3 Initial focus

User innovation in sustainable energy technologies

3.1 Introduction: the active and inventive users of renewable energy technologies¹

Energy innovation has traditionally appeared as a context dominated by research institutes and large incumbent companies, exemplifying a science push in technological change. Technological improvements are seen to emanate from research laboratories and find their way to end consumers via suppliers, retailers, assemblers, maintenance providers, and promotional agencies (Shove, 2010). In this scheme of things, consumer attitudes and perceptions of technology act as predictors of users' adoption (Klein and Rosenberg, 1996; Rogers, 2010; Coombs et al., 1987) and the key issue becomes how to overcome the "social" or "non-technical" obstacles to the flow of adequate energy technology and knowledge into practice (Shove, 2010).

But things are changing, and the reality may have never been so one-directional. Research on residential energy use has consistently found great variations in energy use among similar households (Lutzenhiser, 1993; Guerin et al., 2009) resulting from what consumers do with their products and systems (thermostat settings, the number of showers and the length of showers, leaving lights on, etc.). And rather than following on simply from energy attitudes or diligence to adopting the technology, many differences result from how end-users adopt and adapt the technologies to their local conditions and the particularities of their houses and everyday practices (Shove et al., 2007; Caird and Roy, 2008). The importance of skillful adoption and finding a well-suited blend of appropriate technology options and energy practices has thus been raised to the fore (Heiskanen et al., 2010; Raven et al., 2008).

Similarly important are activities and skills in DIY house and energy efficiency renovations including smaller and larger adaptations to the technology in order to make them suited for the local conditions (Caird and Roy, 2008; Hargreaves et al., 2013; Shove et al., 2007; deVries et al., 2016). This is particularly the case with S-RETs that are directly associated with the existing building stock. The standard technology needs to be fitted to different, country-specific variations of housing, climate, and regulation, as well as to the often considerable variation that results from the particularities of

residential buildings and house owners' everyday practices (Heiskanen et al., 2014; Nyborg, 2015; Judson et al., 2015). Capitalizing on such innovations-in-practice has been seen as part of "Grassroots innovation" (Seyfang, 2010; Heiskanen and Lovio, 2010).

In contrast to the centralized forms of energy provision that leaves only relatively passive roles available to consumers, S-RET systems give their users first-hand access to observe, modify, and improve their equipment. This can result in most thoroughgoing consumer engagement with their energy technology, namely the development of new-to-the-world innovations to the renewable home heating equipment itself. Such extensive citizen innovation activities have been documented in the early formative stages of renewable energy technology development. The role of grassroots communities in the wind turbine development in Denmark (Ornetzeder and Rohrer, 2013; Nielsen, 2016), the emergence and maturation of solar collector development in Austria, and user roles in passive house development in Germany are well documented (Ornetzeder and Rohrer, 2006). In the course of this chapter we see how such consumer innovation is not limited to early technology development stages and exceptional localities, but can be found in 'follower' countries as well and also in the later stages of technology development.

3.2 Consumer innovation and its diffusion

In a broader view, the inventive energy consumers are not exceptional. Users in many other walks of life have been documented to develop technology on their own, both with regard to industrial products and consumer products (for overviews, see von Hippel, 2016; Bogers et al., 2010; Gambardella et al., 2017). In specialist communities, as many as 19–36% of the users of industrial products and 10–38% of the users of consumer products have been found to modify products (for a review, see von Hippel, 2005). In representative surveys of the populations of, for example, Japan, the US, the UK, Canada, and Finland, 3.7–6.1% of consumers reported having created or modified some of the equipment they use (von Hippel, 2016). The sum totals of their reported expenditure (in the US: \$20bn) range from 13% of the total R&D expenditure on consumer products in Japan to 144% of the total R&D expenditure on consumer products in the UK. These users often freely or selectively reveal their innovations within their communities, as well as to companies, creating the phenomenon of open user innovation (Jeppesen and Frederiksen, 2006; Piller and West, 2014). Here *user* denotes any user who directly benefits from an innovation, be this in a professional or consumer context, whereas *consumers* are a non-professional and non-organizational subset of users.

Because of the large proportion of users who develop or modify products and the great amount of time and money they put into their projects, the diffusion of consumer innovations is one of the recent areas of interest in user and open user-innovation research (De Jong et al., 2015; Piller and West, 2014; von Hippel et al., 2017). There are indications that the spread of user innovations

could be structurally hampered. Unlike producers, users do not have to invest in selling the innovation to others to benefit from it—they are innovating for themselves (von Hippel, 1976). From this it follows that efforts to diffuse the innovation may come as something extra and require that users appropriate a new role—either helping others (Freeman, 2007; Habicht et al., 2013), raising their professional profile (von Hippel et al., 2017), or turning into entrepreneurs (Shah and Tripsas, 2007). The last option aside, the gains users may enjoy from their effort to render their innovation diffusible may not be appealing, even if their innovation was socially valuable. “Under-diffusion” may thus prevail, which may present a market failure from a welfare economics point of view (De Jong et al., 2015; von Hippel et al., 2017). For example, Von Hippel and DeMonaco (2017) found that user innovators in medical drugs and devices seldom invest time in publishing their inventions in medical journals but rather only spread them through word of mouth. Similarly, in extreme sports many consumer innovations are initially rough design-wise, and wider adoption only occurs after additional efforts to make them more usable (Baldwin et al., 2006; Hyysalo, 2009). These conditions assumedly equally affect the consumers who innovate in the S-RETs. The research on the diffusion of consumer innovations in S-RETs and energy efficiency remains nascent, basically being limited to documenting that some diffusion has happened (Ornetzeder and Rohrer, 2006, 2013; Nygren et al., 2015; Gavin and Sunikka-Blank, 2014).

At the same time, the increasing digital connectivity among peers provides a range of communication channels to connect physically separated users. Various forms of user communities—ranging from online and consumer-driven hobbyists (e.g., Hyysalo et al., 2013a; Jeppesen and Frederiksen, 2006; Jeppesen and Molin, 2003; Marchi et al., 2011; Haavisto, 2014) to off-line and professional communities (Desouza et al., 2007; Usenyuk et al., 2016)—are supportive of sharing with peers, creating innovations together, and adoption from peers (Jeppesen and Fredriksen, 2006; Hienert et al., 2014; Hyysalo and Usenyuk, 2015).

The nature of the adoption of innovation by peers can have important variations, leading us back to observations of what consumers do when they adopt a new technology. As noted in Chapter 2, since the 2000s diffusion research has increasingly moved beyond *surveys of the adoption decision* onto detailed studies of *actual adoption processes* (Rogers, 2010), as adoption was commonly found to include *adaptations*, including resignifying, repurposing, adding on, modifying, or substantially redesigning the technology (Agarwal, 1983; DeSanctis and Poole, 1994; Douthwaite et al., 2001; Fleck, 1993b; Juntunen, 2014a; McLaughlin, 1999; Kohtala et al., 2020). Adaptation is asserted to increase the adoption of innovation by making it possible to adjust it to the cognitive, social, and material needs of the adopter (Agarwal, 1983; Fleck, 1993b; Rogers, 2010) and has been found to present an alternative to “straight transfer” diffusion in cases when users can turn to adaptation (Agarwal, 1983). An even more thorough blending of innovation and diffusion—“innofusion”—has been documented in rural wells, health programs, industrial robotics, multimedia

and digital environs, agriculture, and vehicles (De Laet and Mol, 2000; Fleck, 1993b; Hyysalo and Usenyuk, 2015; Williams et al., 2005). It follows that attention should be given to the form of the innovations and the form in which they are communicated to peers, as well as to the form in which these innovations have then been adopted/adapted by peers.

