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Empirical application of the multi-level perspective: tracing the history of ground-source heat pumps systems in Finland

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ABSTRACT

The emergence and evolution of more sustainable technologies and related industrial fields is a core concern for sustainability transitions scholars. This interest is accentuated as it has become evident that the upscaling of transition-relevant technologies follows different pathways in varying national and geographic contexts. The usual research approach to studying such industry-field dynamics in particular contexts has been to use the technological innovation systems (TIS) framework, focusing on the emergence of functioning TISs. The current calls for life-cycle TIS and the few existing examples of operationalizing the multi-level perspective (MLP) in a more focused way underscore the need to better account for the contextual specifics, contingencies, and later phases in the proliferation of transition technologies. We elaborate on the benefits of using the MLP in long-term analyses of transition technologies by examining the history of ground-source heat pump (GSHP) systems in Finland from the era of the energy crises in the 1970s until the present day. The investigation reveals how the present success of GSHPs has not followed just from simple innovation-system dynamics or niche-regime landscape relations but is also a result of variations and extent of landscape pressure as well as unplanned support from neighboring niche technologies.

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Introduction

The emergence and evolution of alternative technologies and industrial fields is a core concern for sustainability transitions scholars. This interest is accentuated as it has become evident that particularly the upscaling of transition-relevant technologies follows different pathways in varying national and regional contexts. Transitions must not only be understood as global phenomena but also as uneven and particular developments in specific technologies and settings over time (see, e.g., Geels et al. 2016; Heiskanen et al. 2014; Weber 2014; Levidow, Papaioannou, and Borda-Rodriguez 2014). Within the tradition of research on sustainability transitions (Markard, Raven, and Truffer 2012), analysis focusing on a single technology and specific countries is most commonly carried out by using the technological innovation system (TIS) approach (Bergek et al. 2008; Markard and Truffer 2008). The TIS is strong in explaining the key elements and development dynamics of a new innovation attempting to break through. However, it does not address structural change (Geels 2011) or perform very well in describing the ways of interaction between an innovation system and the wider operational environment consisting of a variety of issues shaping societal development or when looking beyond the initial phase of an innovation attempting to enter the market (Smith and Raven 2012). If the innovation succeeds in gaining a position on the market, the reasons for maintaining this status—or losing it—might be very different from the factors that enabled the innovation to succeed in the initial instance. Over time, the characteristics of the operational environment will change. Amid changing conditions, the success of the innovation hinges upon its ability to develop further and adapt to change. For these reasons, TIS, typically concentrating on the features and functions of an emerging innovation system, may not be best suited to studying development that stretches significantly beyond early phases of implementation (Kern 2015).

To gain a richer understanding of the long-term development of an innovation, taking account of the wider operational environment beyond the innovation system and the dynamics of change between the innovation system and the operational environment, is necessary. There are studies where ideas and views from the multi-level perspective (MLP) and TIS have been combined to capture the issues

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affecting the process of adopting an innovation beyond the elements of an innovation system (Bergek et al. 2015; Haley 2015; Karakaya, Nuur, and Assbring 2018). However, focus in these studies has been on the introductory phase of an innovation, not on long-term processes with varying development phases. We argue that due to its ability to account for the development dynamics of a sector in society over a long period of time (i.e., before and after the successful introduction of an innovation to the market), the MLP might offer a useful framework also when focusing attention on a single technology in a particular country context. This view is needed when studying a case such as ground-source heat pumps (GSHPs) in Finland where the history is characterized by non-linear development, country-specific contextual issues and includes periods of failure and success in attempting to break through to the space-heating market.[1] Using the MLP in such a way requires operationalizing it in a more focused manner than is generally the case in most MLP studies and correspondingly gathering more detailed and granular data than has been customary in prior analyses. This can bring forward uneven changes resulting from dynamics such as combined effects of alterations in the intensity of landscape pressure, interplay among neighboring niches, cross-country influences, and changes to transition pathways in the long evolution of a technology field.

There are some examples of an MLP frame being used for analyzing the development of particular technologies in country-specific contexts (Dzebo and Nykvist 2015; Echternacht, Thema, and Berg 2015; Nykvist and Nilsson 2015; Haley 2015; Antal 2019). For example, Haley uses some of the core ideas of TIS and MLP together, analyzing the innovation performance of electric vehicles using TIS while relying on ideas from MLP to provide larger structural context and by highlighting, specifically, the multi-regime dynamics and regime-TIS interactions. Contrary to most studies using MLP, in this case, the regime was viewed as an enabler for a niche innovation rather than a barrier. Nykvist and Nilsson (2015) use the MLP to identify reasons for modest development in the adoption of electric vehicles (EV) in Stockholm. There the MLP is used in a very narrow spatial setting, resulting in a rich empirical picture of EV development in the selected city taking into account both local niche development and niche developments with global character. While these cases are good examples of using the MLP in specific settings, we contend that the potential of more focused MLP analysis and the methodological and data issues involved ought to be better elaborated, and, along with our empirical findings, we seek to do so in this article. We trace the evolution of a technology in a specific country setting by examining the evolution of GSHP systems in Finland from the era of the energy crises in the 1970s until the present day and discuss what such an application of the MLP requires of methods and data. We divide the analysis into three phases that mark the embryonic formation and collapse of the GSHP niche in Finland (1975–1985), the ensuring period of low niche activity (1985–1995), and the time of acceleration and stabilization when the GSHP niche was strengthened and the use of GSHPs was upscaled significantly, both in numbers and in the types of installation location (from 1995 to the present day). Figure 1 presents the number of GSHPs in use in Finland between 1976 and 2017.

GSHPs have become widespread in Finland particularly in newly constructed detached houses

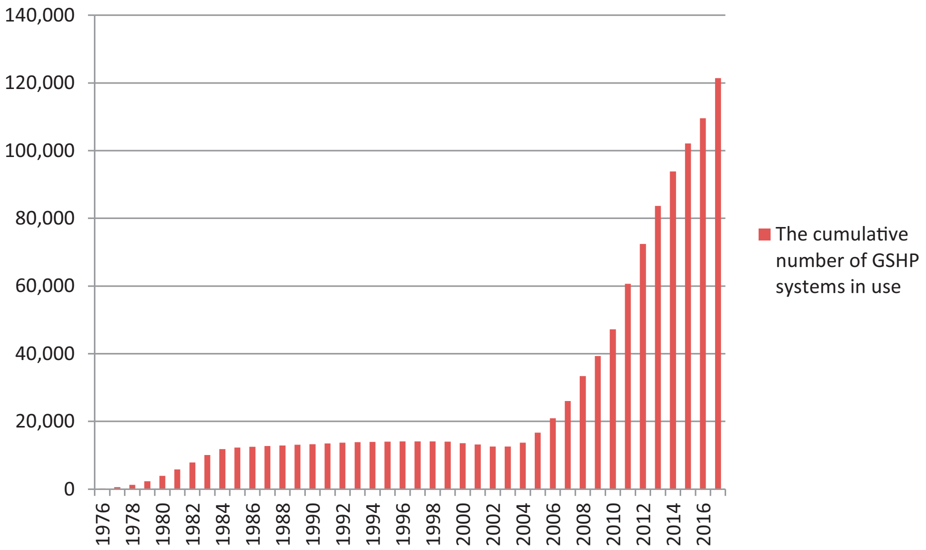

Figure 1. The cumulative number of GSHP systems in Finland, 1976–2017 (Source: Suomen lämpöpumppuyhdistys [Finnish Heat Pump Association 2018])[67].

where they have been the most popular primary heating source since 2011 (Motiva 2012). Most GSHP stock is installed in small buildings, but in recent years the number of large facilities using this form of heating has also increased.[2]

The article proceeds as follows. The theoretical framework is presented in Section 2. Section 3 describes the data and outlines how the MLP was operationalized. The empirical results pertaining to the development of GSHPs in Finland over a long period are presented in Sections 4, 5, and 6. Section 7 discusses features particular to the development path of GSHPs in Finland, presents the main findings of this research and concludes the article.

Theoretical framework

The multi-level perspective on socio-technical transitions

The MLP is a framework for understanding and illustrating processes that have an influence on how socio-technical systems change (Geels 2002, 2011; Geels and Schot 2007). Transitions are considered to be wide-ranging changes in the core logic of socio-technical systems that unfold over a long period of time (Markard, Raven, and Truffer 2012). In the MLP, transitions are understood as non-linear processes that result from developments at three analytical levels: niches, socio-technical regimes, and a socio-technical landscape (Geels 2002, 2004, 2011). Niches form the micro-level of development where innovations are developed and nurtured, and from where they attempt to emerge into greater awareness. The socio-technical regime represents a stable configuration of established practices, technologies, and institutionalized actor-networks that often act as a deterrent to the success of novel ideas. The landscape represents an exogenous environment. Changes on the landscape level affect the operational context faced by actors on lower levels and may open up opportunities for innovations to break out from a niche. Generally, issues on this level are megatrends, such as the need to prevent or mitigate the harmful effects of excessive greenhouse-gas emissions, or other all-embracing issues, such as global crises that influence many areas of societies (Geels and Schot 2007).

In the MLP literature, development over time is typically studied and categorized through two key criteria: the timing and nature of interactions among analytical levels. Sometimes a third factor, the type of landscape change, is also considered (Geels and Schot 2007, 2011; Geels et al. 2016). By applying these criteria, empirical research has produced hypotheses on the types of development paths that a transition might follow (Smith, Stirling, and Berkhout 2005; Geels and Schot 2007; Geels et al. 2016). Six such paths are identified:

1. The technological substitution pathway where significant landscape changes put pressure on the regime and where niche innovations become sufficiently developed to replace the old regime. The resultant regime differs from its predecessor in its operational logic and actor composition.
2. The transformation pathway where landscape pressure exists, but there are no niche solutions mature enough to replace the regime. Regime actors have time to adapt and adjust their activities to meet the demands of new conditions.
3. The reconfiguration pathway where landscape pressure urges the regime to incorporate new solutions developed in niches and where, over time, the operational logic of the regime will change.
4. The de-alignment and re-alignment pathway where significant landscape pressure destabilizes the regime. No clear alternatives exist at the niche level that would be able to substitute for the existing regime. Several potential niche solutions compete against one another until a new regime develops around one of those alternatives.
5. Mixing pathways where development may take the shape of any of the development pathways identified above, depending on the way and timing of regime actors' response to landscape pressure.
6. Reproduction process where no strong landscape pressure exists and where change is incremental and takes place following internal regime logic.

Adapting the MLP to specific technology and country contexts

The MLP is typically used when studying the long-term development of societal sectors, such as energy systems (Raven and Verbong 2009; Dzebo and Nykvist 2017), the traffic sector (Geels 2005), or a specific industry (Berggren, Magnusson, and Sushandoyo 2015; Spinardi and Slayton 2015; Hörisch 2018). When focusing attention on a more detailed issue, such as a single technology, studies of long-term development are not very common. Instead, research on the development of a particular technological application is typically concentrated on the initial phase of an innovation attempting to break through. In this context, the most commonly used framework is the TIS. However, in studying cases with a long, multi-phased history, the TIS can fall short of providing comprehensive explanations on how the diffusion and subsequent development of a certain technology unfolds. We argue that the development of GSHPs in Finland is one such case.

