UNIVERSITY OF TURKU

ABSTRACT

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Abstract

Mitigation of and adaptation to ecological crises such as loss of biodiversity and climate change and meeting the sustainable development goals require sustainability transitions in all fields of life. This thesis focuses on studying possible futures and sustainability transitions of Finnish district heating and which technical and non-technical solutions are essential in such transitions.

This study builds on semi-structured expert interviews. The data was analysed with multi-level perspective and a futures table. Analysis was followed by creation of scenarios. By making use of transition pathways related to multi-level perspective, this thesis produced five possible transition scenarios for Finnish district heating.

The scenarios cover the following transition pathways: transformation, technological substitution, reconfiguration, and de-alignment and re-alignment. Multiple technical and non-technical solutions for sustainability transitions were identified and then included in the scenarios, such as hydrogen economy, small and modular nuclear reactors, renewable energy, energy storages and prosumerism.

The main conclusions are that sustainability transitions can and will be made and are indeed already on their way in the Finnish district heating. A multitude of different solutions exist that can help in and enable sustainability transitions in district heating. Furthermore, many technical solutions are being developed and are expected to mature in the future, providing more ways to produce, store and provide heat. The experts from Finnish district heating were not keen on having new policy measures which would promote transitions. Nevertheless, research and empiric data in the thesis suggest that such policy measures have progressed and could further foster sustainability transitions in Finland. Based on the scenarios created in the study, strategy proposals for companies were made. In addition, the thesis recommends that actors in the field of district heating evaluate their foresight practices and update their strategies.

Key words	District heating, sustainability transitions, multi-level perspective, scenarios

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Tiivistelmä

Ekologisten kriisien kuten ilmastonmuutoksen ja luonnon monimuotoisuuden hupenemisen hillintä ja niihin sopeutuminen sekä kestävän kehityksen tavoitteiden saavuttaminen vaatii kestävyyssiirtymiä kaikilla elämän osa-alueilla. Tämä työ keskittyy tutkimaan suomalaisen kaukolämmön mahdollisia tulevaisuuksia ja kestävyyssiirtymiä sekä sitä, millaiset tekniset ja muut ratkaisut ovat olennaisia tällaisissa siirtymissä.

Tämä työ perustuu kahdeksaan teemahaastatteluun, jotka käytiin alan asiantuntijoiden kanssa. Data analysoitiin monitasoisen näkökulman (multi-level perspective, MLP) ja tulevaisuustaulun avulla. Skenaariot rakennettiin analyysin jälkeen. MLP:n siirtymäpolkuja hyödyntäen tässä työssä luotiin viisi mahdollista siirtymäskenaariota suomalaiselle kaukolämpöalalle.

Skenaariot kattavat seuraavat siirtymäpolut: transformaation, teknologiavaihdoksen, uudelleen konfiguraation sekä suistumisen ja uudelleensuuntautumisen. Työssä tunnistettiin monia teknisia ja muita ratkaisuja kestävyyssiirtymän tueksi. Näitä ratkaisuja sisällytettiin tuotettuihin skenaarioihin. Ratkaisuja olivat mm. vetytalous, pienet ja modulaariset ydinreaktorit, uusiutuva energia, energiavarastot sekä käyttäjä-tuottajuus.

Tärkeimpänä johtopäätöksenä on, että suomalaisessa kaukolämmössä voidaan ja aiotaan tehdä kestävyyssiirtymä, joka on itse asiassa jo käynnissä. Kaukolämmön kestävyyssiirtymää tukevia ja mahdollistavia ratkaisuja on paljon. Lisäksi monia teknisia ratkaisuja kehitetään ja niiden odotetaan kypsyvän tulevaisuudessa, mistä seuraa lisää tapoja tuottaa, varastoida ja jaella lämpöä. Haastatellut suomalaisen kaukolämmön asiantuntijat eivät olleet innoissaan mahdollisista uusista asetuksista, joilla edistettäisiin siirtymää. Siitä huolimatta tutkimus ja tämän työn empiirinen data esittää, että tällaiset asetukset ovat jo edistäneet ja voisivat edelleen edistää kestävyyssiirtymää Suomessa. Työ esittää yrityksille strategisia ehdotuksia luotujen skenaarioiden perusteella. Tämä työ suosittelee kaukolämpöalan toimijoille ennakointikäytäntöjen tarkastamista ja strategioiden päivittämistä.

Avainsanat	Kaukolämpö, kestävyyssiirtymät, monitasoinen näkökulma, skenaariot

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FUTURES AND SUSTAINABILITY TRANSITIONS OF FINNISH DISTRICT HEATING

Master's Thesis
in Futures Studies

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ABBREVIATIONS

BECCS = Bioenergy with Carbon Capture and Storage
CCS = Carbon Capture and Storage
CHP = Combined Heat and Power production
CO_2 = Carbon dioxide
CSP = Concentrated Solar Power
DH = District Heating
DIY = Do It Yourself
EU = European Union

FS = Futures Studies
GSH = Ground-Sourced Heat
HP = Heat Pump
MLP = Multi-Level Perspective
SMR = Small and Modular nuclear Reactor

1 INTRODUCTION

Global warming has been caused by human activities such as unsustainable energy use, land use and land-use change, patterns of consumption and production, and lifestyles. With the current nationally determined contributions, it is likely that during the 21st century the global warming will exceed 1.5°C, which is considered as a crucial threshold. To limit global warming, transitions to sustainable emissions levels are required. (eg. Mukherji et al. 2023.). In addition, the need for sustainability transitions has been identified and justified in earlier works, starting from *Limits to Growth* (Meadows et al. 1972), Brundtland's commission report (World Commission on Environment and Development 1987) to international biodiversity report (IPBES 2019).

In this thesis, heating and especially district heating is considered a field where sustainable energy use, net zero targets and other sustainability goals can be promoted. Finnish houses and buildings require heating throughout the year due to climate conditions. District heating is an interesting field, since approximately half of the households rely on district heating (Statistics Finland 2022a). In 2010, significant amount of heating was produced by burning fossil fuels such as coal and oil (58 % of district heat production, biomass (20 %) and peat (19 %). In transitioning to carbon neutral heating, the share of fossil fuels has decreased. In 2021, fossil fuels accounted for 29 % of district heat production, wherein the share of biomass has increased to 47 % and the share of peat has decreased to 10 %. (Statistics Finland 2022b.) Furthermore, in Finland, coal is banned from 2029 onwards (Finlex 416/2019), and emission trading system and taxation have made peat burning more expensive, making it less appealing. Substituting fossil fuels and peat with renewable fuels is not unproblematic either: as Majava et al. (2022) point out, if several industry sectors, energy sector included, increase the total use of biomass, it may lead to unsustainable and even unrealistic use of biomass.

Despite the wide use of district heating in households, the future of district heating is all but clear. Alternative heating solutions exist, and the field of heating is constantly evolving as a result of technological advancements, fuel prices, and the need to mitigate climate change. In district heating, alternative fuels and technologies for production also exist and are investigated, developed and experimented, but there are certain hindrances and technological lock-ins. In addition, buildings are becoming more energy efficient, decreasing the need for heating. In areas where district heating is available, a share of buildings have resorted to alternative heating solutions and invested in property-based solutions with which the needed heat of the building is produced in situ. Related to indoor climate control, district cooling is offered in some of the new buildings, and hot summers have raised the general interest on air conditioning with heat pumps.

Although district heating has a crucial role in the energy sector and thus in climate change mitigation, there is not much qualitative research on the topic, especially in the Finnish context. The research either focuses on a certain district heating technology, has relatively short timeline, lacks a multi-level perspective, falls short on sustainability transitions, or focuses on a different country or wider spatial context. For example, Lauttamäki (2018) mapped futures of ground-sourced heat[1] for heating Finnish buildings. Nevertheless, the study does not address district heating that much, and its temporal scope is only to 2030. Paiho and Reda (2016) discussed next generation district heating in Finland and suggested some scenarios, but the work focuses mostly on technological solutions. Paiho and Saastamoinen (2018) interviewed organizations about how Finnish district heating should be developed, but their timeline covered only the following five years. In a broader context, Itten et al. (2021) touched upon sustainable heating transitions in Europe, and Nilsson et al. (2020) mapped transition pathways for Swedish heating domain. Swedish heat energy system was assessed for stableness and lock-ins using multi-level perspective by Dzebo and Nykvist (2017), though they focused mainly on the current status of the broader heating regime. Much of future-oriented literature focuses on futures of general energy production (see for example Ford et al. 2021; Heinonen and Lauttamäki, 2012; Lang 2018; Proskuryakova 2017) or electricity production (see for example Rogge et al. 2020; Verbong & Geels 2010). There is clearly a need for qualitative futures research on futures and sustainability transitions of Finnish district heating.

With an aim of mapping possible futures and sustainability transitions for Finnish district heating, this thesis utilizes the multi-level perspective (MLP), which was originally developed to study historical developments (Geels 2002), to depict future developments (see Hofman & Elzen 2010; Moradi & Vagnoni 2018; Verbong & Geels 2010). Following Masini's (1993) third principle of futures studies, not one but many futures are mapped. This is done by creating possible futures and future developments of Finnish district heating towards sustainability with a timespan of 10-30 years, up until 2050. In so doing, the thesis at hand contributes to bringing together literature from the fields of futures studies and sustainability transition studies from the perspective of energy sector. This thesis provides insights of transitions and transformation that lead to a more sustainable world. To conduct the research, the author has received financial support from two research funding instruments: Ympäristötili of Oulun Energia Oy and Ympäristöpooli which is coordinated by Finnish Energy.

Given the principle of many futures, several descriptions of a future are needed. Futures will not appear out of nowhere but there are developments – in the thesis approached through transition pathways or scenarios – leading to those futures. Therefore, the first research question is:

[1] Ground-sourced heat is heat gathered below the ground, anywhere from zero meter to several kilometres deep.

1 What are the possible futures and sustainability transitions for district heating in Finland? (RQ1)

These futures are effected by various technical and non-technical solutions, especially because district heating is a heavily technical industry. Production of heat, producers of heat, location of heat production, practical implementations, and cultural aspects related to indoor air conditions are part of these solutions. A key interest of the thesis is to identify these solutions. The second research question is:

2 What are the (technical and non-technical) solutions for district heating in the future? (RQ2)

Through answering these two research questions, the thesis improves understanding of futures and sustainability transitions of district heating. Multi-level perspective (Geels 2002; Geels & Schot 2007) is taken up as a tool for both analysis (Smith et al. 2010) and guidance (Sovacool & Hess 2017) to study the complexities of the field of district heating and sustainability transitions. The field of district heating is here understood as consisting of heating markets and user preferences, district heat industry, policies, science, culture, and technology. The analysis draws upon eight semi-structured interviews of experts operating within the field of district heating. Multi-level perspective and concepts of futures studies such as trends and weak signals are used to analyse the interview material. Scenarios are created through the use of a futures table, which includes variables and their values from the material.

The thesis is structured as follows. After the introduction, chapter 2 positions the thesis in the field of sustainability transitions. The multi-level perspective is described in chapter 3. Scenarios and futures table are introduced and connections between futures studies, transition studies and the multi-level perspective are made in chapter 4. Chapter 5 describes the field of Finnish district heating with a brief look into historical developments which have resulted in the present situation and which still affect the future developments. Methods of data collection and analysis are described in chapter 6. The results from the empirical research are presented in chapter 7. The chapter 8 discusses the implications of the results and the materials, and strategy proposals are made for companies. In addition, the results are discussed in relation to what kind of policy measures and designs could be introduced to foster sustainability transitions in district heating. Finally, chapter 9 presents the conclusions, theoretical contributions and possible future research.

2 TRANSITION STUDIES

Transformations and transitions are key concepts in transition studies and sustainability transitions. Transition, as used in sustainabilty transition research community, means a fundamental technological, social, economic and institutional change from a regime to another regime. Transformation refers to fundamental shifts in environmental and human interactions. Sometimes transitions can be understood as technocratic and top-down transitions, whereas transformations are more radical, long-term and large-scale changes. (Hölscher et al. 2018). Geels and Schot (2007, 399) define transition as a change from a sociotechnical regime to another. This is how transitions are understood in this thesis. Transformations are deeper, fundamental changes affecting the landscape and regimes, although one of the transition pathways from Geels and Schot (2007) uses the word transformation.

Socio-technical transitions, as the name implies, are more than just transitions from a technology to another. Changes take place in institutional structures such as regulation and culture as well as in user practices, in addition to technologies. (Markard et al. 2012, 956.)

Sustainability transitions are fundamental, multi-dimensional, and long-term change processes towards more sustainable modes of consumption and production in socio-technical systems. Established socio-technical systems go through these processes of fundamental change. There is a wide range of actors involved in a transition. Transitions usually take a considerable amount of time to unfold, even five decades or more. During a transition, there are new services, products, business models and organisations that emerge to complement or substitute current options. Institutional and technological structures and consumers' perceptions of those structures go through a substantial change. (Markard et al. 2012, 956).

In transition studies, Markard et al. (2012) identified four major lines of study:

- transition management,
- strategic niche management,
- multi-level perspectives, and
- technological innovation systems.

Additionally, Lachman (2013) listed the most used and studied approaches for transitions:

- transition management,
- strategic niche management,
- multi-level perspective,
- innovation systems,
- techno-economic paradigm, and
- socio-metabolic transitions.

Each approach and line of study in the lists has its own focus, unit of analysis, purpose and background, to name a few. There are some shared characteristics among them, too, such as the background in evolutionary theories (Schot & Geels 2008). Strategic niche management, transition management and multi-level perspective are present in both lists. The focus of this thesis is not to manage niches nor to manage transition itself. Therefore, strategic niche management and transition management are not chosen.

Multi-level perspective (MLP) utilises socio-technical systems as its unit of analysis. Such systems provide functions for societies such as housing, mobility, sustenance and heating. (Geels 2018, 225.) Furthermore, socio-technical systems are a mix of technologies, markets, regulations, infrastructures, user practices and cultural meanings. The mix is co-evolving and interdependent. (Geels 2004.) District heating is such a socio-technical system. Thus multi-level perspective is chosen for this thesis. More reasoning follows in the next chapter, where multi-level perspective is described in depth.

3 MULTI-LEVEL PERSPECTIVE

Multi-level perspective (MLP) (Geels 2002; Geels & Schot 2007) provides a suitable framework for analysing multi-level systems and their developments and transitions. MLP is based on systems thinking, focusing on system-level transitions. It is flexible, explorative, open, and it allows one to map long-term developments that are not linear (Vähäkari et al. 2020, 2). It has been used to map historical developments (for example Geels 2002) and future developments (Hofman & Elzen 2010; Moradi & Vagnoni 2018; Verbong & Geels 2010). MLP is popular and flexible when analysing dynamics of sociotechnical change (Vähäkari et al. 2020).

MLP is used to conceptualize dynamic patters in socio-technical transitions. It combines several concepts from different fields of studies (Geels 2011, 26):

- science and technology studies (social networks, innovation as a social process, sense making),
- evolutionary economics (regimes, niches, trajectories, speciation, path dependence, routines), and
- structuration theory and neo-institutional theory (‘deep structures’ such as rules and institutions, duality of structure).

