The diffusion of consumer innovation in sustainable energy technologies

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A R T I C L E   I N F O

Article history:
Received 15 April 2015
Received in revised form 20 June 2016
Accepted 8 September 2016
Available online xxx

Keywords:
Renewable energy
Open innovation
Diffusion of innovation
Online innovation communities
User innovation
Consumer innovation

A B S T R A C T

Consumers are no longer mere adopters of small-scale renewable energy technologies (S-RETs) such as solar, pellet and heat-pump technologies. Prosumers create new technology solutions, collaborate with other consumers, and share their ideas, knowledge and inventions with peers in online communities they have formed. These activities by consumers support the proliferation of sustainable energy technology in contexts where institutions and technology characteristics are not yet fully developed for the wide proliferation of S-RET. The issues in the market diffusion of cleaner micro-generation technologies are not limited to “barriers” or “challenges” to top-down diffusion. Given that prosumers do many things to aid the diffusion of S-RET, we investigated how consumer created technology solutions diffused: their existence adds to solution variety, but do others then pick this up? The findings show that 2.7% of the consumer innovations diffused through commercial channels and 8.2% diffused through their straight adoption by peers. A significant share of projects (34.1%) were part of “innovative peer diffusion” adaptations and further modifications carried out among peers. Prosumers’ efforts to diffuse their solutions remain low level and indicate directions for platform development by which prosumer solutions may spread more widely.

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1. Introduction

The mitigation of climate change requires the adoption of cleaner energy production technologies. The share of renewable technologies in the global energy supply is still low at present, but their potential is significant. The real issue is how their potential in energy transition can be realized (Jacobsson and Bergek, 2004; IPCC, 2012). New cost-competitive small-scale renewable energy technologies (S-RETs) are bringing needed new investments to transform the sector and speeding up change (Bergek et al., 2013). In this transition process consumer engagement plays an important role (Schot et al., 2016). Varying social and cultural conditions are not only “barriers” or “challenges” to diffusion (Mignon and Bergek, 2016), but consumer activities related to technological domestication and innovation, as well as to market creation, may be key enablers for mass-market take-up (Caird and Roy, 2008; Smith et al., 2014; Nyborg and Røpke, 2015; Schot et al., 2016; Nielsen et al., 2016).

In addition to adoption and buy-in, end consumers typically need to adapt their practices to suit new S-RET in settings where the technologies are novel (Juntunen, 2014a; Nyborg, 2015; Judson et al., 2015). This can include making smaller and larger adaptations to the technology as well, to make them suited for the local conditions (Caird and Roy, 2008; Hargreaves et al., 2013; Shove et al., 2007; de Vries 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; deVries et al., 2016).

The cleaner production community has been well aware of the importance of citizen innovation activities in the early formative stages of renewable energy technology development. The role of grassroots communities in the wind turbine development in Denmark (Ornetzeder and Rohracher, 2013; Nielsen, 2016), the emergence and maturation of solar collector development and user roles in passive house development in Germany are well...
documented (Ornetzeder and Rohracher, 2006). Grassroots innovation has also remained a persistent alternative form with which to seek solutions for both perceived social injustices or environmental problems (Hargreaves et al., 2013; Smith et al., 2014, 2016).

Yet, consumers also play active roles in technology development after the formative years of generic technology (Juntunen, 2014b). When S-RETS proliferate in new country contexts, considerable adjustment and learning is required in the products, markets and institutions before a mature market and easy diffusion can exist (Heiskanen et al., 2014; cf. Jacobsson and Bergek, 2004). In this process, consumers have been shown to provide peer support for scaling, choosing, comparing, maintaining and modifying (Juntunen, 2014b; Heiskanen et al., 2014; Hyysalo et al., 2013a) and funding (Lam and Law, 2016) S-RET systems and in so doing act as user side intermediaries that aid other consumers in a market in which institutions and services are still under formation (Hyysalo et al., 2013a; Schot et al., 2016).

The most thoroughgoing form of such prosumer roles is when consumers develop new-to-the-world innovations and local adaptations to the renewable home heating equipment itself, such as heat pumps, wood pellet burning systems and solar heat and power (Heiskanen et al., 2014; Hyysalo et al., 2013a, 2013b; Juntunen, 2014b; Freeman, 2015; Mattinen et al., 2014). We have previously investigated these innovations (Hyysalo et al., 2013b; Heiskanen et al., 2014; Mattinen et al., 2014), the support peers give to them (Hyysalo et al., 2013a), what motivates people in conducting innovative projects and to share their ideas and advice with their peers (Hyysalo et al., 2013a,b; Heiskanen et al., 2014; Freeman, 2015). In these studies we have found that these innovations by consumers provide depth to the peer support given in internet-mediated peer support arenas (Hyysalo et al., 2013a, 2013b), and our focus in the present study is on investigating whether the consumer-created new designs and modifications to renewable home heating technology diffuse on their own and, if so, what form does this diffusion take.

2. Consumer innovation and its diffusion

The diffusion of user and consumer innovation 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 and DeMonaco, 2013). Users are known to innovate considerably, both with regard to industrial products and consumer products (for recent overviews see Rogers, 2003; Raasch and von Hippel, 2012). 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 innovation, be this in a professional or consumer context, whereas consumers are non-professional and non-organizational subset of users.

