Domestication pathways of small-scale renewable energy technologies

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The sociology of consumption uses the domestication framework to examine adaptation processes in which technology becomes part of everyday life. This study applies the domestication framework to renewable decentralized energy technologies (DET). Drawing on interviews and Internet material from household and summer-cottage inhabitants using DETs in Finland, the study sheds light on how renewable energy technologies are adapted in local conditions. In such adaptation, multiple domestications are linked and lead to the increasing use of new technologies without a stable final point, a process which can be conceptualized as domestication pathways. Modularity, product multipurposing, and convenient interoperability with other systems are key requirements to enhance the diffusion of renewable energy technologies.

KEYWORDS: renewable energy resources, energy consumption, technology attitudes, residential areas

Introduction

Energy provision has historically been developed based on networked infrastructure and centralized systems, leading to a passive role for most energy end users (van Vliet et al. 2005; Heiskanen et al. 2010). From the standpoint of residential housing, energy systems work in the background and provide air and water heating and cooling with minimal requirements for daily monitoring, configuring, or maintenance by inhabitants. However, the need for low-carbon solutions, along with rising energy prices, is changing residential energy systems and consumption. Consumers are therefore increasingly installing decentralized energy technologies (DETs) in their homes.

Previous studies have shown how consumers have only limited opportunities to significantly reconfigure their own individual routines of consumption and rarely think about the consequences of their actions (Levett, 2003; Southerton et al. 2004). Research on small-scale energy technologies and consumer behavior has focused primarily on motivational factors, barriers to deployment, and early phases of installation and use (Haas et al. 1999; Watson, 2004; Ornetzeder & Rohracher, 2006; Palm & Tengvard, 2011). However, scholars have begun to suggest that the most interesting aspects of consumer behavior occur once energy technologies are installed within the home. When users take actions to produce energy locally, energy technology becomes present in inhabitants’ daily lives, which increases awareness of energy use and decreases energy consumption (Keirstead, 2007). At the household level, DETs require adaptation—learning about use and changing practices—to make technology suitable for the local context. This article seeks to develop a better understanding of the role of end users in technology diffusion processes to help policy makers to formulate energy policy and manufacturers to develop environmentally friendly final products, and to enhance the adoption rate of these technologies and lifestyles.

This study examines sociotechnical change and processes through which DETs become integrated as inseparable parts of everyday life. The analysis follows the domestication framework (Silverstone & Hirsch, 1992; Pantzar, 1997; Berker et al. 2006), a concept used in the sociology of technology to describe and analyze processes of technological acceptance, rejection, and use. The domestication framework emerged from a series of studies that sought to understand the appropriation of artifacts in the specific social setting of the home (Williams et al. 2005). This article’s central question is: What kinds of domestication processes are involved with residential renewable energy production and use? Domestication of DETs is studied via three types of residential renewable energy technologies installed in existing houses in Finland: air-heat pumps, micro-wind stations, and solar-thermal collectors.

The article begins by presenting the background of the domestication framework and how qualitative empirical analysis has used it. I then outline the Finnish market and its characteristics with respect to...
climate, policy, and renewable technology use. The analysis is initially carried out following the domestication framework phases to reveal domestication processes within the scope of a single renewable technology. However, the analysis reveals a pathway-type adaptation where multiple renewable energy technologies were in fact taken into use by the households. I next explain in detail the notion of domestication pathways and discuss the socio-technical background of the phenomenon. I conclude by highlighting the implications for energy policy, technology design, and technology studies.

Domestication Framework

The concept of domestication originated in large part within anthropology and consumption studies (Haddon, 2006a). This particular understanding represents a shift away from models that assumed adoption of innovations to be rational, linear, monocausal, and technologically determined. It presents a framework and research approach that takes into account the diversity and complexity of everyday life and technology’s place within its dynamics, rituals, rules, and routines. The framework implies that the process of domestication has been successful when technologies are not regarded as cold, lifeless, and problematic, but as comfortable, useful tools—functional and symbolic—that are reliable and trustworthy (Berker et al. 2006).

Through domestication, artifacts become invisible, taken-for-granted elements of everyday life (Williams et al. 2005). Silverstone et al. (1992) have presented a theoretical scheme to study technology use by proposing four dimensions or states in the household’s dynamic uptake of the technology: appropriation, objectification, incorporation, and conversion. The appropriation phase centers on the motivations and reasons associated with acquiring technology. During objectification, the household gives a new project a physical location and a timetable of use, which is followed by the incorporation phase when established practices emerge and a technology becomes embedded into everyday-life routines. The final phase in the domestication framework is conversion, which defines the relationship between the household and the outside world and focuses on processes of how the technology’s meaning is shared with others. The sign of successful household-sector integration of technology is that the product has a symbolic aspect in addition to its utility aspect. In addition to these four processes, Sørensen (2006) highlights the importance of cognitive processes related to learning practice as well as meaning.

The adoption of technology is not a one-time event. It happens over a long period, where several different processes advance more or less simultaneously (Røpke, 2001). The preadoption process is reflected in perceptions of technologies and services, in how people imagine the role of technology in their lives, as well as in negotiations around, and sometimes resistance to, its acquisition (Haddon, 2006b). When examining the relationship between technology consumption and the domestic sphere, the emphasis is on the dialogue among the psychological, social, economic, and political, highlighting significant factors such as the gendered nature of users’ relationships with technology (Silverstone & Hirsch, 1992; Berker et al. 2006).

As an analytical tool, the domestication concept offers a viewpoint that makes visible various practices of adopting technology as part of everyday life (Peteri, 2006). Domestication can be seen as a period in the biography of an artifact around its introduction into the domestic setting. The process of consuming and embedding the object into the household is one of sense-making, of transformation of the alien object to ascribe its meaning in the household’s symbolic reality (Berker et al. 2006). Biographies of things describe transformation of technology, but simultaneously they reveal the changing qualities of the shaping environments through which they pass (Kopytoff, 1988; Silverstone & Hirsch, 1992). In consumption, the item is incorporated into the consumer’s personal and social identity (Gell, 1986; Hyyssalo, 2009a). At the same time, people generate interpretations and applications of technological systems that often diverge from the ones originally inscribed by designers (Bakardjieva & Smith, 2001). In this way, domestication represents a step away from belief in the one-sided transformative power of technology; study of innovation and diffusion is an area that the domestication approach clearly develops further (Berker et al. 2006).

