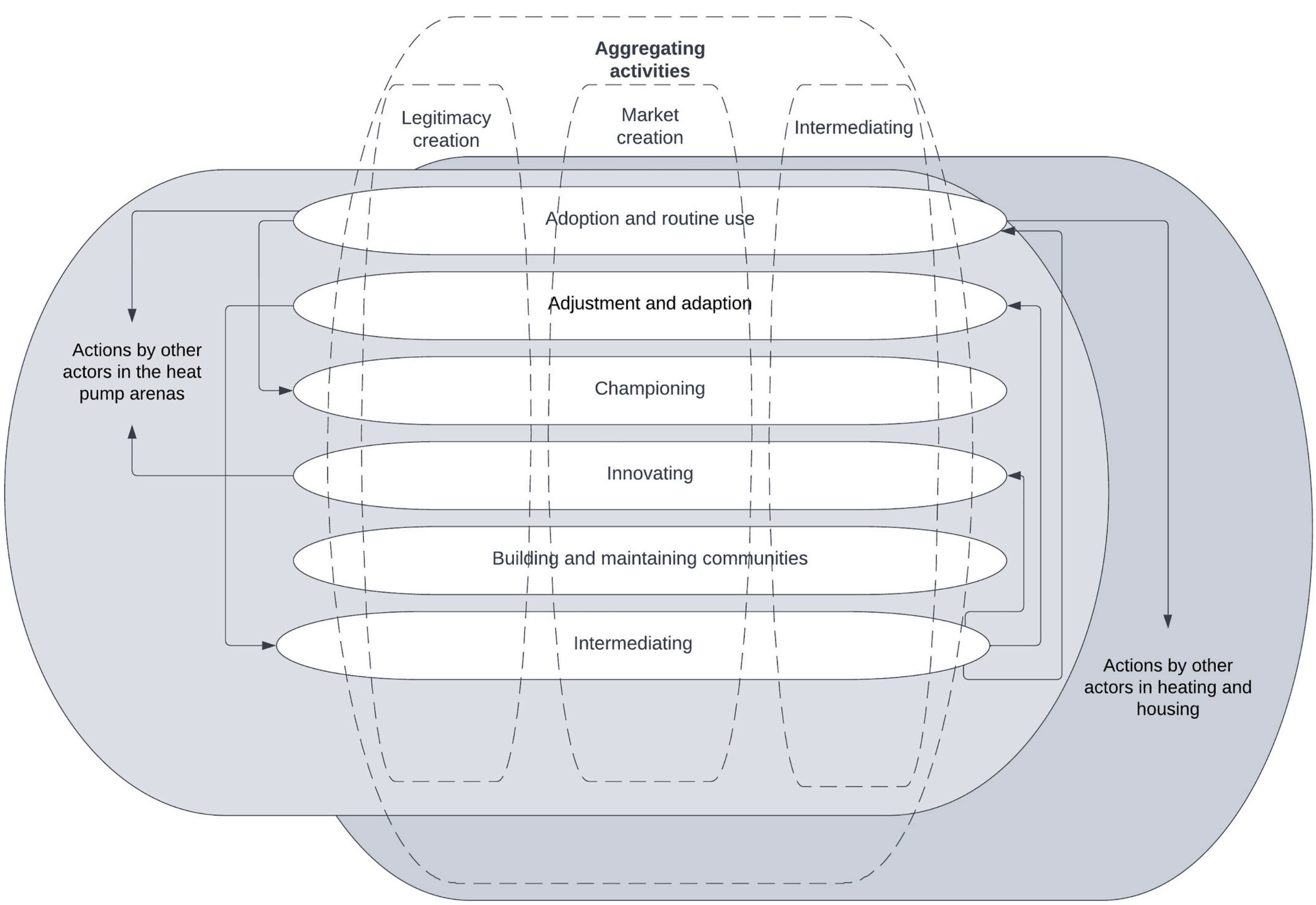


**Fig. 4.** User activities and the actor-level relationships in the technology generalization of heat pumps in Finland.

creation; in all, they create an advocacy effect, albeit (again) few users can be found who are direct citizen advocates of heat pumps. This implies that a role typology cast at whole-transition aggregation level has resulted in constructs that do not find empirical counterparts even when there is an abundance of relevant empirical phenomena involved. Thus, at least the operationalization of the typology needs to be much improved. Yet there may be also epistemic issues involved as the functionalist "transition role" imagery poorly fits the social realities in which users take action and thus it risks theorizing system roles "into being"(Jørgensen, 2012): Often, putting a small environmental subset aside, users do not seek to contribute to a transition but pursue their activities for other motivations, yet advancing sociotechnical change in doing so. This has policy importance as one cannot motivate or support people to better "perform a function" if their action is primarily motivated by something else. Equally, testing a five roles list seems premature as this overlooks empirically salient user activities (see above) and the phased importance construct of different user contributions remains without support in our analysis. Some incidences of all eight user activity types can be found in most of the "transition phases" in our study on heat pumps. But as then incidence and non-incidence cannot be used to settle the relative importance, there is a need for a schemata with which to evaluate the importance of varying incidences across the very different influencing mechanisms of innovation, adoption, consumption, intermediation, and legitimation (and so on). This is likely impossible, even in principle, and it is daunting to attempt to operationalize in practice (Hyysalo, 2021).

The SCM thus points to the need to pursue alternative theorization about generalization processes from "ground up" studies with respect to phenomena that feature empirical intricacy or invisibility (see Section 2.1) and which thus cannot be cleverly proxied from, for example, patent data or public discourse (cf. Heiberg et al., 2022).

## 8. Conclusions

SCM analysis allows generalizing the findings on adoptions to the level of abstraction used in the spread-oriented studies, helping to "connect the dots" of otherwise disconnected studies on the different aspects, sites, and settings of sociotechnical change and without losing sight of the user activities.