The diffusion of user innovation is important because of the large proportion of users who develop or modify products. In specialist communities, as many as 19–36% of the users of industrial products and 10–38% of users of consumer products have been found to modify products (for a review see von Hippel, 2005). In representative surveys of the populations of Japan, the US, the UK, Canada, the Netherlands and Finland, 3.7–6.2% of consumers report having created or modified some equipment they use (De Jong et al., 2015; von Hippel et al., 2012, 2011). 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. It is not trivial whether the outcomes of such expenditures diffuse effectively or not.

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 (Habicht et al., 2013), raising their professional profile (von Hippel and DeMonaco, 2013) 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 (Freeman, 2015). “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 and DeMonaco, 2013). For example von Hippel and DeMonaco (2013) 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 has only occurred after additional efforts to make them more usable (Hienert, 2006; Hyysalo, 2009). These conditions assumedly equally affect the consumers who innovate in the S-RETS. The research on diffusion in the diffusion of consumer innovations in S-RET and energy efficiency remains nascent, basically being limited to documenting that some of it has happened (Ornetzeder and Rohracher, 2006, 2013; Nygrén et al., 2015; Galvin 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 (Haavisto, 2014; Hyysalo et al., 2013a; Jeppesen and Frederiksen, 2006; Jeppesen and Molin, 2003; Marchi et al., 2011) to off-line and professional communities (Desouza et al., 2007; Hu and McLoughlin, 2011; Usenyuk et al. Forthcoming) — are supportive of sharing with peers, creating innovations together and adoption from peers. (Jeppesen and Fredriksen, 2006; Hienert, 2006; Hyysalo and Usenyuk, 2015).

The nature of the adoption of innovation by peers can have important variation, leading us back to the observations about what consumers do when they adopt new technology. Since 2000s diffusion research has moved increasingly beyond surveys of the adoption decision to detailed studies of actual adoption processes (Rogers, 2003) 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, 1988; Juntunen, 2014a; McLaughlin, 1999; Silverstone and Hirsch, 1992). Adoption 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, 1988; Rogers, 2003) and found to present an alternative to “straight transfer” diffusion in cases when users can turn to adoption (Agarwal, 1983). Even more thorough blending of innovation and diffusion — innofusion — has been documented in rural stoves, health programmes, industrial robotics, multimedia and digital environs, agriculture, pumps and vehicles (De Laet and Mol, 2000; Fleck, 1988; Hyysalo and Usenyuk, 2015; Williams et al., 2005). It follows that attention should be given to the form of innovations and the form in which they are communicated to peers, as well as to the form in which these innovations have been then adopted/adapted by peers.

Hence, our interest in this study is in 1) Do consumer innovations diffuse? 2) If they do, do they do so via commercial routes or among peers? and 3) What form does peer diffusion take and what might be the reasons for the prevalence of adoption or adaption in peer diffusion?

Please cite this article in press as: Hyysalo, S., et al., The diffusion of consumer innovation in sustainable energy technologies, Journal of Cleaner Production (2016), http://dx.doi.org/10.1016/j.jclepro.2016.09.045
Linking this interest back to the previous studies of S-RET diffusion, these questions mean clarifying if the innovations by consumers make a difference through adding to the variety of technical solutions available in a given S-RET's development and diffusion. Alternatively, if the consumer innovations do not effectivley spread, should the consumer's technology projects be seen merely as vehicles for competence building among the consumer populations around the new renewable energy solutions that we have documented previously?

We examine these questions through first clarifying our methodology, then making a qualitative account of the data, followed by a quantitative clarification of the observed diffusion patterns before discussing the overall findings.

3. The research context, research design, data and methods

3.1. The research context

We examine consumer innovations in air-source heat pumps, ground-source heat pumps, wood pellet burning, and solar thermal and solar photovoltaic (PV) technologies in Finland from 2005 to 2013.

Finland, as the geographic area under scrutiny, is not home to major manufacturers or developer communities related to any of the technologies we examine (in contrast to, for instance, Austria, Germany, Denmark or Sweden) (Ornetzeder and Rohracher, 2006, 2013). Also, current and expected energy prices in Finland are among the lowest in the EU and the average income is high even though the cold annual average temperature (6 °C in the south of Finland) adds to heating bills. As regards cultural facets, the sparsely populated Finnish countryside has retained some do-it-yourself (DIY) culture that can promote both user innovation and the adoption of solutions by peers. Finland is at the top of the UN education index and this may feature in Finns' capacity and willingness to invent and set up extensive communication forums on how to handle technical novelties. Hence, whilst the economic incentives towards DIY projects and invention are higher in some developing countries, their capability to modify could remain less, or at least be formed differently (Hyysalo et al., 2013a).

As a technological context, the S-RETs we examine have all been around for more than three decades. Consumers have access to modify them since there is nothing legally banning them from doing so. The anonymous public display of modifications does not allow the identification of who exactly made, for example, a potentially hazardous hack that could compromise house insurance (cf. Torrance and Von Hippel, 2013).