The domestication of consumer goods has been quite extensively studied, beginning in the 1990s (Haddon, 2006a; Peteri, 2006). To date, domestication studies have typically examined electronics and media technology in considering the contexts in which information and communications technologies (ICT) are experienced (Silverstone & Hirsch, 1992; Ward, 2005; Berker et al. 2006; Haddon, 2006b; Peteri, 2006). However, domestication has proved a useful tool for analyzing, for example, e-learning technologies (Habib & Sønneland, 2010) and health technology studies (Hyyssalo, 2009a). Aune’s (2007) research on energy use and homes, and Isaksson’s (2009) work on passive houses, are rare examples of a use of the domestication framework within the context of energy technology (see also Sørensen et al. 2000).
Finland has a considerably colder climate than central and southern Europe and is a sparsely populated country, with an average of 17.5 people per square kilometer. Finns have been frontrunners in terms of environmental awareness and have developed several innovative environmental policy instruments over the last 40 years. In addition to regulations, economic instruments, informational product labels, and management schemes have been deployed (Mickwitz et al. 2011). For all consumers, two main policy mechanisms support energy efficiency and renewable DET investments in existing houses. The Energy Support Grant is targeted at selected renewable energy technologies (to replace oil or electric heating with ground-source or air-to-water heat pumps) and can be used to offset up to 20% of the cost of the equipment.1 Furthermore, a tax-deduction

1 The grant is managed by the Housing Finance and Development Center of Finland (ARA) on the basis of annual allocations from

Table 1 The main renewable energy sources, small-scale technologies and characteristics in Finland.

| Energy Source | Energy Technology | Market Penetration in Finland | Annual Operation (Seasonal Predictability) | Stochastic (Daily Predictability) | Central-Heating Requirement | Usability for Regular User |
|---------------|-------------------|-------------------------------|-------------------------------------------|---------------------------------|-----------------------------|--------------------------|
| Wood          | Wood-burning boiler | Main source of heating in >410,000 houses [1] | Year-round | No | No | During heating season daily use |
| Wood          | Fireplaces | >2,900,000 fireplaces in total [1] | Year-round | No | Yes | During heating season daily use. Summer season few days heating intervals |
| Wood pellet   | Wood-pellet boiler | 26,000 [2] | Year-round | No | Yes | During heating season daily use. Frequent maintenance, e.g., cleaning Periodical cleaning of internal unit |
| Outdoor-air heat (+electricity) | Air-source heat pump | 400,000 [3] | Year-round | No | No | Very little management or maintenance |
| Outdoor-air heat (+electricity) | Air-to-water heat pump | 8,000 [3] | Year-round | No | Yes | Very little management or maintenance |
| Ground heat (+electricity) | Ground-source heat pump | 86,000 [3] | Year-round | No | Yes | Very little management or maintenance |
| Indoor-air heat (+electricity) | Exhaust air-source heat pump | 24,000 [3] | Year-round | No | No | Very little management or maintenance |
| Wind          | Wind generator | 1,000 [4] | Year-round | Yes | No [6] | Very little management or maintenance |
| Solar         | PV solar | 50,000 [5] | Summer period | Yes | No | Very little management or maintenance |
| Solar         | Solar-thermal collector | 10,000 [5] | Summer period | Yes | No [6] | Very little management. Annual maintenance check. |
| Solar         | Solar-air collector | Marginal | Summer period | Yes | No | Very little management or maintenance |

[1] Alakangas et al. (2008).
[2] Bioenergiary (2013).
[3] SULPU (Finnish Heat-Pump Association) (2013).
[4] Estimate by Tuulivoimayhdistys (Finnish Wind Power Association) (2012).
[5] Researcher estimate. Official statistics do not exist. Users’ self-import is widely used in addition to do-it-yourself (DIY) systems.
[6] Central water circulation is required if the technology is used for space heating.
system allows a 45% deduction from the cost of manual installation work (service) with a maximum of €2,000 (US$2,700) per annum.

There are 1.1 million detached houses in Finland and almost 500,000 summer cottages in which the use of renewable energy has steadily increased in recent years. Rising energy prices, progress in renewable energy technologies, energy-regulation changes, and changes in attitudes toward sustainable lifestyles are intensifying demand for renewable DETs. Table 1 summarizes the main small-scale renewable energy sources and technologies and their characteristics. Wood is a traditional energy source and comprises 35% of total energy consumption in detached houses. In the present study, heat pumps represent a mass-market technology that is widely adapted and in which installations are rapidly growing. In 2012, over 45,000 new air-source heat pumps were installed, bringing the current countrywide total to more than 400,000 units (SULPU, 2013). Both solar-thermal collectors and micro-wind markets are in an early phase. In 2009, the total installation area of solar-thermal technology was 26,973 square meters that produce 64 million British thermal units (BTUs) of energy annually (ESTIF, 2010). Micro-wind is very rarely used and public statistics include only commercial projects and installed capacity.

An air-heat pump is used for both cooling and heating. The device employs a small amount of energy to move heat from one location to another. In the process, a pump can achieve a coefficient of performance (COP) that is up to 2–4 times larger than direct electric heating. Air-heat pumps can also be used for cooling purposes, which increases electricity consumption.

A solar-thermal collector converts solar radiation into a more usable or storable form, such as water. Water is stored in a hot-water tank. To prevent freezing of the collector in the Nordic climate, a mixture of water and propylene glycol is used as the heat-exchange fluid that warms water in the heat exchanger. The living area is heated by radiant heating, in which heated water is circulated in radiators or through underfloor heating. In Finland and the rest of the Nordic region, a solar-thermal collector is operational only part of the year.