Recognizing that the new technology and markets undergo several transformations during the generalization process in a given setting underscores a range of policy measures that can be used to better anticipate the generalization processes and intervene once potential failures appear evident (cf. Weber and Rohracher, 2012). Field organizing on both the supply and demand sides is an area of high importance and the supply side innovation policy measures are well advanced (Weber and Rohracher, 2012). On the demand side there is clearly unexplored potential in how user activities can be best leveraged—particularly beyond user innovation, user community build-up, and establishing of marketing references (Hyysalo, 2021; Nielsen et al., 2016; von Hippel, 2017). Our results suggest that demand-inducing actions should be complemented by market making- and intermediation-related interventions, which can catalyze some of the needed transformations (Hyysalo et al., 2022). These actions can be aimed at increasing the transparency and trust of the market, and can support peer intermediation, evidencing value among users, and the creation of legitimacy for new technologies. To recalibrate the policy along generalization process developments, multi-party pathway assessment and envisioning tools can be used (Hyysalo et al., 2019). Such multi-party codesign tools can also be developed further in order to better support repeated periodic assessment that has already been developed in the context of the management of radical innovations, only now extended further into the generalization process (Poti et al., 2006).

In regard to managerial implications, the SCM could help to anticipate future technology generalization pathways and feed into companies' technology strategies. The shifts in the configurational movements can influence and be influenced by the various types of organizations contributing to R&D, manufacturing, sales, marketing, or market intermediation. In this paper our focus has been on user activities, and we are aware that our work leaves many things unaddressed or underappreciated in understanding change dynamics, ranging from one configurational movement to another in the course of generalization. A particularly nuanced examination of how organizational activities are bound to particular configurational movements and how organizational interaction with users changes over time deserves further attention in future research.

### Author statement config movements TFSC

Neither of the authors has any competing interests that could affect the data collection, analysis or reporting. Both authors have contributed to the conception, data gathering, analysis, writing and revisions of the manuscript.

No AI has been used in any of the research or writing of the manuscript.

### Data availability

The authors do not have permission to share data.