At the preliminary phases of doing research on GSHPs in Finland, it became evident that in the 1970s and 1980s the domestic GSHP field lacked many structural components of an innovation system and was very weak on most of the system functions identified as explanatory factors in the TIS framework (Hekkert et al. 2007; Bergek et al. 2008).[3] Despite these shortcomings, GSHPs did diffuse. As seen in Figure 1, after initial success, the popularity of GSHPs plummeted. The GSHPs were practically forgotten for almost two decades until a boom in the early years of the 2000s. During this period, there was practically no functioning TIS for GSHPs in Finland. These circumstances prompted speculation that the reasons for early GSHP diffusion were mostly external to the innovation system. TIS scholars have identified the importance of elements external to TIS processes (or context structures) and have suggested that these factors should be taken into account when building understanding of development of a technology (Bergek et al. 2015). Still, in the light of the observations made on the development of GSHPs in the Finnish market with very weak or practically non-existent innovation system, the TIS framework seems to be a rather unsuitable tool for understanding what happened during the timeframe from early development to the boom of the 2000s. As studies using TIS tend to focus on the early stages of innovation diffusion (Markard, Hekkert, and Jacobsson 2015), the framework also appeared less geared for discovering issues that would explain collapse and regrowth two decades after initial diffusion (Kern 2015). The temporal perspective of almost fifty years for the study required an analytical perspective that would allow for a flexible approach on understanding changes unfolding over an extended period of time, and therefore the MLP appeared better equipped than the TIS for analyzing long-term developments (Lovio and Kivimaa 2012).

Recently, a new version of TIS, labeled life-cycle TIS, has been introduced (Markard 2018). Life-cycle TIS attempts to capture long-term dynamics of an innovation through four key stages: formation, growth, maturity, and decline. Since this is a new concept, there are to date only a few empirical studies that have used this approach. In light of current understanding, possibility of start-stop sequences where popularity of the innovation in question crashes before reaching a mature stage and then after some time starts to grow again, does not seem to be addressed in life-cycle TIS. Using the MLP to view a change of a sector (heating) and zooming in on a particular technology (GSHPs) amid that wider change, allows for building a coherent narrative of long-term development of a technology even when its journey is characterized by alternating non-linear stages. Furthermore, the MLP allows for understanding development phases that lack components of a working TIS, such as the period of low niche activity in the case presented here. In addition, paying close attention to landscape and regime developments highlights the role of context and complementary technologies in explaining the pathway of a particular technology. These are issues TIS tends to miss (Markard 2018).

Operationalizing the MLP in a technology- and country-focused analysis requires devoting particular attention to understanding how the positions, objectives, preferences, resources, and interactions between actors at the regime and niche levels are changing over time. This undertaking entails a thorough empirical investigation of the local niche, the neighboring niches that affect it, and the relevant regimes, taking into account issues affecting both supply and demand sides. Studying how and why the incumbents of the field attained their position and how this position has been destabilized and strengthened over time increases understanding of regime dynamics and institutional change, thus complementing the overall picture of the factors shaping transitions (Geels et al. 2016; Dzebo and Nykvist 2017) and bringing explanatory power to the analysis (Turnheim and Geels 2012). Cross-regime interaction involving several regimes is particularly important due to the long-time perspective applied in this research. A series of small, cumulating changes in ways that are related to a regime's function may amount to significant transformation over time (Konrad, Truffer, and Voß 2008). The same goes for niches that are closely linked to the focal technology. The most significant landscape changes are reflected in empirical material in the other two analytical levels. Development-pathway types can be used as a tool with which to seek understanding of how and through what mechanisms the technology has evolved over time and what kind of interaction there has been between the heating regime and niche developments. We will next describe in greater detail the data and methods for investigating the long-term development trajectory of a technology, from its introduction to late stages of diffusion, as well as the factors shaping it.

Data and methodology for operationalizing the MLP to a specific technology and country

Most MLP studies emphasize understanding of the relationship between regime and emerging niches from the perspective of regime transition. However, applying such an approach plausibly to study change in a technology- and country-specific context over a long period of time requires collecting granular information on the domain area and the evolving technology from several perspectives. The source material for this analysis consisted of expert interviews (31 respondents) and articles in major Finnish newspapers, magazines, and trade journals targeted to homeowners, builders, and real estate investors between the years 1978 and 2014 (162 articles in total). In selecting interviewees, the emphasis was on people with long experience with the various heating choices. They represented regime-level actors (19 persons with expertise on various aspects of heating choices) and niche-level actors (12 persons with expertise on GSHPs, representing the relevant actor groups and activities in the GSHP sector).[4]

Factors contributing to the development path of GSHPs in Finland were produced using qualitative content analysis. The analysis had features from both directed and conventional approaches associated with this methodology (Hsieh and Shannon 2005). At the early stages of the analysis, emphasis was on the directed approach. Issues important for understanding the development of the heating market and GSHPs were first coded in accordance with one of the three analytical levels (landscape, regime, or niche) and then, within these levels, according to dimensions derived from the MLP literature (directed content analysis).[5] If issues that emerged from the data did not fit any of the categories suggested by the literature, we created new categories as suggested by the source material (conventional content analysis). Content analysis was performed using NVivo Pro 11 software.

For items belonging to the niche level, material was coded using processes identified as necessary for the successful development of a technological niche with the following preliminary categories: articulation of expectations and visions, building of social networks, and learning processes in multiple dimensions (Verbong and Geels 2007). For items that did not fit these categories, we created alternatives. As coding progressed, categories were further refined. We supplemented interview material with literary material that provided information on contemporary issues related to practical details and the acceptance of GSHPs.

We defined the heating regime as the core regime for understanding GSHP development, comprised of the gradually changing heating sources used over the timespan of the research. In addition, the analysis considered the regimes of wider energy provision and the building industry. These regimes were studied from the perspective of heating sources; in other words, how development in these regimes was reflected in the heating sources that were preferred. The respondents reflect this multi-regime approach. In the analysis, dimensions identified in the MLP literature as central for understanding the characteristics of development were used as starting points when constructing the picture of the heating regime. Geels (2002) distinguishes seven dimensions when mapping change processes on the regime level: technology, user practices and markets, symbolic meaning of technology, infrastructure, industry structure, policy, and techno-scientific knowledge. Another grouping of the dimensions most relevant for capturing the essential features of this level can be found in the work of Van Bree, Verbong, and Kramer (2010) where the socio-technical system, actors, and rules (formal, cognitive, and normative rules) are seen as the most important dimensions to consider. We altered these elements when necessary and formed new categories as coding progressed. As with niche-level analysis, interview data were supported and supplemented with literature sources and these materials provided additional information pertinent to general issues regarding regimes.

For the landscape level, we did not collect any primary data. For the purpose of this work, the most important landscape factors contributing to change in the heating sector and in GSHP diffusion were discovered both from the views of the interviewees representing the other two analytical levels and from literature sources. We assembled additional information on the most important landscape developments from policy documents and studies of attitudes regarding use.

Diverse primary source materials reflecting the views of actors from the niche and regime levels generated interesting information not only with respect to issues dealing with development within these analytical levels but also on development between them. Niche actors' views were used foremost in seeking an understanding of niche development and the internal dynamics among niche actors, and they were also used to gain insight into the regime characteristics that these actors saw as deterrents to wider GSHP diffusion. Vice versa, we collected the views of regime actors on their interaction with the actors of the GSHP sector. This approach brought forward valuable, and sometimes contrasting, views on issues that influenced GSHP diffusion.

In the following sections, we present the empirical results of the study. Perspectives from the interviews and articles are identified in the text with codes that are explained in Appendices A and B.[6] Each section starts with a brief description of the most important landscape developments in the selected timeframe. This is followed by an account of the major developments in the GSHP niche. Finally, we describe relevant aspects of regime development.

Throughout the timeframe of this study, the heating regime and GSHP niche were evolving. In the following discussion, this situation is reflected in the variation of the themes that were seen as most relevant for understanding the development of each period.

Emergence of the GSHP niche in Finland following oil crises (1975–1985)

Landscape

The most distinctive features of the international energy market in the 1970s were the energy crises of 1973 and 1979. The widely shared impression was that supply problems and resultant high prices for conventional energy sources would be sustained for the foreseeable future and this understanding led a wide range of actors in Finnish society to search for ways to cut oil dependency. As oil was the most important energy source for heating, building owners had an incentive to look for options that would cut energy costs. The search for options intensified markedly after the second oil crisis of the decade in 1979.[7]

Compared to the effects of the energy crisis, other landscape-level factors were of lesser importance. One notable change in the Finnish energy situation was the introduction of nuclear energy into the energy mix. Between 1977 and 1982, the country added four nuclear power plant units to the national grid and this development had a stabilizing effect on the supply and price of electricity.

Niche

GSHP systems in Finland and market formation

Soaring oil prices destabilized the heating regime and created an opportunity for solutions that did not rely on petroleum. GSHPs were introduced to the Finnish heating market in the mid-1970s and companies had to convince potential customers that it was possible to produce heat without fire and to extract heat energy from cold ground.[8] The GSHP systems of the period had horizontal heat coils that required a large piece of land or access to open water. This limited the available market for GSHPs and typical adopters were owners of detached houses and farms. The acquisition costs of a GSHP system were higher than the price of an oil-heating system, but GSHPs' selling point was the promise of inexpensive energy over time.[9]

In the late 1970s and early 1980s, sales of GSHP systems grew from year to year. A contributing factor was that by the late 1970s GSHPs had already been introduced as a viable heating solution in Sweden (Dzebo and Nykvist 2017; Nykvist and Dzebo 2014), which helped convince Finnish homeowners to opt for GSHPs, as did positive writing about GSHPs in newspapers and magazines targeted at builders and homeowners (Heiskanen, Lovio, and Louhija 2014).[10] Also, investment subsidies and housing loans were available for houses and farms switching from oil heating to more energy-efficient or domestic energy solutions, although the subsidy for GSHPs was smaller (5–10% of the investment) than it was for more established technologies (where it was 20%) (Juva 1982).[11] GSHP sales peaked in 1982 when 2200 units were installed (SULPU 2018).

Actors, actor networks, research, product development, and education

In the late 1970s, many companies manufacturing GSHPs emerged. The barriers to entry were low for experienced entrepreneurs working in the field of heating, ventilation, and air conditioning (HVAC). Designing and assembling GSHPs were seen as rather simple tasks and building or selling the systems did not require significant investment in the means of production.[12] In a short period, there were more than ten companies manufacturing GSHPs in Finland and many more selling them.[13] Most firms were small and without possibilities for undertaking research and development.