3.2. Research design, methods and data

To investigate the diffusion of consumer innovations, we conducted a sequential mixed method study. Fig. 1 provides an overview of the research process reported below, the main focus of the current article being on consumer innovation diffusion and its analysis.

3.2.1. Background research

To identify consumer innovations we used a combination of network search lead-user identification methods (Hyysalo et al., 2015). The searches came to centre around Finnish online internet discussion forums on renewable energy (www.lampopumput.info, www.maalampofoorumi.fi, www.pelletikeskustelu.net and www ilmaismaisenergia.fi) as next to all of the examined consumer innovations were displayed in these. These user-run online forums have evolved into a major communication medium amongst the users of these energy technologies. By the end of 2014 the largest of the heat pump forums alone had been viewed 80 million times in its eight years of existence.

We sampled and stored typical postings in all of the forum sections that we suspected could reveal consumer inventions, most notably the "modifications and improvements" and technical questions sections (here on "DIY sections"), which, for instance, in air-source heat pumps featured 1206 discussion threads. We read through all these threads in their entirety and coded them. To gain a better idea of the inventions and discussants, and their relationship to those in the DIY sections, we used the general statistics of the forum, as well as manually checking the full user profiles of 115 discussants active in DIY sections. We then conducted 30–120-min long semi-structured interviews with 47 forum-active inventing consumers and five (5) firms that had collaborated with inventive consumers, focusing on the modifications that these consumers had made and their information sharing with other consumers and manufacturers.

3.2.2. Qualitative descriptive content analysis

Our data analysis proceeded through content analysis and categorization of all inventions and modifications. We then categorized findings regarding technology, an improved subsystem and the achieved gain (efficiency, suitability, maintenance or cost savings). In total, we found next to 300 potential consumer inventions or modifications. We required that consumer innovation or modification needed to have been.

d) realized and working, creating a benefit for its maker and not just a hack that was not completed or unsuccessful;

e) innovative, either in terms of novel function or novel material realization of a previously identified function. If the consumer project was relevant to a previously known function, the material realization had to be novel and it had to have a clearly identifiable benefit.

Fig. 2 presents the formal criteria for deciding which projects were consumer innovations.

Each potential consumer innovation was then subjected to scrutiny by domain experts independently for the heat pump, pellet burning and solar technologies. In each field three independent experts were used: one expert represented academia specialized in the technology area, one represented consumer inventors and one represented the specific renewables industry. The use of expert evaluations to verify and evaluate the characteristics of consumer innovations is common practice in user innovation research (Franke et al., 2006; Hienert et al., 2014) as in-depth domain knowledge is required for assessing the often non-patented user projects. The use of external experts to assess the consumer projects reduced the number to 213 consumer projects that improved the technology, its ease of use, purpose of use, energy efficiency or price for the consumer. In addition to its innovativeness, the expert evaluators also assessed each consumer project with regard to its ease of implementation for other competent users, its diffusion potential to existing housing and device stock in Finland, and its direct energy saving potential. We discuss these evaluations further in Section 5.

3.2.3. Qualitative analysis of consumer innovation diffusion

To assess the diffusion of these 213 consumer innovations, we scanned the forums, as well as undertook broader Internet searches, to discover if these solutions had been picked up or if they had a prior, parallel or independent later existence of which both the consumer innovator and our expert evaluators might have been unaware. In this analysis we discarded 22 solutions on which the data available to us was too imprecise for clarifying whether or not
they differed from projects found elsewhere. For each of the remaining 181 consumer projects we proceeded to qualitatively analyse how the diffusion had taken place: whether it had proliferated through commercial channels, among peers, taken place as straight adoption or whether it had included further innovative adaptations (see Section 4).

The net effect of this research approach is that we purposefully do not rely on merely self-reported consumer productions or non-verifiﬁed self-estimations of their possible diffusion (De Jong et al., 2015). Our data consists of a set of content-analysed consumer innovations and content-veriﬁed instances of diffusion. This sets a heavy bias towards not detecting possible proliferation and also limits the amount of variables that could be established across the data set compared to user innovation surveys where self-rating can be used to produce data for a great array of multivariate comparisons yet offers less control over the veriﬁcation of answers.

3.2.4. Statistical analysis

To further clarify the diffusion patterns of consumer innovations we used statistical analysis where we used the results of expert evaluations for predicting whether a given consumer innovation should have diffused. Based on prior literature we formulated seven hypotheses regarding the associations between estimated and actual diffusion (which we detail below in Section 5) and examined them through cross-tabulations, bivariate analyses and multivariate analyses.

Both predicted and actual diffusion were measured with ordinal scales, but because of a heavy non-detection bias these were simpliﬁed to a binary value: no diffusion (0) or diffusion (1) in statistical analyses. All observations from both groups were independent. The distributions of the observations did not meet the normality criterion. For such circumstances the most suitable bivariate tests were Fisher’s exact test for signiﬁcance, because of small cells in the cross-tabulation. In the second bivariate analysis, now concerning peer diffusion (Tables 5 and 6), the larger cell size allowed us to use the Mann-Whitney U test (a rank-based nonparametric test) to determine if there were differences in the predictor scores between peer diffusion and non-diffusion. The Mann-Whitney U test is one of the most commonly used statistical tests in behavioural sciences and has a similar statistical power as the t-test.