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### References

Abbott, A., 2005. Linked ecologies: states and universities as environments for professions. Sociol Theory 23, 245–274.
Agarwal, B., 1983. Diffusion of rural innovations: some analytical issues and the case of wood-burning stoves.Pdf. World Dev. 11, 359–376.
Akera, A., 2007. Constructing a representation for an ecology of knowledge: methodological advances in the integration of knowledge and its various contexts. Soc. Stud. Sci. 37, 413–441. https://doi.org/10.1177/0306312706070742.
Attewell, P., 1992. Technology diffusion and organizational learning: the case of business computing. Organ. Sci. 3, 1–19. https://doi.org/10.1287/orsc.3.1.1.
Benkler, Y., 2006. The Wealth of Networks: How Social Production Transforms Markets and Freedom. Yale University Press, New Haven.
Berker, T., Hartmann, M., Punie, Y., Ward, K. (Eds.), 2006. Domestication of Media and Technology. McGraw-Hill International, Berkshire.
Bijker, W.E., Hughes, T.P., Pinch, T.J., 1987. The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology. MIT.
Callon, M., Méadel, C., Rabeharisoa, V., 2002. The economy of qualities. Econ. Soc. 31, 194–217. https://doi.org/10.1080/03085140220123126.
Clarke, A., 2005. Situational Analysis: Grounded Theory after the Postmodern Turn. Sage.
Clarke, A., Star, S.L., 2003. Symbolic interactionist science, technology, information and biomedicine studies. In: Reynolds, L.T., Herman-Kinney, N.J. (Eds.), Handbook of Symbolic Interactionism. AltaMira Press, Walnut Creek, CA, pp. 539–574.
Cockburn, C., Ormrod, S., 1993. Gender and Technology in the Making. Thousand Oaks, Calif, Sage, London.
De Jong, J.P., Von Hippel, E.A., Gault, F., Kuusisto, J.H., Raasch, C., 2015. The diffusion of consumer-developed innovations: patterns in Finland. Res. Policy 44, 1856–1865.
De Laet, M., Mol, A., 2000. The Zimbabwe bush pump mechanics of a fluid technology. Soc. Stud. Sci. 30, 225–263.
DeSanctis, G., Poole, M.S., 1994. Capturing the complexity in advanced technology use: adaptive structuration theory. Organ. Sci. 5, 121–147.
Dewald, U., Truffer, B., 2011. Market formation in technological innovation systems—diffusion of photovoltaic applications in Germany. Ind. Innov. 18, 285–300. https://doi.org/10.1080/13662716.2011.561028.
Dewald, U., Truffer, B., 2012. The local sources of market formation: explaining regional growth differentials in German photovoltaic markets. Eur. Plan. Stud. 20, 397–420. https://doi.org/10.1080/09654313.2012.651803.
Dzebo, A., Nykvist, B., 2017. A new regime and then what? Cracks and tensions in the socio-technical regime of the Swedish heat energy system. Energy Res. Soc. Sci. 29, 113–122. https://doi.org/10.1016/j.erss.2017.05.018.
EHPA, 2022. European Heat Pump Market and Statistics Report 2021. European Heat Pump Association.

Fleck, J., 1993. Innofusion: Feedback in the innovation process. In: Stowell, F.A., West, D., Howell, J.G. (Eds.), Systems Science: Addressing Global Issues, the Language of Science. Plenum Press, New York.

Franke, N., von Hippel, E., Schreier, M., 2006. Finding commercially attractive user innovations: a test of Lead-user theory*. J. Prod. Innov. Manag. 23, 301–315.

Fuenfschilling, L., Truffer, B., 2014. The structuration of socio-technical regimes—conceptual foundations from institutional theory. Res. Policy 43, 772–791. https://doi.org/10.1016/j.respol.2013.10.010.

Geels, F.W., Schot, J., 2007. Typology of sociotechnical transition pathways. Res. Policy 36, 399–417.

Geels, F.W., Kern, F., Fuchs, G., Hinderer, N., Kungl, G., Mylan, J., Neukirch, M., Wassermann, S., 2016. The enactment of socio-technical transition pathways: a reformulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990–2014). Res. Policy 45, 896–913. https://doi.org/10.1016/j.respol.2016.01.015.

Glaser, V.L., Pollock, N., D'Adderio, L., 2021. The biography of an algorithm: performing algorithmic technologies in organizations. Organization Theory 2, 263178772110046. https://doi.org/10.1177/26317877211004609.

Grabher, G., Ibert, O., 2014. Distance as asset? Knowledge collaboration in hybrid virtual communities. J. Econ. Geogr. 14, 97–123. https://doi.org/10.1093/jeg/lbt014.

Hargreaves, T., Hielscher, S., Seyfang, G., Smith, A., 2013. Grassroots Innovations in Community Energy: The Role of Intermediaries in Niche Development. Global Environmental Change.

Heiberg, J., Truffer, B., Binz, C., 2022. Assessing transitions through socio-technical configuration analysis – a methodological framework and a case study in the water sector. Res. Policy 51, 104363. https://doi.org/10.1016/j.respol.2021.104363.

Heiskanen, E., Lovio, R., Jalas, M., 2011. Path creation for sustainable consumption: promoting alternative heating systems in Finland. J. Clean. Prod. 19, 1892–1900. https://doi.org/10.1016/j.jclepro.2011.02.005.