Public research on GSHP was modest, focused on the heat-recovery potential of energy fields and the results did not have time to inform most of the installations that were carried out during the first boom.[14] The systems were tested at some publically funded renewable energy initiatives, such as those at the Helsinki Housing Fair 1981 and the Kerava solar village (Peltola, Lund, and Routti 1985). However, these experiments failed to meet expected standards and did not provide support for GSHPs.[15] In general, the Finnish GSHP sector lacked many structures supporting market formation; there was no formal training provided to people working with GSHPs, no lobbying power directed toward the authorities or commercial builders, and little information available for homeowners.[16] In sum, GSHPs gained a foothold in the heating market of small buildings in the early 1980s, but subsidies were extremely modest and there were no investors and no significant policy initiatives supporting research activities or field organizing to enable the niche to grow into a coherent innovation system.

Regime

Domestic energy policy steering

The energy crises were the drivers for a transition in the Finnish heating sector in which district heating (DH) became a new regime solution. Along with technology, there were changes in the key actors in the heating regime as well as in ways of producing heat, using fuels, and distributing heat. The attitudes, education, and knowledge of authorities, builders, and designers transformed to support DH as the most favored option.

Before the end of the 1970s, Finland did not formulate a separate energy policy. In political decision-making, energy questions were a part of trade and industrial policies and views on the preferred ways of producing energy were intended to accommodate the interests of various industries.[17] The first national energy policy program was published in 1979. In the program, the most important measures to reduce the use of oil in energy generation were increasing energy efficiency and use of domestic energy sources (Energy Policy Council 1979). The most important ways to improve energy efficiency were insulating buildings and advancing combined heat and power (CHP) production.

The heating market and the building industry

In the 1970s and 1980s, oil dominated the national heating market, representing a more than 50% share of total heat generation in 1980 (Statistics Finland 2014). After the 1970s and 1980s, a distinctive feature in the heating regime was the growth of DH. In Finland, the first buildings were already connected to DH networks in the 1950s, but there were doubts about both the technology and the pricing monopoly that a DH company had over its customers (Mäki 2012).[18] Also, building heating networks was considered to be expensive and these issues, along with inexpensive oil, kept DH in a niche until the 1970s.[19]

DH promised gains in energy efficiency through CHP facilities and allowed for the use of an increasing share of domestic fuels in energy production. The possibility of increasing the use of inexpensive coal in CHP plants offered further cost reductions and pollution could be lowered as large CHP power plants were equipped with filters for combustion gases.[20] As the state provided loans for building DH infrastructure and municipal energy companies around the country were willing to invest in building power plants and heating networks, DH became the favored option, leaving little room in the market for other new heating options in densely populated areas. In addition, the building industry preferred DH over other heating options since it removed the need to consider building-specific heating solutions. Residents appreciated DH because they saw it as a modern form of heating and the price was more stable than that of oil.[21]

The surge in the popularity of DH is evident in Figure 2, which presents the proportional shares of energy sources for heating residential, commercial, and public buildings in Finland between the years 1980 and 2016. Out of the transition pathways described in the MLP literature, the 1980s regime development follows the technological substitution pathway where DH replaces oil-based heating in densely populated areas.

The GSHP niche struggles following loss of landscape pressure: 1985–1995

Landscape

By the mid-1980s, energy prices returned to their pre-crisis levels. This meant removal of the earlier landscape pressure that necessitated improvements in energy efficiency and reduced use of oil. The prices of the most important forms of heat energy stayed very stable until the late 1990s. However, the energy crisis left a permanent mark on Finnish energy consumers.[22] Predictability and stability of energy prices became issues to consider when choosing a heating system and attitudes toward increasing the use of domestic and renewable energy sources became increasingly important (Energy Attitudes of Finns 1983–2014).

Niche

As indicated in Figure 1, annual GSHP sales plummeted from over 2000 units in 1981 and 1982 to about 200 in 1985. Interest in GSHPs remained very low for over a decade with 1995 being the lowest point when only about fifty units were sold. As the market for new GSHP units had almost vanished, many companies operating in this field withdrew from the market. This situation undermined the availability of repair and maintenance services for the existing GSHP stock.[23]

Although most of the GSHP systems installed in the 1970s and 1980s performed with high reliability,[24] there were problems related to poor understanding of the heat-recovery potential of energy fields, the functioning of energy-collection equipment, system design, installation, and the availability and quality of repair and maintenance services.[25] HVAC companies were experienced in using heat pumps for cooling purposes but designing systems for heating proved somewhat challenging for many of them.[26] There were no ready-made GSHP system packages available for homeowners, and the elements of a system—such as the ground-loop energy collector, heat-transfer fluids, and services such as laying the loop in the ground and fitting the GSHP to a building's heat-distribution system—had to be combined from the offerings of various producers. This exposed the GSHP systems to problems as the components selected by homeowners themselves were often not fully compatible.

The poor quality of some of the installed systems, together with failing services, tarnished the reputation of the GSHP sector. In the early 1990s, there were only two companies manufacturing and marketing GSHP systems in Finland. Since the sales of GSHP systems for residential buildings were low, firms developed GSHP applications for specialized uses such as producing warm water for fish farms.[27] They also did grassroots marketing, for example, at very popular housing fairs, thus preparing the ground for the future.[28]

Regime

Development in the heating regime in this period continued the gradual incremental substitution pathway where oil was increasingly replaced by DH and by the end of the 1980s it surpassed oil as the most popular form of heating (see Figure 2). DH was especially targeted at large facilities, although in some urban areas DH networks were also extended to areas of detached houses. DH's strengthening role in the heating regime in 1980s and 1990s was due to its reliability, price stability, and especially close linkages between municipally owned energy companies and urban planning. In many areas in Finland where DH was available, building codes obliged builders to choose DH.[29] Urbanization and consequent building in urban areas provided a growing market for DH. In small buildings, the share of oil was gradually decreasing as electric-resistance heating became the favored new option. By 1995, approximately 70% of new detached houses had electricity as their primary energy source (Statistics Finland 2017a). Regarding the future technical fit of GSHPs, an important development within the building industry was the rising popularity of water-circulated underfloor heating beginning in the 1990s, which required a lower water temperature than traditional radiators and provided a more favorable coefficient of performance for a GSHP.[30]

The acceleration and stabilization phase of GSHPs in small residential buildings and the emergence of a new niche for large buildings (1995–2015)

Landscape

After Finland joined the European Union (EU) in 1995, the ambition level and importance of energy and environment policies grew. This situation was reflected in particular in terms of increasing taxes on nonrenewable energy sources. From 2004 to

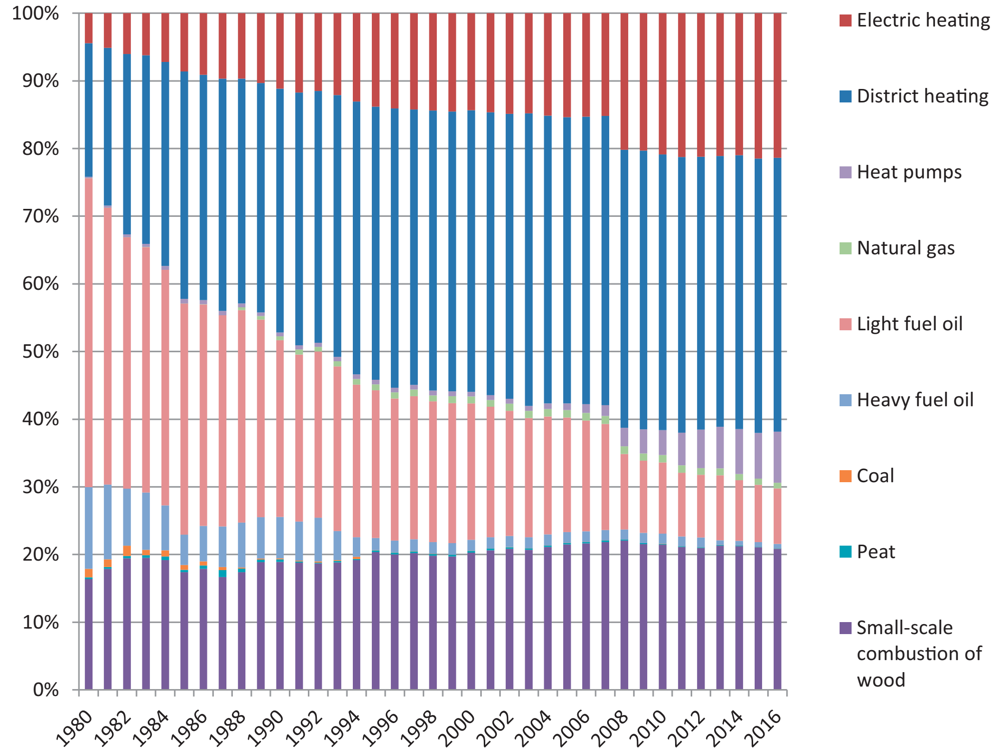

Figure 2. The share of energy sources for heating residential, commercial, and public buildings in Finland 1980–2016. Note: Data for heat pumps covers energy produced with all heat pump types, not just GSHPs (Data source: Statistics Finland 2014 and 2017).

2017, the tax on coal (euros per ton) quadrupled, the tax on natural gas (cents per cubic meter) increased almost six-fold, and the tax on heating oil more than doubled (Statistics Finland 2017a). Another big change was the liberalization of the electricity market from the mid-1990s onwards, which resulted in more fluctuations in electricity prices. The prices of the most popular energy options for heating (DH, electricity, and oil) rose rapidly in the new millennium (Statistics Finland 2017a), intensifying demand for new heating options (Juntunen 2014).[31] The landscape influence was foremost transmitted through EU directives, the most important being the energy-efficiency directive (Directive 2012/27/EU 2018), the energy performance of buildings directive (Directive 2010/31/EU 2018), and the renewable energy directive (Directive 2009/28/EC 2018; FInZEB 2015).

Niche

GSHPs in small buildings and new market formation

The niche for GSHPs in small buildings reemerged in the late 1990s. The increasing prices of conventional forms of energy provided an opportunity for new heating options and GSHP became the most favored alternative for builders of small detached houses, almost stealthily replacing oil heating. There were two separate GSHP niches developing: one for GSHPs in small buildings and another in large buildings.

In detached houses, GSHPs started to gain popularity gradually in the years before the turn of the millennium. The first buildings to take up GSHPs were rather large, new detached houses [200 square meters (m^2)/2153 square feet (ft^2) or more].[32] A few years later, the owners of older detached houses discovered GSHPs and the share of retrofit installations grew to such an extent that they accounted for roughly half of all the GSHP system installations by 2010. In 1999, 1000 GSHP units were sold and sales reached 5000 units in 2007. The peak was in 2011 when almost 14,000 GSHP systems were sold (SULPU 2018).

The rising popularity of GSHPs was mostly market-led. In new houses, GSHPs received no subsidies, and in conversions from oil or electricity to DH, wood pellets, or GSHPs subsidies varying between 15–20% of the equipment and material costs were available from 2006 to 2011 (NEEAP-2 2011; NEEAP-3 2014; Juntunen 2014). Only a tax deduction on household expenses was continuously available for private households making renovations to an old house, which varied between €4000–6000 for a two-adult household (Tax Administration Finland 2012).[33] In other words, the maximum deduction was 18–35% of the price of GSHP installation if no other household services were used.