MLP is a deeply integrative theory by its nature. An integrative theory makes use of multiple theories and concepts. An integrative theory can minimize arrogance and bias, fit best for a research topic, and tighten concepts with critical thinking. (Sovacool & Hess 2017, 742.) MLP combines several transition approaches that present transitions as outcome of developments in three levels: landscape, regime and niche (Moradi & Vagnoni 2018). Transitions in MLP are non-linear processes (Geels 2011, 26). They are the results of interaction between and interplay of developments at the mentioned three levels (Geels 2011, 26).

MLP can describe, map and analyse long-term change processes (Moradi & Vagnoni 2018, 235). MLP provides a broad scope for analysing socio-technical systems providing societal functions such as heat and housing, in contrast to certain other technology-specific approaches (Geels 2018, 225). An illustration of the multi-level perspective on socio-technical transitions is described in Figure 1.

MLP focuses on certain groups and their resources, beliefs, strategies and interactions (Geels 2011, 26). District heating is dependent on many technological solutions such as production, delivery networks and storage. Technologies offer a solid entry point for studying ‘society in the making’ (Callon 1987; Latour 1990; cited in Geels 2019, 189).

In addition to analysis provision, the MLP can be used to give guidance to sustainability transitions (Sovacool & Hess 2017, 734). This thesis utilises MLP for both analysis and guidance. MLP offers a rather linear way to simplify and order the analysis of large-scale, complex structural transformations in consumption and production that are required to meet the normative goals of sustainable development. MLP terminology allows one to communicate and organise these thoughts into clear transition descriptions. (Smith et al. 2010, 441-442.) Terminology is described later, starting from chapter 3.1.

This thesis maps the current status of and possible developments in Finnish district heating. The multi-level perspective offers a powerful tool for the thesis. The MLP accounts for co-evolution of technology and society with its multiple dimensions. Sustainability transitions cannot be done by one single actor. Interactions among actors and different stakeholders are included in the MLP. With the MLP, one can focus on complex dynamics that can be found in regime, landscape and niche levels. Even though the MLP focuses on transitions and radical change, stability is also covered through lock-ins and resistance.

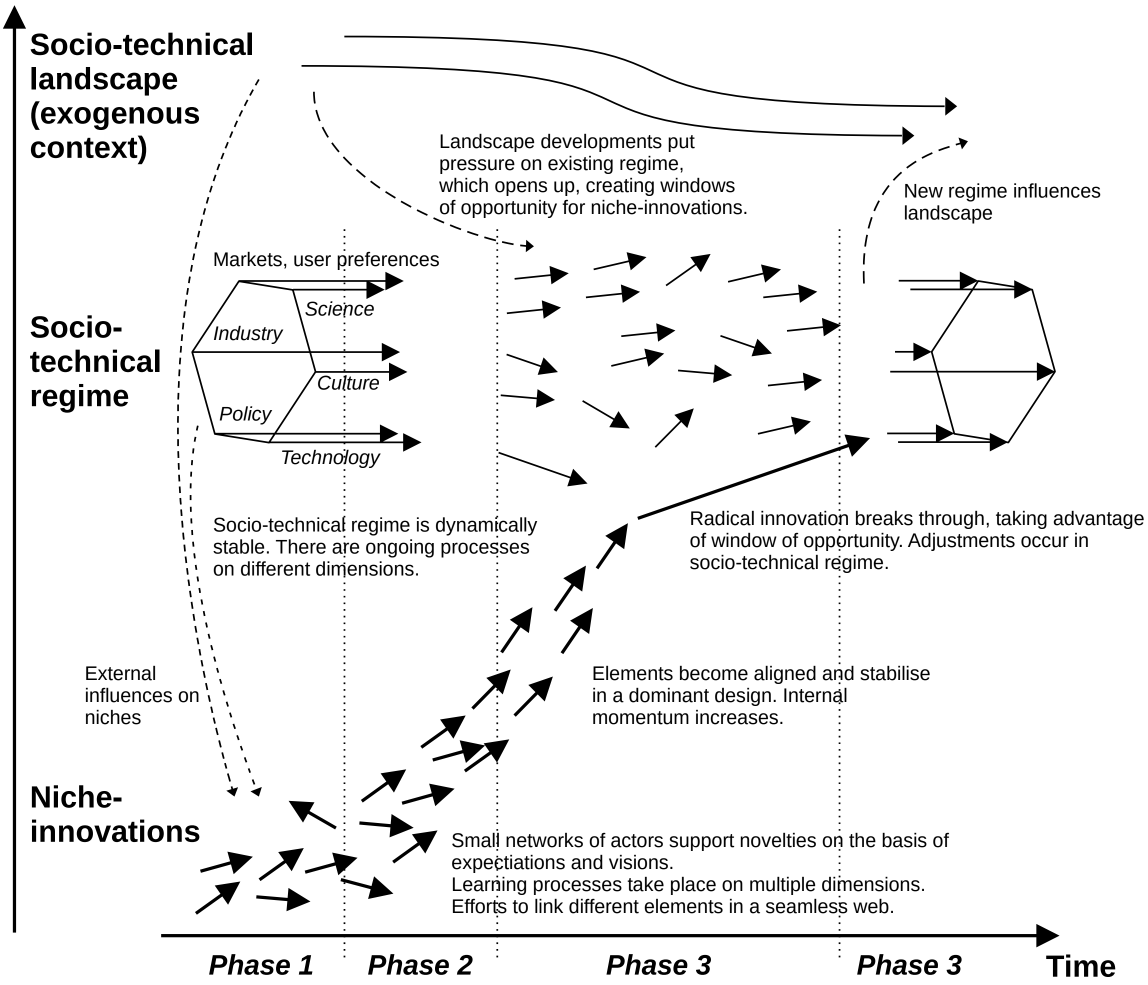

Figure 1. Multi-level perspective on socio-technical transitions (adapted Fig 1. from Geels 2018).

3.1 Levels

MLP consists of three analytical levels: niche, regime and landscape (Geels 2011, 26). The levels are not ontologies of reality but rather analytical and heuristic tools which can help understand the socio-technical change and its complex dynamics (Geels 2002, 1259). Early on, the MLP levels were considered to be nested hierarchically (Geels 2002), but a more recent article suggests that they should not be considered as hierarchical levels. The landscape and niche levels are derived from the concept of and related to the regime level which is of primary interest in MLP. (Geels 2011, 26.) A nested hierarchy would mean that regime exists within landscape and that niche exists within regime. However, as Geels (2011, 26-27) points out niches often emerge outside regimes. Furthermore, he states that landscape is 'an external context' which is not related hierarchically to regimes and niches. Next, each level is described in detail.

3.1.1 Regime

The regime level is the middle level and it is defined as socio-technical regime. It is the locus of established practices and related rules. These rules are both outcome and medium of action. Actors create and enact the rules, and in addition, the rules affect the actors. Examples of these are capabilities and competences, legally binding contracts, cognitive routines and shared beliefs, favorable institutional arrangements and regulations, and lifestyles and user practices. (Geels 2011, 26-27.) The regime rules create a logic for incremental change in the socio-technical system. The change follows the direction of established pathways of development. (Markard et al. 2012, 957.)

The regime level is the level of primary interest because, in MLP, transitions are by definition shifts from a regime configuration to another regime configuration. Innovation occurs incrementally because lock-ins are characteristic of existing regimes. Small adjustments accumulate into stable trajectories. The trajectories are not only about technological developments but occur also in political, cultural, industrial, scientific, and market dimensions. The dimensions have their own sub-regimes and dynamics, and they co-evolve with and interpenetrate each other. The sub-regimes can be aligned to provide regime stability but it can also result in tensions. (Geels 2011, 26-27.) The aim of the socio-technical regime is to capture the meta-coordination that happens between sub-regimes (Geels 2004, 905). The six dimensions offer a hexagonal approach to analyzing and structuring the regime level, similar to a PESTEL framework which is a widely-used tool in futures studies.

The heterogeneous elements and their linkages affect the stability of socio-technical configurations. Consecutively, the elements and linkages are formed by social groups and their activities. (Geels 2002, 1259.) Small changes and dynamics within the regime result from research and development activities and such in regime dimensions or from regulations from government. Both can create de-alignment and re-alignment and incremental development. Additionally, landscape pressure can induce dynamics in the regime. (Smith et al. 2010, 441.) Interaction with other related regimes can also create change in the regime (Raven & Verbong 2007).

There is a semi-coherent set of rules that is carried by different social groups in the regime level, forming socio-technical regimes. These regimes provide co-ordination and orientation to the activities of relevant actor group, and thus they affect the stability of socio-technical configurations. The stability is dynamic so that innovation occurs but it is incremental. (Geels 2002, 1260.) In addition, a regime can cause a structuring force to new ideas in niche level (Smith et al. 2010, 440), further ensuring only incremental changes would happen. However, external innovations are needed if more radical change is to happen in a regime. This is where the niche level steps in.

3.1.2 Niche

The niche level is the place of radical innovations (Geels 2011, 26). Niches are subsidized demonstration projects, research and development laboratories, or small market niches with special user needs and support for emerging innovations. Actors in niches include entrepreneurs, spinoffs of corporations, and start-up companies. They work on radical innovations that are different from incremental innovations in regimes, and they hope the innovations would break through to be used in the regime and even replace existing regimes. Niches provide seeds for systemic change and are thus important for transitions. (Geels 2011, 26-27.) In other words, transitions from a regime configuration to another are highly dependent on niches and their activities (Smith et al. 2010, 440).

The niche level provides safe spaces for radical alternatives that can be path-breaking. They might not survive in competition in the regime. (Kemp et al. 1998.) Niche-level innovations may face difficulties to break through. Breaking through is not easy because lock-ins stabilize the existing regime and radical innovations do not match with existing regime dimensions (see above) (Geels 2011, 27). Niche-level innovations are affected by infrastructure, regulation, user practices, and maintenance networks which are matching the existing technology (Geels 2002, 1258). Some niches may not survive long enough to expand or break through (Smith et al. 2010, 441).

There are three core processes related to niche development: learning and articulation processes on different dimensions (policies, business models, designs, demand and user preferences, infrastructure requirements, symbolic meanings), building of social networks and enrollment of more actors (resulting in expanded resource base), and articulation of visions or expectations that guide innovation activities and intend to gather attention and funding (Kemp et al. 1998; Schot & Geels 2008; cited by Geels 2011, 28). Thus, niches can gain traction if learning processes result in a stable configuration, if networks strengthen and become larger, and if expectations become widely accepted. (Geels 2011, 28.) Historically, niches that successfully made a breakthrough had to link up with bigger change processes, branch out, exceed the constraints of the regime and change the regime structures in the long run (Smith et al. 2010, 440-441).

3.1.3 Landscape

Both niche and regime levels are affected by an exogenous socio-technical landscape (Rip and Kemp 1998, Geels 2002). It is the most stable of the three levels when it comes to number of actors and degrees of alignment between the elements (Geels 2011, 26). Landscape involves processes that spread across societal functions and are independent of individual regimes (Smith et al. 2010, 441). Landscape consists of slowly changing demographic trends, societal values, macro-economic patterns, political ideologies, and technical and material backdrop that keep societies running. While this external context affects niche and regime levels, they can hardly have any influence back on it in the near term. (Geels 2011, 28.) Changes in landscape create pressure for change in regimes. Regimes need to react to the changes. The changes can reinforce current regime trajectories or they can create opportunities for niche innovations. For example, sustainability criteria are creating pressure to regimes that had never considered those issues before. (Smith et al. 2010, 441.) Correspondingly, certain regimes can influence the landscape developments similar to what has been seen to happen with communication and air travel regimes. (Smith et al. 2010, 440.)

3.2 Transitions in MLP

The MLP sees large-scale change as transition. Transitions are shifts from a regime to a different regime (Geels 2011, 26). The socio-technical transitions approach draws on Schumpeterian evolutionary economics with waves of creative destruction and radical innovation. It leans towards change processes and understanding those processes. (Geels 2019, 189.) There are no single causes or drivers for transitions in the multi-level perspective. Transitions result from multi-dimensional and multi-level processes that create circular causality by affecting each other. (Geels 2011, 28.) Regime dynamics, such as research and development activities in companies and regulation, may create windows of opportunities for niche innovations. Dynamics result in de-alignments and realignments, tensions and incremental responses. (Smith et al. 2010, 441.)

There is a tendency in existing systems and regimes that innovation is mostly path-dependent and incremental by nature, as there can be several lock-in mechanisms. Techno-economic lock-ins happen when there are sunk investments creating vested interests, or when existing technologies provide low cost and high performance as a result of years of incremental improvements. (Klitkou et al. 2015; cited by Geels 2019, 189.) Existing regulation, policy networks and standards can support incumbent actors over others (Walker 2000; cited by Geels 2019, 189), and vested interests reduce regulatory change and hamper radical innovation (Normann 2017; cited by Geel 2019, 189). These can result in institutional and political lock-ins. Cognitive and social lock-ins are involved when actors become blinded by their routines and shared mind-sets that they are unable to see developments happening outside their focus (Nelson 2008; cited by Geels 2019, 189), when life styles and user practices are committed to certain technologies, and when social groups have aligned to create social capital (Geels 2019, 189).

Geels and Schot (2010, 11-12) noted that transition is different from an incremental change process in a few aspects. Firstly, transitions require several changes in societal systems. Secondly, transitions are multi-actor processes, which entail interactions between societal groups such as businesses, users, scientific communities, policymakers, social movements, etc. Thirdly, transitions are radical shifts, meaning that the scope of change is vast and the speed does not need to be great. Fourthly, transitions are long-term processes lasting 40–50 years, although breakthroughs can be relatively fast and take for example 10 years. Lastly, transitions are ‘macroscopic’, as they affect a whole ‘organizational field’ (aggregation of consumers, suppliers, regulatory agencies, etc.). Incumbent actors often oppose transitions, because they are committed to current socio-technical systems (Geels 2014, cited by Geels 2019, 194). They are often oriented to maintaining status quo (Geels 2014, 26).

3.3 Transition pathways and scenarios

There have been efforts to create archetypes of transitions which are called transition pathways. These pathways elaborate the way technological innovations mature and develop as a result of different actors, and the way those innovations affect the regime in its large-scale shift towards a new regime. (Moradi & Vagnoni 2018, 235.).

Suarez and Oliva (2005) proposed a typology for environmental change in their article about how companies react to those changes in business environments. It consists of four dimensions: frequency (of disturbances), amplitude (of deviation from initial conditions), speed (of disturbance), and scope (as the number of affected environmental dimensions). Based on the dimensions, they further defined five types of environmental change: regular (all low), hyperturbulence (where frequency and speed are high), specific shock (amplitude and speed are high), disruptive (amplitude is high), and avalanche (amplitude, speed, and scope are high). By making use of these types of environmental change, among other sources of inspiration, Geels and Schot (2007) formed transition pathways for MLP.

Transition pathways (Geels & Schot 2007) can be distinguished by two criteria: nature of interaction and timing of interactions. Landscape developments and niche-innovations can have reinforcing or disruptive interaction with regime. Landscape developments that reinforce the regime stabilize it further and cause no pressure for transition. Correspondingly, disruptive landscape developments create driving force to the regime to change. Niche-innovations interact with regime in a different way. They can have a competitive or symbiotic relationship, either with the aim to replace the regime or by offering add-ons that enhance competence and performance and solve problems in the regime. (Geels and Schot 2007, 406.)