Heiskanen, E., Hyysalo, S., Jalas, M., Juntunen, J.K., Lovio, R., 2014a. The role of users in heating systems transitions: The case of heat pumps in Finland. In: Junginger, S., Christensen, P.R. (Eds.), The Highways and Byways to Radical Innovation: Design Perspectives. University of Southern Denmark, Kolding, Design School Kolding, pp. 171–196.

Heiskanen, E., Lovio, R., Louhija, K., 2014b. Miten uusi teknologia tulee uskottavaksi: esimerkkinä maalämpö Suomessa. Liiketaloudellinen aikakausikirja 277–298.

Heiskanen, E., Nissilä, H., Tainio, P., 2017. Promoting residential renewable energy via peer-to-peer learning. Appl. Environ. Educ. Commun. 16, 105–116. https://doi.org/10.1080/1533015X.2017.1304838.

Herbes, C., Brummer, V., Rognli, J., Blazejewski, S., Gericke, N., 2017. Responding to policy change: new business models for renewable energy cooperatives – barriers perceived by cooperatives' members. Energy Policy 109, 82–95. https://doi.org/10.1016/j.enpol.2017.06.051.

Hess, D.J., 2016. The politics of niche-regime conflicts: distributed solar energy in the United States. Environ. Innov. Soc. Trans. 19, 42–50. https://doi.org/10.1016/j.eist.2015.09.002.

von Hippel, E., 1976. The dominant role of users in the scientific instrument innovation process. Res. Policy 5, 212–239.

von Hippel, E., 2005. Democratizing Innovation. MIT Press, Cambridge Mass.

von Hippel, E., 2017. Free Innovation. The MIT Press, Cambridge, MA.

Hyysalo, S., 2010. Health Technology Development and Use: From Practice-Bound Imagination to Evolving Impacts. Routledge, London.

Hyysalo, S., 2021. Citizen Activities in Energy Transition: User Innovation, New Communities, and the Shaping of a Sustainable Future, 1st ed. Routledge, New York. https://doi.org/10.4324/9781003133919.

Hyysalo, S., Hakkarainen, L., 2014. What difference does a living lab make? Comparing two health technology innovation projects. CoDesign 10, 191–208. https://doi.org/10.1080/15710882.2014.983936.

Hyysalo, S., Juntunen, J.K., Freeman, S., 2013a. Internet forums and the rise of the inventive energy user. Sci. Technol. Stud. 26, 25–51.

Hyysalo, S., Juntunen, J.K., Freeman, S., 2013b. User innovation in sustainable home energy technologies. Energy Policy 55, 490–500.

Hyysalo, S., Johnson, M., Juntunen, J.K., 2017. The diffusion of consumer innovation in sustainable energy technologies. J. Clean. Prod. 162, 70–82.

Hyysalo, S., Juntunen, J.K., Martiskainen, M., 2018. Energy internet forums as acceleration phase transition intermediaries. Res. Policy 47, 872–885. https://doi.org/10.1016/j.respol.2018.02.012.

Hyysalo, S., Pollock, N., Williams, R.A., 2019. Method matters in the social study of technology: investigating the biographies of artifacts and practices. S&TS 32, 2–25. https://doi.org/10.23987/sts.65532.

Hyysalo, S., Heiskanen, E., Lukkarinen, J., Matschoss, K., Jalas, M., Kivimaa, P., Juntunen, J.K., Moilanen, F., Murto, P., Primmer, E., 2022. Market intermediation and its embeddeness – lessons from the Finnish energy transition. Environ. Innov. Soc. Trans. 42, 184–200. https://doi.org/10.1016/j.eist.2021.12.004.

IEA, 2021. World Energy Outlook 2021. International Energy Agency.

IPCC, 2022. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA.

Jalas, M., Hyysalo, S., Heiskanen, E., Lovio, R., Nissinen, A., Mattinen, M., Rinkinen, J., Juntunen, J.K., Tainio, P., Nissilä, H., 2017. Everyday experimentation in energy transition: a practice-theoretical view. J. Clean. Prod. 169, 77–84.

Jeppesen, L.B., Molin, M., 2003. Consumers as co-developers: learning and innovation outside the firm. Tech. Analysis & Strategic Man. 15, 363–383.

Johansson, P., 2017. A Silent Revolution - the Swedish Transition towards Heat Pumps, 1970–2015 (Doctoral Thesis). KTH Royal Institute of Technology, Stockholm, Sweden.