Compared to the situation in earlier decades, in the 2000s much more information was available on the characteristics of GSHPs. There were information campaigns, events organized regularly by actors in the GSHP sector, and good media coverage. Writing in the media had increased since the late 1990s and was generally positive.[34] Information and knowledge exchange among peers increased dramatically through Internet discussion forums,[35] which provided potential and existing GSHP users with peer guidance on purchases, installation, maintenance, user experience, and modifications, thus dispelling common ambiguities and uncertainties related to GSHPs (Hyysalo, Juntunen, and Freeman 2013; Hyysalo, Johnson, and Juntunen 2017).[36]

Emergence of the GSHP market did not happen entirely without growing pains. Customers encountered some problems that were similar to those of two decades earlier related to the poor quality of system design and installation and the availability of maintenance services.[37] However, these problems did not lead to a loss of reputation. Most of the GSHP systems worked well, and through lively Internet forums, the word on good experiences, the conditions for successful system designs, and capable firms in the field spread.[38]

Product development

By the early 2000s, the small number of existing domestic GSHP manufacturers were improving their products, some with help of practice-oriented research programs initiated in the prior decade.[39] A key development was the drilling of vertical boreholes for the heat-collector coil, which also worked in rocky sites and small plots, for instance in urban areas, and made the energy supply more stable and predictable compared to soil or water (Majuri 2016). Also, collecting large amounts of cooling energy became possible.[40] The drilling knowledge and equipment improved rapidly, so the initial 80–100-meter vertical boreholes soon grew to 150 meters, and a decade later, depths of over 300 meters were common.[41] Deeper wells allowed for the collection of more energy from a single borehole, which was associated with gradual decreases in the costs of drilling.

Actors and actor networks

In the early years of the new millennium, emerging market interest for GSHPs encouraged new domestic and foreign, mostly Swedish, manufacturers to offer their products to Finnish homeowners.

New companies providing services necessary for GSHP systems, such as energy-well drillers, also emerged. Increased supply intensified competition and lowered the prices of GSHP systems and related services, thus making the use of this energy source even more appealing to customers.[42] A new feature in the GSHP market in the 2000s was the availability of turnkey packages via direct distributor agents who also had better economic incentives to promote sales than wholesale channels.[43]

A further, important contributing factor to development was the emerging role and visibility of the actors in the heat-pump sector in education, lobbying, and media. This is largely due to the activities of the Finnish Heat Pump Association (SULPU), founded by key actors in the industry in 1999 and part of the Finnish Well Drillers' Association (Poratek) and the State Energy Information Center, founded in 1993 (now named Motiva).[44] A more recent actor in the field is the Geological Survey of Finland that decided to extend its services and research to the area of the ground-source energy-collection fields of large buildings in 2007.[45]

GSHPs in large buildings

GSHPs were perceived initially as a heating system for small buildings, but technology advances opened the heat-pump market up for larger buildings around the year 2005. The first larger structures to use GSHPs in Finland were typically oil-heated buildings that were located outside DH networks.[46] These included service buildings—such as schools, gardening facilities, industrial buildings, and later also apartment buildings[47]—all of which had consumption profiles that were easy to anticipate for GSHP installation but required effort from the customer nonetheless as GSHP companies had not yet targeted their products and services for larger buildings.[48] One reason for this was the strong position of incumbent actors in the heating market. Also, companies had their hands full with the booming market in small buildings and, perhaps most importantly, they had no experience of designing and constructing GSHP systems for larger buildings.[49] The underdeveloped capabilities of GSHP companies meant that building owners needed to be active and bear the risks of under- or overscaling the system.[50] The first adopters for GSHPs were small private companies or municipalities, while construction companies initially shied away from GSHPs due to the risks in scaling and the potential of damaging their reputation.

As with small-scale installations, subsidies for larger GSHPs remained modest, short-lived, and troublesome to access. They accordingly did not play a major role in heating system choices.[51] Subsidies have remained a fortuitous bonus to decisions that building owners have tended to make on the basis of operational profitability.[52]

Problems related to GSHPs in large buildings

In very large buildings (roughly 10,000 m^2/ 107,639 ft^2 and over) and cases where the structure of energy consumption was difficult to profile, GSHP uptake remained limited. There were not enough experts who could credibly handle complex functional design assignments where GSHPs would be used as the primary heating source.[53] Decades of relying on oil and DH had aligned designers' capabilities to a regime of easy peak-load additions, while designing a good-quality GSHP system required more detailed modeling of the energy consumption of the building.[54] This situation presented an added cost, potentially prolonged project planning, and complicated the tendering processes.[55] GSHP designers felt that the heating-system specifications produced by builders were often not precise enough to create a comprehensive plan, which in turn, disappointed builders about the quality and level of detail in GSHP offerings.[56] Furthermore, the small size of companies operating on the GSHP market in Finland limited the availability of working capital, which hindered ability to commit to large building projects.[57]

There are some similarities with the early stages of market formation for small buildings in the 1970s and 1980s, and for large buildings in the first decade of the new millennium. In both cases, there were some difficulties in managing the complexity of providing heating systems for an emerging market. However, as the large building GSHP market continues to grow it appears that the now well-organized GSHP field is able to deliver the new types of GSHP systems and associated services.

Regime

During this period, development of the heating market of large buildings resembled the transformation pathway where niche solutions are not quite sufficiently developed to challenge the strong position of incumbents. The pace of change remained slow and gave heating-regime actors an opportunity to catch up with developments and to maintain their position in the market. Some DH companies began to increase the efficiency of energy production, to expand their share of renewable fuels, and to start using various types of heat pumps in producing DH and cooling.

Development of the heating market of small buildings followed the technological substitution pathway wherein GSHPs became the most favored heating solution. Some elements of the substitution process are still developing. For example, the formal education and training necessary for professionals working with heat-pump technologies is still rather modest in Finland.

Energy-policy steering and developments in the heating market

The most important and consistent policy measures in the energy strategies of the Finnish government in recent decades have been energy-tax increases on nonrenewable sources for heat production (Ministry of Economic Affairs and Employment 2017). The price of DH more than doubled between 2004 and 2015, as did the price of heating oil (Statistics Finland 2017b). Along with rising prices, DH was increasingly confronting a reputation problem. Despite the high energy efficiency of CHP production, the large share of fossil fuels in the energy mix of DH production captured the attention of energy consumers.[58] In new small houses, the implementation of the domestic energy efficiency directive in 2012, particularly the so-called E-value calculation for the threshold for granting a building permit, began to include not only energy use but also the type of energy. This had a negative impact on electrical resistance heating and a positive impact on renewable energy sources such as heat pumps.[59] Overall, constant price increases and eroding legitimacy due to perceived negative climate effects have created tension in the Finnish heating regime with respect to both large and small buildings.

Research and information activities

The goals of cutting down emissions and increasing the share of renewable energy sources resulted in new funding for Finnish energy research. A small portion of this funding was allocated to studying the possibilities of heat pumps in various types of facilities and heat sources. In general, however, most of the funding was targeted at initiatives that increased energy efficiency and the share of renewable energy sources within existing energy infrastructure.[60]

The state energy-efficiency agency, Motiva, has been an important actor in advancing the goals of climate and energy policy in Finland. It has had a significant role in providing neutral and reliable information for both municipal energy advisors and citizens on how to utilize various renewable energy sources in different uses, as well as promoting certificates to new renewables such as GSHPs thus making acquiring new energy technologies more accessible.[61]

The heating market's development

In small buildings, the popularity of oil heating started to diminish considerably in the first decade of the new millennium. Electricity retained its position as the most popular heating solution, but buildings with electrical resistance heating increasingly complemented their existing heating systems with air-source heat pumps (ASHPs). The number of ASHPs grew at a remarkable pace from the late 1990s onwards: from the 1000 units that had been installed by 1997, the number rose to almost 200,000 by 2007 and to over 600,000 by the end of 2015 (SULPU 2018). Due to differences in heat-production capacity (GSHP systems are a heating system capable of providing enough heat energy for the building at all times while ASHPs are typically complementing some other source of heating), ASHPs and GSHPs were not direct competitors. The success of ASHPs built awareness about heat-pump technology and legitimized the use of other types of heat pumps, including GSHPs, in heating buildings.[62] The surge of ASHPs, in turn, was attributable to the previous growth of electric resistance heating in buildings.

GSHPs also benefited from advantageous timing and the good fit of GSHPs to the existing heat-distribution systems of small houses. The heating systems of houses built in a period of intense building during the 1970s and 1980s were in need of an overhaul, and the water radiator heat-distribution systems of old, oil-heated buildings were rather easy to pair with GSHP systems.[63] In newer buildings, underfloor heating had become a standard feature, thus increasing the yield from GSHPs.[64]

A novel feature of the heating market during the last couple of decades has been the rising importance of cooling, especially in commercial facilities. This trend has provided new business opportunities for traditional energy companies, out of which some have started building district-cooling networks. Since GSHP systems can also provide cooling energy very efficiently, this development has provided new business opportunities for companies working with GSHPs.[65]

Discussion and conclusion

The case of GSHPs in Finland features a discontinuous development pattern, which shows how the exploration phase of an alternative technology may be possible even in the absence of a policy-protected niche (or a functioning TIS), when landscape pressure significantly alters the way in which actors perceive the feasibility of regime solutions. GSHPs managed to gain a foothold among the heating choices of detached houses in Finland during the energy crises of the 1970s despite the fact that at the time there was no meaningful innovation system for GSHPs. However, once the landscape pressure subsided, an undeveloped niche no longer could support its success against mature regime solutions. Yet, when moderate, but increasing, landscape pressure began to form at the turn of the millennium, demand-pull from customers was sufficient to accelerate the niche at the expense of previous regime technologies in small buildings. This development was supported by gradual changes in the heating regime, namely the increasing cost of fossil fuel-based heating options and the loss of their legitimacy. GSHP proliferation was further supported by technological development carried out in neighboring countries, by developments in adjacent niche technologies (namely cheaper ASHPs), and by underfloor heating becoming the dominant heat-distribution option in newly built houses. Finally, once the growing niche had matured for another decade, both with respect to technology and market institutions, it could start to challenge other regime technologies in larger buildings in head-on competition with the fossil regime in CHP production. The niche itself became bifurcated as actors dealing with GSHP in small and large buildings and those handling other types of heat pumps are not quite separated, but do not form a uniform niche either.