Furthermore, multi-level interactions can happen with different timings and thus have different outcomes. Landscape pressure on regimes and the state of niche-developments are two important factors. The transition path will be different depending on if niche-innovations are fully or not fully developed at a time when landscape pressure occurs. However, there can be diverging perceptions on the development stage of niche-innovations among niche actors and regime-actors. There are a few indicators of a niche-innovation and whether it's fully developed. These indicators are related to existence and composition of support networks, learning processes, price or performance improvements, and market share of the niche-innovation. (Geels and Schot 2007, 405.)

Combinations of these interactions, their timings and their nature result in the following pathways and possible sequences of the pathways. Geels and Schot (2007) described six different pathways for a transition. The four main pathways are compared in table 1. All six pathways are described next.

Table 1. Taxonomy of the four main transition pathways and the main actors (adopted from Elzen & Hofman 2007, which is based on Geels and Schot [2007]).

Transition pathways	Main actors	Type of interaction	Characterization
1. Transformation	Regime actors and outside groups (social movements)	Regime outsiders voice criticism. Incumbent regime actors adjust goals, guiding principles, search heuristics.	Outside pressure, institutional power struggles, negotiations, adjustment
2. Technological substitution	Incumbent firms versus new firms	Newcomers develop novelties, which compete with technologies from regime actors	Market competition
3. Reconfiguration	Regime actors and suppliers	Regime actors adopt component-innovations, developed by new suppliers. Competition between old and new suppliers	Cumulative component changes and new combinations
4. De-alignment and re-alignment	New niche actors	Incumbents lose faith and legitimacy. Emergence of many new actors, who compete for resources, attention and legitimacy	Erosion, collapse, co-existence of multiple novelties, prolonged uncertainty, competition restabilization

3.3.1 Reproduction

Reproduction process is considered as a regular change (regular as in Suarez and Oliva 2005) within the regime in a time where there is no external pressure from landscape level. The regime is stable, although there can be internal issues and developments. Nevertheless, the process proceeds in a predictable trajectory. (Geels and Schot 2007, 406.) This can be seen as a business-as-usual case, where things move forward with their own pace within the current regime. In the quest for inspiring and thought-provoking scenarios, this pathway is not the obvious choice.

3.3.2 Transformation

Landscape can put moderate, disruptive pressure (disruptive as in Suarez and Oliva 2005) in a time where there are no sufficiently developed niche-innovations. Actors in the regime perceive the pressure and shall respond to it by altering the development paths and innovations. This is called a transformation path. Regime outsiders such as social movements, scientists and companies can help the regime actors perceive the pressure from the landscape by respectively initiating protests, criticizing incumbent solutions and developing alternative solutions. Cumulative adjustments and re-orientations result in new regimes growing out of old regimes. Some changes may happen in social networks, but generally regime actors survive. (Geels and Schot 2007, 406-407.)

3.3.3 De-alignment and re-alignment

Another pathway is called a de-alignment and re-alignment path. There can be a large, divergent and sudden change (avalanche as in Suarez and Oliva 2015) that results in lose of faith within regime actors, and a de-alignment occurs in the regime. Incumbent actors are not investing in research and development anymore. There is no clear substitute as niche-innovations are not ready yet. This opens up a window for multiple niche-innovations that start competing for resources and attention of the regime. A re-alignment unfolds when one innovation claims dominance over others. (Geels and Schot 2007, 408.)

3.3.4 Technological substitution

A technological substitution happens where there is much pressure from landscape, either a specific shock, avalanche or disruptive change (as in Suarez and Oliva 2015) at a time when niche-innovations have become sufficiently developed so that they are ready to enter the regime. The niche-innovations haven’t been able to break through because of the stability of the existing regime. The regime has been relying on incremental innovations, effectively playing a reproduction process. Enabled by landscape pressure, niche-innovations with internal momentum break through to the regime. Regime actors invest in improvements as a way to defend themselves. Competition can lead to niche-innovations replacing old technology. This will further create wider changes in the regime that may lead to the downfall of incumbent actors, eventually creating a new regime. (Geels and Schot 2007, 409-410.)

3.3.5 Reconfiguration

In a reconfiguration pathway, innovations are developed in niches. Some of these innovations can be complementary and they are then adopted in the regime for specific situations as add-ons or replacements. Main motivations for these adoptions are economic as new innovations help solve small problems or increase performance. Furthermore, if the basic architecture of the regime is changed as an outcome, these adoptions result in subsequent changes in the regime. New combinations are explored widely. A new regime is formed from the old regime, based on the new basic architecture. This is relevant for distributed systems that rely on multiple technologies and their interactions. In these systems, transitions can be caused by sequences of many innovations. (Geels and Schot 2007, 411.)

3.3.6 A sequence of pathways

Transition pathways can also occur as a sequence of multiple pathways if disruptive change (as in Suarez and Oliva 2005) is induced by landscape pressure. The pressure causes a slow but disruptive change that is at first perceived as moderate. Disruptive change gradually increases. A sequence can begin as a transformation, turn into a reconfiguration pathway and end up in a technological substitution or in a de-alignment and de-alignment. (Geels and Schot 2007, 413.) A sequence of pathways may be difficult to identify or anticipate.

3.4 MLP for sustainability transitions

There are three characteristics of transitions towards sustainability that distinguish them from many historical transitions. The first characteristic is that sustainability transitions have a goal or a purpose, making them goal-oriented (Smith et al. 2005, in Geels 2011, 25), as they aim to address persistent environmental problems. Historical transitions have been more emergent rather than goal-oriented. The second characteristic is that there tends to be little user benefits from sustainable solutions. Existing systems are unlikely to be replaced by sustainable solutions without changes taking place in policies, taxation, subsidies and other regulation. These changes may face opposition as there can be efforts to secure vested interests. The third characteristic involves complementary assets that the large companies possess. These assets, such as capabilities, channels, experience, and networks, give an edge over newcomers. The incumbent actors can use their complementary assets to suppress or support innovations. (Geels 2011, 25.)

Sustainability transitions could benefit from governance activities and political deliberations to accelerate some green niches and to restructure systems. MLP is a framework that enables researchers to do organized analysis and design ordered policy interventions (Smith et al., 2010, 440). MLP provides an easy way to simplify and arrange analyzing complex and vast transformation that are needed in sustainable development (Smith et al. 2010, 441).

There are a multitude of studies using MLP in contemporary and future sustainability transitions with focus areas in heating (Lauttamäki 2018; Lauttamäki & Hyysalo 2019; Nilsson et al. 2020) and energy (Geels et al. 2018; Heiskanen et al. 2018).

3.5 Criticism and issues

Despite of or because of its allure, the multi-level perspective has not gone without some critical views. Smith et al. (2010) elaborate on challenges that some other authors have identified, including their own thought: relations between niche, regime and landscape levels; plural regimes and niches in interaction; the geography of transitions; empirical operationalization; and governing sustainability transitions. In addition, they identified future research topics on MLP: niche dynamics; unlocking regimes; the spatial aspects of transitions; methodology to map transitions; the politics of transitions; opening the black-box of public policy; and an open agenda. Geels (2011) further elaborates on seven criticisms: lack of agency; operationalization and specification of regimes; bias towards bottom-up change models; heuristics, epistemology and explanatory style; methodology; socio-technical landscape as residual category; and flat ontologies versus hierarchical levels. Furthermore, Geels (2019) discusses with introduced criticism from several authors: politics and power; cultural discourse and framing struggles; grassroots innovation; multiple transition pathways; incumbent firm resistance and reorientation; destabilization and decline; and policy analysis. Clearly, there are plenty of criticism to and elaborations on the multi-level perspective. Next, a few of these criticisms are discussed.

In relation to their complementary systems, Røpke (2016) justfiably criticizes the MLP for not addressing distribution systems and socio-ecological systems, as the MLP focuses on socio-technical aspects. Extra care is needed to consider one crucial part of sustainability. To address this shortcoming, sustainability levels of the created scenarios are evaluated.

Smith et al. (2010) warn about simplifying complex issues with MLP. While MLP allows researchers to simplify complex issues and communicate those, it is important not to simplify too much. This thesis seeks for a balanced approach where the system can be easily understood without simplifying it too much. This is done by paying attention to regime dimensions when interviewing and when analyzing the data.

Lack of agency has been attached to MLP as Geels (2011) concludes. Smith et al. (2005) define agency in the transformation of MLP regimes as the ability to ‘intervene and alter the balance of selection pressures or adaptive capacity' (ibid. 1503). Actors are dependent on other actors as no single actor has enough resources to respond to selection pressures in the regime. Smith et al. (2005, 1492) criticize that MLP is too structural and descriptive that it leaves room for analysis of agency. While Geels (2011) admits that certain types of agency are less present in MLP, he points out that actors enact the trajectories and multi-level alignments. Additionally, Geels and Schot (2007) make efforts to summarize the actors and their actions in different transition pathways. Agency is certainly a part of MLP though it is rather easy to not give it enough weight. This thesis accounts for agency through promoting actions of companies and their executives.

Geels (2018), in a paper comparing the MLP to disruptive innovation theory, points out a few issues that should be addressed in MLP-related research. First, Geels points out that analytical attention should be broadened "from singular niche-innovations to 'whole system' change" (ibid, 230). Multiple niche-innovations and how they relate to ongoing dynamics should be included in broader research designs. Second, Geels asks for better understanding of regime developments as there can be not only barriers to low-carbon transitions such as resistance, delays or derailing from incumbent actors, but also accelerated efforts as strategies of incumbent actors are aligned and reoriented. The author calls for more nuanced assessment and conceptualization of these dynamics. Third, broad analyses of socio-technical systems are the core of MLP. While focusing on particular dimensions can be fruitful, the unit of analysis should be the system itself and not one of its dimensions. This thesis considers multiple niche-innovations and the whole system, pays attention also to positive realignments, and while focusing on technology, takes into account the whole system and neighboring regimes.

4 COMBINING FUTURES STUDIES, TRANSITION STUDIES AND MLP

This thesis is situated within the fields of futures studies and transition studies. The multi-level perspective and futures studies are used together in the thesis. First, a brief description on futures studies is shared. Furthermore, the key tools of futures studies used in this thesis are described. Then, these three aspects are combined to form the theoretical basis for the thesis. Finally, the connections between transition studies, multi-level perspective and futures studies are summarized.

4.1 Futures studies

Future is something that has not yet happened and does not exist. There is history, something that has happened. The present is currently happening. Futures studies is about making sense of the future, by studying history, the present and the future. It is an examination of change in life, done in a multi-disciplinary way, to identify dynamics that are forming the future (Glenn 2009a, 4). It is also about taking responsibility over our actions and decisions in the present as they may have long-term consequences (see Gidley 2017a). Futures studies is a way of thinking about the world and society, a way to conceptualize our everyday actions. With futures studies, we can learn to make decisions while looking into the future. (Masini 1993, 3.). Generally speaking, futures studies aims to 'maintain or improve the freedom and welfare of humankind – – [and] welfare of all living beings' (Bell 1997, 73).

Wendell Bell (1997) describes nine tasks of futures studies. This thesis involves the first eight of those. The tasks of futures studies are

- the study of possible futures,
- the study of probable futures,
- the study of images of the future,
- the study of the ethical foundations of futures studies,
- interpreting the past and orientating the present,
- integrating knowledge and values for designing social action,
- increasing democratic participation in imaging and designing the future,
- communicating and advocating a particular image of the future,
- and the study of the knowledge foundations of futures studies.

The rate of change has an effect on how far into the future one should explore. The faster changes are taking place, the further into the future one should dive. (Glenn 2009a.) Societal change takes time and thus it is a good practice to look ahead for five to thirty years, sometimes even further. There are contemporary acronyms that describe the world and, in some sense, take a stance to the rate of change. The best known is VUCA which stands for Volatility, Uncertainty, Complexity and Ambiguity. It is best for grasping present phenomena and relating them to a context. BANI is more focused on the future world and its effects. It stands for Brittle, Anxious, Non-linear and Incomprehensible. In addition to these two acronyms, there are also RUPT (Rapid, Unpredictable, Paradoxical, Tangled), TUNA (Turbulent, Uncertain, Novel, Ambiguous) and a positive VUCA (Vision, Understanding, Clarity, Adaptability). (VUCA-World 2023.) These can all be used to decide how far into the future one should explore.

In the early days of future studies, positivist approach to the future aimed at extrapolating future from history to predict the future (Gidley 2017b, 26). Nowadays there is a consensus that the future cannot be predicted. In addition, there is one profound aspect of futures studies. The idea is that there is no single future but multiple futures (see Masini 1993; Voros 2017). Some of the possible futures are preferable and some are unwanted. Some are more probable than others. Some futures may seem even preposterous. This has been illustrated by Joseph Voros in his futures cone (see figure 2).

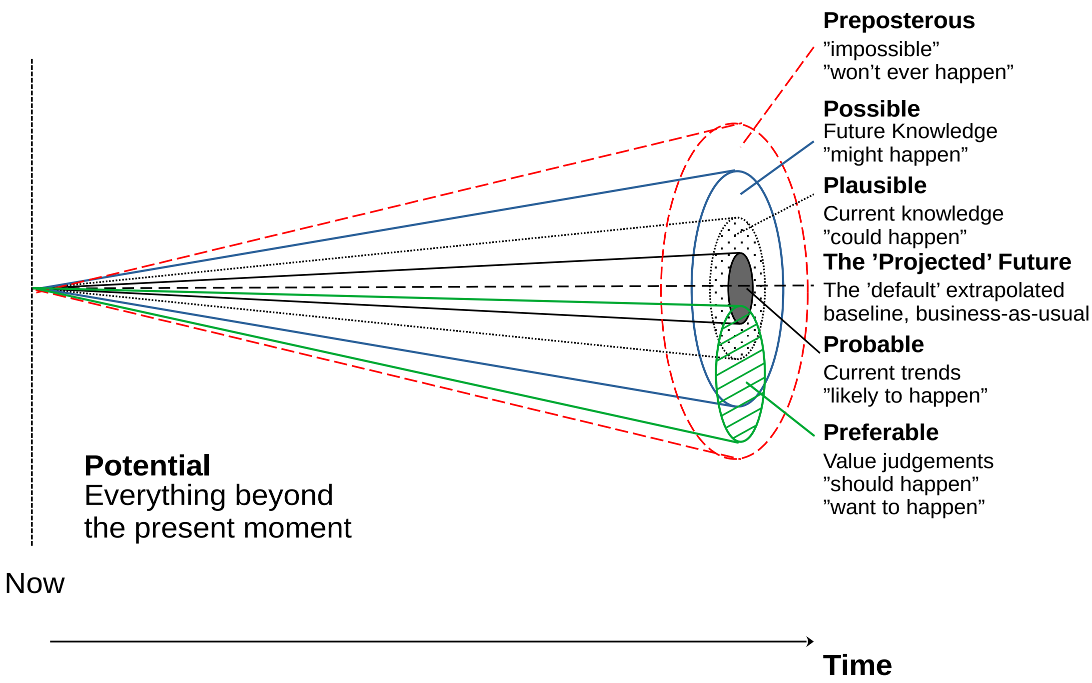

Figure 2: Futures cone illustrating types of futures (adapted Fig. 4 from Voros 2017).