The research interests in this chapter are thus twofold. First, we are interested in whether consumers innovate in an S-RET after the initial development stages, and if so where in the technical system can they innovate and how do they gain the competencies needed to do so. Second, we are interested in how the innovations by consumers diffuse, do they do so via commercial routes or among peers, and what forms does peer diffusion take and why?

These questions mean clarifying if the innovations by consumers make a difference by adding to the variety of technical solutions available in a given S-RET's development and diffusion. We shall also lay the ground for Chapters 4 and 5 by beginning to address the issue of what else is being created by consumers' innovation projects beyond just the solutions, as competence building and peer support may play important roles beyond their roles in innovating.

The chapter is structured as follows. We first examine what users are inventing in sustainable energy technologies and examine where in the technical systems users are able to invent and what issues appear to channel or curb users' inventive actions (Section 3.3). We then focus on the potential of user inventions in expert evaluation and in the LCA analysis of selected innovations, followed by the analysis of their diffusion (Section 3.4) and the chapter's discussion (Section 3.5).

3.3 Consumer inventions in Finnish S-RET systems

The activity of citizen end-users in energy-related adaptations is commonly thought of as being limited to add-ons and DIY renovation, using power tools and the help of DIY videos found on the internet (Shove et al., 2007). This would boil down to technically simple additions, such as placing a sledge under an outdoor air-source heat pump (ASHP) unit in order to remove ice in the winter or building housing for an ASHP in order to make it more aesthetically appealing (Figure 3.1). Such simple add-ons should not be belittled as they ease the use and uptake of new technology and its fit with preferences of its adopters.

However, the user inventions in S-RET technologies also include commercialized products and the very technically sophisticated rebuilding of machinery (see Figure 3.1, bottom row); in fact, they span a whole range of additions, adaptations, reinventions, and new designs, which we discuss in detail below.

3.3.1 User inventions in air-source heat pumps

In our search we found 79 consumer innovations in ASHPs. Thirty of these were *system-level designs* that spanned several subsystems of the technology.

Figure 3.1 Examples of user designs in S-RET systems. A sledge used for ice removal (top left²), a housing for an air-heat pump (top middle³), and a wood pellet burning basket (top right⁴). An example of an advanced heat pump (bottom left⁵) and a wood pellet burning user project (bottom right⁶). Images freely available on the internet, research use granted by Finnish law.

We identified 25 *user modifications*, technical redesigns that were limited to one subsystem. Just as important were 24 cases where user inventiveness was best described as *user add-ons*, *repurposing*, *hacks*, *relocating*, or *workaround*. Let us first give short examples in order to characterize user inventions in these categories and then present a more encompassing view of these inventions in Table 3.1 that classifies the inventions according to subsystems of the ASHP technology.

An example of user design: turning an ASHP into an air-to-water heat pump (ASWHP). Several people turned ASHP models into ASWHPs by removing the ASHP's indoor convector unit and connecting the outdoor air-source collector into a liquid circuit in the water central heating of the house. The design required reconfiguring the coolant circuit, building the indoor circuit heat exchanger, adding new sensors and a control logic for both indoor and outdoor units, creating reference data for a successful control, etc. While the

Table 3.1 User inventions in ASHPs

<i>The part of the technical system</i>	<i>The subsystem</i>	<i>The no. inventions</i>	<i>An example of the invention by consumer</i>
An outdoor ASHP unit	Installation location	2	An outdoor heat-pump unit is installed in an empty space below the roof or floor in order to gain warmer source air
An ASHP unit	Installation conditions	1	Covering the unit with a roof or within an overall cover
An outdoor ASHP unit	A melting mechanism for the bottom cover	9	Adding a resistor parallel to the sensor
An outdoor ASHP unit	A melting mechanism for the outdoor collector coil	4	Using an IR heater to prevent the formulation of frost and ice on the coil
An outdoor ASHP unit	An add-on for the outdoor unit	4	Air input comes from a system that is built from plexiglass
An outdoor ASHP unit	Channeling the water out from the unit	6	The construction of inclines using hard-to-freeze material inside the outdoor unit in order to prevent ice from blocking drainage
An outdoor ASHP unit	Handling water outside of the unit	4	Placing a plastic sledge below the unit to store accumulated ice
An ASHP refrigerant system	Refrigerant fluid	1	Adding propane to 410a refrigerant to improve its functioning
An ASHP heat exchanger	A hot water tank	4	A radiator hot water tank constructed from an old oil tank
An ASHP system	Water circulation	1	Finding a way to install pipes closer to the floor surface than in commercially available models
An internal ASHP unit	Repurposing an ASHP as an ASWHP	15	The removal of the internal unit, replacing it with a water heat exchanger; changes to the control logic are required
The repurposing of an ASHP	Repurposing an ASHP as a geothermal heat pump	1	The outdoor coil is replaced with a heat-exchanger panel
An external ASHP unit	Repurposing a swimming pool heat pump	1	The utilization of recycled material to achieve new functioning

(Continued)

Table 3.1 Continued

<i>The part of the technical system</i>	<i>The subsystem</i>	<i>The no. inventions</i>	<i>An example of the invention by consumer</i>
An internal ASHP unit	Repurposing the internal unit	1	Using the unit as a blow convector
An outdoor ASWHP unit	Utilizing cooled air from the outdoor unit	1	Summertime cooled air can be tunneled back to the apartment for cooling purposes when the pump is just used for heating hot water
An ASHP remote control	An add-on for an internal unit	5	A PC soundcard-based control to replace the remote control and increase the control distance
An internal ASHP unit	Mechanical structure	1	Spraying “noise killer” to reduce the noise of the internal unit
An internal ASHP unit	Sensors in the internal unit	4	Adding transistors and a resistor in order to hack the internal sensor and achieve a lower minimum temperature
An ASHP system	An add-on for monitoring and controlling the overall unit performance	10	The utilization of weather forecasts from the Wunderground weather service in order to optimize performance
An ASHP system	System-level design	4	A DIY unit for industrial buildings
	Total	79	

energy saving is not usually on a par with a commercial ASWHP, the cost is only 10% of an off-the-shelf ASWHP.

An example of user modification and repurposing: adding a resistor to an ASHP to make it maintain an 8°C temperature. Several users fooled the indoor temperature sensors of their ASHPs (in various technical ways) in order to achieve a sought-after lower indoor temperature. In cold countries, garages, summer cabins, and other non-lived-in spaces are heated to non-freezing temperatures in the winter. Heat pumps would cut this maintenance energy use significantly, but only if rigged to work below their minimum specification temperature, usually 16°C. The latest commercially available ASHPs support this type of functionality but at a considerably higher price than rigged cheap models.