Micro-wind generators can provide electricity for private use in both rural and urban environments. In Finland, micro-wind is often deployed to power up off-grid summer cottages, but it is also used in grid-connected houses for micro-generation. Wind power can also be used for heating, with a heat exchanger for water or with electric radiators for indoor space heating. However, a more common setup is to use wind power to charge batteries, which can provide a steady output of electricity for different appliances and purposes during low-wind conditions.

Data and Methods

This article reports on energy technology in both residential homes and summer cottages. The three particular technologies were selected to cover both widely adapted and more niche types of energy equipment. Primary interview data were collected after a broader study that had its starting point in three Internet-based energy-technology forums. With 5,060, 758, and 323 unique users, respectively, and together over 250,000 postings at the start of 2014, these venues cater to active discussions around DETs. Network searches are increasingly popular in user-innovation research to identify so-called lead users (Hyysalo et al. Forthcoming). An initial search of users in the Internet forums was based on the screening method that is widely used in user-innovation research (Sudman, 1985; Von Hippel, 1988). Screening is a standardized, quantitative approach, based on assessing a large number of potentially relevant users (Belz & Baumbach, 2010). Furthermore, snowball sampling was employed in interviews to find people outside the Internet forums (Goodman, 1961; Welch, 1975). These two methods helped to recognize users with lead-user characteristics (cf. Hyysalo et al. Forthcoming). These individuals were interviewed for a separate study focusing on user innovations (Hyysalo et al. 2013a; 2013b), and regular energy users who were part of this study.

The regular users in this study comprised 1) nonprofessionals with no involvement in commercial development of residential energy technology and systems; 2) professionals with involvement in renewable energy technology and systems; and 3) municipalities.

The screening began with the website lampopumput.info which focuses on heat-pump technology. We first developed an overview of all major categories (n = 42) by going through 40–100 thread headings in each and following 5–20 threads in detail to get a sense of the topics and contents in each category. It soon became evident that the “do-it-yourself” section is the most valuable for user-innovation research and that became the focus in our prior project (Hyysalo et al. 2013a; 2013b). For the present study, the “usage experiences” section was used to search potential users. It featured 227 discussion threads which were sampled to identify individuals who would be invited to interviews. The screening continued in the ilmaisenergia.info and poikkis.net forums. We thoroughly read all threads relating to solar-thermal collectors (60 in ilmaisenergia.info and two threads in poikkis.net) and wind energy (94 and 60 threads respectively).
2) individuals who use renewable energy technology in a detached family house or summer cottage and make decisions regarding their own energy-system purchases and use; and 3) people who acquired renewable energy technology more than a year ago. The search resulted in a total of 43 prospective respondents, of which fifteen individuals fulfilled the above-mentioned criteria and were used when researching the domestication processes of DETs (Table 2). The users had diverse educational backgrounds (primary school to university degree) and professional experience (retired and working class to white collar), and various consumer roles regarding energy technology. Bas Van Vliet (2004) divides consumers of network-bound systems into three groups: “normal” consumers who make choices among different market options, citizen-consumers who link consumption with social issues, and co-providers who produce their own electricity. A combination of roles, of course, is possible and in this study most subjects can be characterized as normal users who acquire part of their energy from external sources but are also co-providers.

The 30–60 minute interviews were conducted in 2011–2012. Users were located throughout Finland and the final data set included twelve men and four women, with nine air-heat pump, seven solar-thermal collector, and five micro-wind cases. The interviews were semi-structured and the main themes and questions were planned according to the domestication framework phases. The topics progressed from early information gathering to purchase, installation, early use, and routinized use to capture relationships, meanings, and activities related to DETs. As a secondary source, personal blogs (from two respondents) and Internet-forum discussion material (from four respondents) were used. All interviews were recorded and transcribed. The data were coded and analyzed for emerging sub-themes and, eventually, constructed in accordance with main themes consistent with the

Table 2 Descriptions of interviewees.

| Interviewee       | Gender | Main Energy Source                          | Supporting Energy Systems | Installation Year (Supporting System) |
|-------------------|--------|--------------------------------------------|---------------------------|-------------------------------------|
| Household 1       | F      | Electrical heating (water circulation)     | Air-heat pump             | 2010                                |
| Household 2       | M      | Direct electrical heating                  | Air-heat pump             | 2008                                |
| Household 3       | M      | Oil                                       | Air-heat pump             | 2009                                |
| Household 4       | M      | Wood pellets and oil                       | Solar-thermal collector   | Pellet 2005, Solar 2009             |
| Household 5       | F & M  | Oil                                       | Solar-thermal collector   | 2008                                |
| Household 6       | F      | Wood (water circulation) and air-heat pump | Electricity, solar-thermal collector | 2004 |
| Household 7       | M      | Direct electric heating                    | Air-heat pump             | 2008                                |
| Household 8       | M      | Electrical heating (water circulation)     | Air-heat pump, solar-thermal collector | 2009 |
| Household 9       | M      | Direct electrical heating                  | Fireplace, wind generator | 2011                                |
| Household 10      | M      | Oil and air-heat pump                      | Wind generator            | 2002                                |
| Household 11      | F      | Wood                                       | Electrical heating (water circulation), solar-thermal collector | 2009 |
| Household 12      | M      | Wood pellets, wood, oil                    | Solar-thermal collector, air-heat pump, exhaust air-heat pump | Solar 2009, AHP 2010 |
| Summer Cottage 1  | M      | Combination of multiple sources (no winter heating) | Wood heating, wind generator, PV solar | 1988 |
| Summer Cottage 2  | M      | Wood heating and air-heat pump             | Wind generator            | 2009                                |
| Summer Cottage 3  | M      | Combination of multiple sources (no winter heating) | Wind generator, solar-thermal collector, PV solar, diesel aggregate | 1999 |
primary dimensions of the domestication framework. All quotations that appear below were translated by the author from Finnish.

Analysis of the Domestication Process

Development of Need and Motivation for Renewable Energy Technology

This study of the development trajectories of DETs via the domestication framework reveals how motivations and meaning change over time when energy technology develops and practices and needs of users evolve. While this notion is new in studies related to DETs, scholars working from the perspective of science and technology studies have recognized its relevance (Freeman, 2007).