Several authors have made efforts to describe laws and principles of futures studies. Eleonora Masini (1993) wrote about three principles. The first one is that there is a constant dilemma between knowledge, of wanting to know about futures, and fears and desires about the future, as they may contradict with knowledge. Secondly, people can have an impact only on the future, as history is already behind us and we are currently living the present. Thirdly, there are multiple futures instead of a single future, as was stated earlier. Furthermore, Jim Dator (Dator 2019b) framed his understanding of futures studies into three laws. The first law is that one cannot predict the future because it does not exist. The second law is that ‘any useful idea about the futures should appear to be ridiculous’ (ibid, 2). The third is about tools, both how we shape our tools and how our tools shape us. This thesis does its best to comply with these laws and principles.

There are several ways, methods and tools that can be used in futures studies, to study the future. The Millennium Project (Glenn et al. 2009) has gathered and described a vast number of methods and tools of futures studies. These include environmental scanning, wild cards, statistical modeling, morphological analysis, scenarios, participatory methods, roadmapping, causal layered analysis, to name a few. Scenarios were chosen for this thesis as they are tools to communicate alternative futures and developments. Futures table was chosen as a way to analyze the data and to help form relevant scenarios. Next, these will be introduced.

4.2 Scenarios and futures table

Scenarios are one of the most used ways to outline and analyze alternative futures and developments (Popper 2008, 69). The word ‘scenario’ can have two meanings. First, one can describe conditions of key variables at some point of time as a snapshot. (Glenn 2009, 4.) Second, one can create a history of the future where the present evolves into a future state (Glenn 2009, 4, Elzen & Hofman 2007, 2). Thus, a scenario connects the present with a future state by telling a story with plausible cause and effect links (Glenn 2009, 2). It is a description of what could happen and what would need to happen so that a future state becomes possible.

Scenarios can be used for a multitude of purposes. They can help make better decisions by showing what should be known that is currently unknown. They describe what may be possible or impossible. Significance of uncertainties can be understood with scenarios. Strategic planning can benefit from scenarios by identifying which strategies work in certain scenarios and which elements are robust and contingent. Scenarios help force decision makers to think in new ways by making the future more real for them. Scenarios can also be used to learn about future risks and opportunities. (Glenn 2009, 4.)

There are many criteria for a good scenario, and usually it depends on the use case. Jerome Glenn defines ‘good’ scenarios to be plausible, internally consistent, and sufficiently interesting and exciting (Glenn 2009, 3). Specifically, Elzen and Hofman lay out some characteristics of a good transition scenario, related to their socio-technical scenario approach. A scenario describing a transition should illustrate socio-technical development and continuous development. It should avoid being a linear diffusion story. (Elzen & Hofman 2007, 2.) A scenario description should be long enough to have room for developments, mechanisms, technologies, and, especially in socio-technical scenarios, interactions between regimes (Elzen & Hofman 2007, 11–12). Argumenting for their socio-technical scenarios, Hofman & Elzen (2010) point out that scenarios can help understand the set of rules under which technologies move forward and interact with each other and user preferences, further creating alternative practices (ibid. 667).

Scenarios can be created with multiple different methods and processes, both qualitative and quantitative. Some processes and methods are simplistic whereas others can be complex. (Glenn 2009, 5.) Preferred futures can be backcasted to present day to create clear action plans (see Robinson 1990). Key forces, trends, and uncertainties can be analyzed and then used to create scenarios that address those uncertainties. Main uncertainties can be gathered into a 2x2 matrix which will then produce four scenarios. This method has been made popular by Peter Schwartz of Global Business Network (2007). Software tools can be used to set variables, values and create scenarios (Glenn 2009, 6–7). Elzen and Hofman (2007) have developed a socio-technical scenario approach, where MLP-related scenarios are built through a process. Participatory methods can be used separately and they can be incorporated with the aforementioned methods. Morphological analysis is also a method that can be used to develop scenarios (Ritchey 2009, 2). This thesis uses a simple form of morphological analysis known as a futures table approach to structure future-related information and to produce scenarios.

A futures table is a helpful tool to create different scenarios and images of the future based on different variables and their alternative states. Futures table has its roots in Field Anomaly Relaxation (see Coyle 2009) and morphological analysis (see Ritchey 2009; Seppälä 2018). The key task in building a futures table is to identify the key variables. The key variables are the variables that are of most interest to a given context. States are given for each variable through a workshop or through data analysis. Values or states for each variable should be different from each other. There should be enough variation so that different scenarios can be produced. (Seppälä 2018.)

Scenarios can be created from a futures table in many different ways. One can roll a dice for each variable at a time, and select the state that corresponds the value on the dice. While this may create radically diverse scenarios, they may not be relevant, which is a criterion for a good scenario. Jim Dator describes four archetypes for scenarios (Dator 2019). These can be populated by selecting suitable variable states for each archetype. In a similar manner, transition pathways of the multi-level perspective can be used. Seppälä (2018) describes a few ways to create images of the future from a futures table. Future states can be selected from each variable so that it represents the image of the future that is desired. A variable can be selected as dominating, and the rest of the variables and their selected states will follow. It is also possible to do it in a more systematic way using a dissimilarity index, but I won’t cover it here. (Seppälä 2018, 144-149.)

The futures table method tends to produce static representations of alternative future states rather than dynamic transition scenarios. The socio-technical scenario approach by Elzen and Hofman (2007) introduces ways that can be utilized to tackle similar issues. Their method promotes creation of linkages called ‘transition elements’. They are elements in the three levels of the multi-level perspective that could create novelties through links that they form. The elements can be related to technical, production, financial and societal dimensions, to name a few. (ibid., 10.) Paying attention to dynamic transition elements and identifying transition-related topics from the materials can help prevent static representations and promote dynamic transition scenarios.

In this thesis, scenarios are created from the futures table by selecting dominant technologies for each scenario. In addition, transition pathways are used to guide the selection of variable states for each scenario.

4.3 Putting it all together

The thesis is positioned in futures studies and transition studies, so concepts from both fields are used. Futures table and scenarios are tools from futures studies. From transition studies, multi-level perspective and the related transition pathways are used. Multi-level perspective acts as an over-arching framework for the thesis. Multi-level perspective has traditionally been applied to mapping historical developments (see Geels 2002) but it has gained popularity in mapping future developments as described in Introduction. Hofman and Elzen (2010) explored future developments of energy system by creating socio-technical scenarios based on MLP and transition pathways. Vähäkari et al. (2020, 7) also suggest combining MLP with scenarios. In the thesis, scenarios represent alternative development paths and possible futures.

In addition to mapping future transitions with MLP, the thesis combines MLP and futures studies concepts (see Vähäkari et al. 2020): landscape level and megatrends; regime level and trends; and niche level and weak signals, wild cards and specific shocks (see table 2). These layers and concepts are used to both structure and analyze the interview data.

Table 2. Relations of futures studies and the multi-level perspective (adopted from Vähäkari et al. 2020).

Futures studies	Multi-level perspective
Megatrends	Landscape
Trends	Regime
Weak signals, wild cards, specific shocks	Niche

5 SETTING THE SCENE: DISTRICT HEATING IN FINLAND

District heating is a heat production and delivery system for cities, neighborhoods or groups of buildings. Heat is produced in designated production plants. Produced heat is delivered as heated water through a network of heat pipes to end customers. (Mäkelä & Tuunanen 2015, 11.)

District heating has its roots in the industrialization era. The first district heating system was built in New York, United States of America, in 1877. It used steam to deliver energy. Later, the first water-based district heating system was built in Dresden, Germany. In Finland, the current form of district heating made its first entry in 1940. (Mäkelä & Tuunanen 2015, 12.) District heating made its final breakthrough in the following decades during the post-war reconstruction, in which Finland saw the rise of densely built neighborhoods.

Currently, district heating is the most common form of heating in Finland. In 2020, district heating covered 41 percent of total heat consumption in Finland. More than half of it was produced in combined heat and power (CHP) production. (Hyppänen 2022.) In 2022, 51 percent of households were heated by district heating (Statistics Finland 2022a). Customers are housing associations, property companies and individual house-owners. Heat is produced in local networks, relatively close the end customer, opposite of electricity production which can take place hundreds or thousands of kilometers away from the end user.

In 2021, district heating was available in 177 municipalities in Finland. The main energy source in municipalities was biomass or other carbon-neutral energy source (see table 3). District heating network had continued its steady flow of expansion, now covering a total distance of 16 090 kilometres. There were 106 power plants with capacities of 9 100 MW of heat and 5 600 MW of electricity in total. 835 heating stations and 25 heat pump stations had a capacity of 14 100 MW in total. In addition, there were 275 mobile heating stations with a capacity of 1 000 MW. The total amount of produced district heating was 39 100 GWh, of which 33 700 GWh was produced from fuel sources. Heat pumps and heat recovery from waste heat accounted for the remaining 5 400 GWh. The amount of electricity produced with CHP was 9 900 GWh. (Finnish Energy 2022.)

A variety of energy companies are involved with district heating. In 2021, there were at least 108 companies that sell district heating to end customers and 77 companies that sell heat to these district heating companies in Finland (Finnish Energy 2022). Many of the 77 heat producers are usually pulp and paper companies and sawmills in the vicinity of district heating networks. Companies that sell district heating come in many sizes. Most of district heating companies are publicly owned. A municipality owns an energy company which takes care of providing district heating within the area of the municipality. There are a few publicly listed companies, too. One of the biggest energy companies in district heating is Helen Oy, owned by the city of Helsinki. Helen

Oy had a yearly revenue of 1.8 billion euro and assets worth of 3.8 billion euro in 2022. District heating accounted for 31 percent of the revenue. (Helen Oy 2023.) Nurmeksen lämpö Oy is an example of a small district heating company. It provides district heating in two towns and is owned by the municipality of Nurmes and an regional energy company (Nurmeksen Lämpö Oy 2023a). The revenue was four million euro with assets of 6.8 million euro in 2022 (Nurmeksen Lämpö Oy, 2023b). It is clear that both the needs and the capabilities for innovation and investments are different between these two companies and among district heating companies in general. The operating environments are also different, considering logistics, networks, available fuel sources, and political ambitions.

Table 3: Main sources of energy for district heating in Finnish municipalities. (Finnish Energy 2022; Statistics Finland 2022b)

Main source of energy	**Count of municipalities**	**Share of main source of energy used in district heating (percentage, year 2021)**
Biomass and other carbon-neutral energy sources	152	47.1[2]
Peat	17	9.5
Natural gas	3	10.7
Coal	0	12.0
Oil	0	3.0
Other or not available	5	17.6[3]

District heating is characterized by its seasonal fluctuation in demand. The demand in winter months can be more than five times the demand in summer months. Different means of production are needed depending on the season. (Finnish Energy 2023.) Years are different from each other, which means that there is different demand for and thus different production of heat every year as can be seen in Figure 3. The figure also illustrates the increase in production over the years. It is noteworthy that while production has increased, the use of fossil fuels has decreased.

[2] Renewable fuels total.
[3] Other fossil fuels and other energy.

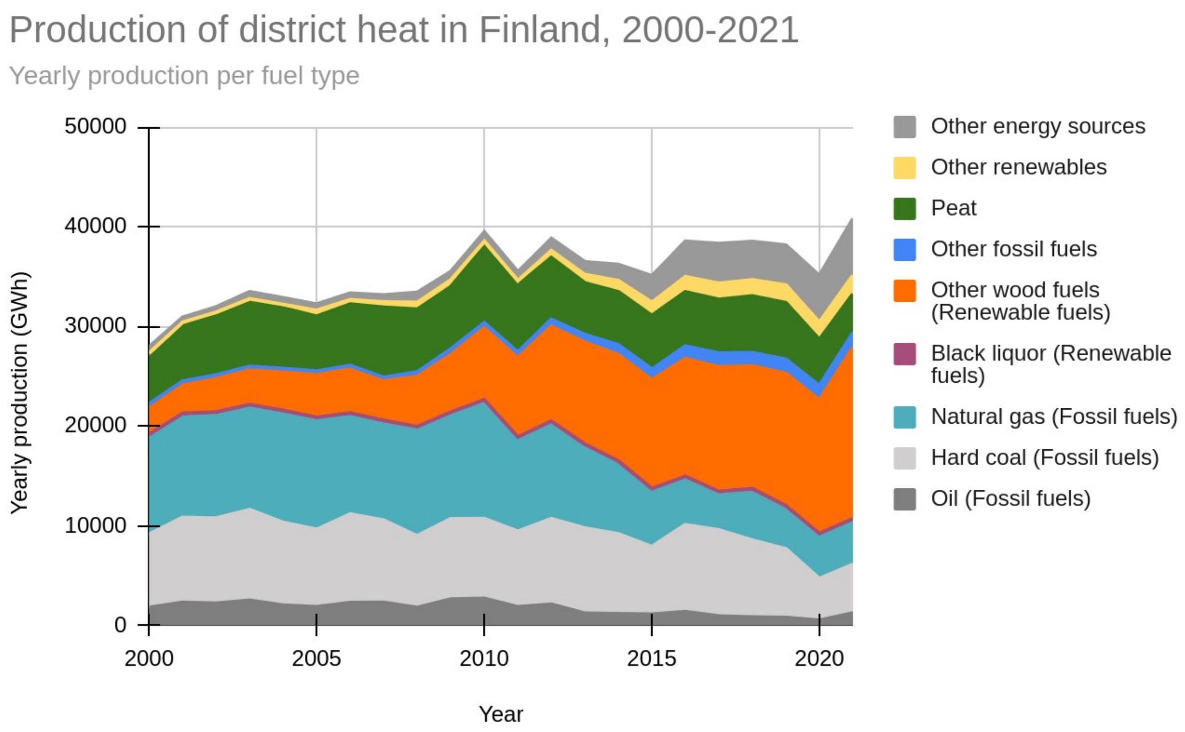

Figure 3: Production of district heating per fuel type in Finland, 2000-2021 (Statistics Finland 2022b).

The Finnish district heating industry has already gone through a significant transition on energy sources in the past years. In 2010, fossil fuels like coal and natural gas were the main source for energy for district heating, covering 58 percent of total heat production. However, the share had dropped down to half at 29 percent in 2021. Similar development can be seen in the use of peat with 19 percent share in 2010, and around 10 percent in 2021. The total yearly amount of energy used in district heating has not dropped but rather increased slightly during that time (from 39.5 TWh to 40.8 TWh). Biomass use has increased from 20 percent up to 47 %, covering for most of the changes in fossil fuels. (Statistics Finland 2022b.) Figure 4 shows the relative shares of each fuel of yearly district heat production in Finland from 2000 to 2021.

As the fuels and energy sources have changes, the emissions of district heating have changed, too. In 2022, the total carbon emissions from district heating were 3.7 million tonnes. This is significantly less than 6.7 million tonnes in 2011. (Finnish Energy 2023.) This is mostly due to the decline in the use of fossil fuels and incline in renewable fuels such as forest biomass. However, this has not happened without criticism (see Majava et al. 2022; Vadén et al. 2019).