An example of a user add-on to an ASHP: A remote control is provided with several ASHP models to control, for example, the temperature and strength of the air flow. When the home includes several energy technologies, home automation systems are often used to simplify the daily use of the systems. The

home automation can be PC based and can monitor and control several systems within the house. Users developed an add-on USB-connected infrared box, which is used to replace the infrared remote control of the internal unit and control the heat pump via the automation system.

Let us now shift the perspective to consider the clustering of such inventions within the technological configuration of this technology. Table 3.1 discusses the extent and distribution of the found user inventions within ASHP parts and technical subsystems.

Most modifications have been dedicated to the outdoors unit's problems with freezing and to the replacement of the indoor convector unit with water circulation. What is salient, however, is that users were able to invent in virtually all parts of the technical system, including the coolant gas mixes, control logics, and system-level design. Only three parts of the configuration were left untouched by the studied inventing users: the insides of the compressor unit, the reversing valve, and the expansion device.

These user activities with ASHPs make it clear that some users' capacity to improve their energy technology is considerable. Alongside a few new-to-the-world inventions with commercial potential, a fair amount of other limited improvements emerged. This is noteworthy as heat pumps are not the easiest or most likely sites for user invention because of their technical complexity, mass production, low configurability, manufacturer disinterest in niche development, equipment integrating several technology areas (coolant systems, electronics, mechanics, software, and, in ASWHPs, also plumbing), and the loss of warranty and insurance coverage upon making modifications.

In user forum discussions and in our interviews with the inventors, the inventions were seen to be spurred on by the inadequacies of most commercial models in regard to dealing with cold climates and the ensuing room for improving their energy efficiency and usability. The relatively cheap price of ASHP models, particularly of the lower-end models encouraged experimentation, as did advice received in user-run internet forums where heat-pump owners exchange experiences, ideas, and help.

3.3.2 User inventions in ground-source heat pumps

In ground-source heat pumps (GSHPs) we found four system-level designs, eight user modifications, and 14 user add-ons, repurposings, hacks, relocations, or workarounds. Let us again first present short examples to characterize user inventions in these categories and then clarify their range and extent (see Table 3.2) according to the subsystems of GSHP technology.

An example of user design: an ASHP with a ground-source outdoor circuit. The typical GSHP is connected to a water circulation based central heating system, which houses heated with direct electricity do not have. An air-heat-pump convector unit with a ground-source outdoor circuit enables a cost-competitive GSHP solution that suits this building stock. The outdoors unit of heat pump, as well as

Table 3.2 User inventions in GSHPs

<i>The part of the technical system</i>	<i>The subsystem</i>	<i>The no. of user inventions</i>	<i>An example descriptor of the user invention</i>
GSHP	An add-on for monitoring and controlling the overall unit performance	8	Using a Linux USB drive for storing automation data; low power consumption compared to a constantly powered PC
GSHP	An add-on for monitoring the ground heat exchanger	4	Using extra temperature sensors for measurements with a ground heat exchanger
A GSHP outdoor coil	Coil location or modified use of coil and well	5	The coil is embedded in wastewater infiltration ground
GSHP/geothermal heat-to-air pump	System-level design	1	An air-heat pump with an underground air/liquid pipe
GSHP superheating buffer tank	Water piping	2	Changing the valve to a thermostat valve to gain improved performance
An outdoor GSHP unit	Well	2	Use of a plastic drainpipe to build a maintenance well
A GSHP add-on	An add-on for the control logic	1	The transfer of exhaust heat to the GSHP source field
A GSHP add-on	An external hot water tank as an add-on	2	The system is designed to work with a small domestic hot water tank; a separate lower-temperature tank is installed for circulating water
Radiators	The heat distribution system	1	Increasing heat distribution with a fan with radiators
	Total	26	

the control logic and connections between inside and outside units, are modified. The “GSAHP” user innovation is commercialized by Jääsähkö Oy in Finland.

An example of user modification to a GSHP. Some GSHP models utilize so-called superheater solutions in which the domestic hot water is heated to a higher temperature with one additional heat exchanger. The user changed the piping in the unit in order to circumvent the lower-temperature water tank through which the unit circulated the water. He channeled the piping outside of the unit and installed a temperature changer to the piping in order to keep the water temperature as constant as possible, regardless of the status of the heat pump.

An example of a user add-on to a GSHP. One practice innovation to improve GSHP efficiency is to insulate its outdoor coil with snow. The outdoor coil of the GSHP is typically installed either vertically in a deep rock well or horizontally in the yard or in a field. In the latter installation method, the coil is 1-meter deep in the ground. In the Nordic environment snow can be used as insulation during the wintertime. When snow is accumulated in a heap above the installed field it prevents the ground from cooling from the outdoor air, and the coil stays in a warmer environment.

The overall amount of GSHP inventions has been smaller than in ASHPs, but on a slightly higher level when compared to the number of units installed in Finland (by 2016 ASHP 0.02/ GSHP 0.04%). As with ASHPs, users have modified most parts of the GSHP systems, but the core unit, including a compressor, evaporator, condenser, and coolant liquids, has only been subject to alteration in two more encompassing designs. Based on the list discussions and interviews with inventors, the main reason lies in the substantially higher price of GSHP installation (up to €30,000), which inhibits citizens' behavior in regard to violating the integrity and warranty of the equipment. GSHP equipment is also more targeted to cold climates and thus features less obvious space for improvement. Nonetheless, as with the ASHPs local conditions feature variation that generic designs do not fully cater for and thus leave unexplored design space, on which some users focus. As with the ASHPs and wood pellet burner technology that we discuss below, most user inventors were active in the user-run internet forum dedicated to this technology. Similarly, cost reduction or improvements in performance were the expressed motives, and the common pattern is that most modifications concern fitting the technology to local particularities, be those particular opportunities, such as the possibility to easily use snow to insulate the horizontal collector field, or constraints, such as the lack of water central heating.

3.3.3 User inventions in pellet wood burning systems

In wood pellet systems we found 12 system-level designs, 51 user modifications, and 24 user add-ons, repurposings, hacks, relocations, or workarounds. Let us again first present short examples in order to characterize the user inventions in these categories and then clarify their range and extent (see Table 3.3) according to the subsystems of the wood pellet burning technology.

An example of user design: Building a wood pellet burner and control logics from scratch. Several users built either their own burners or control logics. For instance, a father first used his welding skills to build the hardware, and his son built the needed control logics with his software programming and electronics skills. The resulting design lights up faster than commercial alternatives and minimizes burning gases. Several other users already use this new design.