To further elaborate these bivariate analyses, we conducted multivariate analysis, which consisted of scatterplots, exact logistic regression, binomial logistic regression and two-step cluster analysis. These conﬁrmed our results from the bivariate analysis but did not shed any new light on the relations between dependent and independent variables.

4. Qualitative analysis of consumer innovation diffusion in S-RET

To understand the diffusion mechanisms of S-RET consumer innovations we need to ﬁrst understand how adopters can learn about the innovation, in other words the interaction arenas through which the originator of an innovation and its potential adopters are in contact (Heiskanen et al., 2014; Hyysalo and Usenyuk, 2015). In the Finnish cases, the contacts between innovating consumers and their peers were sometimes face-to-face but 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 advise” 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 author that initiates this and it is in the author’s interests that become represented. The physical character of 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 advise sequences tend to create an imperfect documentation trace. They may detail well 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 documentation trace that this mode of display creates is not geared for copying. Not only are innovative solutions not well categorized for adoption (as to which model, housing type or problem they provide solutions for and if the solutions were effective) but they are not documented so as to aid adoption: the adopter has to be very interested and often needs to contact the innovator to be able to copy the solution. The forum size and installation amounts and amount of consumer innovations we examine are presented in Table 1.

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 adaption: the innovator becoming an entrepreneur (as with Case A) or revealing innovation to a company (as with case B). Our main interest is in how peer diffusion happens (straight diffusion or innovative adaption by peers) or does not happen. We thus elaborate this further and give fuller examples of these innovations in Cases C, D and E.

As discussed in the literature review, the most common sense case of consumer innovation diffusion is the one where an innovation originally built for the innovator's own use is further developed by the innovator to a product in a 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 A illustrates this innovation diffusion path.

**Case A: The consumer becomes an entrepreneur.** A user living in the far north of Finland had been active with heat pump technology and had built several improvements and prototypes for himself. He eventually designed and prototyped a unit combining a ground-source heat pump's underground liquid circuit with an air-source heat pump's convector unit, forming a “ground-source air-heat-pump”, which was a globally new design. The design required new system-level design and changes in various subsystems. The user had close connections to a small coolant application company, owned by a relative, and eventually joined the business as minority owner. Existing ground-source heat pumps on the market relied on water central heating for transmitting the heat around the house. However, many older houses using wood or direct electric heating lack water central heating, and for such homes, the cost of the necessary plumbing makes ground-source heat unfeasible. 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 but 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 air-source heat pumps are not effective (cf. Hyysalo et al., 2013a; Mattinen et al., 2014).

The second path of 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 voluntary 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 the Internet forum and then iterated by several users and adopted, through self-building, by some of them. At some point the original consumer contacted a Chinese producer of the air-source heat pump and suggested that they design a dual-source heat pump. The manufacturer responded by apologizing, 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 co-incidentally from the same city as the one the Finn had contacted) listed exactly the same design on the Internet market place 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 consumer innovation 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 other consumers, yet kept the development in his own hands. The open licence program was then downloaded, installed and updated by other consumers as is. The Interaction arena for the adoption and feedback was one of the Internet discussion forums.

Straight adoption also happened with physical features and not just with software. Three cases of straight adoption took place among the solutions that users created for adjusting the air source heat pump’s ice melting phase. The cooled surface of the heat pump’s outdoors unit condenses moisture, which freezes in low temperatures. The machines thus 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 temperatures the melt water must remain melted until it dripped out of the outdoors unit box. Most air source heat pump models have an additional melting coil that is on whenever the outdoors temperature is below zero. The melting sequence and the additional melting coil were a common points of user adjustment and innovation as the commercial models were not optimized for temperatures below zero. For instance, in many models melting coil was on continuously for four months even when they only needed to run for a few minutes every 40–60 min. This was reported to waste 500 kWh out of 4500 kWh of annual energy use (i.e. over 10% of energy use) in comparison to an optimized system.

One solution copied by several peers as is was an additional control logic for the melting relay in the outdoor box. The control logic monitored the relative temperature of incoming and outgoing freezer circuit liquids and thus detected the melting sequence of the machine. It then activated the relay at the bottom of the casing only when the melting sequence began and kept it on for 5 min after it, thus removing unnecessary heating of the coil.

In another user adjustment, the use of the melting coil was optimized through incorporating an additional thermostat in the machine and this was equally reportedly adopted as is by peers. A third, additional solution to the minimization of the energy used in keeping the melt water from freezing was to make the melting coil, normally lying at the bottom of the doors box to go through the bottom of the outdoors unit box to ensure faster water dripping out. This too had been adopted as is by many peers active in the Internet forums.