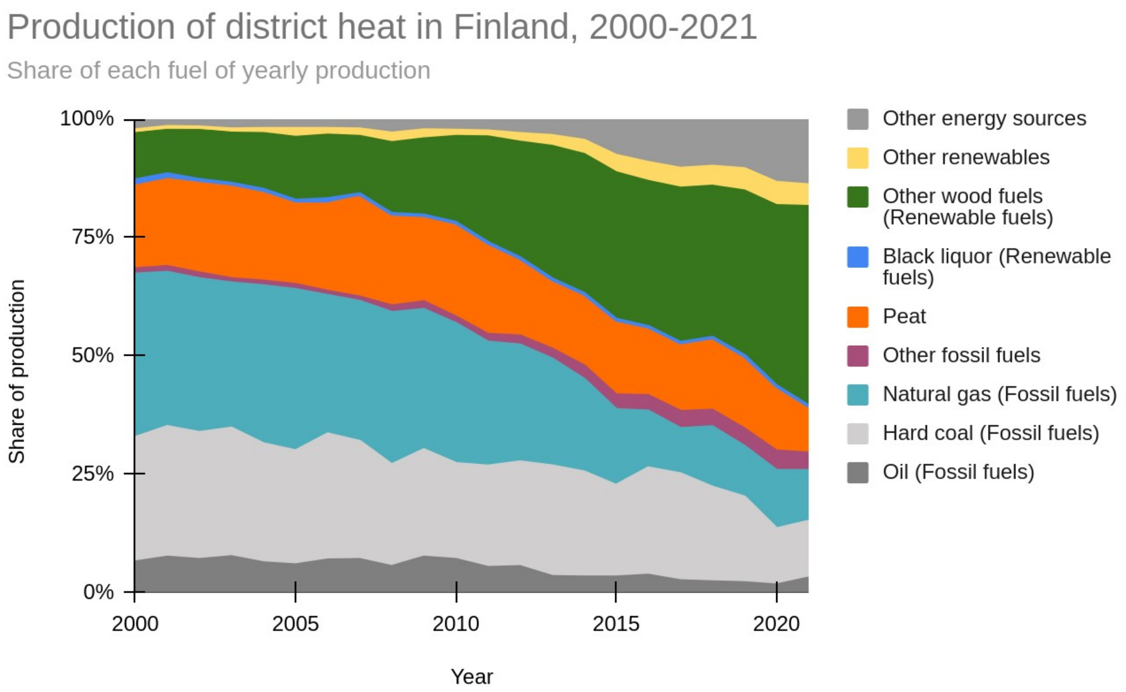

Figure 4: Production of district heat in Finland, 2000-2021, share of each fuel of yearly production (Statistics Finland 2022b).

There have been fuel price related developments, too. In 2017, the carbon emission allowance was priced at around 5 euros per tonne of CO_2. Five years later in 2022, the price was already around 80 euros per tonne. (Sandbag 2023.) This has resulted in peat price going from 17 €/MWh to 50 €/MWh during the same time period, while changes in taxation account for a small share of the increase, too. As a result, forest chips has become the cheaper option, with a price tag of 26 €/MWh. (Finnish Energy 2023.) Coal prices have changed from 100 USD/tonne in 2010 to 400 USD/tonne in 2022 (author’s note: this happened after the interviews), and the recent prices are at 150 USD/tonne (May 2023) (Trading Economics 2023). Other fossil fuels have seen similar price developments.

District heating operates within its own regime but also tightly involved in energy regime. The same fuels are used in both, and CHP production yields electricity. Hyytinen and Toivonen (2015) identified eight main trends in the development of sustainable energy and energy related services:

- Increasing use of renewable energy sources,
- increasing use of hybrid solutions,
- development of smart grids,
- development of smart energy markets,
- distributed and local production of energy,
- demand response,
- optimization for overall sustainability, and

- energy is increasingly seen as an opportunity and as service.

Many of these may impact district heating or appear within district heating, too, as a result of the tight connection with energy regime. As shown above, use of renewable energy sources has increased.

Furthermore, Paiho & Saastamoinen (2018) identified five business challenges in Finnish district heating by interviewing industry experts. The challenges were competitiveness, opening of networks, pricing, subsidies and fiscal policy. The interviewees in this thesis got the opportunity to reflect these issues and their relevance for the future of district heating.

The Finnish district heating could be described as going through a de-alignment and re-alignment pathway, a technological substitution pathway and a reconfiguration pathway at the same time. Costs have increased, landscape puts pressure on net-zero targets, alternatives for coal and other fossil fuels are not completely sufficient and ready for large-scale production use, and there are multiple niche-innovations ready to take their place in the regime. Some incumbent actors are affected more by coal ban than others. Some have already achieved or are about to achieve net-zero as their fuel sources are fully based on locally available biomass.

Finnish Energy, a branch organization for the industrial and labor market policy of the energy sector, has created a low-carbon roadmap which aligns the energy sector with Finland’s commitment of achieving carbon neutrality by 2035 (Finnish Energy 2020). The roadmap introduces two scenarios, a baseline scenario and a low-carbon scenario. The roadmap claims that district heating and combined heat and power production will play a major role in a low carbon future. Moderate emphasis is put on CHP production, which seems to be one of the key assets in a low carbon future. Biomass is said to dominate the fuel mix in both scenarios. Heat pumps and geothermal heat are mentioned, too, as playing a large role, though there are expressed uncertainties around geothermal heat. SMR and concentrated solar power (CSP) are seen as possible and likely technologies in the future.

This thesis presents possible future sustainability transitions for Finnish district heating.

6 EMPIRICAL RESEARCH

6.1 Introduction

The research objectives include describing possible futures and future developments of Finnish district heating. Interview questions are used to gather information about experts' views on possible futures and transitions. Another objective is to bring light to possible future solutions for district heating. Thoughts, ideas and opinions on these technical and non-technical solutions are gathered in the interviews.

There are a plenty of strategy papers, roadmaps, policy papers, reports and other written materials about energy sector. However, not much interview data from expert interviews is available for analysis. In addition, the materials tend to focus on international or global level. On the other hand, not all expert knowledge can be found in written materials. Written materials are usually also products of group work where views of individuals get diluted into consensus and corporate opinions. Therefore, this study conducts expert interviews to gain up-to-date insight of the status, futures and sustainability transitions of Finnish district heating.

In the following subchapters, research design and data collection are described. Secondly, data analysis methods and process are depicted. Lastly, limitations and ethical aspects are discussed.

6.2 Data collection

In addition to the literature review in chapter 5, empirical material was gathered. Furthermore, semi-structured interviews were conducted. Eight (8) experts from the field of heat and power were interviewed. Interviewees had expertise in business, policy, research and technology, with a focus or background on niche and regime level. Nevertheless, it was assumed that the interviewees have a decent understanding and foresight of landscape level, too. Interviewees were as follows:

- three mid- or top-level managers from district heating and energy companies,
- one researcher, and
- four experts from interest or industry groups.

Semi-structured or thematic interviews were selected for a few reasons. They enable collection of arguments to back up views (Nathan et al. 2018, 3). Semi-structured interviews are suited for gathering data about a particular topic, generating data to enable theory development, encouraging people to share their own perspectives, and gaining insights into people's lifeworlds (Cassell 2015 in Saunders & Lewis 2018, 158). In this case, the particular topic is district heating and its futures.

Interview questions were based on concepts and levels of MLP and concepts of futures studies. Certain concepts of MLP, such as landscape level, were briefly described to interviewees to ensure data comparison and reliability. Literature review was used as a source of inspiration for the interview questions. Some questions were inspired by relevant academic papers. The interview outline with questions and their possible source of inspiration can be found in Appendix 1.

Interviews were conducted using teleconference software Zoom. The interviews were recorded using the built-in recording feature of the software. A permission for recording was asked from each interviewee with a consent form. The invitation and the consent form were sent via email in advance.

6.3 Data analysis

Interview data was transcribed, coded and analyzed using R, Rstudio and an additional library called RQDA. Unit of data for codes varied from a single phrase or term to a paragraph. Data was analyzed using thematic analysis. A combination of MLP and futures studies concepts were used as lenses to help the analysis. Thus, topics and issues were inductively identified for each MLP level and concept from the data, and futures studies and MLP concepts were deductively identified in the data. Landscape, regime, and niche levels were used as code categories. Additionally, the six regime dimensions were used as code categories, too. Transition was used as another category to provide a way to structure all dynamics and transition related codes.

A futures table was created and filled out based on MLP levels, MLP regime-level aspects, futures studies concepts (megatrends, trends, etc.) and other identified topic areas such as different technologies. Gaps were filled out with the author's intuition and ideas from academic sources. Additionally, the author had discussions on the topic with ChatGPT, a chatbot powered by a powerful artificial intelligence. The ideas from those discussions were also filled into the futures table. In addition, the data was analyzed to see if there were similar transition pathways as has been described in literature (see Geels & Schot 2007; Smith et al. 2010). Scenarios were built by interpreting the research data, identifying certain transition pathways and selecting suitable variable values for each scenario. The scenarios are aimed to "stretch mental maps and increase awareness and acceptance of 'radical' alternatives" and to "inform policy-making and business strategy" as stated in Elzen & Hofman (2007, 9).

6.4 Limitations and ethical considerations

The most obvious limitation of this methodology is that interviews do not provide all inclusive data on the topic. In the interviews, the available time is limited. All interviewees had dedicated one hour for the interview as requested in the invitation. However, not everything can be said or discussed during the interview. Another limitation is that the number of interviewees was below ten. It is desirable to have more interviewees but due to time-related and personal issues, the number remained below ten. The author does not have any doubts whether the interviewees were being honest and sharing trustworthy information. Validity of some of their claims was confirmed through literature review and related statistical data. The results are not objective as they are the result of interviews, literature sources, and the author’s knowledge.

7 RESULTS

The results are divided into four categories. First, interview results are described and a few excerpts are presented. Second, a multi-level perspective diagram is delivered to further communicate the findings from interviews. Third, an edited futures table with the used values is shared. Fourth, the scenarios are described one by one.

7.1 Interviews

In total, eight interviews were conducted. The interviewees were top and mid-level management of district heating and energy companies, industry experts, researchers and energy experts from stakeholders as stated in chapter 6. The interviews took place between December 2021 and early March 2022, most of them being before Russia initiated war on Ukraine on February 24th 2022.

Data analysis resulted in 129 codes in 10 code categories. Codes included different technologies such as Boiler, EnergyStorage, Hydrogen, SolarEnergy; different energy sources such as Peat, Gas, WasteHeat, BiomassBioenergy; different culture, industry and market related issues such as IndividualFreedom, CompanyOwnership, FreeMarkets; and megatrends and landscape level phenomena such as Security, Urbanization, and EnergyEfficiencyDirective.

Next, some selected highlights from the interviews are presented. Each topic is either its own code or a code category. Missing words have been added by the author, marked within [] characters. Freeform translations to English have been made by the author. Original Finnish excerpts can be found in Appendix 3.

7.1.1 Change and sustainability transition

The process where new technologies are discovered and taken into use takes time. A general opinion among interviewees was that new and unknown technologies are unlikely to emerge within the next twenty to thirty years. Therefore, no radical, new and currently unknown technologies were included in the futures table. Interviewee A put it like this:

A: "If the target is in the next 30 years, perhaps I'm starting to feel old and cynical, that they would achieve market scalability and be effective within the time period, what we don't know and is not within the radar, I highly doubt it. Thus the weight lays on these current affairs."

However, there are divergent views on the speed of change. Interviewee H emphasized that a lot can happen already in the next ten years:

H: "Yes it will show in the next ten years will happen a lot. Electrification of district heat and these sector integrations are now on so strongly, that I believe that we'll see within ten years that these traditional old [ways of production] are taken down, and there are then these new production possibilities and storage possibilities."

The conservative nature of district heating was discussed in a few interviews. Interviewee G noted that district heating sector is rather conservative and that changes have been slow. In their opinion, political decisions have played an important role in getting things moving. This may be seen as a call for more ambitious regulation and policy, which is a claim that many other interviewees did not prefer at all.

G: "I think district heating industry is rather conservative. That they are perhaps a bit slow, the changes. Perhaps that's why when we [in Finland] decided to ban coal so fast, it has boosted this change further. But if no [ban was set], I doubt it."

Almost as a part of an active Delphi process, interviewee C questions the conservative image of district heating which interviewee G had stated. The interviewees were not aware of the statements nor the identities of each other, which makes this dialogue rather interesting.

C: "When I think about I've been following this for about 25 years, a whole lot has happened that I could not have thought of 25 years back. Even if they say that district heating is like, [laughter] a bit conservative industry but indeed, for example, heat and heat pumps and heat pump technologies have resulted in many new things…"

This thesis focuses on sustainability transitions in Finnish district heating. When discussing with the interviewees whether there is a sustainability transition about to begin or if it is already on-going, interviewee B replied:

B: "-- There must be differing situations around Finland in each town, but if we think about it from heating market's perspective, we do have the change in effect."

Furthermore, interviewee C highlights the role of district heating in sustainability transitions:

C: "Big part of this solution in Finland, in relation to Finland's sustainability transition, is that district heating plays a big role in the whole. I'd say it this way that we have a huge advantage *compared to other Europe that how we can do the sustainability transition, and a big factor in that is district heating and its big role in our energy system.”*

Additionally, interviewee C brings out that the most significant and rapid change is about heat and its production turning into carbon neutral:

C: “Yeah the market is constantly changing, and the district heat itself as a product is changing, even the means of production in the background, it has been extremely fast, for example think about the heat is turning into carbon neutral and that is the greatest change of all there, in essence being emission free in the background, around the product itself.”

There seems to be an active sustainability transition in the Finnish district heating sector. Additionally, the importance of carbon neutral district heating to Finnish climate targets was justified. While many interviewees agreed that no significantly new technologies will emerge within the given time frame, there were notes about rapid changes in the past and expectations towards similar changes in the near future.

7.1.2 Incumbent actors

Slow and incremental change is related to incumbent actors in MLP. Therefore, some questions were related to incumbent actors. The topic was discussed in all interviews. Interviewee D relates development and innovation actions of an actor to its status as a thought leader:

D: “I’d say that these companies that are investing heavily on developing district heating, innovation, for example hydrogen economy related solutions, they are the biggest influencers at the moment.”

Interviewee F noted that incumbent actors have taken in a new generation of people, allowing and enabling change in the companies. This seems related to change and transitions in the industry as discussed earlier.

F: “I do know this field quite well, these companies, they have proper young people, they have thrown such old people out already. That they don’t have [old] people [slowing down change] in the management, that there are people that thrive to look for change and they are really working for it.”

It would make sense to conclude that despite their attached characteristics from MLP, incumbent actors in the Finnish district heating sector can illustrate innovation and accelerated change potential. This seems to be the result from investment in research, development, and innovation activities and active recruitment of young professionals.

7.1.3 Public opinions

Image, brand and public opinions shape consumer behavior. There were concerns over public opinion on district heating during the interviews. Interviewee F talked about how easily one can get a false image on district heating when following the national news.

PH: "Yeah there has been a partial hit on the image [of district heating]."

F: "Incoming all the time. Now that people out there are watching the half past eight news, they say [in the news] that district heating is becoming more expensive everywhere, so what is the image that remains."

Similar topic was discussed further down the same interview. The role of media and the influence of a single actor in the industry were raised up for discussion.

F: "And that Helsinki has to increase prices, well that's a catastrophe for the whole industry, especially when the Finnish Broadcasting Company and others deliver a message that price of district heating has increased, and one receives an image that it has happened everywhere and with false mental images you start going forward with it. And then the media repeats this."

