Routledge
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Technology Analysis & Strategic Management

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ctas20

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TECHNOLOGY ANALYSIS & STRATEGIC MANAGEMENT
https://doi.org/10.1080/09537325.2021.2008345

Futures of the Finnish heating regime: actors' views on the coexistence of district heating and ground-source heat pumps

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ABSTRACT
The current Finnish heating regime is characterized by the strong position of district heating (DH). However, in recent years the DH regime has been challenged by the need to decarbonize energy production as well as intensified competition from new forms of heating, especially ground-source heat pumps (GSHPs). For the first time in decades, there is uncertainty about the future of DH. This paper investigates how the Finnish heating regime might change by 2030. Special attention is devoted to the coexistence of DH with GSHPs. Possible futures of the DH regime are examined using qualitative scenarios. The scenarios are based on the views of experts engaged in various heating demand and supply activities, including actors working with GSHPs. Development pathways identified in sustainability transitions studies are used as scenario frames. The research yielded three plausible scenarios for the potential future development of the DH regime in Finland and the role of GSHPs in these futures. In a scenario that was seen as the most probable, DH companies maintain their position but change their operational logic. Heat production shifts from highly centralized to more distributed production, and the role of DH companies changes from being energy producers to administrators of heat flows.

ARTICLE HISTORY
Received 3 September 2020
Revised 11 November 2021
Accepted 12 November 2021

KEYWORDS
District heating; ground-source heat pump; qualitative scenarios; multi-level perspective

1. Introduction

In countries with a cold climate, heating represents a large share of total energy consumption.[1] District heating (DH) is the most popular heating choice in Finland. Figure 1 shows the relative share of different heating options in Finnish building stock, and their development from 2000 to 2018. During this timeframe, the share of DH stays rather stable at about 40% of all heat consumed across all building types.

Traditionally building owners have been eager to choose DH if it is available. However, in recent years three factors have generated uncertainty about the future of DH: need to increase the share of renewable energy resources in energy production,[2] intensified competition from new distributed heat production (ReDHP) and declining heat demand (measured in heat per cubic meter). So far measures to decarbonize DH production in Finland have focused on replacing fossil fuels with biofuels, typically wood chips or wood pellets. Efforts to incorporate distributed heat production into DH networks have been rather modest thus far, except intensified use of surplus heat from industrial processes.

Several ReDHP technologies have been offered as ways to decarbonize heating in a Finnish context, such as heat pumps, technologies using different forms of bioenergy, and solar thermal

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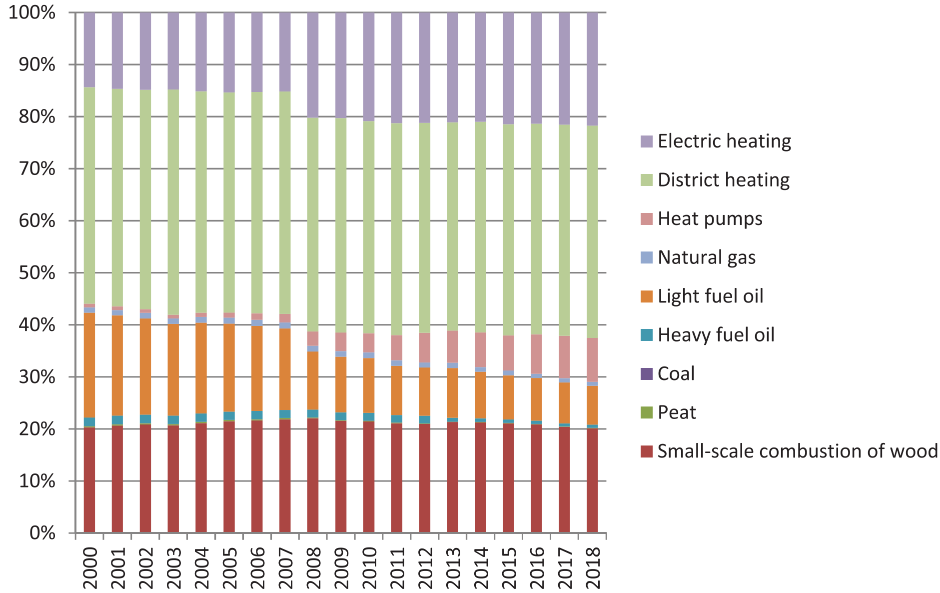