An example of user modification and repurposing: turning an old oil burner into a pellet burner. Several users modified and repurposed their old oil burners to suit pellet burning. These modifications differed depending on the oil burner

Table 3.3 User inventions in wood pellet systems

<i>The part of the technical system</i>	<i>The subsystem</i>	<i>The no. of user inventions</i>	<i>An example descriptor of the user invention</i>
Pellet boiler	Burner	11	Building the user's burner design from metal
A pellet boiler system	A pellet boiler system	11	Welding a whole new boiler unit
A pellet boiler	Burner control	2	Programming the software logics and wiring the electronics for the user's burner
Pellet transfer	A pellet auger	3	A pellet auger formed from a single piece of rust-resistant metal
Pellet transfer	Cyclon	5	A 100-liter barrel, attached to a recycled, efficient vacuum cleaner with a rubber chain
Pellet storage	Indoor silo	5	Using a big, used metal container for building a daily pellet storage
Pellet storage	Outdoor silo	9	Building a separate outhouse for pellet storage
A pellet system	Measurement	5	Monitoring burner temperature and a failure alarm
A pellet system	Automation	9	A graphical temperature monitoring system with 1-wire sensors
A pellet boiler	An exhaust gas vacuum	1	An old oil tank turned into an exhaust gas vacuum
A heat system	Hot water tank	1	Building a 4000 l hot water tank out of rust-resistant metal
Other systems	Other pellet burning systems	23	Building a burner basket that enables the flow of air in the burning process
Other	Pellet production	1	Building a transferrable pellet mill on top of a pickup truck
Total		87	

brand. The problem with most oil burners with respect to burning wood pellets is that the fire hearth and the ash compartment are too small. Modification and repurposing required extending the burner cavity of the oil boiler lengthwise to enable a larger flame and hence cleaner burning, a prerequisite of efficient pellet burning.

An example of a user add-on to pellet systems: building a burning basket to add to burner or fireplace. Several users made burner basket add-ons that were to be used either inside old oil burners or in the fireplace because some old oil

burners lack a suitable “fireplace” and fireplaces lack a tray for placing the pellets. Burner baskets can be made from almost any metal thing by bending and cutting. Such an add-on enabled the control of air deflecting in the burning process, a quality that was seen to be lacking in commercial products that were otherwise suited for users’ particular conditions.

Examining the user inventions in wood pellet burners reveals that users have also invented in all aspects of this technology. In fact, only the radiators inside the house received no alterations. The Finnish wood pellet burning systems feature two new-to-the-world designs, while the remaining 65 inventive user projects created systems or modifications that recreated the existing types of equipment from metal parts that happened to be available or modified extant equipment (e.g., oil-burning stoves) for wood pellet use.

As with heat pumps internet discussion forums played a major role in the dissemination of ideas and peer assistance, as well as cost reduction appearing to play a role as self-building can produce a working pellet system for 10% of the price of purchasing a commercial one. Again, we also find local conditions, means, and resources being utilized. However, in relation to this lies a difference between wood pellet and heat-pump projects. Most pellet systems are based on direct engagement with the materials at hand and on-site (i.e., they are not mediated by accurate blueprints or design tools and their distribution over the internet) and consumers create the technology from available materials (cf. Usenyuk et al. 2016), not *building on* commercially available systems, as was the case in the heat-pump projects.

3.3.4 Expert evaluations of consumer inventions

To improve our understanding of the novelty and value of the solutions and the technical difficulty of making them, we proceeded to subject all the innovations (from the above heat pump and pellet burner data, supplemented with solar PV and solar heat inventions—altogether 214 inventions) to expert evaluations, wherein we used four aspects that could be estimated based on the data available on all the consumer innovations in the data set. The first aspect evaluated was inventiveness: how new to the world each innovation was and how radical they were technically. The second aspect was the ease of implementation for potential adopters. The third item in the evaluations was the diffusion potential of the inventions in the total Finnish consumer base: to how large a proportion of the Finnish consumer base could the invention be potentially beneficial and applicable? The experts took the market size as the consumer base into which the modification can proliferate rather than, for example, evaluating the sales potential of the improved model.

The final item for evaluation was energy-saving potential, a proxy for indisputable economic benefit. Here the expert evaluations proved less helpful than in the other categories. For wood pellet burning systems it became too hard to reliably assess the energy saving achieved without field trials. For heat pumps this was easier as, in most cases, there was already a model upon which the

invention or modification was built. However, over 40% of the consumer inventions were in fact improvements to the usability, control, and monitoring of the systems. In some such cases, our evaluators provided estimates of indirect energy saving that were mostly higher than the mean direct energy saving of the evaluated inventions. However, we have discarded all but the estimates of indisputable direct savings in order to err on the conservative side in assessing the potential of the consumer innovations.

Overall the three sets of evaluators provided well-aligned appraisals of the inventions (at most, a difference of one degree was found in cross-comparisons), and thus the score for each consumer project could be settled by the majority value among evaluator scores.

In Table 3.4 we can see that most of the innovations were relatively incremental (albeit there were a few technically radical, new-to-the-world innovations). However, particularly the heat pump and solar technology inventions were moderately difficult to implement, typically requiring fair technical sophistication from any adopter wishing to copy the invention. Most of these consumer innovations had limited proliferation potential because the majority of the inventions arose from local contingencies or were specific to a particular model (Hyysalo et al., 2013b).

As expert evaluations of user innovation have been critiqued as featuring potential evaluator sentiment bias and also as we wished to gain a clearer view of the climate change mitigation potential of the user innovations, our colleagues in the Finnish Environment Institute calculated life-cycle carbon assessments for the example user innovations (Mattinen et al., 2014). In short, comparing the ground-source to air-convective heat pump (see the vignette above) with direct electricity (DE) and a high quality, off-the-shelf, ASHP show significant improvements in all of Finland's four climate zones; with ASHP roughly halving the energy use from DE, and GSAHP again halving the energy use of ASHP. What also is worth a remark is the proportion of end-of-life greenhouse gases as this equals the total loss of all refrigerants that are potent greenhouse gases remaining less than 10% of the GHGs resulting from energy use. This calculation was made in response to a counter-argument expressed many times to us by energy system professionals that “amateurs will just spill the refrigerants and do more harm than good for the climate.” Our interviews reveal that refrigerant spilling is quite rare, and if it happens, the life-cycle saving far outweighs it.

3.4 The diffusion of consumer innovation in S-RETs

To understand the diffusion mechanisms of S-RET consumer innovations, we need to first understand how adopters can learn about the innovations; in other words, we need to understand the *interaction arenas* through which the originator of an innovation and its potential adopters are in contact (Heiskanen et al., 2014; Johnson et al., 2014; Hyysalo and Usenyuk, 2015). In the Finnish cases, the contacts between innovating consumers and their peers were sometimes

Table 3.4 Expert evaluations of the inventions' inventiveness, ease of implementation, diffusion potential, and energy-saving potential

<i>Innovation characteristic</i>	<i>Scale max.</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>Scale min.</i>
Innovativeness	New to the world	2%	3%	15%	31%	49%	—
Ease of implementation	Easy	20%	24%	27%	24%	6%	Minor improvement
Diffusion potential	All equipment	4%	8%	20%	34%	33%	Difficult
Energy-saving potential		21%	29%	42%	2%	3%	Marginal
	% of annual energy use	<1%	<3%	3–6%	6–9%	9–12%	12–15%

face-to-face but were predominantly mediated by the internet-based discussion forums (Hyysalo et al., 2013a, 2013b).