7.1.4 Possibilities and opportunities

Some possibilities and opportunities were introduced during the interviews. Such topics were related to small and modular nuclear reactors, electrification, and hydrogen, among others. Interviewee H brought up the value that can be achieved with energy storages.

H: "[Energy storage] gives a hell lot of flexibility to production. -- take an old CHP plant, if electricity prices are not good enough, then there's not need to run it only for heat, which has been the case earlier, that you need to run the whole plant, to get heat for the city. But now you can take the heat from the storage. That's very good."

7.1.5 Summary of the interviews

A general consensus emerged from the interviews. A sustainability transition is active in the Finnish district heating. On one side, it is a local activity which individual district heating companies execute. Each actor makes use of their local strengths and opportunities. On the other side, policies such as coal ban and market changes such as fuel price increases have forced actors to react and adjust their operations and strategies accordingly. Based on the interviews of especially the experts from companies and industry associations, it seems that no more policies are needed to accelerate transitions and that the regime actors are proactively striving for transition and making district heating more sustainable. However, the ban on coal and the feedback on its effects suggest that policies could accelerate transitions. Additionally, it is unclear what kind of a transition would emerge in relation to transition pathways in MLP. There were varying views especially on the speed of change, possible technologies, policies and legislation. A reproduction pathway and a transformation pathway are mostly present in the interviews. This emphasizes the need to create alternative futures and descriptions of transitions which can document the communicated ideas and thoughts of the interviewees.

7.2 Multi-level perspective

The interviews provided a moderate amount of data to be processed. A key diagram of MLP provides a simple way to identify and communicate topics and issues from the interviews. Topics and issues were assigned to each level. Landscape level topics are bold, regime topics are with normal font, and niches are in italics. The dark arrows from landscape to regime show the exogenous pressure from various topics and megatrends. Some niche innovations are waiting to break through to regime level. It is the goal of this thesis to fill the question mark with possible futures and transition pathways. The figure 5 presents this MLP diagram. Only a selection of topics and issues can be found in the diagram to maintain readability of the diagram.

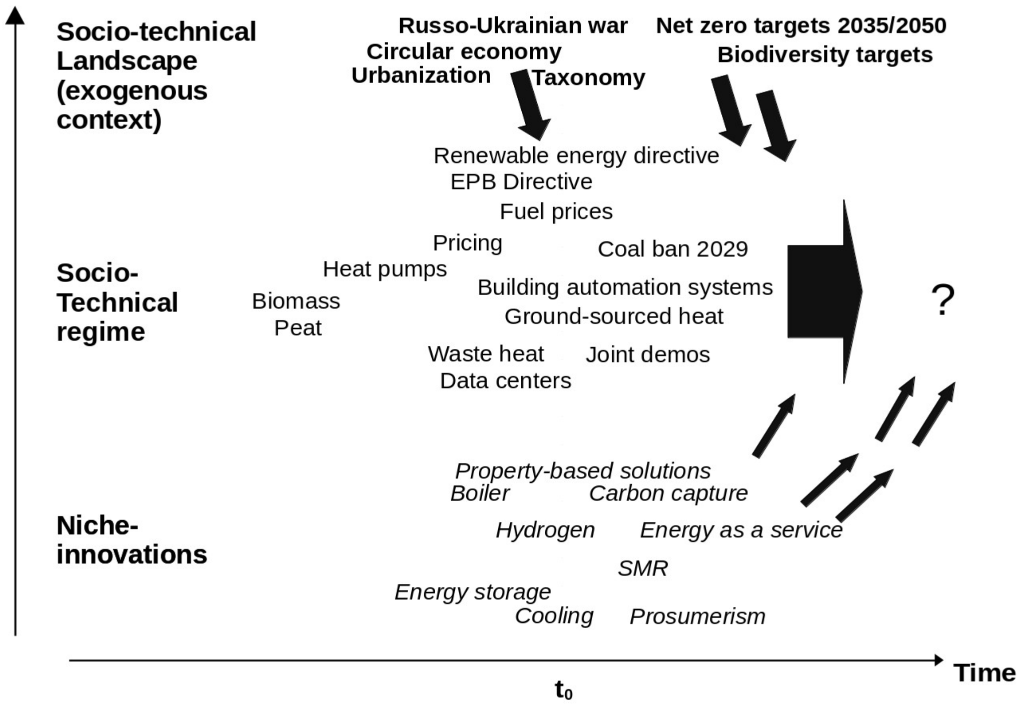

Figure 5. Multi-level perspective of the present in 2022.

7.3 Futures table

The variables in the futures table were selected based on core concepts of MLP and futures studies. Multi-level perspective has three levels and, within the regime level, six dimensions. Each level was included and the regime level was divided into each of its six dimensions.

MLP technology variable was labeled as Dominant District Heating Heat Production technology, as there was a lot of discussion and varying views among the interviewees. There is more to technology in District Heating, so an additional variable was added with the title of Other technological aspects. This was to cover for networks and storage technologies which are not a part of heat production yet are important in the value chain.

MLP Market and user preferences was distributed over two variables, too. Competition and demand addresses rivalry and other aspects that appear within the heat market. A few issues related to Energy market regulations were brought up in the interviews, which lead to having it as a variable. The values are related to external policies and market regulation.

The interviewees showed little to no interest in major scientific breakthroughs in the next decades. Therefore, Most prominent scientific and technological advancements provides interesting possibilities for rather unanticipated breakthroughs.

MLP industry variable was labeled as Operating Principle, as some interviewees mentioned collaboration among non-rivalry incumbent actors as one of the key drivers for industry development. Another MLP industry variable was added, too. Business models are addressed as there are many possibilities and opportunities in the current and future heat and energy market.

MLP policy was labeled as Impactful Policy and Legislation, as there were several concerns regarding policy, European directives and national legislation. An additional MLP policy variable was appended, with a title of Impactful local policy. This was to include special interest into local policymaking and how much impact it might have on the developments.

MLP Culture was included so that cultural phenomena can be taken into account. Niche level deserved its own variable as MLP would not be complete without it. MLP landscape was labeled as Dominant Megatrend while multiple megatrends were identified to have an impact on District Heating.

In order to bring more process thinking into otherwise static Futures Table and to promote MLP pathway thinking, Speed was added as one of the variables. A common factor of MLP and Futures Studies – Specific Shock – was added to help illustrate possible shocks that can act as a spark to further developments. Specific shock is an important aspect in transition pathways. Last, Realised Weak Signal was added to the table to account for some weak signals and taboos in the regime as they were specifically asked for in the interviews.

References to individual interviewees have been marked in the futures table right after each variable. Ideas from the author have been marked with italics. Bold text means that it was inspired by discussions about sustainability transitions in the Finnish district heating industry with ChatGPT, a publicly available chatbot powered by artificial intelligence. In the case of both bold and italics are present, the author has had the idea in mind and ChatGPT has also mentioned it. An excerpt of the futures table can be found in Table 4. The complete futures table is available as Appendix 2.

Table 4. An excerpt from the futures table with the selected values most of which were used in scenarios.

Classification	Variable title	Value 1	Value 2	Value 3
MLP technology	Dominant DH heat production technology	Cheap and energy-efficient hydrogen production (A, B, C, D, F, G)	SMR easy and cheap (A, B, C, E, F, G)	Heat pumps (A, B, C, D, F, G, H)
MLP technology	Other technological aspects	DH networks upgraded	Energy storage (B, E, F, G, H)	CCS (A, D)
MLP Market and user preferences	Competition and demand	Declining demand due to energy efficiency and property solutions like HP, GSH, Solar thermal, Biomass	Increasing demand due to urbanization	Shifting customer preferences: bi-directional prosumers (A)
MLP Market and user preferences	**Energy market regulations**	Deregulation of energy markets	Competition policy (A)	Security of supply regulations
MLP Science	Most prominent scientific and technological advancements	Technological breakthrough: fusion or other significant excess power source	Systemic design with data, AI and monitoring	No major breakthroughs
MLP Industry	Operating principle	Collaboration among DH industry: research, pilot projects, joint investments, joint ventures (A, ChatGPT)	International big money ownership (A), diluted business operating district borders, increased rivalry	City-ownership and public-private partnerships (A)
MLP Industry	**Business models**	**Peer-to-peer energy trading**	**Demand response management services**	**Energy as a service**
MLP Policy	Impactful national and EU policy and legislation	Opening of networks (B)	Forest biomass restricted or limited (A, E)	Taxonomy (A)
MLP Policy	Impactful local policy	**Support for DH expansion**	**Zoning and building codes (D, G)**	
MLP Culture	Cultural influence	Compensation services (A)	Negative perception, media trumps DH (A)	DIY, prosumers, energy awareness, smart home
MLP Niche	Niche	Building automation systems	Elasticity of demand and demand response systems (B, E)	Hydrogen (G)
MLP Landscape	Dominant megatrend	***Urbanization and demographic changes***	Energy poverty (A)	***Green transition: increasing demand for renewable energy sources***
Speed	Speeding or slowing	Old DH network infrastructure completely transformed and upgraded(A)	Support and incentives for energy renovations	
Specific shock	Specific shock	Demand for 100% renewable	Fossil fuel supply errors	Actor with endless demand for energy, always ready to buy excess energy
Realised weak signal	Realised weak signal	Cooling services (F, H)	Burning restricted, ie. only with CCS (A, B, C, E, H)	Business outside network area (B)

7.4 Scenarios and transitions

Scenarios were built to help grasp the possible sustainability transitions of Finnish district heating. The scenarios share certain common characteristics, while they still have their own unique qualities. All scenarios end up in a future where district heating is more sustainable than the current status. There are significantly less greenhouse gas emissions in each scenario. The ambition level of climate change mitigation in the society would remain as it is or even increase in some scenarios. Biodiversity is taken into account in each scenario, though with varying levels of impact. Social and cultural sustainability were not directly addressed, although those aspects were briefly discussed with a few interviewees.

Unit of analysis for the scenarios is the Finnish district heating sector, as transitions are multi-actor processes (see Geels & Schot 2010). Particular interest was put into technologies and niche-innovations. Even though there was some discussion about and mentions of individual energy companies and district heating companies in the interviews, the scenarios were built for the district heating sector while still acknowledging the tight relation to the greater energy sector and the moderate relation to the forest industry. The target audience of the scenarios consists mainly of district heating actors such as industry branch organizations, lobbyists, and incumbent heat producers, focusing on the employees in mid-level and top-level management. While the scenarios are not from the perspective of an individual company, companies should still be able to get valuable insights from the scenarios. In addition, there is content to digest for policy makers, regional and city planners, and technology providers.

During the interviews, most if not all interviewees talked about a transformation pathway or a reproduction pathway. They saw only incremental changes or if major changes were to happen, they would happen one at a time through the activities of incumbent actors. Thus a transformation pathway should be created, as it would on one hand reflect the shared understanding of rather controlled change, and on the other hand allow the author to take some freedom in selecting outside-the-box values for variables. The transformation pathway can be found in Scenario 1. A reproduction pathway would have offered nothing new, and such business-as-usual scenarios can already be found in other literature as mentioned in Chapter 5. Reputed to the father of scenarios, Herman Kahn, it would be a surprise if a business-as-usual scenario would actually occur (Glenn 2009b, 1).

The uncertainty related to technological solutions is addressed by the scenarios. Two major technologies with unknown future development were clearly available in the interview material. Either of those making a breakthrough would change the regime significantly. Small and modular nuclear reactors (SMR) could provide a steady flow of heat all year round, possibly combined with power production for seasons with decreased demand for heat. Hydrogen production through electrolysis produces considerable amounts of waste heat which could be collected and used in district heating. Either of the technologies, SMR and hydrogen, would produce a technological substitution pathway on its own as neither of them is actually ready for large-scale production. Thus, it became quickly apparent that one technological substitution pathway is not enough in a highly technology dependent industry. Therefore, two scenarios were built where the first is dominated by small and modular reactors, found as Scenario 2, and the second one illustrates the rise of hydrogen economy and its effect on district heating, found as Scenario 3.

With three scenarios representing two different transition pathways, it made sense to build two more, each representing the remaining two main transition pathways. A reconfiguration pathway was created to illustrate moderate pressure for renewable energy from landscape level, when niche-innovations are ready. This pathway can be found as Scenario 4. A de-alignment and re-alignment pathway was created to illustrate a large and sudden change in landscape, related to burning and forest biomass, when niche-innovations are not ready. This scenario is Scenario 5.

A scenario with a sequence of multiple pathways was left out of the scope of this thesis. This ensures comparison of scenarios as they involve only one pathway each. Nevertheless, some possibilities of transition sequences are discussed in the Conclusions section.

Next, each scenario is described. Scenario names include the related transition pathway in round brackets. At the end of each description, the sustainability level of the scenario is evaluated in a scale of excellent – good – moderate – compromised. Each scenario also includes a table with variables and the selected values.

7.4.1 Scenario 1: Preparing for winter (Transformation)

Green transition and increasing demand for renewable energy, from both customers and regulation, puts moderate pressure on district heating. Peat and coal are discarded well before the deadlines. Initially, sufficient niche-innovations have not yet been developed. As a result, the regime actors respond by implementing gradual modifications to the direction of development paths. Small and gradual modifications with heat pumps and burning for energy allow regime to comply with landscape pressure. The incumbent actors put great efforts into finding and utilizing all possible and feasible waste heat sources. In addition, the forest industry and forest owners respond to increased demand of wood energy by initiating massive first and second thinnings that had been waiting in the queue. This is further strengthened by incentives and a media campaign from the government.

Once energy storage technology is developed enough by startups, demonstration projects and joint ventures, this symbiotic niche-innovation is added to regime. As a result, heat can be stored off-season with HP and used from storage during high season. Industrial heat storages enable prosumerism where waste heat from various sources and intentionally generated heat from a wide range of actors can be stored. In the meanwhile, customer preferences in district heating shift moderately towards bi-directional prosumerism, as there is always the district heating company buying the excess heat to be stored for winter. Government support and incentives for energy renovations promote low energy use and excess production capacity in households, leading to sufficient capacity to generate heat for winter during warm seasons. New district heating networks are built so that enough energy can be transferred to and from distributed energy storages. Eventually, the regime has transformed into a moderately sustainable regime due to landscape pressure in a time where niche-innovations were not readily available.

Sustainability level of the scenario is moderate. Greenhouse emissions are at least net-zero as burning bio-based fuels and heat pumps provide majority of energy. However, massive thinnings have had a negative impact on forest biodiversity.

Table 5. Futures table values for Scenario 1.