Johnson, M., 2013. How Social Media Changes User-Centred Design (Doctoral Thesis). Aalto University School of Science and Engineering, Espoo.

Johnson, M., Mozaffar, H., Campagnolo, G.M., Hyysalo, S., Pollock, N., Williams, R., 2014. The managed prosumer: evolving knowledge strategies in the design of information infrastructures. Inf. Commun. Soc. 17, 795–813. https://doi.org/10.1080/1369118X.2013.830635.

Jørgensen, U., 2012. Mapping and navigating transitions—the multi-level perspective compared with arenas of development. Res. Policy 41, 996–1010. https://doi.org/10.1016/j.respol.2012.03.001.

Judson, E.P., Bell, S., Bulkeley, H., Powells, G., 2015. The co-construction of energy provision and everyday practice: integrating heat pumps in social housing in England. Technology Studies 28, 26–53.

Juntunen, J.K., 2014a. Prosuming Energy–User Innovation and New Energy Communities in Renewable Micro-Generation (PhD thesis). Aalto University School of Business, Helsinki.

Juntunen, J.K., 2014b. Domestication pathways of small-scale renewable energy technologies. Sustainability: science. Practice, & Policy 10, 28–42.

Juntunen, J.K., Hyysalo, S., 2015. Renewable micro-generation of heat and electricity—review on common and missing socio-technical configurations. Renew. Sust. Energ. Rev. 49, 857–870.

Kanger, L., Schot, J., 2016. User-made immobilities: a transitions perspective. Mobilities 11, 598–613. https://doi.org/10.1080/17450101.2016.1211827.

Kanger, L., Geels, F.W., Sovacool, B., Schot, J., 2019. Technological diffusion as a process of societal embedding: lessons from historical automobile transitions for future electric mobility. Transp. Res. Part D: Transp. Environ. 71, 47–66. https://doi.org/10.1016/j.trd.2018.11.012.

Kivimaa, P., Martiskainen, M., 2018. Dynamics of policy change and intermediation: the arduous transition towards low-energy homes in the United Kingdom. Energy Res. Soc. Sci. 44, 83–99. https://doi.org/10.1016/j.erss.2018.04.032.

Köhler, J., Geels, F.W., Kern, F., Markard, J., Onsongo, E., Wieczorek, A., Alkemade, F., Avelino, F., Bergek, A., Boons, F., Fünfschilling, L., Hess, D., Holtz, G., Hyysalo, S., Jenkins, K., Kivimaa, P., Martiskainen, M., McMeekin, A., Mühlemeier, M.S., Nykvist, B., Pel, B., Raven, R., Rohracher, H., Sandén, B., Schot, J., Sovacool, B., Turnheim, B., Welch, D., Wells, P., 2019. An agenda for sustainability transitions research: state of the art and future directions. Environ. Innov. Soc. Trans. 31, 1–32. https://doi.org/10.1016/j.eist.2019.01.004.

Kohtala, C., 2016. Making Sustainability : How Fab Labs Address Environmental Issues (PhD thesis). Aalto University School of Arts, Design and Architecture, Helsinki.

Kohtala, C., Hyysalo, S., Whalen, J., 2020. A taxonomy of users' active design engagement in the 21st century. Des. Stud. 67, 27–54. https://doi.org/10.1016/j.destud.2019.11.008.

Kuznetsov, S., Paulos, E., 2010. Rise of the Expert Amateur: DIY Projects, Communities, and Cultures, in: Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries. ACM, New York, pp. 295–304.

Latour, B., 2005. Reassembling the Social: An Introduction to Actor-Network-Theory, Clarendon Lectures in Management Studies. Oxford University Press, Oxford ; New York.

Lauttamäki, V., 2018. Geoenergia kiinteistöjen lämmitysratkaisujen markkinoilla Suomessa energiakriisien ajoista 2030-luvulle (Doctoral Thesis). University of Turku, Turku, Finland.

Lauttamäki, V., Hyysalo, S., 2019. Empirical application of the multi-level perspective: tracing the history of ground-source heat pumps systems in Finland. Sustainability: science. Practice and Policy 15, 82–103. https://doi.org/10.1080/15487733.2019.1678372.

Leminen, S., Westerlund, M., Nyström, A.-G., 2014. On becoming creative consumers - user roles in living labs networks. Int. J. Technol. Mark. 9, 33–52.