Understanding the characteristics of such a twisty and long-term development with complex interactions in and between the regimes and niches requires a research approach that is flexible toward issues that might shape development and sensitive to cumulating effects, gradual changes, and contingent developments that shape relevant technologies. Indeed, while we can explain the turn toward GSHPs during the 1980s almost solely by demand-pull effects in the aftermath of large landscape changes, the reemergence in 2000s was due to a much richer range of contributing developments. Flexibility allowed identification of specific elements that contributed to solidification of the GSHP niche in small buildings after the turn of the millennium such as positive cross-niche interactions and the role of peer advice in market development (Hyysalo, Juntunen, and Freeman 2013; Hyysalo, Juntunen, and Martiskainen 2018).[66]

As presented in this article, the MLP, when operationalized by using more granular data, provides an analytical frame that is able to capture characteristics of diverse developments. To discover niche and regime trends and how GSHPs were perceived among regime actors, we collected empirical data from the actors working at these levels. We analyzed this and supporting secondary data through qualitative content analysis, and the results were paired with the development-path types identified in the MLP literature. The development-path types corresponding with the collected data were used as analytical support for tracing the linkages and timing of events on various levels and interactions among actors. Through these paths, we formed an integrated and comprehensive view of the issues that shaped the development and market penetration of GSHPs during selected timeframes. In this case, it was relatively easy to match key events of different timeframes that were discovered through qualitative content analysis with particular development paths described in the literature. The fact that we found for each timeframe, with differing landscape conditions, regime configurations, and niche activities, a development path that matched the events, offers confirmation that paths from existing literature do indeed capture key development elements and may offer tools in identifying change dynamics and mechanisms of change within a sector. Careful selection of expert respondents and use of conventional content analysis to complement the investigation, based on the categories identified in the MLP literature, helped us to incorporate findings on issues that are often seen as shortcomings in the MLP. These considerations included the inability of the MLP to engage with the motives of actors (Spinardi and Slayton 2015), to underplay the role of agency (Smith, Stirling, and Berkhout 2005; Farla et al. 2012), to neglect issues of politics and power (Grin, Rotmans, and Schot 2011), and to underestimate the role of user groups (Shove and Walker 2007).

In conclusion, operationalizing the MLP to study specific technology and country contexts enables study of a single technology together with gradually changing regime and landscape issues, as well as their interaction in one coherent frame over a long period. Taking into account the wider selection environment and issues shaping its transition might make such use of the MLP in single-technology and single-country diffusion a laborious task in comparison to, for instance, simple diffusion analysis or temporally more limited TIS analyses. However, we contend that the resulting rich and detailed—yet widely contextual and multi-causal picture of the characteristics of a transition process—is worth the effort.

Notes

1. For descriptions on how a GSHP system works see Rawlings and Sykulski (1999), Omar (2008), and Karytsas and Choropanitis (2017).
2. For purposes of this article, buildings of less than 1,000 m^2 (10,763 ft^2) are considered small.
3. Hekkert et al. (2007) identify seven such functions: entrepreneurial activities, knowledge development, knowledge diffusion through networks, guidance of the search, market formation, resources

mobilization, and creation of legitimacy/counteract resistance to change.

4. See Appendix A for details about the respondents.
5. See Appendix D for details about the coding scheme.
6. Appendix B provides a list of the articles that used in the research process. Due to space constraints, this article does not discuss every detail on GSHP development and all of the articles in Appendix B are not referred to in this text. A detailed version is available in a book-length doctoral thesis available in Finnish (Lauttamäki 2018).
7. R1, R2, R4, R11, N1, N2, N3, N6, N7
8. A3, A4, N2, N3, N7
9. A3, N1, N2, N3
10. A2, A5, A6, A7, A9, A10, A11, A15, A17, A18
11. A19, N7
12. N1, N2, N3, N7
13. A3, A14
14. N6
15. N12
16. R10, N2, N3
17. R1, R11
18. R4, R7
19. R2, R12, R13, R14, R15
20. R1, R14
21. R5, R6
22. R4, R5, R6, R9, R10, R11, R15, N1, N2, N3, N8
23. R10, N1
24. A20, A22, A23, A24, A27, A34, N1, N2, N3, N6
25. A5, A17, A48, N1, N2, N3, N5, N6, N7, N10, N12
26. N7
27. N2, N3
28. N2, N3, N4
29. R1, R2, R6, R15, N1
30. N2, N3, N10
31. N1, N2, N3, N4, N9
32. HS2–HS6, N10
33. R4, N1, N5, N9
34. A29–A39, A41–43, A45–50, A53–A60, HS2–HS6
35. N10, N11, N12
36. N10, N11, N12
37. N10, N12
38. N11, N12
39. N1, N2, N3, N9
40. N1, N2, N3, N6, N7, N12
41. R10, N5, N9
42. N2, N4, N9
43. N1
44. N1, N2, N3
45. N5
46. A69, A71, A79, R5
47. A55, A56, A58, A62, A67, A68, A69, A71, A82, A84, HS42, HS43, HS45, HS54
48. N1, N2, N3, N5, N7
49. A54, A81, R4, N1, N9
50. R4, R5, R6, R7, R8, R11
51. R4, R7, R8, R10, R11
52. R7, R8, R10
53. R4, R6, N5, N6, N7
54. R7, N9
55. R8
56. R7, R10, R11
57. N9
58. R1, R2, R3, R4, R5, R10, R12
59. N4
60. N2, N3, N6, N7
61. N10, N1, N7
62. N1, N2, N3
63. N9
64. N2, N3, N10
65. R14, R15, N6, N8, N9
66. By contrast, in Denmark support for heat pumps from power companies framed the technology as just another way of electrical heating and this tended to make them unacceptable for actors supporting renewable energy (Nyborg and Røpke 2015).
67. The data set assumes a lifespan of twenty years for GSHPs.

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Appendix A. Competence of interviewed persons

The matrix below presents the competence of respondents and their position with respect to applied analytical levels in the article. Some of the interviewees emphasized that the views they shared were not official positions of the companies for which they worked but rather were personal perspectives. Therefore, no names of organizations are presented in the matrix below.

In total, we interviewed 31 persons. In interview R6 there were three persons from the company present and in interviews R9 and R15 two persons All the other interviews involved a single person. Interviewee N9 had long experience installing GSHPs; during the time of the interview he worked for a company selling turnkey GSHP systems.

Competence of interviewed persons	Codes in text
Regime	
Trade organizations within energy sector	R1, R2, R3
Facility owner's trade organization	R4
Construction companies	R5, R6
Property developers/investors	R7, R8, R9
Publicly owned real estate companies	R10, R11
Energy companies	R12, R13, R14, R15
Niche	
Organizations supporting use of distributed and renewable energy	N1, N10
Finnish GSHP technology developers	N2, N3
GSHP importers	N4
Research institutions	N5, N6
GSHP system designers	N7
Companies selling turnkey GSHP systems	N8, N9
GSHP system installation and borehole-drilling companies	N9
Views of private homeowners/energy consumers (through experts on issues related to energy consumption and energy consumers)	N11, N12

Appendix B. Articles used as material in content analysis

Articles labeled A1–A46 are from Finnish trade and economic journals. These articles were searched by using the www.finna.fi. . . . . library and archive search engines. Articles HS1–HS64 are from the largest daily newspaper in Finland, *Helsingin Sanomat*.

A1 Karjalainen, U. (1959) Talo ilman savupiippua [A house without a chimney]. *Uusi kuvalehti* 10: 26–27.

A2 Wiik, J. (1978). Lämpöpumppu lievittää energiapulaa [Heat pump alleviates energy shortage]. *Teollisuustekniikka* 50(3): 59–61.

A3 Avomaa, P. (1979) Maalämpölaitteiden markkinat aukeavat [Market for heat pump devices are opening up]. *Talouselämä* 42(18): 16–17, 19–20.

A4 Hämäläinen, R. (1979). Maalämpö, ilmainen renki [Ground-source heat, a free servant]. *Tekniikan maailma* 35(16): 85–87.

A5 Wikstén, R. (1979) Pientalon lämmitys lämpöpumpulla [Heating a small building with a heat pump] *Rakennustaito: rakentajain aikakauslehti* 74: 8, 10, 18–19.

A6 Aittomäki, A. and Wikstén, R. (1979) Lämpöpumpun lämmonlähteet [Heat sources for a heat pump] *LVI : lämpö-, vesi- ja ilmastointitekninen aikakauslehti* 31: 5, 54–58, 72.

A7 Alijoki, T., Aittomäki, A. (1980) Säteilyn kerääjä maalämpöpumpussa [Heat radiation collector in a ground-source heat pump] *LVI : lämpö-, vesi- ja ilmastointitekninen aikakauslehti* 32: 3, 156–157, 159–160 .

A8 Aittomäki, A. (1980) Lämpöpumppujen hyväksikäyttö [Using heat pumps] *TTA: tutkimus ja tekniikka* 1980: 2–3, 23–27.

A9 Koivisto, H. (1980) Lämpöpumpun käyttö ja käyttötavat rakennusten lämpöhuollossa [Use of a heat pump and ways to utilize heat pumps in heating buildings] *LVI: lämpö-, vesi- ja ilmastointitekninen aikakauslehti* 32: 8, 68–72.

A10 Junni, K. (1980) Lämpöpumppu - taloudellisin lämmitysratkaisu [Heat pump – the most economical way to heat a building] *Kotitalous* 44: 3, 102–104.

A11 Suominen, P. (1980) Lämpöä maaperästä [Heat from the ground] *Suomen luonto* 39: 6–7, 322–324 .

A12 Lundin, S.-E. (1980). Maaperä lämpövarasto ja lämmönlähde. [Ground, a heat storage and a heat source] *Suomen kunnallislehti* 12: 26.

A13 Kiiskinen, K. (1981). Millä ehdoilla maalämpö? [Ground-source heat: under what conditions?] *Tekniikan maailma* 37(17): 126–127.

A14 Kalenius, V. (1981) Pientalojen lämpöpumput. [Heat pumps for small buildings] *Rakennustaito: rakentajain aikakauslehti* 76: 16, s. 46–49, 52, 54.

A15 Eriksson, K. (1981) Lämpöpumpputalo "Saituri" Laihialla. [Heat pump house ”Scrooge” in Laihia] *LVI: lämpö-, vesi- ja ilmastointitekninen aikakauslehti* 33: 9, 22–23.

A16 Wiksten, R. (1981) Pientalolämpöpumppujen tutkimuksesta Valtion teknillisessä tutkimuskeskuksessa. [On heat pump research for small buildings at Technical Research Center of Finland] *Rakennustaito: rakentajain aikakauslehti* 76: 16, 6–7, 27.

A17 Ylhäisi, M. (1981) Lämpöä järvestä - rakennushallituksen lämpöpumppukokeilu. [Heat from a lake –heat pump experiment at National Board of Public Building] *LVI: lämpö-, vesi- ja ilmastointitekninen aikakauslehti* 33: 10.

A18 Vihervaara, J. and Roivainen, U. (1982) Monipuolinen lämpöpumppu [Versatile heat pump] *Vaihtoehto ydinvoimalle* 1, 28–29.

A19 Lämpöä maasta, vedestä ja ilmasta (1982) [Heat from earth, water and air] *Meidän talo: pienrakentajan arkkitehti ja rakennusmestari* 23: 12, 58–62.