Figure 1. Relative share of heating options used in Finnish building stock, 2000–2018 (Data source: Statistics Finland 2020).

collectors (Juntunen 2014; Ruggiero, Varho, and Rikkonen 2015; Varho, Rikkonen, and Rasi 2016; Kainiemi, Eloneva, and Levänen 2019). These technologies in general, and ground-source heat pumps (GSHPs) in particular, have expedited transition towards more sustainable heating in small buildings by displacing oil heating (Lauttamäki 2018, 2019). However, small buildings with building-specific heating systems are only a part of the overall picture. Decarbonizing centralized heating systems (such as DH) is a formidable challenge that may be tackled, at least in part, by integrating ReDHP into centralized systems. DH infrastructure has been identified as an integral part of sustainable energy system (Lund et al. 2014), but there are not many studies looking into how a transition to a system combining elements of centralized and distributed heat production might play out.

This article aims to contribute to filling an existing gap in understanding how DH and ReDHP might co-exist and how a transition in the Finnish heat sector might proceed. Of the different ReDHP technologies available, this article focusses on GSHPs. This choice is motivated by the fact that unlike most ReDHP technologies, GSHPs may be used as a primary heating source for a building of any size and function. From a heat consumer's perspective, this makes GSHPs a competitor for all other heating options, including DH. So far, most of GSHP systems in Finland have been installed in small buildings (typically detached houses), but installations in large buildings (industrial facilities, apartment buildings, offices, etc.) have been growing in recent years (Lauttamäki 2018, 2019). Most large buildings with GSHP systems in Finland are in areas outside of DH networks, but more and more heat customers are choosing GSHPs even in areas where DH is available. This has created some rivalry between GSHP and DH proponents. In this article, the aim is to look beyond current rivalry and to identify how GSHPs and DH might co-exist.

In this paper, the future of heating and the interplay between a DH regime and the GSHP niche is viewed through qualitative sociotechnical scenarios. Development paths identified in sustainability transition studies using multi-level perspective on sociotechnical transitions (MLP) are used as guidance in constructing scenarios. Future-oriented analysis using MLP has been rather rare until recently, and this paper adds to that body of MLP studies. The year 2030 was selected as the futures horizon due to the availability of several future-oriented climate and energy policy documents that provide guidelines on how heating's operational environment is expected to change up until that year. In these policy documents, the direction of change is clearly stated (i.e.

towards lower emissions from heating), but there is some degree of uncertainty concerning how the change takes place.

Somewhat similar research work has been done in the Swedish context (Åberg et al. 2020); there are also examples of studies concerning the feasibility of incorporating various types of heat pumps with DH (Rinne and Syri 2013; Lund et al. 2014; Levihn 2017). Paiho and Saastamoinen (2018) have studied the perspectives of actors on the future of Finnish heating regime. However, in their study, consideration was given to the views of actors representing just one supply-side heat producer (DH). This work supplements existing understanding on the use of GSHPs and the future of heating in markets where DH dominates and enriches it by bringing forth the views of a range of actors relevant for making a transition in the heating sector, including regime outsiders and heat customers.

From here, this paper proceeds as follows: Section 2 presents the theoretical insights that this work is based on. Section 3 outlines the material and methods used in this research. In Section 4, the scenarios of heating futures are presented. Section 5 discusses findings of the paper. The article concludes with Section 6.

2. Theoretical framework

MLP views transitions through three analytical levels: landscape, regime and niche. In brief, the landscape represents the exogenous operating environment, the regime captures the essential operating logic and stabilizing forces of the system in question, and the niche level is where innovations are developed (Kemp, Schot, and Hoogma 1998; Geels 2002). Transitions take place through dynamics occurring in and between the three analytical levels. Different alignments of events, actions and inputs from the three analytical levels produce different interaction patterns, leading to various development paths. These development paths describe the aggregate effect of changes across all three analytical levels (Geels 2002, 2010). In this research, transitions are defined as co-evolutionary processes resulting in changes to the sociotechnical configuration of the regime, in this case heating. The events, actors and inputs driving changes in the Finnish heating regime are identified more specifically in due course. MLP has been used successfully to study characteristics of past sustainability developments, but using MLP to map potential future developments is less common (e.g. Konrad, Truffer, and Voβ 2008; Verbong and Geels 2010; Geels, McMeekin, and Pfluger 2020). Examples of scenarios using insights from MLP have been presented earlier by Hofman, Elzen, and Geels (2004), Hofman and Elzen (2010) and Bennett (2012). The approach presented in this paper makes use of many of the ideas presented in future-oriented MLP papers mentioned above. However, the particular way in which MLP is operationalized here, and the use of development pathways in building scenarios, is believed to be unique.