Leonard-Barton, D., 1995. Wellsprings of Knowledge: Building and Sustaining the Sources of Innovation. Harvard Business School Press, Boston, Mass.

Lie, M., Sørensen, K.H. (Eds.), 1996. Making Technology our Own?. Domesticating Technology into Everyday Life. Scandinavian University Press, Oslo.

Lundqvist, P., 2008. The heat pump in the refurbishment of existing buildings perspectives from Sweden. In: joint REHVA/AICARR workshop on the refurbishment of existing buildings. Milan, Italy. 31 October 2008. Milan, Italy.

Martiskainen, M., 2014. Developing Community Energy Projects: Experiences from Finland and the UK. University of Sussex, Brighton, UK.

Martiskainen, M., Kivimaa, P., 2018. Creating innovative zero carbon homes in the United Kingdom — intermediaries and champions in building projects. Environ. Innov. Soc. Trans. 26, 15–31. https://doi.org/10.1016/j.eist.2017.08.002.

Martiskainen, M., Schot, J., Sovacool, B.K., 2021. User innovation, niche construction and regime destabilization in heat pump transitions. Environ. Innov. Soc. Trans. 39, 119–140. https://doi.org/10.1016/j.eist.2021.03.001.

Mattinen, M., Nissinen, A., Hyysalo, S., Juntunen, J.K., 2015. Energy use and greenhouse gas emissions of air-source heat pump and innovative ground-source air heat pump in cold climate. J. Ind. Ecol. 19, 61–70.

McLaughlin, J., 1999. Valuing Technology: Organisations, Culture, and Change. Routledge, London.

Meelen, T., Truffer, B., Schwanen, T., 2019. Virtual user communities contributing to upscaling innovations in transitions: the case of electric vehicles. Environ. Innov. Soc. Trans. 31, 96–109. https://doi.org/10.1016/j.eist.2019.01.002.

Miörner, J., Heiberg, J., Binz, C., 2022. How global regimes diffuse in space – explaining a missed transition in San Diego's water sector. Environ. Innov. Soc. Trans. 44, 29–47. https://doi.org/10.1016/j.eist.2022.05.005.