The innovating consumers mostly used online discussion forums to connect with their geographically dispersed peers during their projects. The form by which they did so followed a “display-and-advice” sequence. They display their projects, ask for advice, and are then provided with comments and suggestions that typically lead to the next display and next round of comments. It is the forum post’s author who initiates this, and it is the author’s interests that mostly steer the exchanges. The physical character of an S-RET prevents people from directly pooling their work into the same projects as they do in open-source software projects, yet the discussion forums did allow them to solicit problem-solving advice from peers. Regarding diffusion, the display-and-advice sequences tend to create an imperfect documentation trace. They may provide good detail of the innovation project goals, most of the steps the person went through in building it, and the knowledge about what worked and how well. Yet the ensuing documentation trace is not geared toward copying. Not only are innovative solutions not well categorized for adoption (in regard to which model, housing type, or problem they provide solutions for and if the solutions were effective), they are not documented so as to aid adoption: the adopter has to be very interested and often needs to contact the innovator in order to be able to copy the solution as the solution is typically displayed in detail only with respect to aspects that the innovator wished peer commentary.

In the following we examine the types of diffusion paths that were found in the data set. We do this by discussing the original consumer innovation and then proceed to its subsequent diffusion. Empirical studies to date have predominantly examined commercial adaptation: the innovator becoming an entrepreneur (as with Case A below) or revealing an innovation to a company (as with Case B). Our main interest is in how peer diffusion happens (through straight diffusion or innovative adaptation by peers) or does not happen. We thus elaborate on this and give fuller examples of the innovations in Cases C, D, and E.

As discussed in the literature review, a common case of consumer innovation diffusion is the one wherein an innovation originally built for the innovator’s own use is further developed by the innovator into a product on the market—in other words, the innovator becomes a consumer entrepreneur (Shah and Tripsas, 2007). In our data set three (3) consumers had developed their designs into a marketable product. The following case, Case A, illustrates this innovation diffusion path.

Case A: The consumer becomes an entrepreneur. The “ground-source air-heat pump” described above is an example of a user becoming an entrepreneur. The inventor had close connections to a small coolant application company, owned by a relative, and he eventually joined the business as a minority owner and the system is now commercially available from Jääsähkö Oy. This company wanted to find a niche solution that would not attract large heat-pump vendors as competitors. In this case the interaction arena for development included various

knowledge repositories and, most importantly, face-to-face meetings between the kinsmen. The design targets a big CO₂ problem in the Finnish housing stock, namely the considerable number of houses (400,000) with direct electric heating, some of them located in regions where ASHPs are not effective.

The second route for consumer innovation diffusion is revealing the innovation to a company, which consumer innovators commonly do (von Hippel, 2005). In our data set we found one case of voluntarily revealing an innovation and one case of it being revealed involuntarily (our Case B here).

Case B: Revealing an innovation to a company. A user ideated a dual-source heat pump, which uses ground-source or air-source heat depending on which one is in a more effective temperature range. The idea was posted in an internet forum and then iterated by several users and adopted, through self-building, by some of them. At some point the original user-designer contacted a Chinese producer of the ASHP he had modified and suggested that they design a dual-source heat pump. The manufacturer responded by apologizing and stating that they could not produce the model and were not interested in pursuing it. However, only a year later another Chinese manufacturer (perhaps not coincidentally from the same city as the one the Finn had contacted) listed exactly the same design on the internet marketplace alibaba.com as its own invention. The interaction arenas here consisted of internet discussion forums, contact between the consumer and manufacturer, and the commercial forum where the innovation became listed.

Case C: The straight adoption of an innovation by peers. The third type of diffusion in our data is the adoption of an innovation by peers through self-building the design of another consumer. The most widespread example of straight adoption by peers was an open license “house logger” program, used to monitor energy solutions in the house. It was coded by a single user who received feedback from peers yet kept the development in his own hands. The open license program was then downloaded, installed, and updated by others. The interaction arena for the adoption and feedback was one of the internet discussion forums.

Straight adoption also happened with physical solutions, such as among the solutions that users created for adjusting the ASHP’s ice melting phase. The cooled surface of the heat pump’s outdoor unit condenses moisture, which freezes in low temperatures. The machines have a melting sequence to get rid of the cumulated ice, during which time the pump does not heat. A derivative issue about melting the ice is that in below-zero outdoor temperatures, the meltwater must remain melted until it has dripped out of the outdoor unit’s box. Most ASHP models have an additional melting coil that is on whenever the outdoor temperature is below zero. The melting sequence and the additional melting coil were common points of user adjustment and innovation as the commercial models were poorly optimized. For instance, in many models the melting coil was on continuously for four months (!), even when it only needed to run for a few minutes every 40–60 minutes. This was reported to waste 500 kWh out of 4500 kWh of ASHPs annual energy use (i.e., over 10%

of energy use) in comparison with an optimized system. One solution, copied by several peers without modification, was an additional control to monitor the relative temperature of incoming and outgoing freezer-circuit liquids and thus detect when the melting sequence of the machine was on, switching on and off the melting coil.

As discussed in the literature review on diffusion, not all diffusion takes a straight adoption character. In our data set, innovative diffusion was, in fact, more plentiful than straight adoption, and it came in many varieties (see below). In 26 consumer innovations it was impossible to pinpoint who was the exact originator of a cluster of different consumer solutions for the same or similar problem, which Case D clarifies with one example.

Case D: Diffusion through innovative adaptation by peers. As noted above, several users redesigned ASHPs into ASWHPs. User reports of the most extensive and apparently most prolific project received over 300 replies and 18,000 reads in one of the internet forums. Online community members actively contributed to the design issues faced by user innovator and there were at least tens, if not hundreds, of other users who repeated the design using the posted descriptions.

Over the course of these building efforts, altogether 14 distinct consumer innovations emerged to enhance the converted ASWHPs. All had different parts and sub-configurations, as well as a different ‘starting-point’ ASHP model. At least three of these consumer designs were copied as they were by several other consumers, but for the other 11 designs there was no evidence of such further copying (though in all likelihood, some of it happened). At some point an initiative for a joint open-hardware project (“the world’s best cold-climate air-heat pump”) was initiated, but it withered away after several pages of the initial specifications.

In these projects we can differentiate three different types of innovation and diffusion. The most straightforward is where the second adopting consumer *adds* further features to the first consumer’s design upon adopting it. Some adapting consumers also *removed* unneeded features and, in so doing, ended up making further reconfigurations in order to make the redesign work. Finally, some users ended making a *series of changes* in adopting the original design, but adopted it nonetheless. For our present discussion, we should bear in mind that these three types of innovation and diffusion are all instances of innovative diffusion if the add-ons or changes in themselves are not novel, but the final outcome differs from the original. (note: if the further changes themselves are novel, the resulting solution would classify as user innovation.) In Figure 3.2 below, these three types of innovation and diffusion are marked as innovative diffusion types D1, D2, and D3. Figure 3.2 clarifies the Cases A–D that show different diffusion paths for innovations by consumers. In all of these cases the interaction arena consisted of the internet discussion forum for displaying projects and comments, and in many cases also of its private messaging functions.

In a further 39 cases, a company solution pre-existed, but consumers had innovated a new solution (not a direct DIY copy) using different materials, eventually resulting in a cheaper price. Case D also clarifies this case as a

Figure 3.2 The diffusion paths of consumer innovations in S-RETs.

different type of ASWHP was commercially available all along. Such innovative peer diffusion solutions could be coded just as validly as *user innovations* or as (*strongly*) *adaptive adoptions*.

Finally, not all consumer innovations had diffusion that could be verified, even in cases when the solution was deemed original and to have potential value for later adopters/adapters by experts who evaluated the potential of consumer innovations for us.