A20 Kervinen, S. (1983) Maan lämpö, maamiehen ystävä [Heat of the ground, farmer's friend] *Pellervo* 4: 18–21.

A21 Kiiskinen, K. (1984) Pienlämpöpumput odottavat uutta tulemista [Small heat pumps await resurgence] *Insinööriuutiset: tekniikan sanomalehti* 31, 27.

A22 Pöntynen, T. (1984) Näinkin voit lämmittää: kuiva maa ja syvä vesi lämmön lähteinä [You may also heat like this: dry ground and deep water as heat sources] *Meidän talo: pienrakentajan arkkitehti ja rakennusmestari* 25: 4, 196–198, 202–203.

A23 Kiiskinen, K. (1986). Jäädyttikö routa maalämmön? [Did frost put ground-source heat on ice?] *Pellervo* 7: 20–22.

A24 Aaltonen, J. (1986) Nyt on virinnyt maausko uus. [Kindled interest on groung] *Meidän talo: pienrakentajan arkkitehti ja rakennusmestari* 27: 3, 54–57.

A25 Käyhkö, T. (1986) Seuraako Suomi perässä?: lämpöpumpuilla Ruotsissa ennätyssuosio. [Will Finland follow? Heat pumps are record-breaking popular in Sweden] *Insinööriuutiset: tekniikan sanomalehti* 13: 12.

A26 Risku-Norja, H. (1987) Bergvärme - ett framtida energialternativ [Ground-source heat – an energy alternative of the future] *Finlands natur* 45: 4, 4–7.

A27 Silvennoinen, T. (1987) Energiaa säästävä koulu [School that saves energy] *Suomen kunnallislehti* 71: 14, 87.

A28 Laine, P. J. (1989). Minne katosi lämpöpumppu? 70-luvun suosikin tutkimuskin jäissä. [Where did heat pumps disappear? Even research of the favorite of the 70's is frozen] *Tekniikka and Talous*. 29(28): 22.

A29 Jussila, R. (1993). Maasta leipä ja lämpö. [From ground comes bread and heat] *Pellervo*. (7): 18–20.

A30 Kauppinen, K. (1993). Maalämpö on talon lämmitysvaihtoehto. [Ground-source heat is a heating option for a house] *Talomestari*. (2): 36–37.

A31 Pervonsuo, A. (1994). IEA5-tutkimusprojekti säästeliäs talo. [IEA5-research project economical house] *Tekniikan maailma*. 50(12): 48–51.

A32 Ahola, J. (1994). Maalämpö voittaa alaa, lämpö taloon omalta tontilta putkiston ja pumpun avulla. [Ground-source heat is gaining ground, heat for a house from an own plot with pipes and a pump] *Talomestari* 1: 31.

A33 Palomäki, P. (1994) Omakotitalo voimalaitoksena [Detached house as a power plant] *Meidän talo and koti* 35: 6, 34–38.

A34 Maalämpöpumppu on ajan hermolla [eng. Ground-source heat pump echos spirit of the times] *Talotekniikka: LVI, VVS* 3: 1, 22–23.

A35 Jalonen, P. (1995) Talon lämpö marjapensaiden alta [Heat for a house from below berry bushes] *Koneviesti: puolueeton tekninen ammattilehti* 43: 11, 8–9.

A36 Lämpöpumppukilpailun voittaneilla tuotteilla hyvä suorituskyky ja matala hinta [Winners of heat pump competition have a good performance and low price] *Talotekniikka: LVI, VVS* 3: 7, 60

A37 Kaksi Ruotsin ydinreaktoria voidaan korvata lämpöpumpuilla [Two Swedish nuclear reactors may be replaced by heat pumps] *Talotekniikka: LVI, VVS* 3: 7, 36.

A38 Energiaa säästävät talot tulevat; Tutkimuksesta markkinoille kuitenkin vielä pitkä matka. [Energy saving houses are coming; There's still a long way from research to markets] *Uusi luonto* 2: 22–23.

A39 Suomesta tehokas maalämpöpumppu pientalojen lämmitykseen. [An effective ground-source heat pump for heating detached houses from Finland] *Projektiuutiset: rakennusalan ammattilehti* 10: 1, 118.

A40 Kinnunen, L. (1998) Prototyypit toimivat hyvin: Lämpöpumput testattu käyttöolosuhteissa. [Prototypes work well: Heat pumps tested in actual use conditions] *Energia: energia-alan aikakauslehti* 1, 58.

A41 Aittomäki, A. (2000) Nykyiset lämpöpumput toimivat hyvin: maalämpöpumppu säästää energiaa jopa 2/3 pientalon lämmityksessä [Currently available heat pumps work well: heat pump saves up to 2/3 of energy in heating a detached building] *Anturi: Tamperelainen tiedeyhteisölehti* 1: 5.

A42 Viitanen, M. (2000) Maalämpö. [Ground-source heat] *Suomen Omakotilehti* 1.

A43 Hirvonen, J. (2001) Lämpöpumppujen myynti tuplautuu vuosittain. [Sales of ground-source heat pumps is doubling every year] *Projektiuutiset* 2: 20–21.

A44 Koivisto, H. (2001) Maalämpö jäähdyttää ja lämmittää halvalla Laitisen sikalaa. [Ground-source heat cools and heats Laitinen pig house on the cheap.] *Koneviesti* 1, 44.

A45 Maalämpöbuumi Suomessa [Ground-source boom in Finland] *Voima ja käyttö* 9, 29.

A46 Hammarström, K. (2002) Fakta och myter om värmepumpar. [Facts and myth about ground-source heat pumps] *Finlands Natur* 2, 8–9.

A47 Andersson, O. (2003) Lämpöpumppuihin kannattaa nyt investoida. [It pays off to invest to heat pumps now] *Rakennettu ympäristö* 4, 66–69.

A48 Yle (2004) Miksi maalämpö ei yleisty Suomessa? [Why is ground-source heat not becoming more common?] Yle verkkosivut, 25 March.

A49 Vuori, E. (2004) Maasta lämpö tomaateille. [Heat for tomatoes from ground] *Puutarha and kauppa* 47, 4–5.

A50 Tertsunen, S. (2005) Lämpöä maasta, vedestä ja ilmasta. [Heat from earth, water and air] *Käytännön maamies* 3, 62–64.

A51 Krögerström, L. (2005) Explosiv marknad för värmepumpar. [Explosive market for heat pumps] *Energivärlden* 3, 6–9.

A52 Krögerström, L. (2005) Marknaden dräller av osaklig reklam. [The market is overflowing with inappropriate commercials] *Energivärlden* 3, 10.

A53 Kujala, H. (2005) Maalämpö pitää porarin kiireisenä. [Ground-source heat keeps drillers busy] *Rakennuslehti* 39: 27, 13.

A54 Pöysä, J. (2007) Rakennusten energiasuunnittelijoista kova pula. [Major shortage for energy designers of buildings] *Kauppalehti*, 29 May, 10.

A55 Rissanen, H. (2008) Rivitalo siirtyi öljystä maalämpöön. [Row house exchanged from oil to ground-source heat] *Kiinteistöposti* 6.

A56 Hellsten, J. (2008). Maalämpö tuli teollisuushalliin. [Ground-source heat came to an industrial hall] *Rakennuslehti* 42:10, 18–19.

A57 Tompuri, V. (2008) Maalämpö vanhasta porakaivosta pienentää asennuskustannuksia. [Ground-source from an old bored well diminishes installation costs] *Rakennuslehti* 42: 25, 20.

A58 Hellsten, J. (2008) Maalämpö yleistyy isoissa kiinteistöissä. [Ground-source heat is becoming increasingly common in large facilities] *Rakennuslehti* 42: 30, 7.

A59 Yle (2009) Nupurinkartanoon kalliolämpölaitos. [Rock heat facility at Nupurinkartano*] Yle Uutisten verkkosivut*, 26 January.

A60 Lukkari, E. (2009) Maalämpö syrjäyttää sähkön lämmitystapana. [Ground-source heat is replacing electricity as a heating option] *Kauppalehti*, 24 January.

A61 Puustinen, T. (2009) Pannuhuoneessani kävi täysi tunari. [A complete bungler visited my boiler room] Energia, 4 August.

A62 Puustinen, T. (2009) Isän, pojan ja maalämmön nimeen. [In the name of the father, the son and ground-source heat] *Energia*, 8 June.

A63 Törmänen, E. (2009) Fortum tekee kalliolämmöstä monopolin. [Fortum makes a monopoly from Ground-source heat] *Tekniikka and Talous.*

A64 Majaniemi, R. (2009) Yrityspuisto lämpiää järven pohjasta. [Business park collects its heat from bottom of a lake] *Tekniikka and Talous.*

A65 Harala, S. (2009) Mikset lämmittäisi kesämökkiä maalämmöllä? [Why wouldn't you heat a summer cottage with ground-source heat?] *Tekniikka and Talous.*

A66 Rakennuslehti (2009) SOK:n logistiikkakeskukseen Suomen suurin uusiutuvaa energiaa käyttävä hybridilaitos. [SOK's logistics center to be equipped with Finland's largest hybrid power plant using renewable energy sources] *Rakennuslehti*, 28 August.

A67 Nurmi, A. (2009) Maalämpö tulee vauhdilla myös suuriin rakennuksiin. [Ground-source heat comes at speed also to large buildings] *Yle Uutisten verkkosivut*, 19 November.

A68 Mustonen, E. (2009) Suuret hallit lämpimiksi maalämpöpumpuilla. [Large industrial halls heated with ground-source heat pumps] *Käytännön maamies* 14, 46–48 .

A69 Kauppalehti (2010) Kallis kaukolämpö kyllästytti - Kerrostalo vaihtoi maalämpöön. [Had enough of expensive district heating – an apartment building switched to ground-source heat] *Kauppalehti*, 12 January.

A70 Hänninen, K. (2010) Maalämpömies: Naurattaa kun katselen lämpölaskua. [Ground-source heat guy: I laugh when I look at my heating bill] *Kauppalehti*, 4 February.

A71 Heiska, K. (2010) Rivitalot siirtyvät öljyä edullisempaan maalämpöön Tampereella. [Row houses are switching to ground-source heat from more expensive oil in Tampere] *Bioenergia* 1, 16.

A72 Saastamoinen, J. (2010) Kiire tulee. [Risk of running out of time] *Kauppalehti Optio* 15, 54–55.

A73 Huhtiniemi, K. (2010) Halpalaitteet pilaavat lämpöpumpun mainetta. [Cheapo devices are tarnishing the reputation of heat pumps] *Tekniikka and Talous.*

A74 Mauno, A. (2010) Lämpöpumput leviävät länsinaapurissakin. [Heat pumps becoming more common also among our western neighbors] *Kauppalehti*, 29 April.

A75 Yle (2010) Nollaenergiatalot tekevät tuloaan Suomeen. [Zero energy houses are making their way to Finland] *Yle Uutisten verkkosivut* 25 May.

A76 Kauppalehti (2010) Ministeriö jyrähtää: Kaupunki ei voi kieltää maalämpöä. [The ministry thunders: a city cannot put a ban on ground-source heat] *Kauppalehti*, 20 August.