Motiva, 2012. ELVARI ilmalämpöpumpun energiataloudellinen käyttö [WWW Document]. URL. https://www.motiva.fi/files/3472/Ilmalampopumpun_energiataloudellinen_kaytto.pdf. accessed 3.13.19.
Mozaffar, H., 2016. User communities as multifunctional spaces: Innovation, collective voice, demand articulation, peer informing and professional identity (and more). In: Hyysalo, S., Jensen, T.E., Oudshoorn, N. (Eds.), New Production of Users: Changing Innovation Collectives and Involvement. Routledge, S.l., pp. 219–248
Murto, P., Jalas, M., Juntunen, J., Hyysalo, S., 2019a. Devices and strategies: an analysis of managing complexity in energy retrofit projects. Renew. Sust. Energ. Rev. 114, 109294 https://doi.org/10.1016/j.rser.2019.109294.
Murto, Pekka, Jalas, M., Juntunen, J., Hyysalo, S., 2019b. The difficult process of adopting a comprehensive energy retrofit in housing companies: barriers posed by nascent markets and complicated calculability. Energy Policy 132, 955–964. https://doi.org/10.1016/j.enpol.2019.06.062.
Nielsen, K.H., 2016. How user assemblage matters: Constructing learning by using in the case of wind turbine Technology in Denmark. In: Hyysalo, S., Jensen, T.E., Oudshoorn, N. (Eds.), New Production of Users: Changing Innovation Collectives and Involvement. Routledge, S.l., pp. 101–122
Nielsen, K.R., Reisch, L.A., Thøgersen, J., 2016. Sustainable user innovation from a policy perspective: a systematic literature review. J. Clean. Prod. 133, 65–77.
Numminen, S., Silvikko de Villafrance, M., Hyysalo, S., 2023. Päälämmityslähteestä monilämmitykseen: suomalaisista pientaloista on tullut toisiaan täydentävien ja vuorottelevien energiajärjestelmien hybrideitä. Alue & Ympäristö.
Nyborg, S., 2015. Pilot users and their families: inventing flexible practices in the smart grid. Sci. Technol. Stud. 28, 54–80.
Ornetzeder, M., Rohracher, H., 2006. User-led innovations and participation processes: lessons from sustainable energy technologies. Energy Policy 34, 138–150.
Ornetzeder, M., Rohracher, H., 2013. Of solar collectors, wind power, and car sharing: comparing and understanding successful cases of grassroots innovations. Glob. Environ. Chang. 23, 856–867.
Oudshoorn, N., Pinch, T.J. (Eds.), 2003. How Users Matter: The co-Construction of Users and Technology. MIT Press, Cambridge, Mass.
Peters, G.P., Andrew, R.M., Canadell, J.G., Fuss, S., Jackson, R.B., Korsbakken, J.I., Le Quéré, C., Nakicenovic, N., 2017. Key indicators to track current progress and future ambition of the Paris agreement. Nat. Clim. Chang. 7, 118–122. https://doi.org/10.1038/nclimate3202.
Pfaffenberger, B., 1992. Technological dramas. Sci. Technol. Hum. Values 17, 282.
Pollock, N., Williams, R., 2008. Software and Organisations: the biography of the Enterprise-wide system or how SAP conquered the world. Routledge, London. https://doi.org/10.4324/9780203891940.
Poti, B.M., Mourik, R.M., Raven, R.P.J.M., Jolivet, E., Alcantud Torrent, A., Bauknecht, D., Brohmann, B., Feenstra, C.F.J., Fritsche, U.R., Fucsko, J., Heiskanen, E., Hodson, M., Maack, M.H., Oniszk-Poplawska, A., Schaefer, B., 2006. Manual on the Socrobust tool and recent experiences with using Socrobust: Deliverable 1 (ECN-E–07-049). Create Acceptance, EC.
Redmond, W.H., 2003. Innovation, diffusion, and institutional change. J. Econ. Issues 37, 665–679. https://doi.org/10.1080/00213624.2003.11506608.
Robinson, D., Borras, S., Boon, W., Rogge, K., 2022. Generalisation: Reimagining the Diffusion of Innovation in an Era of Grand Societal Challenges. Technological Forecasting and Social Change.
Rogers, E.M., 2003. Diffusion of Innovations, 5th ed. Free Press, New York.
Rosen, P., 2002. Framing Production: Technology, Culture, and Change in the British Bicycle Industry. MIT Press, Cambridge, Mass, Inside technology.
Ryghaug, M., Skjølsvold, T.M., 2021. Pilot society and the energy transition: the co-shaping of innovation, participation and politics. Springer International Publishing, Cham. https://doi.org/10.1007/978-3-030-61184-2.
Salmela, E., 2021. Ajattelin kysyä palstan asiantuntijoilta ennen kääntymistä lipevien myyntimiesten puoleen. In: Erikoisalaan liittyvien neuvojen ja tiedon pyytäminen verkkoyhteisöissä. University of Vaasa, Vaasa (Doctoral Thesis).
Schot, J., Kanger, L., Verbong, G., 2016. The roles of users in shaping transitions to new energy systems. Nat. Energy 1, 16054.
Sengers, F., Turnheim, B., Berkhout, F., 2021. Beyond experiments: embedding outcomes in climate governance. Environment and Planning C: Politics and Space 39, 1148–1171. https://doi.org/10.1177/2399654420953861.
Seyfang, G., 2010. Community action for sustainable housing: building a low-carbon future. Energy Policy 38, 7624–7633. https://doi.org/10.1016/j.enpol.2009.10.027.
Seyfang, G., Hielscher, S., Hargreaves, T., Martiskainen, M., Smith, A., 2014. A grassroots sustainable energy niche? Reflections on community energy in the UK. Environ. Innov. Soc. Trans. 13, 21–44. https://doi.org/10.1016/j.eist.2014.04.004.