Case E: No diffusion. Consumer innovations can remain underused, although the innovations provide clear benefits. We noticed several solar PV cases that received no diffusion.

A solar panel user noticed that the aluminum frame of solar PV panels froze and the lower rim also began to gather snow, which blocked the sunlight. The user attached a small melting cable, connected to the power grid, to the lower rim of the panels in order to melt the snow. The required heating of the rim necessitates some tens of watts before the panel starts to get sunlight, heats up, and removes the rest of the snow. The yield of these panels on a winter day

in Finland has been 200–300 Wh, so there is a clear payback. Solar panels are predominantly designed for and assembled in areas where it does not snow. This small consumer addition helps to make use of them in colder conditions. Despite the positive yield and rather easy implementation, there was no evidence that this solution has spread among other users or to manufacturers.

Some user solutions did not spread because they were not actively displayed: for instance, one of the user innovators replaced the above-described melting coil thermostat relay solution (Case C) with a time relay solution synced to the melting cycle and reported higher reliability with it to us (the researchers), yet did not display it to other users.

These diffusion paths found in the material can thus be presented schematically as forming six different paths of diffusion along with no diffusion (Figure 3.2).

When we examine the whole data set regarding diffusion, the 181 projects feature one case that spread through both commercial and non-commercial channels: the dual-source heat-pump project, Case B. As these two diffusion channels are not mutually exclusive, the total number of diffusions examined was 182. As to the extent of diffusion, the businesses of the consumers are either run on the side of their main occupation, or they also sell other services or products. Concerning peer diffusion, the diffusions are hard to track objectively, most projects necessarily remaining unidentified, and it appeared sensible to treat them as less-than-a-hundred diffusions and more-than-a-hundred diffusions in order to match the uncertainty in identifying the diffusions. With this division there is only one case of diffusion that ran to tens of thousands of adopters: the placing of a sledge underneath an outdoor ASHP unit. There are three instances where the verifiable diffusion measured in the hundreds, 17 measuring at least in the tens of diffusions, and in the rest of the cases there were less than ten verifiable instances of diffusion.

The four solutions that have diffused widely merit some description. On the one hand there were two software applications, the “house logger” open license program described above and a spreadsheet software for estimating energy consumption and production, which had an unknown origin and a range of annotations, and was subject to both adaptations and adoptions. On the other hand, there were two physical designs. The first was housing built to cover an outdoor ASHP unit, designed in order to make it fit better with the aesthetics of the house (something that commercial versions did not provide), and the second was the idea of placing a medium-sized plastic box, children’s sledge, or some other suitable plastic receptacle underneath an outdoor ASHP unit so that the ice formed and piled under the unit is easy to remove (see Figure 3.1). While these four solutions had a clear value to the consumer, none provided direct energy saving. All of these could also be adopted in almost the full Finnish installation stock, and with the physical designs, adaptive diffusion was easy to accomplish and required no detailed instructions: adopters could use whatever ready-made receptacle they had to hand or build a different housing to match their house. The interaction arenas in these cases were predominantly internet discussion forums.

Table 3.5 documents the distribution of consumer innovation diffusion. It reveals that commercialization is the smallest subset of diffusion and the cases of innovative diffusion form a class that is four times larger than straight transfer peer diffusion.

The expert evaluations of the user inventions (see the end of Section 3.3) can be further associated with the realized diffusion and linked to existing research on consumer innovation diffusion. Prior user-innovation research on *commercial diffusion* is relatively established and suggests that the following patterns should take place (Gambardella et al., 2017; Shah and Tripsas, 2007; von Hippel, 2005). Innovations that are patentable, not obvious, and hold wide-diffusion potential should encourage consumer innovators to seek to commercialize them. If they imply a direct energy saving, this saving should be positively correlated with their commercialization. Concerning the path of the consumer innovation being revealed to and adopted by an outside manufacturer, those that are less innovative and have less diffusion potential are more likely to be revealed. An entrepreneur or production company needs to have the competences and resources to produce an innovation on a commercial scale, and hence the ease or difficulty of implementation should not matter.

For further statistical analysis these interrelations can be formed into four hypotheses:

Hypothesis 1: Consumer innovations that are rated highly for innovativeness are associated with consumers turning into entrepreneurs.

Hypothesis 2: Consumer innovations that are rated highly for diffusion potential are associated with consumers turning into entrepreneurs.

Hypothesis 3: Consumer innovations that are freely revealed to companies are associated with less innovativeness or less diffusion potential.

Hypothesis 4: Consumer innovations that are rated highly for their energy-saving potential are associated with consumers turning into entrepreneurs.

We examined commercial diffusion with regard to rated innovativeness, ease of implementation, diffusion potential, and energy saving. Due to the small

Table 3.5 The diffusion of consumer innovations when innovative peer diffusion is included

Type of diffusion	Instances	%	Scale of diffusion
No diffusion	100	54.9%	0
P2P straight peer diffusion	15	8.2%	1 diffusion > 100 14 diffusion < 1–100
P2P innovative peer diffusion	62	34.1%	3 diffusions > 100 58 diffusions < 1–100
User entrepreneur	3	1.7%	3 < 1–100
Revealed to the company	2	1.1%	Not available
Total	182	100%	

number of diffusions in our sample, Fisher’s test is adequate for evaluating how significantly associated the predictor of innovativeness is for these observed diffusions.

We found that the innovativeness of a consumer innovation is significantly associated with the consumer becoming an entrepreneur, with a significance level below 1% (see Table 3.6). Similarly, the consumer becoming an entrepreneur is also a function of the diffusion potential ($p = 1\%$), the ease of implementation ($p < 5\%$), and the energy-saving potential ($p < 5\%$). The consumer innovations commercialized by user turning to entrepreneur were new to the world, and the two innovations revealed to companies were less innovative, in line with Hypotheses 1 and 3. Innovations leading to consumer entrepreneurship were at the *difficult* end of implementation and held the highest or second-to-highest diffusion potential, unlike those revealed to companies, in line with Hypotheses 2 and 3. With regard to the energy-saving potential (a general value approximation), two out of three consumer entrepreneur cases were for wood pellet burning systems where the estimation of energy saving was impossible for the experts without field trials. The remaining case resides at the second-highest step of the scale, with a saving of 12%, unlike the two innovations revealed to companies, in line with Hypotheses 3 and 4. Overall, the hypotheses are supported: consumer innovations that have diffused commercially stand out as having the potential to do so.

To date, research on the peer diffusion of consumer innovation remains less mature than commercial diffusion, but in light of the research there is (De Jong et al., 2015; Gambardella et al., 2017; von Hippel et al., 2017) innovativeness could have “a cool factor,” motivating some technically oriented peers to adopt. But if adopters focus on the costs and benefits, the ease of implementation should be associated with diffusion, as should the higher energy-saving potential of those innovations that directly concern energy saving. Diffusion potential should predict realized diffusion because the population that could adopt it is larger. For statistical analysis these can be expressed as hypotheses on peer diffusion as follows:

Hypothesis 5: Consumer innovations that are rated highly for ease of implementation are associated with peer diffusion.