Sustainability transitions literature identifies six development pathways that can result from multi-level interactions, based on their varying nature and timing. These pathways are[3]:

1. *The transformation pathway*, where moderate landscape pressure causes tension in the regime, but there are no new niche alternatives available that are matured enough to replace the existing regime. Regime actors have time to respond to changing conditions by improving and introducing new elements to the dominant sociotechnical design.
2. *The de-alignment and re-alignment pathway*, where significant and sudden landscape pressure makes maintaining the current regime difficult. There are no niches that are sufficiently developed to be clear substitutes for managing the functions of the earlier regime. Different niche solutions emerge and compete with each other. Eventually, a new regime configuration is formed around one of these solutions.
3. *The technological substitution pathway*, where landscape pressure presents itself at a moment when a technology or group of technologies are mature enough to replace functions of the earlier regime. While the diffusion of new innovations is taking place, old regime actors attempt to improve their products to better respond to the requirements of the new conditions.

The actors and operational logic of the old regime are gradually merged with or replaced by actors and innovations from the niche level.

4. *The reconfiguration pathway*, where landscape pressure occurs when niche innovations have matured substantially. The nature of new innovations allows them to be incorporated as add-ons to existing regime configurations. As time progresses, the operational logic of the regime is also altered so that the new shape of the regime corresponds well with its changed operational environment. Old regime actors are largely able to maintain their positions.
5. *Mixing pathways*, where development may take the shape of any of the development pathways identified above, alternating between different development path types. The development unfolds depending on how regime actors' respond to landscape pressures, and timing of their responses.
6. *Reproduction process*, where no strong landscape pressure exists. Change is incremental and takes place according to the internal logic of the regime.

In this study, the transition pathways are used to guide scenario construction.

3. Material and methods

The research material of this study consisted of 31 interviews with experts representing the current heating regime (19 persons) and GSHP niche (12 persons).[4] In the interviews with GSHP niche actors, an attempt was made to build understanding on the future development of GSHPs and the issues influencing niche-regime interactions, i.e. what these actors see either as deterrents or as enablers of wider GSHP diffusion in the future. In interviews with regime actors, the goal was to understand how the heating sector might change up until the year 2030 and collect views on the feasibility of GSHPs as part of the heating systems of the future.[5] Interviewees were selected so that there would be representatives from most important fields of expertise related to DH-GSHP interaction. All of the interviews were recorded and transcribed.

Policy papers and research reports relating to the future of the heating market were studied to map expected changes influencing the heating regime from the landscape level. The most important sources of this type were documents connected to the most recent national energy and climate strategy process in Finland, which extends to year 2030 (Ministry of Economic Affairs and Employment 2016).

The transcribed interviews and documents were analysed in two stages. The first stage involved qualitative content analysis using NVivo Pro 11 software. This analysis had features of both directed and conventional content analysis approaches (Hsieh and Shannon 2005). Analysis began with the coding of findings from source material on one of the three analytical levels of MLP (landscape, regime or niche). Within these levels, the issues were first coded by directed content analysis according to categories derived from MLP literature. For both niche and regime levels, these preliminary categories were adjusted when necessary and new categories were formed when needed. As work progressed, conventional content analysis took over as the dominant way to proceed.

The results of the content analysis provided the first layer of analysis. Building scenarios guided by the typology of transition pathways identified in studies applying MLP (Geels and Schot 2007; Geels and Schot 2011; Walrave and Raven 2016) was the second analytical layer.