Silvast, A., Virtanen, M.J., 2023. On Theory–Methods Packages in Science and Technology Studies. Sci. Technol. Hum. Values 48, 167–189. https://doi.org/10.1177/01622439211040241.
Silverstone, R., Hirsch, E., Morley, D., Hirsch, E., 1992. Information and communication technologies and the moral economy of the household. In: Silverstone, R. (Ed.), Consuming Technologies: Media and Information in Domestic Spaces. Routledge, London, pp. 15–31.
Slater, D., Miller, D., 2007. Moments and movements in the study of consumer culture: a discussion between Daniel Miller and Don Slater. J. Consum. Cult. 7, 5–23. https://doi.org/10.1177/1469540507073506.
Smith, A., 2012. Civil society in sustainable energy transitions. In: Verbong, G., Loorbach, D. (Eds.), Governing the Energy Transition: Reality, Illusion or Necessity? Routledge, New York, pp. 180–202.
Smith, A., Stirling, A., Berkhout, F., 2005. The governance of sustainable socio-technical transitions. Res. Policy 34, 1491–1510.
Smith, A., Fressoli, M., Thomas, H., 2014. Grassroots innovation movements: challenges and contributions. J. Clean. Prod. 63, 114–124.
Smith, A., Hargreaves, T., Hielscher, S., Martiskainen, M., Seyfang, G., 2016. Making the most of community energies: three perspectives on grassroots innovation. Environ. Plan. A 48, 407–432.
Sørensen, K.H., Williams, R. (Eds.), 2002. Shaping Technology, Guiding Policy: Concepts, Spaces, and Tools. Elgar, Cheltenham, UK.
Star, S.L. (Ed.), 1995. Ecologies of Knowledge: Work and Politics in Science and Technology, SUNY Series in Science, Technology, and Society. State University of New York Press, Albany.
Star, S.L., Griesemer, J.R., 1989. Institutional ecology, "translations" and boundary objects: amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. Soc. Stud. Sci. 19, 397–420.
Star, S.L., Strauss, A., 1999. Layers of silence, arenas of voice: the ecology of visible and invisible work. Comput. Supported Coop. Work 8, 9–30.
Stewart, J., 2007. Local experts in the domestication of information and communication technologies. Inf. Commun. Soc. 10, 547–569. https://doi.org/10.1080/13691180701560093.
Stewart, J., Hyysalo, S., 2008. Intermediaries, users and social learning in technological innovation. Int. J. Innov. Manag. 12, 295–325.
Strauss, A., 1978. A social world perspective. Studies in Symbolic Interaction 1, 119–128.
Strauss, A.L., 1993. Continual Permutations of Action. Communication and social order, Aldine de Gruyter, New York.
Suchman, L., n.d. Making work visible. Commun. ACM 38.
SULPU - Suomen Lämpöpumppuyhdistys, 2022. Heat pump statistics, p. 2022.
Szymanski, M.H., Whalen, J., 2011. Making Work Visible: Ethnographically Grounded Case Studies of Work Practice, Learning in Doing : Social, Cognitive, and Computational Perspectives. Cambridge University Press, Cambridge, New York.
Truffer, B., 2003. User-led innovation processes: the development of professional car sharing by environmentally concerned citizens. Innovation: The European Journal of Social Science Research 16, 139–154.
Van Winden, W., Van Den Buuse, D., 2017. Smart City pilot projects: exploring the dimensions and conditions of scaling up. J. Urban Technol. 24, 51–72. https://doi.org/10.1080/10630732.2017.1348884.
Verhaegh, S., Oudshoorn, N., 2016. Innovation in civil society: The socio-material dynamics of community innovation. In: Hyysalo, S., Jensen, T.E., Oudshoorn, N. (Eds.), New Production of Users: Changing Innovation Collectives and Involvement. Routledge, New York, pp. 193–218.
Voss, A., 2009. Configuring User-Designer Relations: Interdisciplinary Perspectives. Springer.
Walker, G., Cass, N., 2010. Public Roles and Socio-Technical Configurations: Diversity in renewable energy deployment in the UK and its implications. In: Devine-Wright, P (Ed.), Renewable energy and the public from Nimby to participation. Earthscan, London, pp. 43–56.
Walker, G., Devine-Wright, P., 2008. Community renewable energy: what should it mean? Energy Policy 36, 497–500.
Weber, K.M., Rohracher, H., 2012. Legitimizing research, technology and innovation policies for transformative change. Res. Policy 41, 1037–1047. https://doi.org/10.1016/j.respol.2011.10.015.
Wigboldus, S., Klerkx, L., Leeuwis, C., Schut, M., Muilerman, S., Jochemsen, H., 2016. Systemic perspectives on scaling agricultural innovations. A review. Agron. Sustain. Dev. 36, 46. https://doi.org/10.1007/s13593-016-0380-z.
Williams, R., Stewart, J.K., Slack, R.S., 2005. Social Learning and Technological Innovation. Edward Elgar, Cheltenham.
Zarazua De Rubens, G., Noel, L., Sovacool, B.K., 2018. Dismissive and deceptive car dealerships create barriers to electric vehicle adoption at the point of sale. Nat. Energy 3, 501–507. https://doi.org/10.1038/s41560-018-0152-x.

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