Financial circumstances are central in energy-technology purchases. Increased energy costs, especially oil prices before 2008, induced homeowners to consider alternative options. During this timeframe, the financial crisis and other developments in the global economy led to lower energy prices and spurred a period of high volatility and unpredictability in energy markets. To reduce their dependency on market fluctuations, many homeowners started to seek alternative solutions. In this context, renewable energy was considered to provide predictability and attenuate uncertainty. However, the sudden drop in energy prices influenced homeowners’ decision making. In situations of high energy prices, more eco-efficient solutions, such as ground-source heat pumps, were actively considered. When energy prices declined, other less expensive and easy-to-install solutions, such as air-heat pumps, provided less attractive savings but were selected instead, because of their shorter payback period.

The emphasis on finances in energy-equipment purchases illustrates how payback time and cost-savings arguments are used to rationalize purchases of products with production capabilities. When consumers purchase a new consumer item, its monetary value afterward is unclear and is usually diminishing. The product always ties up capital, it does not provide dividends, its price rarely increases, and thus people are not interested in payback time. Householder 6 maintains an Internet blog and on one post she pays attention to these different standards of reasoning for products with production and consumption capabilities:

> When do you get your money back? When are these solar collectors paying themselves back? Is this a profitable system? I doubt that in normal renovations people need to answer similar questions: “When is your satellite antenna paying back, or swimming pool, or skylight?”

Environmental concern was rarely mentioned as the reason for installing renewable energy technology. For early adaptors of emergent types of energy technology, environmental concerns were moderately present as a motivational factor. For mass-market technology, the reasons behind the purchase are financial or increased comfort rather than the notion of larger environmental problems related to energy production.

Before the purchase decision, the users gathered information from newspapers, magazines, neighbors, the Internet, and salespersons. However, interviewees expressed great doubt concerning the information acquired from commercial vendors. They also saw their own comments as more influential than marketing. Some of the users can be characterized as “warm experts” who are active in the sharing of knowledge (cf. Bakardjieva, 2005). An air-heat pumps user explains:

> They know I’m crazy about this system. There was one neighbor who was building a new house and after our discussion he changed his heating system plan totally. He said that I’m more convincing than any of the sales people he has met (Householder 2).

The different reasons for selecting renewable DETs become especially visible between permanent residences and temporary summer cottages. In the interviews, convenience was brought up as a reason to install supporting energy sources for permanent residencies. In summer cottages, the general availability of electricity means increased convenience. It operates various electrical devices and operations, such as charging a mobile phone, listening to the radio, watching television, or using a refrigerator. In this type of off-grid environment, the daily convenience of energy technology is not highlighted in a similar manner to that of permanent residences. Even if energy technology includes some inconvenience, it is still seen as an improvement to the previous situation.

Although users’ personal experience is highly case specific, it is seen to be neutral from commercial interests. In neighborhoods with similar houses of similar age, construction materials, and energy systems, advice from local experts is highly valued. In addition to information sharing, the warm experts

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5 The warm expert mediates between the technological universal and the concrete situation, needs, and background of the novice user with whom she has a close personal relationship.
help neighbors plan the work and installation. These users had carried out self-installation for their own homes, and working with neighbors’ projects is a way to continue their activities. The phenomenon is especially visible with emergent technologies such as micro-wind. One wind-energy user explains how technical work with a generator eventually turned into a hobby:

It’s leisure time well spent. Time flies so fast. I’m also interested in the technical side. There are always opportunities to improve the design of the controller (Householder 9).

In such instances, traditional motivations to acquire DETs, such as cost or immediate convenience, lose explanatory power and the purpose of the activity is reversed. The meaning of technology and of time invested changes from a necessity to a voluntary pastime. Renewable energy technology forums on the Internet and the communities embedded within this mode of communication manifest this otherwise almost invisible phenomenon.

### Making Technology Fit

In the case of DETs, the objectification process is mainly characterized by practical considerations. When finding and selecting a suitable location for the technology, noise, aesthetics, and energy efficiency are the main concerns and balancing the benefits and disadvantages is required. Table 3 gives examples of installation discourse and users’ concerns during the appropriation and objectification phases in domestication.

Householders often implemented minor modifications or add-ons to improve the technology’s suitability in a local context. The energy systems in existing houses are diverse, possessing unique combinations of technologies from different periods of time. Because of these variable conditions, user needs

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Table 3 Examples of installation requirements and user considerations with domestic renewable energy technology.

| Users’ Concern                        | Users’ Consideration                                                                 | Exemplifying Quote                                                                 |
|---------------------------------------|-------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| Noise of air-heat pump external unit  | Placing of both internal and external unit requires careful consideration. Noise and wintertime ice impose requirements for external unit location. In the countryside, even modest metallic industrial noise can be considered annoying. | Those start to rattle anyway like old fridges and so, there will be a noise problem and visibility problem and everything like that, annoyances (Householder 2). |
| Aesthetics of air-heat pump external unit | Aesthetics influence selection of installation location of external unit. The unit is often hidden by cover. | I’m not concerned about either one (external or internal unit). I made a cover from a lathe and slab. You can’t see it immediately. If someone passing by looks, it’s quite hidden (Householder 3). |
| Aesthetics of air-heat pump internal unit | Benefits outweigh problems of the new system. | If I say it straight, that (air-heat pump) is quite ugly. On the other hand, it has so many benefits that I don’t mind (Householder 1). |
| Efficiency of air-heat pump           | The optimal place for an internal unit can be different for winter heating and summer cooling, but the selected installation point and the main usage purpose has a high impact on the decision. | It’s very difficult to find suitable locations (for an air-heat pump) in the apartment. There is no single right place. All the apartments are different and you must take into account air ventilation, whether it’s natural gravitational ventilation or mechanical ventilation, and whether it’s mechanical ventilation blowing directly against the air-heat pump. If a heat pump is too large, it causes more noise and nobody wants it to be in the living room. And then it is placed somewhere where it doesn’t heat the whole area and is otherwise an extremely bad solution (Householder 2). |
| Aesthetics of solar thermal collector external unit | Solar collector pipes or panels are installed on the roof. In roof renovation, embedding of the collector is easy and a flat collector becomes almost invisible. Solar collectors on the roof were not considered disturbing. | Those are not disturbing. Yes, those blue pipes on the roof are quite pretty (Household 11). |
| Location for wind generator           | Good wind conditions are a basic requirement in selection of wind-station location. The area should be open, preferably from all directions. In principle, the higher the installation tower, the better the wind condition is, but in a real environment a larger set of factors should be taken into consideration. | Initially it was one block higher, but I removed one meter. I noticed that the trees have fewer branches down here. I have also removed some branches (Summer cottage 1). |
vary and commercial products often face challenges fulfilling all user requirements. Users create, for example, re- and deconfigurations, where they alter technologies to fit in better with their own use and proximate circumstances (cf. Hyysalo 2009a on different configurations). The following three cases show how users employ micro-innovation, adaptations, and different types of configurations to increase usability of the system, ease of use, and comfort (cf. Hyysalo, 2009b).