Results of content analysis provided the themes for understanding change in the heating sector and future use of GSHPs in the two market niches identified in the research, namely small and large buildings.[6] Scenario elements were collected in a futures table (Appendix C). Organizing the material in futures table provided understanding on what development pathway types appeared plausible to be used as scenario frames in the selected context and timeframe.

To validate the choices made in organizing the material into scenarios, and to gain further understanding about probable future developments, a second round of collecting information was carried out. This was done using a questionnaire,[7] which was sent to the same experts who had been interviewed earlier. The goal was to test the plausibility and relative probability of each constructed scenario, and to specify characteristics of potential future development of GSHPs. The aim of the questionnaire was also to check whether the method applied produced meaningful scenarios. Respondents were asked to familiarize themselves with short descriptions of three scenarios, as well as a table showing relevant elements of each scenario.

The questionnaire was successfully delivered to 24 of the interviewed 31 persons. 14 people representing most of the expert categories filled out the entire questionnaire.

4. Future of heating and GSHPs up to year 2030

Three transition pathways emerged as plausible alternatives for the future of heating in Finland up to 2030. These were a *transformation pathway*, *technological substitution pathway* and *reconfiguration pathway*. Of the pathways identified from MLP literature, the *de-alignment and re-alignment pathway* was ruled out because it assumes fast-developing landscape shocks. The information gathered in this research did not indicate that such shocks would be probable from the perspective of the Finnish heating market. The *reproduction process* pathway was not considered plausible because it suggests that there is no significant pressure from the landscape level. Measures to prevent and

Table 1. Competitive district heating (transformation pathway).

	Scenario 1: competitive district heating (transformation pathway)
Transition process	• The share of renewable energy sources in combined heat and power (CHP) production increases • Subsidies for CHP production improve DHs competitiveness • New energy products utilizing price elasticity of demand are introduced • Information on beneficial features of CHP production is disseminated widely • The regime remains stable and regime actors adopt new ways of producing energy that complement the existing energy infrastructure
Key actors	• Large energy companies • Companies with a long history in DH • Companies developing and selling technologies using renewable or waste heat solutions that are compatible with DH • Owners of surplus heat resources
Politics and values	• Energy policies are predictable • CHP has most-favoured status over distributed energy solutions in energy policy • Energy consumers' attitudes towards DH become more favourable
Infrastructure	• In densely built areas, DH networks are being maintained; in growing cities they are extended • District cooling networks are extended
Technologies	• CHP • Heat exchangers enabling two-way energy flows between the heating network and large producers of excess heat • Large heat pumps • Very deep energy wells (up to depth of 1 km)
Dominant business model	• Mainly traditional, where roles of producers and consumers are separated • More flexibility with large heat customers, energy products utilizing price elasticity of demand are introduced
Using GSHPs in small buildings in 2030	• Role of GSHPs in new and renovated buildings is very small; most small buildings rely other heat pumps (air–water, exhaust air) and renewable energy sources
Using GSHPs in large buildings in 2030	• Widely used on areas outside DH networks • In special properties using low-temperature heat to protect them from freezing (e.g. sidewalks, yards, outdoor sports venues)

mitigate harmful effects of climate change are landscape level forces of change affecting the operational environment in heating. A third development type identified in the MLP studies, *mixing pathways,* was also ruled out here. The slow pace of change expected in the heating market, together with the chosen future horizon of the research, made the probability of several transitions taking place within that timeframe low. Since the information collected did not indicate transition pathways that would considerably differ from the types described above, no completely new models of potential transition pathways were constructed. Interestingly, recent research on the responses of two major Finnish energy companies to landscape pressures identified similar patterns to two of the pathways seen as plausible above (the transformation pathway and reconfiguration pathway) (Heiskanen et al. 2018). The challenges and opportunities for the future of DH identified in this study also correspond well with results obtained by Paiho and Saastamoinen (2018).

The three plausible scenarios will be referred to as 'Competitive district heating' (transformation pathway), 'Renewables locally' (technological substitution pathway) and 'Two-way profitability' (reconfiguration pathway). Essential elements of the three scenarios are described in Tables 1–3. A brief description of a transition process by which the scenario in question could develop precedes each table.

Table 2. Renewables locally (technological substitution pathway).