Dominant DH heat production technology	Heat pumps; Burning bio-based fuels
Other technological aspects	Energy storage; Waste heat
Competition and demand	Shifting customer preferences: bi-directional prosumers
Energy market regulations	Deregulation of energy markets
Most prominent scientific and technological advancements	Systemic design with data, AI and monitoring; Energy storage enables long-term storing, making use of intermittent nature of renewable energy; Social engineering breakthrough
Operating principle	Collaboration among DH industry: research, pilot projects, joint investments, joint ventures
Business models	Energy as a service
Impactful national and EU policy and legislation	N/A
Impactful local policy	N/A
Cultural influence	Green transition, environmental aspects;
Niche	Peak production capacity
Dominant megatrend	Green transition: increasing demand for renewable energy sources
Speeding or slowing	Support and incentives for energy renovations; Old DH network infrastructure completely transformed and upgraded
Specific shock	N/A
Realised weak signal	Replacing DH with property solutions (A)

7.4.2 Scenario 2: Nuclear power enters the room (Technological substitution)

In the beginning, there's a rather stable regime where small and modular nuclear reactors (SMR) are expensive and the regulation is strict. However, there are technically feasible SMR solutions in the market. Then the market faces a double shock: European subsidies for long-term energy storage as a result from the prolonged Russo-Ukrainian war, and long-awaited eased national regulation for SMR. The first nuclear-powered district heating networks start operating within five years from the shock which was made possible by existing plans in incumbent companies. Stabilized and standardized SMR technology replaces current dominant technologies and thus burning becomes a secondary option. Substitution further creates turmoil in the regime, promoting sustainable heat in urban areas. Big DH networks become powered by SMR, leaving smaller networks rely on alternative solutions such as burning and energy storage, which is also used alongside SMR in big networks to address peak demands. SMR uses CHP so that power and heat output ratio can be adjusted to match energy needs in energy storages and in electricity markets. This creates some turbulence in electricity markets. Furthermore, decreased demand of biomass leads to lower prices for biomass and further to lower prices for many district heating customers.

The public opinion on SMR and nuclear in general has been on a positive trend as it is seen as a must to mitigate climate change and to reach national net zero targets. Demographic changes and urbanization promote district heating further as the go-to solution for urban heating and cooling. Biodiversity is increased as the forest industry cannot pump energy wood into DH production in same quantities as before. In addition, DH companies are paying their debt to forest nature by launching campaigns to preserve old forests and other important ecosystems.

Sustainability level at the end of this scenario good. Mining of nuclear fuel causes some negative environmental impact although most of the fuel is reused and recycled nuclear fuel. Decreased demand of biomass has improved environmental sustainability. There are significantly less carbon and other greenhouse gas emissions from district heating.

Table 6. Futures table values for Scenario 2.

Dominant DH heat production technology	SMR
Other technological aspects	Energy storage
Competition and demand	Increased demand due to urbanization
Energy market regulations	N/A

Most prominent scientific and technological advancements	SMR; Energy storage enables long-term storing, making use of intermittent nature of renewable energy
Operating principle	City-ownership and public-private partnerships
Business models	Demand response management services
Impactful national and EU policy and legislation	Taxonomy; Emission trading and carbon pricing; Eased regulation for SMR
Impactful local policy	Zoning and building codes
Cultural influence	Positive perception, acceptance of DH as best solution
Niche	Elasticity of demand and demand response systems
Dominant megatrend	Urbanization and demographic changes; Technological innovation and disruption
Speeding or slowing	N/A
Specific shock	Eased regulation for SMR
Realised weak signal	Biodiversity

7.4.3 Scenario 3: Hydrogen has arrived (Technological substitution)

Rather stable regime with low energy prices as wind and solar power production is continuously growing. Hydrogen production exists but can be considered as niche. Then there's a shock – significant EU subsidies for hydrogen production and synthetic fuels. It seems that without large availability and use of synthetic fuels, traffic and transport emission targets cannot be reached on time with only electric vehicles. Stabilized hydrogen production technology replaces current regime technology in district heating. Waste heat from electrolysis is used. Substitution further creates turmoil in the regime, promoting hydrogen production close to renewable energy sources. Cheap renewable energy, availability of hydrogen and subsidies for synthetic fuels enable smaller networks be powered with small-scale hydrogen production or using hydrogen. Bioenergy remains in use with CCS (=BECCS), thus providing carbon for synthetic fuels. Excess heat in small cities and rural areas is used for indoor food production, creating clear sectoral integrations and synergies. Production of synthetic fuels lures in big money from fossil economy incumbent actors who are looking for green transitions that support their value chains, further integrating district heating with energy and fuel sector. This leads to vertical integration in synthetic fuel value chain or joint ventures across the regime. Next generation heating networks are built as a part of hydrogen economy integration into district heating.

Sustainability level at the end of this scenario is not ideal but decent. Net zero targets are achieved in district heating and, through of hydrogen economy, in other sectors, too. International big money risks social sustainability as ownership of energy production shifts away from city ownership.

Table 7. Futures table values for Scenario 3.

Dominant DH heat production technology	Cheap and energy-efficient hydrogen production
Other technological aspects	Synthetic fuels; CCS; bio-based fuels
Competition and demand	Shifting customer preferences: district cold and air conditioning, in-door air quality and other services
Energy market regulations	Energy market integration
Most prominent scientific and tech-nological advancements	Technological breakthrough: fusion or other significant excess power source
Operating principle	International big money ownership, diluted business operating dis-trict borders, increased rivalry
Business models	Energy as a service
Impactful national and EU policy and legislation	Renewable energy mandates; Feed-in tariffs
Impactful local policy	Zoning and building codes
Cultural influence	Green transition, environmental aspects
Niche	Hydrogen
Dominant megatrend	Global energy and climate trends: International agreements to re-duce greenhouse gas emissions
Speeding or slowing	Old DH network infrastructure completely transformed and up-graded
Specific shock	Subsidies for synthetic fuels
Realised weak signal	N/A

7.4.4 Scenario 4: Regime hegemony (Reconfiguration)

Solar energy, wind power, electric boilers, energy storage, CCS, biofuel peak production, heat pumps, hydrogen production. These technologies are adopted as add-ons or replacements for current components. Solar energy and wind power lead to cheap intermittent energy. This creates the incentive to store cheap energy with continuously maturing energy storage systems. Burning biomass and waste is still allowed but landscape pressure demands CCS after a ten-year transit period. This creates supply of carbon dioxide, which boosts the already developed hydrogen economy to create synthetic fuels. Enabled by cheap energy, hydrogen production becomes one major component in district heating production. Hydrogen economy leads to energy market integration. There are now more possible business models for incumbent actors and newcomers.

Technology development is boosted by increased competition to provide best solutions for DH. In addition, collaboration with stakeholders and other energy companies is increased, resulting in pilot projects, public-private partnerships and joint ventures. Encouraged by joint ventures, some aggressive energy companies continue expanding their business outside their network area. This, however, may cause discord among regime actors. Property-based solutions gain more traction and small-scale prosumership is possible as big actors can store energy. These property-based solutions are a major driver for expanding business areas. Most of the time, these solutions, such as cooling and air conditioning, are wrapped in services where customers pay for the service, not actual energy used. Property-based solutions keep improving their performance and efficiency which leads to incumbent actors restraining from improving old networks. The basic delivery architecture becomes a secondary concern as property-based solutions are more profitable.

The public opinion is against SMR, especially if it was close to populated areas. The people do not want nuclear power plants in their backyards even if it would grant them with affordable and continuous heating. They prefer renewable energy. This is further emphasized with local zoning which prohibits nuclear power plants near residential areas. National regulation for SMR remains the same as for industrial scale nuclear power plants which effectively blocks SMR dreams in Finland. District heating is generally perceived as a viable option for heating in densely populated areas. However, networks are not expanded and old networks are slowly replaced with property-based solutions such as heat pumps and small energy storages.

Sustainability level at the end of this scenario is good. Especially after implementing BECCS, carbon emissions have decreased significantly. However, the captured carbon is later emitted through the use of synthetic fuels in internal combustion engines in the traffic and transport sector. Demand for bioenergy has decreased as other sources of energy are used, too. This further has a positive impact on biodiversity as more forests can be migrated to restricted forestry mode.

Table 8. Futures table values for Scenario 4.

Dominant DH heat production technology	Hybrid systems; Burning bio-based fuels; Heat pumps; Hydrogen
Other technological aspects	Energy storage; CCS; Waste heat
Competition and demand	Shifting customer preferences: district cold and air conditioning, in-door air quality and other services
Energy market regulations	Energy market integration
Most prominent scientific and technological advancements	N/A
Operating principle	A: minority ownership already City-ownership and public-private partnerships (A)
Business models	Energy as a service
Impactful national and EU policy and legislation	Renewable energy mandates
Impactful local policy	Zoning and building codes
Cultural influence	Positive perception, acceptance of DH as best solution; Opposition to SMR – NIMBY
Niche	Increased availability of renewable heating technologies
Dominant megatrend	Global energy and climate trends: International agreements to reduce greenhouse gas emissions
Speeding or slowing	N/A
Specific shock	N/A
Realised weak signal	Business outside network area

7.4.5 Scenario 5: Fight back to glory (De-alignment and re-alignment)

Burning becomes highly restricted and regulated as European Union passes new green transition regulation. Companies can choose to start implementing Carbon Capture and Storage with Bioenergy (BECCS) or otherwise burning falls under emission trading, thus increasing costs. The crown jewel of Finnish energy sector – the combined heat and power production (CHP) – is at stake. There are serious discussions and citizen campaigns on banning biomass burning altogether, which creates uncertainty about the future. Availability of burnable material is compromised at the same time as the same new green transition regulation limits felling of timber in favor of biodiversity. At the same time, demand for timber and forest biomass remains high and even increases as products of fossil economy are replaced with renewable alternatives. The regime becomes unstable quite rapidly as costly adjustments need to and should be taken. These two factors significantly increase cost of production and thus also the price of district heating increases. This leads to discontent among customers, which further leads to some replacing district heating with property-based solutions such as ground-sourced heat.

Alternative niche solutions for CHP are not sufficiently developed, and there is fierce competition among alternative, underdeveloped production technologies. Incumbent actors lose faith in the potential of the regime to respond. They do not defend the regime, signaled by declining R&D investments, especially after a few failed projects which they had big hopes for. They just hope to milk the cow as long as they can with their current setups and adjust themselves to market dynamics. Years later, a savior arrives as international big money sees the potential that has become apparent as niche-innovations are maturing. Big money starts investing into these “walking dead” incumbent actors. While heat pumps, ground-sourced heat, solar thermal and bioenergy with CCS compete at first, breakthroughs in heat pump technology enable good enough efficiency in cold environmental conditions of Finland. Thus HP and GSH become dominant. This is further strengthened by energy-efficient buildings and property-based solutions which lower the overall demand for district heating. As European Union finally finds a long-term agreement that side-stream biomass can be burned for energy if CCS is used, biomass secures its place as a backup and peak production energy source.

Sustainability level at the end of this scenario is good. The use of fossil fuels has decreased significantly. Forest biodiversity has increased due to limits to forest felling. Carbon capture and storage prevents carbon emissions even from carbon-neutral bioenergy, making them carbon-negative as the captured carbon is deposited into soil.

Table 9. Futures table values for Scenario 5.

Dominant DH heat production technology	Hybrid systems; Heat pumps
Other technological aspects	Ground-sourced heat; Heat pumps
Competition and demand	Declining demand due to energy efficiency and property solutions like HP, GSH, Solar thermal, Biomass
Energy market regulations	N/A
Most prominent scientific and technological advancements	Ground-sourced heat; Materials science
Operating principle	International big money ownership (A), diluted business operating

	district borders, increased rivalry; Collaboration among DH industry: research, pilot projects, joint investments, joint ventures
Business models	Traditional
Impactful national and EU policy and legislation	Forest biomass restricted or limited; Emission trading and carbon pricing
Impactful local policy	Support for DH expansion
Cultural influence	Green transition, environmental aspects; Compensation services; DIY, prosumers, energy awareness, smart home
Niche	Building automation systems
Dominant megatrend	Global energy and climate trends: International agreements to reduce greenhouse gas emissions
Speeding or slowing	N/A
Specific shock	N/A
Realised weak signal	Replacing DH with property solutions (A)

8 DISCUSSION

The purpose of this thesis was to present possible futures and sustainability transitions of Finnish district heating. The current status and a brief history of the Finnish district heating were presented. In total, eight expert interviews were conducted as semi-structured interviews. Multi-level perspective was used as a tool and framework to form and structure interview questions and to analyze the data. In addition, key concepts of futures studies were analyzed from the data. A futures table was used to organize the gathered and analyzed data, and MLP transition pathways were used to help build relevant and possible sustainability transition scenarios. The scenarios were built using the data gathered and analyzed from the interviews.

The main results of the thesis include the MLP diagram of the current status and five possible scenarios for the Finnish district heating. The MLP diagram presented a multitude of topics, technologies and megatrends that are taking place or affecting the regime of district heating.

Scenario 1 describes a transformation pathway where gradual readjustments are made in the regime in response to landscape pressure. Developments happen across the regime: user preferences change, industry itself changes, new incentives are implemented. As energy storage technology is mature enough, it is appended into the regime by incumbent actors. Finally, the regime has transformed into a sustainable regime, mostly by gradual readjustments. This is an interesting case showing the capabilities of the regime to implement a transformation without major shocks or niche penetration.

Nuclear reactors play the principal role in Scenario 2. Following the technological substitution pathway, SMR is introduced through a landscape shock, mature technology, and related policies. The introduction is followed by further turbulence in other areas of the regime such as decreased demand of biomass leading to lower fuel prices. While it is a technological substitution scenario, SMR does not entirely replace other means of production. Especially burning of biomass remains a vital solution for small and medium sized networks. In reality, it is uncertain if nuclear safety regulation could and should be loosened for SMR. Thus this scenario provides food for thought if the regulation was eased.

Scenario 3 is also a technological substitution scenario but with hydrogen instead of SMR. Policies on both domestic and European level create a shock in the energy sector and in the society. The regime starts readjusting to comply with hydrogen production and hydrogen economy. Carbon capture and storage becomes implemented for bioenergy which plays well together with hydrogen economy and the incentives for synthetic fuels. This scenario is a great example of how shocking policies can have huge snowball effects. Hydrogen economy is likely to start booming in the future, making this scenario quite interesting.

Scenario 4 presents a storyline of choosing renewable energy as the main energy source. Moderate pressure from the landscape causes reconfigurations in the regime. Production technologies are adjusted to rely on and support renewable energy sources. Carbon capture and storage is required after a transition period which is a highly likely development to happen. Niche alternatives are mature and thus become integrated in the regime. This scenario is a rather likely transition which requires that the investments into renewable energy are maintained and that niches mature soon enough so that they can be integrated. Furthermore, new products and services are offered to customers which help maintain the interest of customers towards district heating.

Scenario 5 of *Fight back to glory* demonstrates the impact of two unwanted regulations: CCS and limits to felling of timber. It also introduces an interesting idea from an interview related to the ownership of Finnish district heating companies. Whereas companies are currently mostly owned by the municipalities, this is radically changed in the scenario. The role of low innovation capabilities and activities is perfectly illustrated as decreased interest and as a loser mentality. However, the final state of the scenario is still a bright image of the future.

The probability of each scenario is different. The likelihood of scenarios is based on the strength of relevant trends at the time of writing and number of expert opinions in favor. The most probable future is a mixture of a few scenarios, similar to the current status of the industry. Small and modular nuclear reactors (SMR) have already been covered in the news since the interviews took place (see Yle Uutiset 2022; 2023c; 2023d). This is an indicator that the scenario with SMR is rather likely, too, if the public opinion stays positive towards nuclear power. SMR with hydrogen would mean that there is a steady flow of power and heat throughout the year. Excess power can be stored in energy storages and as hydrogen for later times and for other uses. Significant investments in wind power and resulting increases in electricity production provide inexpensive and intermittent energy. There have been news about hydrogen economy, where international companies plan to invest in Finland and where steel industry is transitioning from coal based processes to hydrogen based processes. Hydrogen is likely to break through, and that could have a significant impact on district heating as was described in the hydrogen scenario. Energy storage, geothermal energy and distributed production act as weak signals and niche solutions. Nevertheless, the reconfiguration pathway scenario is probably the most likely scenario to happen as it also includes some elements from hydrogen while thriving on renewable energy.