1) Wind generators produce electricity that is usually either used immediately or stored in batteries. Batteries are relatively expensive and users often consider their duration too short. Householder 9 in a grid-connected house deconfigured a wind-energy system to produce heat directly from electricity. The need for batteries was eliminated.

2) Users create reconfigurations for air-heat pumps. Placing of the internal unit can be challenging, especially if the room is high and height differs among rooms. If a unit is up on the roof, its embedded sensor does not operate in an optimal manner. Householder 2 solved the problem by installing an extension cord for the sensor to improve accuracy.

3) In the Nordic climate, winter conditions prompt increased maintenance activities for air-heat pump users. A heat pump creates frost and ice that accumulates and, without regular removal of accumulations from below the pump, can damage the unit. For example, Householder 3 used a plastic children’s sledge used to collect ice below the unit to make the removal process easier.

Examples 1 and 2 above highlight alternations of the technology and Example 3 demonstrates that adaptation can entail a simple practice to make everyday use easier.

In the early-use phase, users become acquainted with the technology. Small tasks are gradually incorporated into the routines. When the system is new, monitoring energy-production performance is considered to be interesting, so supervision is frequent and optimal performance is sought (Table 4). In this dataset, monitoring habits change rapidly, usually within the first year, from intrusive technology monitoring to sporadic checking in which the user just confirms that everything is working. In some cases,

### Table 4 Activities during incorporation phase.

| Use Phase                        | Activity                          | Exemplifying Quote                                                                 |
|----------------------------------|-----------------------------------|-----------------------------------------------------------------------------------|
| Early use (solar-thermal collectors) | Seeking performance gain          | Pollen comes in early summer. May is usually very sunny in Finland. But rain comes sooner or later and I clean up the collectors. Sometimes I have cleaned the collectors even in February. It’s nice to look at how the sun warms up the collector. January has been the only month when the circulation pump of the collector hasn’t been turned on (circulation is automatic when threshold temperature is exceeded). In production, this is a totally curiosity, but it’s interesting anyway (Householder 6). |
| Early use (wind generator)       | Monitoring of performance          | Of course, I monitored the electricity production at the beginning. I sandpapered the poles of the battery to improve the production (Summer cottage 1). |
| Routinized use (wind generator, PV solar, off-grid summer cottage) | Monitoring energy sufficiency     | I follow how much power there is in the battery. So I read the meter every day. If we consider, let’s say watching a DVD, I go and check the status of the meter and more importantly, if it’s a sunny day. If it’s sunny, TV can be on for the whole day, but if it has been rainy for 3-4 days and hasn’t been windy much, I carefully check the status and consider if I have work issues where I need to use my PC (Summer cottage 3). |
| Routinized use (solar-thermal collector) | Monitoring energy sufficiency     | Especially with this wood stove (that is capable of water heating) it is easy to put the fire on. And it’s one load in spring time when the sun is not heating it enough. So I don’t let the water-cylinder temperature drop down too much and I just put the stove on if needed. I use it for other purposes as well (Householder 6). |
| Routinized use (solar-thermal collector) | Monitoring of monitoring system   | I do nothing more than check that the logging computer is on. There was just one Windows update and it (the logging system) started acting up (Householder 4). |
| Routinized use (solar-thermal collector) | Maintenance during winter         | Snow has to be cleaned a couple of times per winter. It was just yesterday when my husband dropped snow from there. It can handle 30 centimeters snow but there was slightly more snow now so this was the second time to clean them. That’s the only worry during winter. |
| Routinized use (solar-thermal collector) | Maintenance after winter break    | It’s quite maintenance free. When it starts to work in spring, I just check that it has enough liquid in the system. The liquid can somehow disappear during winter (Householder 11). |
| Routinized use (air-heat pump)    | Seamless use                      | Using (an air-heat pump) hasn’t changed. I have almost forgotten the whole thing that it’s there, working the whole time. There is no actual need to “use” it (Householder 7). |
an automation system is used to log performance data and control the system. Additional system-level monitoring through computer-based automation can make regular oversight a permanent practice. Home automation represents a technology add-on that hides the original system and introduces a new layer between users and the energy system. User monitoring and checking is no longer aimed at the energy-production system itself, but interest can even turn to ensuring that automatic logging works properly (Table 4).

As time goes on, interest in maximizing performance loses significance. Once running an air-heat pump is not considered as “use,” the technology becomes “infrastructural” (cf. Bowker & Star, 1999). However, the presence of DETs is less seamless in the off-grid environment, where electricity provision is limited and, as a consequence, the number of connected appliances is restricted. In the learning process, users seek to test the limits of energy sufficiency and to identify new combinations. In the current dataset, consideration of limits and variations becomes a normal part of use, and users keep in mind the priority of energy-consuming activities and environmental conditions that influence production.

In the grid-connected environment, after the learning period and when systems are working together in an optimal way, the source of the energy is rarely noteworthy in normal domestic activities. Nonetheless, some suspicions can linger. An air-heat pump user is wary about having the pump on when baking:

I don’t know if it makes any difference, but usually, when I bake, I don’t keep it on. If I bake, for example, a cake, I really don’t know if there is any impact but I don’t keep doors open and so on, because it can spoil the cake. It might be just a belief (Householder 1).