	Scenario 2: renewables locally (technological substitution pathway)
Transition process	• The price of electricity has been low for a long period, eroding the profitability of CHP production. To compensate for this, DH companies have repeatedly increased the price of heat • Demand for heat has diminished considerably due to stringent energy efficiency measures in buildings • The DH regime is under pressure from new energy service actors • The earlier heating regime is partly replaced by new actors who offer distributed heating solutions
Key actors	• Energy technology and energy service companies offer heating solutions based on versatile ways of using renewable energy sources • Households, housing co-operatives and companies are energy producers
Politics and values	• Requirements for energy efficiency in both new and renovated buildings are tightened considerably • Subsidies for energy efficiency improvements in old buildings • Customers consider self-sufficiency and using renewable energy important
Infrastructure	• In growing city areas most of the existing DH networks are maintained; no new high-temperature heating networks are built • Low-temperature heat networks are built in some new areas
Technologies	• Various technologies of distributed renewable energy production • Building service engineering solutions that allow remote monitoring and control of building conditions • Electricity storage solutions at building scale
Dominant business model	• Providing inexpensive heating options that rely on renewable energy technologies, especially to customers in areas where the price of DH is high • Building new heating systems for customers and operating them until the revenues collected have paid off the customer's investment in the system
Using GSHPs in small buildings in 2030	• The role of GSHPs in new and renovated buildings is small; most small buildings are heated with other kinds of heat pumps (air–water, exhaust air) and renewable energy sources. In buildings requiring a lot of cooling, GSHPs are an option
Using GSHPs in large buildings in 2030	• Widespread adoption; GSHPs are an important source for heating and cooling energy in large buildings everywhere • GSHPs are also used to produce energy for local, low-temperature heat networks

Table 3. Two-way profitability (reconfiguration pathway).

	Scenario 3: two-way profitability (reconfiguration pathway)
Transition process	• Through the introduction of two-way heat networks in some areas, many earlier customers become partners in energy production for traditional energy companies • The operational logic of regime actors changes from being a pure energy producer to an administrator of energy flows • Not all regime actors are capable to change; there are winners and losers among earlier regime actors
Key actors	• Traditional DH companies in many large urban areas • New actors offering various services using renewable energy sources in more rural areas • Building owners (as owners of heat energy production and storage resources)
Politics & values	• Energy policies are predictable • Subsidies are available for developing and acquiring energy-saving low-emission technologies
Infrastructure	• Low-temperature heat networks • Heat networks opened up to new heat producers
Technologies	• Heat exchangers enabling two-way heat transfer between and within both traditional and low-temperature heat networks • Heat storage technologies • Very deep energy wells (up to depth of 1 km) • Building service engineering solutions that allow remote monitoring and control of building conditions • Various technologies for distributed renewable energy production
Dominant business model	• Most energy producers and heat network operators in cities are large traditional companies producing heat in large CHP plants and managing heat coming from distributed production points • Energy users take part in energy production, but the heat system is controlled by large companies. Customers get a discount on heat bills by producing heat, or from being flexible in times of peak demand • Managing many different types of customers is crucial for profitability • In rural areas produced heat typically stays within one building complex; energy service companies may offer solutions for building, operating and maintaining such energy systems
Using GSHPs in small buildings in 2030	• The role of GSHPs in new and renovated buildings small; in some large old detached houses GSHPs covering 100% of energy needs at all times are used
Using GSHPs in large buildings in 2030	• Widely used, especially in areas of low-temperature heat networks and rural areas. GSHPs are used in large buildings and local heat networks • In large buildings where cooling is needed, GSHPs are a particularly good option

4.1. Competitive district heating

In this scenario, the goals and means of advancing long-term climate and energy policies are clear and predictable. Energy policy focusses on supply-oriented measures that give DH preferential status over distributed heating solutions. Slow and foreseeable change favours incumbent actors of the current energy regime by giving them an opportunity to gradually adjust their operations. DH remains the most popular form of heating in the Finnish building stock. The use of GSHPs grows in large buildings located outside DH networks.

4.2. Renewables locally

The level of climate and energy policy ambition has increased. As new buildings have been built very energy efficient, the focus in energy policy measures is on energy renovations of old buildings in addition to cutting emissions from centralized energy production. Means of advancing energy

Table 4. Expert's view on probability of scenarios.