As discussed in the literature review on diffusion, not all diffusion takes an adopted-as-is 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 adaption by peers.** In the late 2000s, several users began redesigning air-to-air heat pumps (ASHP) into a novel kind an air-to-water heat pump (ASWHP) by removing the indoor convector unit and connecting the outdoor air-source collector to a liquid circuit in the water central-heating of the house (Fig. 3). The design required extensive changes, including reconfiguring the coolant circuit, building the indoor circuit heat exchanger, adding new sensors and control logic for both indoor and outdoor units, and creating reference data for successful control. The rationale behind the enthusiasm was that off-the-self ASWHPs were considered expensive and even as the energy efficiency gains (and thus energy saving) in self-built designs were not optimal, they beat an ordinary ASHP (the donor system) and the cost is only 10% of the price of an off-the-shelf ASWHP. 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 that faced consumer innovators. There were at least tens, if not hundreds, of other consumers who repeated the design using the posted descriptions.

Over the course of the building efforts, altogether 14 distinct consumer innovations emerged to enhance the converted ASWHPs. All had different parts and subconfigurations, as well as a different donor ASHP model. At least three (3) of these consumer designs were copied further “as is” by several other consumers but for the other 11 designs there is no evidence of further copying (though in all likelihood it has happened). At some point an initiative for a joint open-source 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 adaptations one can analytically discern three different types of innovative diffusion. The most straightforward is the one where the second (adopting) consumer adds new features to the first consumer’s design on adopting it. Some adapting consumers also removed unneeded features and in so doing ended up with further reconfigurations to make the design work. Finally some consumer designs, for instance those that used an entirely different make of donor unit, ended making a series of changes to adapt the original design. For our present discussion, we should bear in mind that these three types are all instances of innovative diffusion, even

### Table 1

The penetration of the case technologies in Finland, the user innovations examined in this study and the sizes of the online forums on which these technologies are exchanged.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Air-source heat pumps</th>
<th>Ground-source heat pumps</th>
<th>Wood pellet burning systems</th>
<th>Solar thermal collectors</th>
<th>Solar PV systems</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>User population*</td>
<td>440 000</td>
<td>70 000</td>
<td>25 000</td>
<td>10 000</td>
<td>50 000</td>
<td>595 000</td>
</tr>
<tr>
<td>Number of innovations</td>
<td>69</td>
<td>19</td>
<td>75</td>
<td>12</td>
<td>6</td>
<td>181</td>
</tr>
<tr>
<td>Size of online forum</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
<td>Small</td>
<td>Small</td>
<td></td>
</tr>
</tbody>
</table>

* The user population of the product or service class in question at the time of conducting the research (between 2012 and 2013).
introduced a novel way of building a concentrating solar collector electric pump to the heat exchanger in the house. This user project if these can be analytically separated (in Fig. 4 below these are Section 5).

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 and eventually resulting in a cheaper price. Case D also clarifies this case as a different type of ASWHP was commercially available all along, yet consumers created different versions of it. Such innovative peer diffusion solutions could be coded just as validly as 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 having potential value for later adopters/adopters by experts who evaluated the potential of consumer innovations for us (see Section 5).

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

A solar panel user noticed that the aluminium frame of solar PV panels froze and the lower rim also began to gather snow, which blocked sunlight. The user attached a small melting cable, connected to the power grid, to the lower rim of the panels to melt the snow. The required heating of the rim requires some tens of watts before the panel starts to get sunlight, heats up and discards the rest of the snow. The yield of these panels on a winter day in Finland has been 200–300 Wh. 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.

A user created a small-scale concentrated solar thermal collector, including an azimuth and a declination tracking system, 104 steel plate mirrors (each 30 × 30 cm), computerized control, and programs for tracking the sun’s exact location year-round. The system heated hot water (with a maximum surface temperature of 400 °C on the heating plate) and the water was circulated by an electric pump to the heat exchanger in the house. This user project introduced a novel way of building a concentrating solar collector even though the general principles for solar tracking and concentration are old. The particular construction, design principles, software, and solar tracking equations in this particular construction were novel. When the steel plates wore out, the user reconfigured his system into a sun-tracking solar PV system by replacing the steel plates with solar PV panels. Both these innovations were displayed in the Internet forums, but no adoption by others has been documented. The likely reasons for this were the considerable difficulty of implementing the system, and the size and esthetic qualities of the installation when located in the yard of a private home.

Some of the user solutions also appeared to compete regarding diffusion among peers. There were several other solutions to the air source heat pump’s melting coil optimization described in case C, yet there was no evidence that any of these had spread any wider. One solution involved cutting off material from the bottom of the outdoor unit box to make the water drip out faster; another was to apply silicon spray to the surfaces to prevent icing and to speed the movement of water. Whilst both these solutions were viable they needed care in their application as too large a hole in the casing could affect the airflow through the outdoor unit and the silicon spray application ran the danger of getting silicone in other parts of the unit as well as being a solution that required regular repetition (as the silicon wears out). Some user solutions did not spread because they were not actively displayed: for instance one of the user innovators replaced the above described (case C) melting coil thermostat relay solution with a time relay solution synced to the melting cycle and reported higher reliability with it to us (the researchers) yet did not openly 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 (see Fig. 4).