Studying DET use and technology monitoring leads to questions of how technologies should be present in an optimal case. Historically, when energy production became centralized, it lost its visibility for consumers. Should the decentralized model change this situation and thereby make the production of energy more apparent, and if so, in what way? DETs reduce energy consumption (Keirstead, 2007), thus product design should increase the conservation impact without making technology intrusive and cumbersome in its normal use.

Domestication Pathways

Previous domestication literature reveals economic, spatial, temporal, and social processes in technology adaptation (Russo-Lemor, 2006; Sørensen, 2006). These aspects are all visible in the DET context. In addition, the pathway type of formation in technology domestication, how it creates and produces practices that lead to the adaptation of new technologies and practices, is especially apparent. This phenomenon can be conceptualized as domestication pathways. The earlier four-phase domestication framework usually leads to analysis, where new technology-adaptation processes are followed and the process has clear starting and ending points with a new “normal,” where new technology has become part of everyday life. However, multiple domestications can be linked and lead to adaptation of new technologies without a stable final point.

Examples of Domestication Pathways

The following three cases provide examples of different types of domestication pathways discernible in the current study.

Pathways and a Changing Motivation: The Case of Micro-wind Energy in the Off-grid Summer Cottage

For many Finns, life and home are divided into two places, the city and the summer cottage. The cottage is an everyday phenomenon and accordingly lacks the elitist connotations associated with owning a second home in most countries. In Finland, summer cottages are often primitive, which can be a well-considered choice. In fact, a summer-cottage life can be a ritual where it is possible to live today in a way that might have existed in the past. Simplicity and roughness make possible sensuously rich experiences (Periäinen, 2006). Life in the countryside can be seen as an escape from the material and service overflow of cities.

A retired man explains how the off-grid energy system that powers his summer cottage has developed over a twenty-year period (Summer cottage 1). Motivation, usage purposes, and the meaning of technology have changed over time as life situations and technologies have evolved and new product categories have even emerged. The cottage was originally built in 1981 with very few conveniences. It had no electricity and a wood fireplace was used for heating, but as his sons grew new requirements started to arise:

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When the twins were teenagers, they wanted to have television in the summer cottage and a solar panel was then installed (Summer cottage 1).

After a few years, the situation changed again and the children no longer wanted to spend much time in the cottage. A television was no longer desired, but new needs emerged. Charging a mobile phone became the most important use for electricity. When the first solar panel was installed in the cottage in 1988, there were no mobile phones that needed regular charging. Phone availability in a summer cottage was not standard. During the 1990s, this respondent started to stay at the cottage for longer periods. Because daylight in the Nordic latitudes is significantly shorter in the autumn, the solar technology was not able to provide electricity with similar efficiency to the summer period and a new energy solution was required. In 1995, he decided to extend renewable energy sources to wind. The installed wind generator used the same infrastructure that had been built earlier to accommodate the solar technology and this equipment continued the evolutionary way of adopting technology both in a physical sense (renewable DETs) and cognitively (small-scale electricity to generate just the required amount, when needed).

**Pathways and Changing Meaning of DETs: Departing from the Traditional Role of Consumer**

The meaning of renewable energy production, and especially energy distribution, can go through significant conversion processes. Householder 6 is an artist who lives in an old school building originally constructed in 1904. At that time, most houses in Finland were heated by wood fireplaces and were without radiators and central heating systems. During later renovations, a water boiler was installed along with electrical floor heating in some rooms. An energy renovation took place in 2004 and the old hot-water tank was replaced by a new model with solar-thermal collectors on the roof. The tank normally would have been placed in a utility room but in this case it was not hidden away, but placed in the artist’s studio. She calls the tank Sun Cow (Aurinkolehmä in Finnish) (Figure 1). The tank is covered with blackboard paint and is used for drawings and to mark temperature and energy-production notes. She calls the solar collector on the roof the “Sun Spinner.” This wordplay changes the name of the modern artifact to something that has a historically romantic tone with reference to spinning: “sun collector” vs. “sun spinner” (in Finnish aurinkokeräin vs. aurinkokeskäräin). With its new name, the water tank becomes almost part of the living world; it is a cow that “milks” hot water for the household.

In Finland, relying solely on a solar-thermal collector for hot water provision is possible only from late spring to early autumn. A supplementary source is needed during the colder months of the year. Electricity is typically the complementary source, but in this case the solution that works year-round is based on renewable sources. A wood stove, capable of water heating, was installed in 2009. Also in this example, the purchase of renewable energy technology, a solar-thermal collector, built a pathway and a bridge to a new system supported by the infrastructure of the previous technology. In future expansion plans, pathway creation is likely to continue. The interview revealed plans to install a photovoltaic (PV) or micro-wind generator which would be natural expansions when the energy market opens up, particularly if Finland institutes a feed-in-tariff.

Investment in micro-generation for one’s own purposes can be seen as capability building toward grid-connected DETs as users begin to see opportunities for the grid in a new way:

Before, I was dreaming about organizing a celebration where big cable cutters were used to cut the lines to the national power grid. Now, I dream about solar panels that
are connected via inverters to the grid (Householder 6).

The main purpose for DETs still remains in micro-generation for personal use. Providing electricity back to the network is a natural extension when the energy user becomes independent and production starts to exceed personal requirements and usage. The household is moving partly from a state of consumption outside of economic production activity, toward a highly intertwined, inseparable state of both production and consumption. The most advanced users see opportunities in networked co-provision of energy and are willing to make additional investments when the smart grid enables a more open energy market for small producers. Detached family houses and dispersed community structures provide favorable conditions for micro-generation and a smart grid that can be used for small-scale trials before mass-market operations.

**Pathways from Multiple Appropriation Hooks: The Case of the Air-Heat Pump**

In Finland, air-heat pumps are purchased either for summer cooling or winter heating. This also makes an air-heat pump a device for both consumption and production. Users may first approach air-heat pumps from one perspective then move toward the other as their usage practices evolve. Two types of change were evident in the current study. In two cases, an air-heat pump was purchased for cooling purposes during summer, but later in one case was extended to heating in the winter. In another instance, usage was extended in the reverse direction, from heating to cooling.