Scenario	1 competitive district heating	2 renewables locally	3 two-way profitability
Probability mean	3.21	3.64	3.86
Standard deviation	1.12	1.22	0.92

policies are technology neutral, i.e. they do not give preferred status to any particular energy production or distribution method. DH companies struggle with rising costs and falling revenues. New actors providing heating solutions challenge DH. GSHPs are widely used in large buildings both inside and outside of DH networks. In some areas, facilities with GSHPs are integrated to new two-way, low-temperature heat networks.

4.3. Two-way profitability

The goals and means of advancing long-term climate and energy policies are clear and predictable. The means of advancing energy policies are technology neutral. Regime incumbents maintain their position, but the operational logic of companies changes. Controlling heat flows becomes the key issue for DH companies. Heat production is distributed across a greater number of production points. Compared to the current situation, GSHPs are used more frequently in large facilities, also in areas of DH networks. In these areas especially facilities with a need for cooling energy will opt for GSHPs. In areas with low-temperature heat networks, GSHPs are a part of two-way DH system.

4.4. Experts' views on scenarios and the future of GSHPs

Experts were asked to assess the probability of each scenario on a scale 1–5, where 1 corresponded to a view that the scenario was 'not at all probable' and 5 to a view that it was 'very probable'. Table 4 shows how the group assessed the probability of each scenario. Standard deviation is a measure reflecting the degree of consensus among respondents.

Scenario 3 'two-way profitability' was judged to be most probable. In respondents' comments this scenario was described as versatile and flexible with regards to the use of various heat sources. DH systems were thought to continue to play a key role also in the future, albeit in an adapted form with qualities of fourth generation district heating (e.g. Lund et al. 2014, 2018). New actors possessing energy reserves or working with distributed energy technologies, presently regime outsiders, will be integrated into the regime. From the more detailed issues in the scenario, heat storage technologies were seen to have a growing role in managing temporal allocation of energy flows over time, for instance by using surplus electricity to produce and store heat.

5. Discussion

This research set out to investigate possible futures of the DH regime and its integration with GSHPs in Finland. Potential futures were mapped using development pathways of sociotechnical change as frames for scenarios. Leaning on existing understanding of change patterns made assumptions about core elements of transitions and transition dynamics transparent, thus adding credibility (Coates 2000) and enabling thorough review and constructive critique of the scenarios. The scenarios got positive feedback from experts involved in the study for their clear depiction of wide-ranging drivers of development (landscape forces), motives and capabilities of key actors (regime) and interplay between regime and GSHP niche actors.

Focusing on the views of actors offered understanding about how different groups involved in the research (the DH regime and GSHP niche) saw the future of heating, possible roles of GSHPs in different futures, and best opportunities for future collaboration. Not surprisingly, there were some differences in how groups saw the future of GSHPs in DH areas. Actors in the GSHP niche saw that large buildings, especially apartment buildings in areas where the price of DH[8] is relatively high, might present opportunities for new business in the future. Regime actors downplayed the threat of DH customers switching to distributed heating systems such as GSHPs (as presented in scenario 2) and were rather confident that DH will be an attractive heating option in the future.

To be competitive in the future, and to decarbonize energy production, DH companies need to be open to using new ways of producing heat and to accept new sources of heat into district heating systems, including heat produced with GSHPs. This is how development unfolds in the scenario seen most probable, i.e. 'two-way profitability'. In the study, many GSHP actors had concerns about DH companies' willingness and ability to adopt new ways of producing heat. They suggested that some DH companies have difficulty in understanding and incorporating forms of energy production that do not rely on burning. On the other hand, actors of heating regime actors expressed that at least some of the difficulties of incorporating GSHPs into large buildings and heat networks relate to the poor capabilities of GSHP actors in providing them with good quality information and services. Companies working with GSHP systems need to improve the quality of their planning procedures and project propositions, so that GSHPs can be better integrated to large building and infrastructure projects.

In this research, scenarios were constructed from the perspective of actors in the heating regime and GSHP niche. Actor focus alone is not enough to explicate the feasibility or societal preferability of various heating configurations, but it may be a fruitful and complementary addition to the quantitative approaches that dominate research on energy futures.