Some of these cases of peer adoption had wide diffusion and we wish to examine these most widespread cases in more detail. In our data set there were four solutions that have diffused widely. On the one hand there were two software applications. First, the “house logger” open licence program described above, which was adopted as is. Second was spreadsheet software for estimating energy consumption and production, which had an unknown origin and a range of annotations, witnessing of both adoptions and adaptations. On the other hand there were two physical designs. The first was a housing built to cover an air-source heat pump outdoor 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 under-neath an air-source heat pump outdoor unit so that the ice formed and piled under the unit is easy to remove. While all these had 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 in the three adaptive diffusion ones the variations were technically easy to accomplish and required no detailed in-structions: using whatever the ready-made receptacle the con-sumer had at hand instead of particular sledge or building a different housing to match the house. The interaction arenas in these cases were predominantly the Internet discussion forums.

When we examine the whole data set regarding these types of diffusion, the 181 projects feature one case that has 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 is 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, and it appeared more sensible to treat it as less-than-a-hundred and more-than-a-hundred diffusions to match the uncertainty in identifying the diffusions. With this di-vision there is only one case of diffusion to tens of thousands of adopters: the placing of a sledge underneath an air-source heat pump outdoor unit. There are three instances whose veri-fiable diffusion measures in the hundreds, 17 measuring at least in tens and in the rest of the cases there are less than ten verifiable in-stances of diffusion.

Table 2 documents the distribution of consumer innovation diffusion. It reveals that the 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.

5. Verifying the diffusion of consumer innovations through quantitative analysis

5.1. Expert evaluations of the innovations

To improve our understanding of the diffusion of solutions by consumers we proceed to examine their characteristics and link these to the diffusion amounts statistically. The first step in doing so was to subject all the innovations 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 by potential adopters. The third item in the evaluations was the diffusion potential of the in-novations to the total Finnish consumer-base: to how large a pro-portion of the Finnish consumer base would the invention be potentially beneficial and applicable? The experts took the market size as the consumer base into which the modi-fi-cation can prolif-erate, rather than, for example, evaluating the sales potential of the improved model.

The final item in our evaluations was the 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 onto 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, which were mostly higher than the mean direct energy saving of the
evaluated inventions. However, we have discarded all but 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.

From Table 3 we can see that most innovations were relatively incremental (albeit a few technically radical new-to-the-world ones existed). However, particularly the heat pump and solar technology inventions were moderately difficult to 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, as the Finnish market for both heat pumps and wood pellet burning systems is divided among several brands and tens of models (Hyysalo et al., 2013b).

5.2. Quantitative analysis of innovation diffusion

The expert evaluations can further be 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 (Raasch and von Hippel, 2012; Shah and Tripsas, 2007; von Hippel, 2005). Innovations that are patentable, not obvious and hold wide diffusion potential should encourage the consumer innovators to seek to commercialize them. If they imply a direct energy saving, this saving should be correlated positively 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 would need 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. These interrelations can be formed into four hypotheses:

Hypothesis 1. Consumer innovations that rate highly for innovativeness are associated with consumers turning entrepreneurs.

Hypothesis 2. Consumer innovations that rate highly for diffusion potential are associated with consumers turning 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 rate highly for their energy saving potential are associated with consumers turning entrepreneurs.

We examined commercial diffusion with regard to rated innovativeness, ease of implementation, diffusion potential and energy saving. Due to the small number of diffusions in our sample, Fisher’s exact test is adequate for evaluating how significantly associated the predictor of innovativeness is for these observed diffusions.

We find (Table 4) that the innovativeness of a consumer innovation is significantly associated with the consumer becoming an entrepreneur, at a significance level below one per cent. Similarly, the consumer becoming an entrepreneur is also a function of the diffusion potential ($p = 0.01$), the ease of implementation ($p < 0.05$) and the energy saving potential ($p < 0.05$). All the observed consumer innovations that were new-to-the-world have been commercialized by consumer entrepreneurs, 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 in 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, at 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, but in light of research on consumer innovation (De Jong et al., 2015; Raasch and von Hippel, 2012; von Hippel and DeMonaco, 2013), 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 concern energy saving directly. Diffusion potential should predict realized diffusion

Table 2
The diffusion of consumer innovations when innovative peer diffusion is included.

<table>
<thead>
<tr>
<th>Type of diffusion</th>
<th>Instances</th>
<th>%</th>
<th>Scale of diffusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>No diffusion</td>
<td>100</td>
<td>54.9%</td>
<td>0</td>
</tr>
<tr>
<td>P2P straight peer diffusion &lt; 1C 100</td>
<td>15</td>
<td>8.2%</td>
<td>1 diffusion &gt;100</td>
</tr>
<tr>
<td>P2P innovative peer diffusion &lt; 1C 100</td>
<td>62</td>
<td>34.1%</td>
<td>3 diffusions &gt;100</td>
</tr>
<tr>
<td>User entrepreneur</td>
<td>3</td>
<td>1.7%</td>
<td>3 &lt; 1 C 100</td>
</tr>
<tr>
<td>Revealed to company</td>
<td>2</td>
<td>1.1%</td>
<td>Not available</td>
</tr>
<tr>
<td>Total</td>
<td>182</td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

Table 3
Expert evaluation of inventiveness, ease of implementation, diffusion potential and energy saving potential.