Table 3.6 The measures of the association between independent and dependent variables through Fisher’s exact test

	<i>Commercial diffusion</i>			
	<i>“User entrepreneur”</i>		<i>“Revealed to comp.”</i>	
Innovativeness	27.3**	(.000)	5.1	(.454)
Ease of implementation	6.1*	(.045)	3.9	(.337)
Diffusion potential	8.8**	(.010)	3.6	(.501)
Energy-saving potential	15.7*	(.047)	8.6	(.379)

Hypothesis 6: Consumer innovations that are rated highly for diffusion potential are associated with peer diffusion.

Hypothesis 7: Consumer innovations that concern direct energy saving are associated with peer diffusion.

Since there were more cases of peer diffusion than commercial diffusion, we used the Mann-Whitney U test (a rank-based nonparametric test that can be used to determine if there were differences in the predictor scores between peer diffusion and non-diffusion). We will first examine straight adoption by peers (see Table 3.7). Here the only statistically significant difference was found in the ease of implementation: $U = 1674.5$, $z = 2.272$, $p = 0.023$. The ease of implementation scores for straight peer diffusion (mean rank = 119.63) were higher than for no diffusion (mean rank = 88.41); in other words, the more difficult-to-implement projects have diffused, which indicates an opposite association to that stated in Hypothesis 5.

Next we examine how innovative peer diffusion (see Table 3.8) is associated with evaluations of the consumer innovation's potential in terms of expert evaluations.

Here the relation between the diffusion potential and actual diffusion is significant ($p < 0.5$). Hypothesis 6 gains further support from the cases that have diffused widely. Three out of four were predicted to have diffusion potential

Table 3.7 Mann-Whitney U test results for straight transfer peer diffusion

	<i>Straight transfer peer diffusion</i>				
	U	r	Sig.	Mean no. of diffusions	Mean diffusion
Innovativeness	937.5	0.13	(0.086)	92.85	70.50
Ease of implementation	1674.5*	0.17*	(0.023)	88.41	119.63
Diffusion potential	1244.5	0.00	(0.998)	91.00	90.97
Energy-saving potential	291.5	0.03	(0.830)	31.28	32.50

Table 3.8 Mann-Whitney U test results for innovative peer diffusion

	<i>Peer diffusion: innovative diffusion</i>				
	U	r	Sig.	Mean lack of diffusion	Mean diffusion
Innovativeness	4372.5	0.08	(0.269)	87.55	95.56
Ease of implementation	5410.5**	0.30**	(0.000)	77.47	108.87
Diffusion potential	4820.5*	0.18*	(0.016)	83.20	101.30
Energy-saving potential	513.5	0.08	(0.538)	29.98	32.67

for all equipment on the market. Fisher's exact test's two-sided significance for wide-diffusion items is 0.000.

The other significant association is between the ease of implementation and realized diffusion ($p < 0.01$; the r value of 0.30 signifies a medium-sized effect). The mean rank scores (108.87 for diffusion and 77.47 for no diffusion) indicate that more difficult-to-implement projects have diffused than easy-to-implement projects. However, when we examine those projects that have diffused wider than 100 verified instances of diffusion, we find they are *all* at the *easiest* level of implementation. We interpret this as follows. The rational diffusion predictor for peer diffusion explains the wide adoption (Hypothesis 5). More limited adoption predominantly takes place among technically competent consumers who are not hindered by the difficulty of implementation and in fact may view the technical challenge positively, that is to say as a "process benefit" (Franke and Schreier, 2010).

General economic benefits (in our data, measured by direct energy-saving potential) were not associated with peer diffusion (Hypothesis 7), a finding that parallels the survey of De Jong et al. (2015) on the general Finnish population innovating in any consumer product category.

3.5 Chapter discussion: user innovation in S-RETs and their diffusion

Unlike assumed by the mainstream of energy innovation research, citizen users hold considerable ability to modify and invent in their home energy technologies. Over 200 user inventions, designs, modifications, and add-ons could be identified in the Finnish context alone. Our analyses show that users were able to invent in practically all parts and subsystems of the S-RET technologies. The subsystems that did not feature user modifications, such as compressors and radiators, appeared to be parts that users did not find a need to tinker with rather than those that were too difficult to modify.

To understand why citizen users choose to innovate, an analysis of the content of their innovations is instructive. In the first instance, user inventions point at what is missing in the market: These consumers become aware of the limitations of the technology and try to solve the problems by inventing (cf. von Hippel, 1988). Most user inventors built solutions that had one or several facets that would have rendered them unsuitable for the mass producers of the systems. The inventions were either useful for relatively specific locales, compromised the durability or reliability of the system in a manner that could be locally compensated for but would not suit all users, or combined different technologies in a manner that commercial manufacturers would not find appealing, even when local benefits were obvious. In this capacity user invention presents a complementary direction for the advancement of technology to research- or manufacturer-driven R&D. The inventors were aware of the risks their experimental projects could entail and, judging from the forum discussions, had created functional local arrangements to handle the risks. This

Figure 3.3 A schematic illustration of design spaces under conditions of high variation in user needs.

dynamic is schematically illustrated in Figure 3.3 through depicting the inter-relations between design spaces that feature local particularities that invite user innovations as commercial offerings only seek to appeal to larger sets of clientele to recoup investments and in doing so leave aspects of design space uncatered for. In Figure 3.3, the user needs and preferences (dark background) form a space in which majority of needs are shared by many customers and can thus be profitably met by commercial solutions (white circles) targeted at different customer segments. Even as the market matures, the design space continues to feature need spaces that are too particular for profitable commercial products (dark corners) and the unserved users with these needs continue to innovate to serve themselves (light grey circles), with some of their innovations growing into products appropriated by the wider customer base as well.

Taken together, these findings indicate that some energy users have significant competence and the will to have a deep and active relationship with their energy technologies. The rise, spread, and visibility of sophisticated DIY competences and projects have been facilitated by user-run internet forums that allow peer help and thus the mixing of professional competences that are often requisites for user inventors to achieve their designs. As with most other technologies, the making of inventive modifications is concentrated on a few individuals (von Hippel, 2005).

Regarding diffusion, the next chapters of this book elaborate how innovating consumers have aided the overall diffusion of renewables in Finland through peer assistance on online forums. The spread of consumer solutions themselves shows that only three cases (1.7% of those studied) led to the

consumer becoming an entrepreneur and two (1.1%) were revealed to companies. Widespread (> 100), verifiable diffusion among peers took place in four cases (2.2%). Thus, the direct impact of solution diffusion appears somewhat limited.

The reason may well lie in that few projects were accompanied with detailed instructions concerning how to replicate them—they were thus poorly observable and could not be trialed without extensive effort (Rogers, 2010). Innovations that diffused widely were in the easiest category of implementation and in the widest category of diffusion potential. For such simple-to-replicate solutions, the work of exhibiting them on online forums would be sufficient to spur their wide diffusion. In contrast, modest-scale diffusion occurred in 71 of the 181 projects (39.2%), mostly through innovative peer diffusion. This is likely to be no coincidence. Innovating consumers only leaving a display-and-advice trace is in line with previous findings on how user innovators lack incentives to further the adoption of their solutions (von Hippel et al., 2017). However, the low diffusion of innovations that have been evaluated by experts as being socially valuable could be a market failure in terms of welfare economics (Gambardella et al., 2017; von Hippel et al., 2017).