6. Conclusion

In the timeframe up until 2030, DH systems will remain a significant part of future heating systems in Finland. DH systems have the potential to serve as an important element in flexible heating systems of the future (Lund et al. 2014, 2018), but the most suitable ways of incorporating new sources of distributed heat production into the mix in a manner that is attractive for both energy companies and energy customers, remains an open question. Decarbonizing DH is a challenge that requires changes in ways of operating DH system and diversification in means of energy production. Several elements that were identified being relevant for decarbonizing DH were included the scenarios (Tables 1–3), but further research and discussion on how to integrate all these elements when attempting to build a heating system that is based on renewable energy sources, has high energy efficiency and is affordable, is needed. This research focused specifically on interaction between DH and one distributed source of heat energy, GSHPs.

At present, building owners, particularly in areas where DH is expensive, have an incentive to abandon DH for GSHPs. If this development intensifies, it might erode future possibilities to build a heating system that would combine the positive qualities of DH, such as its ability to store energy in order to balance fluctuating heat demand over time, with those of renewable distributed heat production. This research points to what kind of role one particular ReDHP technology, GSHPs, might have in an upcoming transition, as well as what kind of collaboration is seen most promising from the perspective of actors in the heating regime and GSHP niche. The method applied in this research may be useful in settings where there is pressure for the current regime to change, but where stakeholders lack insight into the contours of possible futures and on how, and through what kind of mechanisms, change might take place.

Notes

1. In 2018, 26% of all energy consumed in Finland was used for heating buildings. That year energy sector produced 74% of all greenhouse gas emissions in Finland (Statistics Finland 2019a, 2019b).
2. DH is part of EU's emissions trading system. Rising prices of emission allowances (EEX 2021) in recent years underscore the need to decarbonize DH. In 2019, 52% of DH in Finland was produced with non-renewable

resources. Coal was the most important such fuel (21%). Other significant non-renewable energy sources of DH were peat (16%) and natural gas (13%). Wood residues and wood chips were the most important renewable sources with 39% share. Recovered fuel (typically municipal waste) had 9% share (Statistics Finland 2021). Most recent Finnish energy and climate strategy initiatives are aiming to phase out coal in energy production by 2030 and replace it largely with bio-based energy sources (Ministry of Economic Affairs and Employment 2016).

3. Pathways are described in detail in Geels and Schot (2007), Geels and Schot (2011), Walrave and Raven (2016).
4. Details of interviewed persons in Appendix A.
5. Interview questions asked to all interviewed persons in Appendix B.
6. Focus here is on large buildings since this segment is more relevant for the future of DH.
7. Questionnaire in Appendix D.
8. Prices vary in different areas. Price range for large apartment building in Finland in 2018 was from 52.79 €/MWh to 110.24 €/MWh (Finnish Energy 2019).

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This research was conducted as part of two projects funded by the Academy of Finland: ‘Towards a future-oriented ‘Energiewende’: an anticipatory multi-level approach to the decentralized renewable energy transition (FutWend)’ (Academy of Finland Consortium 297747) and ‘Towards deliberative climate and energy foresight (DECENT)’ (Academy of Finland consortium 325207).

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Appendix

Appendix A

Table A1. Background information on informants of the study.

Core competence of interviewed persons	Number of interviewed persons	Number of answers to questionnaire
Regime		
Trade organisations within energy branch	3	1
Facility owner's organisation	1	1
Construction companies	4	0
Property developers/investors	4	1
Publicly owned real estate companies	2	1
DH companies	5	1
Niche		
Organisations supporting the use of distributed and renewable energy	2	2
GSHP technology developers	2	1
GSHP importers	1	1
GSHP commercialisation companies	2*	1
GSHP system designers	1	0
GSHP system installation & borehole drilling companies	1*	1
Research institutions	2	1
Private house owners/energy consumers (through experts on the issue)	2	2

For one of the interviewees, determining just one professional role was difficult. The two roles this person identified with are marked with *.

Appendix B

Questions asked from all interviewees are listed below. In addition, a set of tailored questions addressing particular expertise of each interviewee, were asked.
Recent past and present

- What issues have contributed to recent development in heating technologies?
- Can you identify policy initiatives that have significantly influenced to recent change?
- How have policy initiatives you mentioned affected DH/GSHPs?
- Besides political actors, what other actors can you identify that have significance on the development of DH/GSHPs?
- Why did the GSHP market boom the way it did in the 2010s?
- Since when have the GSHPs been perceived as a viable option for heating and cooling in large buildings?
- Why is DH so dominant in large buildings?
- Compare customer experience between DH and GSHPs.