<table>
<thead>
<tr>
<th>Innovation characteristic</th>
<th>Scale max</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>–</th>
<th>Scale min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Innovativeness</td>
<td>New to the world</td>
<td>2%</td>
<td>3%</td>
<td>15%</td>
<td>31%</td>
<td>49%</td>
<td>–</td>
<td>Minor improvement</td>
</tr>
<tr>
<td>Easy</td>
<td>Easy</td>
<td>20%</td>
<td>24%</td>
<td>27%</td>
<td>24%</td>
<td>6%</td>
<td>–</td>
<td>Difficult</td>
</tr>
<tr>
<td>To all equipment</td>
<td>Diffusion potential</td>
<td>4%</td>
<td>8%</td>
<td>20%</td>
<td>34%</td>
<td>33%</td>
<td>–</td>
<td>Marginal</td>
</tr>
<tr>
<td>Energy-Saving Potential</td>
<td>% of annual energy use</td>
<td>&lt;1%</td>
<td>&lt;3%</td>
<td>3–6%</td>
<td>6–9%</td>
<td>9–12%</td>
<td>12–15%</td>
<td></td>
</tr>
</tbody>
</table>
because the population that could adopt it is larger. These can be expressed as hypotheses on peer diffusion, as follows:

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

**Hypothesis 6.** Consumer innovations that rate 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 (Table 5). 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 the opposite association to that stated in Hypothesis 5.

Next we examine how innovative peer diffusion (Table 6) 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 ($p < 0.5$). Our Hypothesis 6 gains further support from the cases that have diffused widely. Three out of four were predicted to have diffusion potential for all equipment in the market. The Fisher’s exact test two-sided significance for wide diffusion items is 0.000.

The other significant association is between the ease of implementation and realized diffusion ($p < 0.01$ and 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 have easy-to-implement ones. However, when we examine those projects that have diffused more widely 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 takes place predominantly 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 Finnish general population innovating in any consumer product category.

### 6. Discussion

Previous research indicates that innovating consumers have aided the overall diffusion of renewables in Finland through their peer assistance on online forums (Heiskanen et al., 2014; Hyysalo et al., 2013a; Juntunen, 2014b). In most cases, the competency of consumers had been built or deepened through their engagement in their innovation projects. The aim of the present study was to clarify whether the consumer solutions themselves also spread and, if so, how this has happened. 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 likely to be of less impact than the previously established indirect support of the technology type that is provided by innovating consumers.

#### 6.1. The potential under-diffusion of consumer innovations

Almost all of the examined consumer innovations had been displayed on widely read online forums, yet they had not been posted there to help others to adopt them but mostly to either solicit help with some pressing problem to do with the project or simply to share the project. Few projects were accompanied with detailed instructions concerning how to replicate them — overall, they were thus poorly observable and not triable (Rogers, 2003).

Innovations that diffused widely were in the easiest category of implementation and in the widest category of diffusion potential. For such simple-to-relicate solutions, the work of displaying on online forums would be sufficient to spur their wide diffusion. In contrast, modest scale diffusion occurred in 71 out of the 181 projects (39.2%), mostly through innovative peer diffusion.

This is likely to be no coincidence. The display-and-advice display orientation by innovating consumers is in line with previous findings on how user innovators lack incentives to further the adoption of their solutions (von Hippel and DeMonaco, 2013). 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 (Raasch and von Hippel, 2012; von Hippel and DeMonaco, 2013).

#### 6.2. Innovative diffusion among peers

Our data underscores how equating the diffusion of consumer innovations with adoption or straight peer diffusion may require reconsideration. In classic diffusion studies the confused item was taken for granted — usually a discreet item such as new seed or simple tool introduced by a commercial entity or change agency (Rogers, 2003). In contrast, S-RET installed in a house are at least moderately complex technical configurations. In our data set the largest type of diffusion was innovative peer diffusion, where different consumers have continued to incrementally and iteratively adapt the solution they adopted. This results in materially and conceptually distinct consumer solutions that have influenced each other. The phenomenon is known to previous research. *Adaptive diffusion, innofusion, innovation at adoption and the fluid deployment of technology* are terms used to describe variations of innovative technology uptake (Agarwal, 1983; De Laet and Møl, 2000; Douthwaite et al., 2001; Fleck, 1988; Hyysalo and Usenyuk, 2015; Williams et al., 2005).

The high incidence of innovative peer diffusion in our data set makes sense in light of consumer innovation research. Its basic premise is that consumers innovate for themselves because each consumer has a somewhat different set of competences, preferences and contexts of use and also some consumers remain

<table>
<thead>
<tr>
<th>Table 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>The measures of association between independent and dependent variables through Fisher’s exact test.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Commercial diffusion</th>
<th>User entrepreneur</th>
<th>Revealed to comp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Innovativeness</td>
<td>27.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Ease of implementation</td>
<td>6.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>(0.045)</td>
</tr>
<tr>
<td>Diffusion potential</td>
<td>8.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(0.010)</td>
</tr>
<tr>
<td>Energy saving potential</td>
<td>15.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>(0.047)</td>
</tr>
</tbody>
</table>

Note: Two-sided significance marked with.