A77 Kosk, M. (2010) Fjärrvärme har svårt att konkurrera, Jordvärmen är en ren energiform som bör byggas ut. [District heating has difficulties to compete; ground-source heat is a clean energy source whose use should be increased] Hufvudstadsbladet, 27 August.

A78 Kiinteistölehti (2010) Suurten kiinteistöjen lämpöpumput yleistyvät vauhdilla. [Heat pumps becoming increasingly popular in large buildings] *Kiinteistölehti* 4.

A79 Pihlava, M. (2011) Rakennusyhtiöt tarttuvat maalämpöön. [Building companies are seizing ground-source heat] *Talouselämä*, 26 January.

A80 Yle (2011) Maalämpöä suuriinkin rakennuksiin. [Ground-source heat also for large buildings] *Yle Uutisten verkkosivut*, 17 February.

A81 Rakennuslehti (2011) VTT: Vähäinen kysyntä ja puutteelliset suunnittelumenetelmät estävät kestävää rakentamista. [Technical Research Center of Finland: Low demand and inadequate design processes are hindering sustainable construction] *Rakennuslehti*, 10 May.

A82 Seppälä, J. (2011) Yle: Nunnaluostarikin siirtyy maalämpöön. [Yle: even a convent is converting to ground-source heat] *Tekniikka and Talous*, 18 May.

A83 Esa, M. (2011) Nyt yskii lämpöpumppuväki: "Meillä menee huonosti." [Heat pump actors are struggling: "we are doing poorly"] *Taloussanomat*, 25 September.

A84 Lukkari, E. (2011) Kaukolämpö ja maalämpö kilpailevat nyt kerrostaloista. [District heating and ground-source heating are now competing for apartment buildings] *Kauppalehti*, 29 November.

A85 Yle (2012). Forssalainen kauppakeskus säästää ottamalla pakasteista lämpöä. html [A shopping center in Forssa is saving by extracting heat from frozen products] *Yle Uutisten verkkosivut*, 1 September.

A86 Yle (2012) Maalämpö hyödyksi kaupparakentamisessa. [Ground-source heat to be used in commercial buildings] *Yle Uutisten verkkosivut.* 14 February.

A87 Yle (2012) Moni talo saa lämpönsä maasta. [Many houses are getting their heat from the ground] *Yle Uutisten verkkosivut*, 14 August.

A88 Talouselämä (2012) Suora sähkölämmitys on ainoa järkevä vaihtoehto [Direct electricity resistance heating is the only sensible option] *Talouselämä*, 4 September.

A89 Yle (2012) Maalämpö teki taloyhtiöstä viranomaisten heittopussin. [Ground-source heat made housing cooperative a pawn for the authorities] *Yle Uutisten verkkosivut*, 11 October.

A90 Yle (2013) Oulussa syynättiin koko kaupungin maalämpövarat. [Ground-source heat resources of the city were charted in Oulu] *Yle Uutisten verkkosivut*, 9 July.

A91 Talouselämä (2013) Kova väite: lämpöpumput vähentävät päästöjä enemmän kuin tuulivoima – ja ilman tukiaisia! [A tough claim: heat pumps diminish emissions more than wind power – and without subsidies!] *Talouselämä*, 6 September.

A92 Yle (2013) Maalämpö on siisti juttu, mutta ei sovi kaikkialle. [Ground-source heat is cool, but not suitable for all] *Yle Uutisten verkkosivut*, 10 December.

A93 Luotola, J. (2014) Vaihteet lämpiävät maalämmön avulla – junien myöhästymiset historiaan? [Gears are heated with ground-source heat – train delays a thing of the past?] *Tekniikka and Talous*, 10 March.

A94 Yle (2014) Espoossa aletaan nostaa kaukolämpöä maasta – 120 asteista vettä kilometrien syvyydestä. [Heat for district heating is drawn from the ground in Espoo – 120 degrees warm water from depth of several kilometers] *Yle Uutisten verkkosivut*, 28 November.

A95 Taloussanomat (2015) SS: Lämpöpumppuongelma paisuu – "ihmisestä tulee raivohullu" [Heat pump problem is escalating – "one becomes a raving lunatic"] *Talousssanomat*, 27 March.

A96 Ikkala, T. (2015) Tutkimus: Lämpöpumput selvästi edullisempia kuin kaukolämpö. [Research: Heat pumps are considerably cheaper than district heating] *Tekniikka and Talous*, 26 May.

A97 Muukkonen, H. (2011) Outo ilmiö aurinkokeräinmarkkinoilla [Strange phenomenon on the market of solar collectors] *Talouselämä*, 8 December.

A98 Yle (2015) Tutkija uskoo: Maalämpö syrjäyttää kaukolämmön kotien lämmittäjänä. [Researcher believes: Ground-source heat will replace district heating in warming homes] *Yle Uutisten verkkosivut*, 15 July.

HS1 Mannila, J. (1992) Messutalo lajittelee jätteet Mäntsälän taloissa lämpökompostori ja neljä jätesankoa "Tämä on vasta alku kestävän kehityksen asuinalueeksi." [Housing fair building is sorting its rubbish. Houses in Mäntsälä have heat compost and four waste bins "This is merely a beginning in becoming an area of sustainable development"] *HS*, 16 June.

HS2 Välimäki, P. (1997) Etsin lämpöä yötunteina. [I seek warmth in the dead of night] *HS*, May 7.

HS3 Tuomisto, J. (1998) Investointi ilmastoon aktivoi taloutta. [Investment on climate stimulates the economy] *HS*, 9 May.

HS4 Mainio, T. (1998) Aurinkokeräimiä tai maalämpöä kannattaa jo harkita omakoteihin. [Solar collectors or ground-source heat are worth considering for detached houses] *HS*, 12 May.

HS5 Mainio, T. (1998) Vasta 10000 suomalaista taloutta hankkii energiaa lämpöpumpulla. [Only 10,000 Finnish households are collecting energy using heat pumps] *HS*, 9 June.

HS6 Parkkonen, M. (2000) "Ilmainen" maalämpö kiehtoo omakotitalojen rakentajia. [”Free” ground-source heat is attracting builders of detached houses] *HS*, September 9.

HS7 Yli-Kovero, K. (2000) Sähkölämmitys säästää tuhansia. [Heating with electricity will save you thousands] *HS*, 12 November.

HS8 Patrikka, J. (2001) Maalämmön käyttö saisi olla yleisempää. [Use of ground-source heat ought to be more common] *HS*, 22 January.

HS9 Merivaara, R. (2001) Maalämpö ei ole kovin vihreää. [Ground-source heat is not particularly green] *HS*, 6 February.

HS10 Virtala, P. (2001) Kokemukseni maalämmön käytöstä pääosin myönteisiä. [Experiences on using ground-source heat are mainly positive] *HS*, 12 February.

HS11 Andersson, J. (2001) Maalämpöhankkeita pitäisi tukea paljon enemmän. [Ground-source heat projects should receive much more support] *HS*, 31 March.

HS12 Lassila, A. (2003) Omakotitalon lämmitystapa on maku- ja arvovalinta. [Heating a detached house is a matter of taste and a value judgement.] *HS*, 11 February.

HS13 Talli, R. (2003) Rakentajan kannattaa jättää pelivaraa. [It makes sense for a builder to leave some leeway] *HS*, 27 July.

HS14 Korhonen, M.-L. (2003) Maalämpö on selvä parannus. [Ground-source heat is a clear improvement] *HS*, 19 September.

HS15 Kivistö, J. (2003) Maalämpö ei paranna tilannetta pakkasilla. [Ground-source heat doesn't improve the situation in subzero temperatures] *HS*, 21 September.

HS16 Lankinen, A. (2003) Maalämpö säästää sähköä. [Ground-source heat saves electricity] *HS*, 30 September.

HS17 Korhonen, M.-L. (2003) Maalämpö riittää lämmönlähteeksi. [Ground-source heat pump suffices for an energy source] *HS*, 2 October.

HS18 Lassila, A. (2003) Pientalon piippu on paha päästäjä. [Chimney of a detached house is a bad emitter] *HS*, 12 November.

HS19 Salmela, M. (2004) Omalla työllä syntyi säästöä. [Savings through own work] HS, 17 July.

HS20 Teiskonen, J. and Kempe, M. (2005) Pellettilämmitys on kotimainen vaihtoehto. [Pellet heating is a domestic alternative] *HS*, 22 March.

HS21 Niiranen, S. (2005) Pitäisikö ottaa käyttöön pakkasvero? [Should a frost tax be imposed?] *HS*, 27 July.

HS22 Posti, S. (2005) Maalämpö ei ratkaise pakkasongelmaa. [Ground-source heat doesn't solve frost problem] *HS*, 27 July.

HS23 Ylönen, P. (2005) Yhä useampi koti lämpiää lämpöpumpuilla. [Increasing number of homes are heated with ground-source heat pumps] *HS*, 4 September.

HS24 Koponen, K. (2006) Fortum korotti Tukholmassa tylysti hintoja kun kaukolämmön markkinat vapautuivat. [Fortum made considerable increases for district heating prices in Stockholm after market liberalization] *HS*, 20 January.

HS25 Mainio, T. (2006) Jos rakentaisin nyt, valitsisin toisin. [If I were to build now, I'd choose differently] *HS*, 7 May.

HS26 Astikainen, A. (2006) Bioenergiaa lisää, ydinvoimakin kelpaa. [More bioenergy, nuclear power will also do] *HS*, 6 June.

HS27 Raivio, J. (2007) Kuinka päästä eroon hiilen ylivallasta? [How to get rid of coal hegemony?] *HS*, August 1.

HS28 Pyykkönen, A.-L. (2007) Maalämpö käy nyt kaupaksi. [Ground-source heat pumps are selling well] *HS*, 18 March.

HS29 Vainio, R. (2007) Innovatiivisia energiaratkaisuja. [Innovative energy solutions] *HS*, 26 March.

HS30 Rautava, R. and Luukkanen, H. (2007) Omakotitalot kuuluvat myös Helsinkiin. [Detatched houses belong to Helsinki also] *HS*, 14 September.

HS31 Ojansivu, M. (2007) Ekoautoilu, maalämpö ja energiatehokkuus jyllläävät Ruotsissa. [Eco driving, ground-source heat and energy efficiency are ruling in Sweden] *HS*, 2 October.

HS32 Arola, H. (2007) Vanhanen syyllistää kotitalouksia aiheetta. [Vanhanen is making households feeling guilty unnecessarily] *HS*, 11 October.

HS33 Järvinen, H. (2007) Ekologista lämmitystä tuettava lainoilla. [Ecological heating must be supported with loans] *HS*, 28 October.

HS34 Vanhanen, M. (2008) Terveisiä Helsingin kaupungin ilmastopäättäjille. [Greetings for climate decision-makers of the city of Helsinki] *HS*, 9 January.

HS35 Huotari, P. (2008) Lapsiperhe taloa rakentamassa. [Family with children building a house] *HS*, 21 May.