Household 1’s residents already knew before moving into their home, built in 1962, that it was rather hot during summer months. They therefore undertook renovations and bought an air-heat pump in 2010 to increase summer comfort. The first winter proved very cold and electrical radiators were not sufficient to maintain a comfortable indoor temperature so the users decided to support electrical heating with the air-heat pump. In the case of air-heat pumps and summer users, the cooling function works as a convenience argument to adapt the technology. Multipurpose abilities open the pathway for new modes of usage during later stage of use.

6 Using a heat pump for cooling consumes electricity and produces cool air. It always uses more energy in comparison to a situation when there is no heat pump. By contrast, using a heat pump for heating consumes electricity as well but it produces heat for space heating. Electricity is used to take outdoor air heat (coming from the sun) to transfer it to indoor air.

**Socio-Technical Background of Domestication Pathways**

This study provides evidence that domestication pathways are formed through opportunities and limitations of material products and learning in the adaptation of technology. First, domestication pathway creation can be seen as a result of technological path creation wherein previous technology choices open up and define the route for new alternatives. Second, a new product can create opportunities for new kinds of uses. Third, domestication pathways are a result of cognitive processes related to learning through practice, where acquired experience and knowledge increase trust in renewable technologies.

The energy systems of houses develop in an evolutionary way. The existing housing stock in Finland has changed over a long period and general renovations in houses also entail energy-system improvements. Pathway creation is a natural development in this context. All of the households in this study were reliant on hybrid-energy systems, including more than one source or technology. Parts of the system were acquired in several phases over the life cycle of the house and respondents had carried out earlier renewable energy investments. These findings are in line with results from earlier studies on PV solar. Haas et al. (1999) suggested that the purchase of the technology may be part of a series of energy-saving investments and called this a “conservation chain.” Keirstead (2007) asked PV users about their pre-PV energy-efficiency actions, and respondents were found to have had significantly higher rates of loft and cavity-wall insulation and efficient lighting when compared to national figures.

The requirements of the Nordic climate and the capabilities of renewable energy technology drive the system toward hybridization. In Nordic countries, energy production from renewable sources other than wood-based fuels or heat-pump technologies cannot be used on a year-round basis. Solar and wind technologies provide intermittent production, necessitating supporting sources to provide a stable provision of energy (see Table 1). Even in cases where year-round production is predictable, a supplementary source can provide improved usability (e.g., a pellet-burning technology with a solar-thermal collector). Building the system around various sources removes unpredictability and can improve convenience.

A domestic energy product is usually designed and built for a single purpose, providing heat or electricity. A metamorphosis of domestic energy technology is rather inflexible; the actual purpose is fixed. If the purpose is altered, radical technical modification is needed; thus, incremental adjustments to accommodate gradual transformations of use are not common. However, in some cases, ambiguity supports
the appropriation of technology. Energy technology could be designed to enable incremental adjustments and to accommodate gradual transformations in use (cf., Salovaara, 2012). A novel product can open up opportunities for new kinds of uses with built-in features or with extensions such as accessories. At the same time, a product provides clear benefits for early adaptation but sufficient flexibility toward multifunctionality to support later transformation of use. In the current study, air-heat pumps can be categorized as a multipurpose product that demonstrates these opportunities.

Technological adaptation can be seen as a set of trials where the real performance of a technology is tested and new purposes are found (Lehtonen, 2003). With a first renewable DET, users learn concretely what this type of technology can do, what its limitations are, and what one, as a user, can do with it. In such situations, a user’s expectation level is not necessarily high before the purchase and during early stages of utilization. Users are not seeking a radical single solution that fixes all previous needs and problems. Instead, the acquired new component will complement the existing system, working with it and making it more cost efficient or convenient. The new addition rarely replaces previous technologies completely. As the domestication process proceeds, users develop multiple skills and accumulate various experiences. The trust of alternative technologies increases in general and thresholds decrease to make changes, configurations, modifications, and new investments.

**Implications**

**Energy-Policy Implications**

Infrastructures and material organization of spaces create constraints on consumption and condition a “package deal” of choices, which are available as a result of a particular set of policies and which preclude other choices (Southerton et al. 2004; see also Levett, 2003). In an optimal case, established technology legacies pave the way for a new renewable extension and make add-ons easier; thus, regulation should recognize the importance of increased flexibility in energy-system building over the life cycle of a house. In both heating and electrical systems, “platform technologies” are necessary to enable various energy sources and hybridization of a household’s energy system. With heating systems, water circulation operates as the technology platform. Similarly, with electrical systems, direct current (DC) wires, batteries, and inverters form the platform.

Central heating with boilers and water circulation makes the heating system highly flexible regarding energy source. The source can be changed or multiple sources can be added. A boiler optimizes the production of heat energy by enabling the storage of energy. The cost of central heating is relatively small in the case of new buildings when compared to the cost of renovation work, and thus the existence of central heating heavily influences a house’s future energy options. In Finland, the former popularity of direct electric heating has declined slowly during the last ten years. For example, from 2005 to 2009 installations of direct electric heating in newly built detached houses dropped from 33% to 20% (Vihola & Heljo, 2012). Sweden and Denmark are forerunners in this type of policy, and direct electric heating has been restricted in new houses, since it is inexpensive to install but inefficient. While increased flexibility often leads to higher cost in the initial investment phase, public financial incentives can help to compensate for the additional cost of extendable systems that are cost- and energy-efficient in the long run. Regulatory measures and standardization can prevent manufacturer lock-ins and unnecessarily high technology switching costs.

**Design Implications**

Enabling multipurpose use can improve the marketability and adaptation curve of renewable energy technologies. The heat-pump case is an example of how a certain energy-consuming function, where value is in increased comfort, can be a sales argument for a unit that can actually reduce the total energy consumption of a house. Energy efficiency is improved when the unit also replaces other heating methods. Improved diffusion capabilities in the marketplace through multipurpose functionality can also have undesirable effects, such as modestly decreased energy-efficiency gains because of rebound. In the case of the air-heat pump, use for cooling during the summer can partly consume the power savings gained by the improved heating efficiency.