<sup>a</sup> $p < 0.01$

<sup>b</sup> $p < 0.05$

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underserved by the offers available on the market (von Hippel, 2005, 1976). 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 geographically dispersed physical goods and are united by digital forums that are geared only for discussions. The nature of their projects and their interaction arena allows them to enjoy some of these pooling gains, but not all:

- 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 solution directions.
- They can gain solution outlines and advice in 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 in the present data set).
- 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.
- 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 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 collaborations 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. This latter is likely to remain the prevalent case of S-RET peer diffusion as S-RETs are united by digital forums that are geared only for discussions. The nature of their projects and their interaction arena allows them to enjoy some of these pooling gains, but not all:

- 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 solution directions.
- They can gain solution outlines and advice in realizing related solution search directions from their peers.

6.3. Implications for consumer innovation in S-RET

Consumer innovations and adaptations add to the variety of technical solutions available for adopters/adapters of S-RET. 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 part lists and recipe-like texts (as found at instructables.com), are unlikely to work as solutions. Following the reasoning of von Hippel and DeMonaco (2013) 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. an easy way to make blueprints available, 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 platforms for physically sharing designs among peers.

7. Conclusions

Consumer innovators in S-RET add to the solution variety of S-RETs available for other adopters. However, our study indicates that the direct solution spread remains limited apart from a handful of solutions. This is a disappointing finding to 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 appears not so much to be an issue of the solution quality as domain experts assess many of the innovations to be socially valuable and their assessment predicts 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 the 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 is. As noted above, more research is required on the dynamics of the peer diffusion of consumer innovation, particularly on the prevalence and rationales of

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### Table 5

Mann-Whitney U test results for straight transfer peer diffusion. Significance (sig.) **p < 0.01, *p < 0.05.

<table>
<thead>
<tr>
<th></th>
<th>U</th>
<th>r</th>
<th>Sig.</th>
<th>Mean no diffusion</th>
<th>Mean diffusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Innovativeness</td>
<td>937.5</td>
<td>0.13</td>
<td>(0.086)</td>
<td>92.85</td>
<td>70.50</td>
</tr>
<tr>
<td>Ease of implementation</td>
<td>1674.5*</td>
<td>0.17*</td>
<td>(0.023)</td>
<td>88.41</td>
<td>119.63</td>
</tr>
<tr>
<td>Diffusion potential</td>
<td>1244.5</td>
<td>0.00</td>
<td>(0.998)</td>
<td>91.00</td>
<td>90.97</td>
</tr>
<tr>
<td>Energy saving potential</td>
<td>291.5</td>
<td>0.03</td>
<td>(0.830)</td>
<td>31.28</td>
<td>32.50</td>
</tr>
</tbody>
</table>

### Table 6

Mann-Whitney U test results for innovative peer diffusion. Significance (sig.) **p < 0.01, *p < 0.05.

<table>
<thead>
<tr>
<th></th>
<th>U</th>
<th>r</th>
<th>Sig.</th>
<th>Mean lack of diffusion</th>
<th>Mean diffusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Innovativeness</td>
<td>4372.5</td>
<td>0.08</td>
<td>(0.269)</td>
<td>87.55</td>
<td>95.56</td>
</tr>
<tr>
<td>Ease of implementation</td>
<td>5410.5**</td>
<td>0.30**</td>
<td>(0.000)</td>
<td>77.47</td>
<td>108.87</td>
</tr>
<tr>
<td>Diffusion potential</td>
<td>4820.5*</td>
<td>0.18*</td>
<td>(0.016)</td>
<td>83.20</td>
<td>101.30</td>
</tr>
<tr>
<td>Energy saving potential</td>
<td>513.5</td>
<td>0.08</td>
<td>(0.538)</td>
<td>29.98</td>
<td>32.67</td>
</tr>
</tbody>
</table>

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innovative diffusion. The current study identified which types of sharing and pooling of efforts the consumer innovators in physical technologies (such as S-RET) could enjoy and which they could not. However, we could not suggest remedies for the limitations these consumers experienced. Particularly the ways in which consumers can document their solutions and how peers can better trial them would merit further research and experimentation. At the same time, the innovative diffusion does foster competence development among consumers who pursue it, and the competence built up through hacking and designing S-RET has been previously found to contribute to the quality of help given to other consumers regarding their commercially acquired S-RET systems (Hyysalo et al., 2013a, 2013b). The Finnish case underlines 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 fit optimally upon their market entry.

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 innovation and renewable energy systems articulation can be used 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 for improvement needed 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.

Further research is needed to understand more fully the range of roles these citizens play as intermediaries in sustainability transition, as well as in the overall dynamics by which Internet discussion forums allow proliferating technologies (such as S-RET) to emerge, grow, thrive, or wither.

Acknowledgements

The research has been conducted with financial support from Academy of Finland grants “User Innovation Pathways to Utility” (AKA 138187) and “Intermediaries in the energy transition: The invisible work of creating markets for sustainable energy solutions (TRIPOD)” (AKA 288402), and the Academy of Finland strategic research council consortium 293405 “Smart Energy Transition – Realizing its potential for sustainable growth for Finland’s second century”.

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