HS36 Mainio, T. (2008) Maalämpöä monenlaisilla pumpuilla. [Ground-source heat with many different kind of pumps] *HS*, 29 June.

HS37 Pirilä-Mänttäri, A. (2009) Maalämpöä 147 metrin syvyydestä. [Ground-source heat from depth of 147 meters] *HS*, 8 February.

HS38 Pirilä-Mänttäri, A. (2009) Rintamamiestalo lämpenee vaivatta puupelleteillä. [An old detached house is being heated easily with wood pellets] *HS*, 15 February.

HS39 Passi, M. (2009) Yrittäjäperheen luomuinto ei ole vähentynyt. [Eco-ethusiasm of an entrepeneur family has not suffered] *HS*, 14 March.

HS40 Ojansivu, M. (2009) Aaltoluodon perhe etsii taloonsa energiapihiä lämmitystapaa. [Family Aaltoluoto is searching an energy-stingy way to heat their building] *HS*, 23 August.

HS41 Huhta, M. (2009) Helsinki teettää matalaenergiavuokrataloja Viikinmäkeen. [Helsinki is having low-energy tenements made at Viikinmäki] *HS*, 29 November.

HS42 Mainio, T. (2009) Maalämpö ja energiansäästö yleistyvät myös marketeissa. [Ground-source heat and energy saving are becoming more common also in supermarkets] *HS*, 6 December.

HS43 Mainio, T. (2009) Poriin Suomen ensimmäinen hiilidioksiditon kauppakeskus. [Finland's first CO2-free shopping center to be built in Pori] *HS*, 22 December.

HS44 Mainio, T. (2010) Taloyhtiöt jättivät kaukolämmön. [Housing co-operatives abandoned district heating] *HS*, 25 January.

HS45 Mainio, T. (2010) Kerrostalon patteritkin toimivat maalämmöllä. [Even radiators of an apartment building work with ground-source heat] *HS*, 25 January.

HS46 Salmela, M. and Valtavaara, M. (2010) Porkkana pellettiin siirtyjille. [A carrot for those switching to pellets] *HS*, 21 August.

HS47 Huhtanen, J. (2010) Maalämmön käyttöön kieltoja. [Bans on using ground-source heat] *HS*, 25 August.

HS 48 Huhtanen, J. (2010) Nollaenergiatalot saivat jyrkän vastustajan Helsingin Energiasta. [Zero-energy buildings got a stern adversary from Helsinki Energy] *HS*, 27 August.

HS 49 Huhtanen, J. (2010) Kun kaukolämmöstä tuli ongelma. [When district heating became a problem] *HS*, 31 August.

HS50 Arola, H. (2010) Kaukolämpö kestää maapumpun uhan. [District heating can stand the test of ground-source heat pump] *HS*, 13 September.

HS51 Huhtanen, J. (2010) Siemens myi Perkkaan maansa rakennuttajille. [Siemens sold its plot at Perkkaa for developers] *HS*, 12 October.

HS52 Masalin, S. (2011) Järjestelmää voi täydentää. [System may be supplemented] *HS*, 26 March.

HS53 Salmela, M. (2011) Uudenlaisten luomutalojen ilmastointi toimii ilman koneita. [Ventilation of new eco-houses functions without machines] *HS*, 17 June.

HS54 Berner, A.-S. (2011) Töölöläistalo siirtyy maalämpöön ensimmäisenä kantakaupungissa. [An apartment building in Töölö is switching to ground-source heat as a first building in city center] *HS*, 23 December.

HS55 Arola, H. (2011) Maalämpö ylitti odotukset kerrostalossa. [Ground-source heat exceeded expectations in an apartment building] *HS*, 23 November.

HS55 Arola, H. and Palovaara, J. (2012) Lämmitys syö sähköä asumisessa. [Heating consumes electricity in residing] *HS*, 27 February.

HS56 Saavalainen, H. (2013) Päästöt vähenivät etuajassa. [Emissions abated ahead of time] *HS*, 243 April.

HS57 Mainio, T. (2014) Lämpöpumpun jyrinä ei jätä rauhaan. [Rumbling of a ground-source heat pump is disturbing] *HS*, 6 April.

HS58 Mäkelä, H. (2014) Vanhoissa taloissa riittää urakkaa. [Old houses are a handful] *HS*, 6 April.

HS59 Mäkelä, H. (2014) Sähkö vaihtui rintamamiestalossa maalämpöön. [Electricity heating was switched to ground-source heating in an old detached house] *HS*, 7 July.

HS60 Mainio, T. (2014) Tuhannet vaihtoivat maalämpöön. [Thousands switched for ground-source heating] *HS*, 26 May.

HS61 Pohjanpalo, O. (2014) Vihreät korvaisivat ydinsähkön uusiutuvilla. [The green party would replace nuclear energy with renewables] *HS*, 7 October.

HS62 Mainio, T. (2014) Lämpö talteen asfaltista. [Heat recovered from asphalt roads] *HS*, 3 November.

HS63 von Konow, M. (2014) Maalämpö syrjäytti öljyn. [Ground-source heat relpaced oil] *HS*, 26 November.

HS64 HS (2014) Tänä vuonna 12 000 taloutta on siirtynyt maalämpöön. [This year over 12 000 households have switched to ground-source heat] *HS*, 26 November.

Appendix C. Interview questions

We asked in each interview roughly the same set of questions regarding landscape and regime development and interaction among all analytical levels. Some partsthe of questions were tailored to fit the expertise of particular interviewees. With niche-level actors, these customized questions related to niche activities and GSHP niche-regime interaction. In the case of regime-level actors, they were adapted to regime activities and regime-GSHP niche interaction. The question list below is specifically from an interview with a Finnish GSHP technology developer and is meant to be suggestive of the content of our other interviews.

Boom and crash (concentrating on development form 1970s to mid-1980s)

Heating regime/niche development and interaction

- How did GSHPs enter the Finnish heating market? What actors were involved?
- In what kind of facilities were GSHPs first used?

- Were there any differences among different areas in Finlandthe in early adoption of GSHPs? If so, what areas were first to adopt GSHPs and why?
- For builders and facility owners, what was the motivation for taking up GSHPs?
- What was the performance of GSHP systems at that time (price/performance compared with other heating options)?
- What were the most important/popular heating options at the time? How did they develop to gain their position? Were there any factors that would provide stability or instability for their use (e.g., available resources, habit, politics).
- Were there any support or subsidy systems (e.g., information, education, subsidized loans, direct subsidies for acquiring GSHP systems) to expedite GSHPs becoming more common?
- How did builders and building owners find information on GSHPs? How big a role did self-directed information search paly?
- How many companies were there that operated with GSHPs during the 1970s and 1980s? What types of different companies were there (e.g., importers, sellers, technology developers, installers, service providers)? Were GSHPs typically something that existing companies operating within the heating sector added to their assortment or did companies specializing in GSHPs emerge?
- What was the institutional environment around GSHPs during the 1970s and 1980s? Were there activities related to GSHP research, testing, certification for systems or elements of the system, or so forth?
- Was there any networking or organization among actors operating with GSHPs? If yes, what activities were there?
- What were the reasons explaining the crash of the GSHP market by the mid-1980s?
- Were there any measures that could have prevented this crash?
- How did GSHP actors cope during the downturn of GSHPs (until mid-1990s)? How did other heating options develop during this time?
- Why do development paths for GSHPs differ so greatly between Finland and Sweden?

Questions specific for a company developing technology

- When, how, and why did your company choose to enter the business of manufacturing, selling, and installing GSHPs?
- How did you (and other companies you know of) attempt to form a market in Finland during the 1970s and 1980s?
- What were the key challenges in marketing GSHPs to homeowners and builders during the 1970s and 1980s?
- Were there gaps in some part of the process in getting a functioning GSHP system to customers? If yes, what problems were there?

New boom and stabilization (concentrating on development form mid-1990s to 2010s)

- What issues contributed to new boom of GSHPs from the late 1990s onwards?
- What changed in the market environment compared to 1980s?
- Were there any differences among various areas in Finland in adoption of GSHPs during the 2000s? If yes, what areas were first to adopt GSHPs and why?
- For builders and facility owners, what was the motivation for taking up GSHPs?
- What was the performance of GSHP systems at that time (price/performance compared with other heating options)? How did the performance compare to the 1980s?
- What were the most important/popular heating options at the time? How did they develop to gain their position? Were there any factors that would provide stability or instability for their use (e.g., available resources, habit, politics)?
- Were there any support or subsidy systems (e.g., information, education, subsidized loans, direct subsidies for acquiring GSHP systems) to expedite GSHPs becoming more common?
- How did builders and building owners find information on GSHPs? How big a role did self-directed information search paly?
- What was the role and importance of new actors to the field of renewable energy (e.g., Motiva, SULPU) in supporting GSHPs becoming more widely used?
- Why was it just builders and owners of detached houses who adopted GSHPs in the first place? Why was the boom so strong in the early years of the 2000s?
- From the perspective of GSHPs, was there any flexibility in which energy options companies selling pre-fabricated detached houses could offer to their customers?
- Regarding vertical boreholes as a new method of collecting energy, when and how did this become more common? Were there any problems with this technique? What was the competence of borehole companies?

Questions specific for a company developing technology, emphasis in large facilities

- How many of the GSHP projects completed by your company were done for small facilities and how many for large facilities? How do the ways of doing these projects differ?
- Against who do you compete? How do products and services on the market differ from one another?
- Is there a "typical customer" for large-scale GSHP systems? Do ownership issues (public/private/large company/family-owned company) seem to play a role in who and where GSHPs are installed?
- What is the share of retrofit GSHP system installations in large-scale GSHP systems?
- Among customers who are willing to change their existing energy solution for GSHPs, what type of energy source have they previously used in their building?
- Were/are there gaps in some part of the process in getting a functioning large-scale GSHP system to customers? If yes, what problems were there?
- GSHP installations for large buildings that your company has made have grown considerably since 2011. What might be contributing to this boom in large buildings?
- Why is the popularity of GSHP systems in large buildings lagging compared to small buildings?

Appendix D. Preliminary coding scheme

Below is the coding scheme that we used in the first (directed) phase of content analysis. Coding was done separately for each time frame of the research. With all time frames, the first round of coding was done using the outline below.

Landscape

- International cooperation in climate and energy policy
- Discussion of climate and energy issues
- International energy markets
- International energy policy

Regime

- Domestic heating markets
- Domestic building industry
- Domestic energy industry
- Values related to climate and energy issues
- Research and education in energy issues
- Heating technologies
- Culture

Niche

- Research and education related to heat pumps in general and GSHPs in particular
- Market formation of heat pumps in general and GSHPs in particular
- Information activities related to heat pumps
- Different applications of heat pumps in general and GSHPs in particular
- Experiments related to heat pumps in general and GSHPs in particular
- Experiences of using heat pumps in general and GSHPs in particular (e.g., successes, problems)
- Actors and actor networks within heat-pump sector in general and GSHPs in particular