Increased options for expandability and customization enable future integration with other options, energy sources, and system hybridization. In the design of energy technology, well-planned system interfaces and designing modularity for expansion should be high on manufacturers’ agendas.

**Methodological Implications and Future Research**

When studying adaptation and the use of interlinked technologies over a long time period, the notion of domestication pathways has methodological implications outside of the energy-technology domain. The technology adaptations in this study are highly networked and not limited to a single application. Proper understanding of technology-development trajectories requires a longitudinal-
research approach. Previous domestication studies, especially in ICT, have followed the uptake and diffusion of a single technology. Similarly, the domestication pathway is visible outside the systems of provision context. Multiple device ownership of mobile technology (e.g., smartphones and tablets) and highly interconnected Internet social-media use are examples of this phenomenon. The use of one product or service, if not a prerequisite, strongly supports the diffusion of new technologies, products, and services. Studying the domestication of multiple technologies simultaneously strengthens the methodological applicability of the domestication concept in general.

Finally, learning by using has a key role in technology adaptation. Learning is required to realize the potential of technology. Users’ increasing skill and understanding in working with the product leads to new uses (Rosenberg, 1976; Hyysalo, 2006). In earlier domestication research, Sørensen et al. (2000) emphasized cognitive processes related to the learning of practice when studying the uptake and diffusion of a technology. Processes and dynamics of learning, and how learning continues throughout domestication pathways of multiple technologies, deserve more attention in future research.

**Conclusion**

This article examines development trajectories of DETs to describe how renewable energy technology has been domesticated to support the energy provision of residential housing in Finland. Research on the social shaping of renewable DETs in the context of residential housing provides valuable insights for policy makers and designers, helping them to better understand the role of the inhabitants when designing and regulating residential DET systems. The use of the domestication framework reveals changing motivations, issues influencing installation, and types of technology and practice changes during the early-use period, before a technology becomes embedded in daily life. Central here is the notion of an evolutionary approach in energy-system development. New renewable-energy systems are trialed before larger use and finally become supporting sources beside other technology. The use of one renewable technology easily leads to other renewable sources later on. In this hybridization, modularity and multipurposing are the main design implications for manufacturers. Energy policy and supporting schemes should recognize this gradual nature of domestic energy-technology adaption.

The present study highlights the roles of users as energy producers. In the case of decentralized technology, energy consumption and production are increasingly intertwined and the distinction becomes blurred. Decentralized production is democratizing consumption by building stronger autonomy from centralized utilities and taking back the power to influence source, price, and availability of energy.

Individual routines of consumption change slowly in network-bound systems (Southerton et al. 2004). However, in this study, when the users were ready to purchase renewable technology and produce electricity or heat for their own use, problems or barriers occurred on a local level in socio-technical configurations, rather than on the infrastructural level, and thus were relatively easy to resolve by (sometimes minimally altered) standard products, individual choices, users’ own actions, and changing practices. When micro-generation is scaled up and moves toward, for example, community energy, micro-grids, or more universal co-provision on smart grids, mutual negotiations among different stakeholders and larger changes in infrastructural arrangements become crucial.

DET users in residential housing are building capabilities for a future smart-grid environment. Although the production of a single household can be small today, often not even fulfilling the needs of the household itself, the same technologies can be expected to perform well when the smart grid opens up. There is a thin line from self-production today to co-production tomorrow.

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**References**

Alakangas, E., Erkkila A., & Oravainen, H. 2008. Tehokas ja Ympäristöystävällinen Tulisijalammitys: Polttopuun Tuotanto ja Käyttö. [Efficient and Sustainable Stoveheating: Wood-based Biomass Production and Use]. Report VTT-R-10553-08. Jyväskylä: VTT Technical Research Center of Finland (in Finnish).

Aune, M. 2007. Energy comes home. *Energy Policy* 35(11):5457–5465.

Bakardjieva, M. 2005. *Internet Society: The Internet in Everyday Life*. Thousand Oaks, CA: Sage.

Bakardjieva, M. & Smith, R. 2001. The Internet in everyday life: computer networking from the standpoint of the domestic user. *New Media & Society* 3(1):67–83.

Belz, F. & Baumbach, W. 2010. Netnography as a method of lead user identification. *Creativity and Innovation Management* 19(3):304–313.

Berker, T., Hartmann, M., & Punie, Y. 2006. Domestication of Media and Technology. New York: McGraw-Hill.

Bioenergiary. 2013. Pellettilämmitys. [Pellet Heating]. http://www.pellettienergia.fi/pellettilämmitys. January 8, 2014 (in Finnish).

Bowker, G. & Star, S. 1999. *Sorting Things Out: Classification and Its Consequences*. Cambridge, MA: MIT Press.
Juntunen: Small-Scale Renewable Energy Technologies
Van Vliet, B., Chappells, H., & Shove, E. 2005. *Infrastructures of Consumption: Environmental Innovation in the Utility Industries*. London: Earthscan.

Vihola, J. & Heljo, J. 2012. *Lämmitystapojen Kehitys 2000–2012: Aineistoselvitys* [Heating Habits Development 2000–2012: The Data Report]. Construction Management and Economics Report 10. Tampere: Tampere University of Technology, Department of Civil Engineering (in Finnish).

Von Hippel, E. 1988. *The Sources of Innovation*. New York: Oxford University Press.

Ward, K. 2005. Internet consumption in Ireland: towards a “connected” domestic life. In R. Silverstone (Ed.), *Media, Technology, and Everyday Life in Europe: From Information to Communication*, pp.107–124. Aldershot: Ashgate.

Watson, J. 2004. Co-provision in sustainable energy systems: the case of micro-generation. *Energy Policy* 32(17):1981–1990.

Welch, S. 1975. Sampling by referral in a dispersed population. *Public Opinion Quarterly* 39(2):237–245.

Williams, R., Stewart, J., & Slack, R. 2005. *Social Learning and Technological Innovation*. Northampton, MA: Edward Elgar.