Future

- What are key trends affecting the change in the heating market within the next 10–15 years?
- What sociopolitical issues are most important in determining how the future unfolds in heating?
- How will need for heating develop within the next 10–15 years?
- What technical developments related to producing or distributing DH are expected?
- How do you think relative shares of different forms of heating will change?
- Will some completely new energy sources or means of storing energy play a role in heating within the next 10–15 years?
- In what kind of facilities do GSHPs have the biggest potential to grow?
- What issues or developments favour DH/GSHPs in the future?
- What issues or developments might work against DH/GSHPs in the future?
- How do you see competition between DH and GSHPs developing?
- How do you see possible interaction between DH and GSHPs developing? In what kind of areas there are best possibilities for co-operation?

Appendix C

Table C1. Futures table.

	Pathway 1	Pathway 2	Pathway 3	Pathway 4	Pathway 5	Pathway 6
Transition process						
Key actors						
Politics & values						
Infrastructure						
Key technologies						
Dominant business model						
Using GSHPs in small buildings						
Using GSHPs in large buildings						

Analytical procedure in brief: The names of the pathway types identified in studies using MLP were written on the top of each column (Pathways 1–6). After that, condensed descriptions of each transition pathway, adapted to depict possible future development in heating sector, were written in the 'Transition Process' row. Finally, items depicting details of development found in research material were arranged under suitable transition pathways.

Appendix D

(See Table 1)

1. How probable do you see scenario 1?
Not at all probable – very probable (scale 1–5, value 3 corresponding 'neutral')
2. What individual elements do you consider probable/improbable in the scenario?
3. Assess probability of some elements presented in the scenario up until 2030

All questions below: Not at all probable – very probable (scale 1–5, value 3 corresponding 'neutral')
Policy:

- energy policies are stable and predictable
- biofuels used for CHP production will be granted subsidies, if needed

Energy market:

- current DH operators will remain key actors in the heating market

New technologies:

- two-way energy trade will increase between DH companies and actors with surplus heat resources
- geothermal energy (from depths of 5 km and over) will be used in DH networks

New products:

- information gathered from heat consumption patterns of various energy users in the DH network has been used to develop new heat products
- flexible heat contracts are offered to DH customers

(See Table 2)

4. How probable do you see scenario 2?
Not at all probable – very probable (scale 1–5, value 3 corresponding 'neutral')
5. What individual elements do you consider probable/improbable in the scenario?
6. Assess probability of some elements presented in the scenario up until 2030

All questions below: Not at all probable – very probable (scale 1–5, value 3 corresponding 'neutral')
Policy:

- energy policies with regards to CO2 emissions and share of renewable energy sources will be more stringent in the future
- energy efficiency norms of old buildings become more stringent
- there are generous subsidies available for energy renovations of old buildings

Energy market:

- CHP is in trouble
- new buildings are increasingly choosing not to join DH when it would be available
- district cooling networks have been extended only marginally

New technologies:

- new heat networks are increasingly low-temperature networks
- building -specific electricity storage devices are commonly in use

New products:

- energy companies administrate networks of several renewable distributed energy production points
- energy products and services that help to solve the problem of balancing the electricity network will develop significantly

(See Table 3)

7. How probable do you see scenario 3?
Not at all probable – very probable (scale 1–5, value 3 corresponding 'neutral')
8. What individual elements do you consider probable/improbable in the scenario?
9. Assess probability of some elements presented in the scenario up until 2030

All questions below: Not at all probable – very probable (scale 1–5, value 3 corresponding 'neutral')
Policy:

- there are no permanent subsidies for any energy form or fuel

Energy market:

- temperature of DH has been lowered
- two-way heat networks are common
- DH companies that have not been able to adopt two-way heating are in trouble

New technologies:

- different technologies of ReDHP are used as part of DH networks
- heat storage technologies are commonly used

New products:

- companies operating in heating offer flexible electricity and heat products to a wide range of different customers.