Our data underscores how equating the diffusion of consumer innovations with adoption, or in other words straight peer diffusion, may require reconsideration. In classic diffusion studies, the diffused item was taken for granted—usually a discreet item such as a new agricultural seed type or a simple tool introduced by a commercial entity or change agency (Rogers, 2010). In contrast, S-RETs are at least moderately complex technical configurations. In our data set the largest type of diffusion was innovative peer diffusion, where different consumers continued to incrementally and iteratively adapt the solution they adopted. This results in materially and conceptually distinct consumer solutions that influence each other. This phenomenon is known to previous research. Adaptive diffusion, innofusion, innovation at adoption, design-in-use, and the fluid deployment of technology are terms used to describe variations of innovative technology uptake (Agarwal, 1983; De Laet and Mol, 2000; Douthwaite et al., 2001; Fleck, 1993b; Hyysalo and Usenyuk, 2015; Williams et al., 2005; Kohtala et al., 2020).

The high incidence of innovative peer diffusion in our data set has not previously been recognized by the user-innovation literature but makes sense in the context of it. Its basic premise is that users innovate for themselves because each consumer has a somewhat different set of competences, preferences, and contexts of use, and also some consumers remain underserved by the offers available on the market (von Hippel, 2005, 2016). It is cost-effective for users to pool their competences if communication and design costs are low enough, which can be achieved through computer-mediated communication and modular design architectures (Baldwin and von Hippel, 2011). After all, if users hold roughly analogous needs it would be wasteful for each of them to seek to independently invent the same solution (von Hippel, 2005).

However, the consumers examined in the present study consume goods in geographically and socially differentiated contexts and are united by digital

forums that are only geared toward discussions. The nature of their projects and their interaction arenas allow them to enjoy some pooling gains, but lack others:

- + They can gain information on which solutions have and which have not worked for their peers and thus focus their own solution search and reduce the (often considerable) costs of trialing entirely untested solutions.
- + They can gain solution outlines and advice in regard to realizing related-solution search directions from their peers.
- They have a somewhat different technical configuration with sunk investments (such as the heating equipment and house) and thus direct copying may not make sense for them.
- They cannot assess the quality of another user's solution and its fit and value for themselves by just running it (as in software)—they need to build it up and fit it before they can verify its value, which may pose a barrier to adoption.
- They are likely to be unable to each build a module and fit it into an architecture that benefits them all; hence their complementary output cannot add up in a manner similar to using software, even if organized.
- They do not have a way to share instructions with other users without the extra effort of making such instructions (see the above section on under-diffusion).

With these possibilities and limitations, it becomes sensible for consumers to pursue innovative peer diffusion in order to satisfy their unmet needs. The risk that organized community collaboration would not pay back is high, yet seeking independent solutions in “packs” offers them some of the innovation community benefits. The findings thus raise a question for further research with regard to whether studies of the peer diffusion of physical products should expect two qualitatively different peer diffusion pathways: one of adoption and one of adaptive innovative diffusion. The latter is likely to remain the prevalent case for S-RET peer diffusion as S-RETs will remain physical technologies in the future.

To sum up this chapter, citizen consumers display considerable ability and willingness to innovate in S-RETs. The Finnish cases underscore how active consumer roles remain important after the formative stages of S-RETs as they proliferate in new country contexts, markets, and institutional settings (Juntunen, 2014b; Heiskanen et al., 2014) where the standard commercial S-RET solutions may not optimally fit upon their market entry. Consumer innovators of S-RETs add to the solution variety of the S-RETs available for other adopters. It is worth remembering that the accumulation of minor improvements is responsible for a major part of technological progress (Rosenberg, 1979). However, our study indicates that the direct solution spread remains limited, apart from a handful of solutions. This is a disappointing finding for those who envision consumer innovations as a direct additional

means for energy and climate policy to boost S-RET solution development: the solutions add variety rather more in principle than in practice.

The other item we clarified is that the low diffusion of innovations by consumers does not appear to be an issue of solution quality, as domain experts assess many of the innovations to be socially valuable, and their assessments predict well which solutions lead to commercialization. The rest of the solutions, in principle freely available for peer-to-peer adoption, suffer from not being rendered in an easily adoptable form. These solutions are free but not easy to replicate, even after peers have become aware of them. As a consequence, peer adoption happens more through innovative peer diffusion, yet this form of adoption requires higher competence and active engagement with technology in contrast to adopting a well-documented solution as it stands. At the same time, inventing and innovative diffusion fosters competence development among the consumers who pursue it. As we will discuss in the next chapters, the users peer-to-peer interactions and competence building may eventually be more important for the overall shaping of sociotechnical change than user innovation.

Our results underscore that it would be a mistake to isolate the significance of each user innovation and user modification, and only consider their straight adoption without considering how they feed into further projects. Thus, the formed pathways of user improvements lead to the articulation of demand for improving the commercial systems for new market areas. The managerial implication is that on entry to new markets, producers would benefit from following the interaction arenas where users discuss the technology and display their problems and solutions, thus revealing the points that need improvement in the generic technology for the market particularities.

The ensuing policy implication is that peer support among consumers is a valuable resource that should not be accidentally curbed through, for instance, measures that would affect their anonymity or any of the other self-organizing principles by which they thrive.

What could be done to counter the potential under-diffusion of consumers' innovations in S-RETs? The solutions that exist to date, such as platforms for physically making things in the form of parts lists and recipe-like texts (as found at instructables.com), are unlikely to work as solutions. Following the reasoning of von Hippel et al. (2017), few innovating consumers would have the incentive to take the time and energy to document their often complex hacks and designs. The innovating consumers could, however, be motivated to do so if there were templates available for the effective display of their problems in such a way that it would help to present them and, as a side effect, make a more structured information package out of the display (e.g., if an easy way to make blueprints was available or if there was an easy way for the user to point to the exact location of the modification and make parts lists). Our findings on innovative diffusion thus call for further technology development in the platforms for physically sharing designs among peers.

From the BOAP methodological perspective, the studies on user innovation show a string pattern that ensued after a surprisingly large number of innovations found in the initial study. It became interesting to better understand their nature, social value, the competences needed to make them, and their diffusion, thus producing a string of studies with complementary foci to zooming in interesting issues. In the discussions of the original articles, one can observe that diffusion in particular was assumed to be much higher and to be concentrated on easy-to-make solutions and commercialized solutions—both assumptions that proved untenable on closer analysis. Moreover, research foci increasingly shifted from the innovations to the competencies leading to them and the peer-to-peer knowledge creation in user communities that gave rise to these competencies. This is what we will examine next in Chapter 4.

Notes

- 1 This chapter integrates and expands research that has previously appeared in “Hyysalo et al. (2013a)” and “Hyysalo et al. (2017).”
- 2 <http://lampopumpput.info/foorumi/index.php?topic=1279.0>
- 3 <http://lampopumpput.info/foorumi/index.php?topic=7482.30>
- 4 <http://kotisivu.dnainternet.net/juslaat2/innovaatio.html>
- 5 <http://lampopumpput.info/foorumi/index.php?topic=2185.0>
- 6 <http://www.pellettikeskustelu.net/keskustelu/viewtopic.php?f=7&t=2618>