Interactions and interconnectedness with related regimes such as electricity and forestry can trigger sequences of transition pathways. One possible interaction is the production of district heat with electricity, using electric boilers (see Yle Uutiset 2023a). This decreases demand for wood and bioenergy and may trigger further changes in forestry and wood industry.

8.1 In relation to literature

Paiho and Saastamoinen (2018) listed major challenges and opportunities in Finnish district heating. The listed challenges and opportunities were still found relevant in the interviews conducted for this thesis. Several interviewees stated clear wishes about district heating remaining rather reasonably regulated in Finland which means that no new regulation is welcome. This is in line with what Paiho & Saastamoinen (2018) identified. However, the concern over the public opinion on district heating was a new topic that the earlier work had not identified.

Dzebo and Nykvist (2017) identified dilemmas concerning waste incineration as part of Swedish district heating. However, this topic did not come up in the interviews and thus was not included in scenarios either. Recently, there have been news articles on Finnish district heating companies importing waste from Italy to secure their supply for incineration (Yle Uutiset 2023b). As recycling rates are expected to increase both domestically and in European Union, the security of supply for incineration might be at stake. It remains unclear how the Finnish district heating companies that rely on waste incineration are prepared for the future.

The low-carbon roadmap of Finnish Energy (Finnish Energy 2020) supports achieving carbon neutrality in Finland during 2030s. Emissions from district heating are to decrease rather low by 2030. The scenarios in this thesis support and follow similar developments. The net-zero transitions is actively pursued by the incumbent actors, according to some interviewees. Although, this was also criticized as is discussed later. The roadmap of Finnish Energy emphasizes CHP production. However, the scenarios of this thesis incorporate varying levels of CHP. The scenarios thus question the dominant role of CHP. This is to open up new futures as it is one of the aims of this thesis.

8.2 Policy designs

Many interviewees stated that sustainability transitions are already an on-going practice in Finnish district heating for some time already. In addition, the interviewees seemed not to be welcoming new regulation and policies. If economies should operate within the boundaries set by nature and humanity, as illustrated in *Doughnut economics* (Raworth 2017), how can we ensure that the boundaries and limits of nature and humanity are not breached in the quest for sustainable transitions in district heating? The literature on sustainability transitions highlights the need to implement policy measures to speed up sustainability transitions. While bans and incentives were not requested or preferred by the interviewees, especially the coal ban was mentioned as a success story about how policies can accelerate and foster sustainability transitions.

MLP framework emphasizes policy measures that work across the field. Policy should focus on dynamic policy mixes, not isolated or static instruments (Geels et al. 2017). Measures should destabilize the incumbent regime so that there are more opportunity windows for structural changes. Measures should promote radical sustainable niches in order to widen the portfolio of promising solutions. They should also help translate practices and ideas from niche level to the regime level. (Smith et al. 2010, 445.)

There is certainly a need for horizontal policy coordination (see Geels 2019, 197). *Hydrogen has arrived* scenario introduces a specific shock from landscape level, where incentives are implemented to improve availability of synthetic fuels for traffic and transport. This shock induces increased investments into hydrogen production, allowing district heating to benefit from sectoral integration in the form of waste heat from hydrogen production processes. Hydrogen production with electrolysis requires a significant amount of energy, which means that there is more demand for renewable or carbon-neutral energy production. The world is already seeing a huge step into renewables such as wind and solar power. A targeted incentive policy in one sector may create a snowball effect to other interrelated sectors through high and increasing sectoral integration.

Many of the interviewees stated that the market should be allowed to do its job in selecting the best options to achieve the set goals. They also added that policies should focus only on setting the goals and targets. Furthermore, issues were raised about technology neutrality in policies, which means that policies should not favor certain technologies through incentives or tax relief. However, it is the job of the government to set limits and guidelines, such as the ban for coal. This was supported by some interviewees. Similar bans with deadlines could and perhaps even should be implemented to encourage otherwise slow and conservative incumbent actors to foster sustainability transitions. The need for implementation of new policies and changes in taxation and incentives to foster sustainability transitions is consistent with what Geels (2011) suggests. However, such policies can be controversial if there are no alternative solutions available. In that case, it could produce a de-alignment and re-alignment pathway and compromise security of supply for district heating. A safe environment for such bans and restrictions would mean that there are sufficiently developed niche alternatives available and joint demonstration projects have validated the niches. This would produce a rather controlled technological substitution pathway or a transformation pathway, which would probably be the preferred outcome for both the government and the industry. Nevertheless, niches should be able to join bigger change processes to make a breakthrough as literature suggests (see Smith et al. 2010, 440-441).

Small and modular nuclear reactors were of interest to some interviewees. There have also been some news articles about companies developing and planning for SMR (Yle Uutiset 2021; 2022; 2023c). The legislation seems to be an issue as small reactors require the same level of documentation and conformability to safety standards as the currently operating nuclear power plants. If there was a safe way to lower the bar for SMR (see Yle Uutiset 2023d), would it make sense to do it? The results of this thesis imply that if SMR is considered as a sustainable and acceptable solution, it might be sensible to reconsider the regulation for SMR. While SMR is not a solution for the whole district heating industry, it is an alluring option for the big cities and municipalities.

This thesis has also raised alternative solutions to SMR. Other carbon-neutral solutions such as heat pumps, waste heat, and solar and wind power are in a fast-forward phase. Is there really a need for SMR if renewable and other sources can provide enough energy for district heating? Another question that is raised in the thesis is that how would hydrogen economy and SMR play together. The both technologies are not included in a single scenario.

In addition to production technologies, energy storages are important for overcoming the issues of the intermittent nature of renewable energy. Fluctuating energy prices and summertime production surplus provide some incentive for the actors to make investments in energy storages. However, the technology doesn't seem to be quite mature yet. Government or European Union support for energy storages could have wide positive effects on various forms of renewable energy. Furthermore, it could boost prosumership if small-scale energy and heat production became even more profitable. Security of supply would increase with storing energy. Energy storages did not emerge in discussions about technology-neutral policies. Thus it could be possible to introduce incentives without compromising the neutrality towards production technologies and without destabilizing the balance between district heating and property-based solutions. It is worth noting that energy storages do slightly favor renewable and intermittent energy sources over continuous sources such as SMR. Nevertheless, it seems that incumbent actors might be willing to accept such support.

8.3 Strategy proposals for companies

This thesis raised the concern of long-term foresight in district heating. Energy, utilities and heating companies should be the perfect pupils in practicing long-term foresight. They have significant investments and capital tied to their operational infrastructure in the form of production facilities and heat delivery networks. Are they really thinking about significantly different alternative futures and far enough into the future? Certain voices were raised about fears towards European Union and what kinds of directives there were to come. Are the incumbent actors ready if their worst nightmares become reality? Scenario 2 introduced a situation where burning becomes restricted, which represents a nightmare for all those 152 Finnish municipalities which rely mainly on biomass in their district heating systems. While the industry seems to promote technology-neutral policies, the incumbent actors are heavily dependent on certain technologies. Another terrifying directive which many interviewees mentioned would be the opening of district heating networks.

The future scenarios concerned multiple technologies. By making sure that there are on-going demonstration projects of new technologies, incumbent actors can secure their stances towards landscape and industry-specific shocks. Interviewees mentioned joint projects which are focused on exploring the technological feasibility and economical viability of ground-sourced heat. Similar joint projects allow lowering the barrier to test, demonstrate and validate new technologies. Considering the spatially restricted nature and almost non-existing competition among incumbent district heat actors, there should not be any major obstacles for deepening similar collaboration. Nevertheless, scenario 4 involved a storyline of aggressive business expansion outside the normal operating area of district heating companies.

The public opinion on district heating was raised as an issue in some interviews. The rise of viable and feasible property-based solutions and the price increases of some district heating companies have both had their impact on the public opinion on district heating. It might be wise to invest in consumer campaigns, to stay close to and listen to their customers. Additionally, incumbent actors should maintain and improve their competitiveness and value proposition. They should emphasize the ease of sustainability transitions and achievement of net-zero targets through the wide use of district heating with little to none required actions from their customers. Otherwise the sales figures might start declining as property-based solutions increase their market share.

Additionally, the incumbent actors could extend their product portfolios in response to customer preferences. In the futures table and in the scenarios, the thesis addressed prosumerism as well as the movement to drop using district heating and favoring property-based solutions. In electricity sector, energy companies are eager to offer solar energy solutions to customers as a part of their product and service portfolio. There should be nothing preventing district heating companies from offering equivalent solutions in the business of heat and indoor air conditioning. Building automation and home automation, heat production at the customer’s premises, cooling systems and indoor air quality monitoring are all examples of what the companies could offer. Otherwise they face the risk of losing their customers to actors who offer these services and products. Incumbent actors could acquire or collaborate with companies from the niche level as a way to expand their portfolios.

Putting these strategy proposals into action requires a healthy corporate culture. How open are the incumbent actors to new ideas both from within the organization and from outside? Actors that offer property-based solutions tend to be smaller in size. Additionally, they do not have heat networks creating lock-ins and path-dependencies. Thus, they are able to move rapidly from a technology to another as viability and feasibility of a technology changes.

8.4 Research questions

The introduction chapter presented the two research questions of this thesis. Next, each question is discussed and evaluated in relation to the results.

8.4.1 RQ1: What are the possible futures and sustainability transitions for district heating in Finland?

The scenarios described possible futures and transitions for Finnish district heating. A total of five different scenarios, covering the four main transition pathways in MLP, give food for thought. The scenarios present a transformation pathway of *Preparing for winter*, two technological substitution pathways called *Nuclear power enters the room* and *Hydrogen has arrived*, a reconfiguration pathway of *Regime hegemony*, and a de-alignment and re-alignment pathway called *Fight back to glory*. The scenarios present possible futures with different parameters. Despite of the interview data indicating that a sustainability transition is already happening, the scenarios present alternative development paths all of which are possible.

8.4.2 RQ2: What are the (technical and non-technical) solutions for district heating in the future?

Several technological solutions were asked about and discussed during the interviews. The technological solutions were added to the futures table and finally, some were selected for the scenarios. There are a wide range of technical solutions including but not limited to SMR, hydrogen, waste heat, next generation heat networks, sector integration, solar and wind power, electric boilers, biomass and bioenergy, carbon capture and storage, synthetic fuels, and energy storage. Non-technical solutions were introduced, too. Such solutions include cultural aspects of indoor conditions like expectations towards temperature. Prosumerism where consumers also act as heat producers did not get much traction among the interviewees but was still included in scenarios. Additionally, the product portfolios and available services of district heating companies can affect the future of district heating.

9 CONCLUSIONS

The thesis concludes that a sustainability transition is already going on in the field of Finnish district heating. A multitude of different solutions exist that can help in and enable sustainability transitions. Furthermore, many technical solutions are being developed and are thus maturing in the future, providing more ways to produce heat. Additionally, policy measures, despite of not being warmly welcomed by the field, can foster and speed up these transitions.

It was identified that the local and spatially dependent nature of district heating makes it challenging to have other transition pathways than a transformation pathway, which emphasizes aligning innovation and development activities to landscape pressure. The interview data hardly suggested any other pathway. However, this thesis has proved that the dominant mental model of the future should and can be challenged. Scenarios were created for each of the four main transition pathways, and sequences of pathways were discussed.

The interview data and the scenarios point out two major technological wild cards for the Finnish district heating: SMR and hydrogen. Both seemed uncertain at the time of interviews. Recently, we have seen news articles about possible investments in both technologies.

It is easy to discard the thesis by judging the scenarios about how unrealistic or realistic they seem to be. However, it is not about if the scenarios are realistic but whether they and the built understanding with data and the theoretical framework correspond a realistic pattern of behavior (see Meadows & Wright 2009, 48). Scenarios are tools of communication. They deliver the created and analyzed understanding of possible futures. Therefore, one should see the forest from the trees. The results of this thesis should be judged not by how right or wrong the scenarios are, but by their ability to help make better decisions now (Glenn 2009a, 5).

Companies and the industry should pay more attention to alternative futures. There seems to be a hegemony and a set discourse on a very narrow set of very similar futures (for example Finnish Energy 2020). The concepts of VUCA and BANI describe our time quite well. The future is nothing but certain, and if major investments, policy designs and strategic decisions are made based on a single scenario, a roadmap or an image of the future, it is even likely that some other future will unfold.

This thesis has provided transition scenarios about Finnish district heating. It is up to the reader to "*be the judge of which scenario, if any, should be taken seriously as a future that might really be possible*" (Meadows & Wright 2009, 46). The scenarios are only the beginning. Although they help educate the audience about future possibilities, they could eventually be used to assess strategies and policies.

The thesis is not value-agnostic as it and my interests are in sustainability and sustainability transitions. Unsustainable transitions may be described as something unwanted and thus could be used as worst-case scenarios. This thesis applies the principle that “the future is narrowed toward the preferred” (Inayatullah 2008, 18). The possible futures in this thesis tend to be mostly preferred and plausible futures.

The interviews took place during winter 2021-2022. A few interviews were made within weeks after Russia’s aggressive attack on Ukraine. The energy markets have since then been in a rather unstable or unpredictable state. The fuel and electricity prices surged, and companies and consumers have had to adapt to the new situation, and not without damage. In Finland, a planned and prepared nuclear power plant was cancelled. As fuel prices have increased, several district heating companies have had to increase their prices significantly. However, compared to the electricity sector, district heating seems to have had an easier time. Nevertheless, the dependencies on fossil fuels have at least by now been evaluated carefully and plans and actions have been made to decrease those dependencies. These actions tend to include a shift from oil to natural gas and onto biogas, incineration of waste, energy storages, and increased use of biomass as a source of energy. Especially the increased dependency on forest biomass is worth following in the future. Will there be policies such as BECCS that put pressure on the dependency? Which kind of an effect would that have on transitions? There are also continuing discussions on limiting felling of timber and how forestry can contribute to enhancing biodiversity. These will definitely have impact on biomass-dependent district heating. Scenarios can help answer these questions.

Another war-related issue that has been brought up recently is about security. Critical infrastructure, such as district heating, is facing security threats and risks on a completely different level. Related information technology systems and physical infrastructure can be attacked in multiple ways as Russia has demonstrated in Ukraine. This has brought these issues into discussions and resulted in preventive actions. These issues, however, were not brought up in the interviews. Surely and hopefully it had already been someone’s duty to account for these before and during the interviews. It is likely that the interviewees were not very keen on the topic at the time of the interviews. Nevertheless, everyone should by now be aware of the threats.

9.1 Theoretical contributions

This thesis demonstrates that multi-level perspective can be used to probe future developments and transitions. MLP is useful in identifying, structuring and communicating findings of a systemic change and transition. Transition pathways can be used in many ways in scenario-making. This thesis used the transition pathways as models or archetypes of transitions, similar to Dator’s scenario archetypes. Using scenario archetypes or models ensures that different perspectives and aspects are considered in the scenario-making process. Companies and industry associations should avoid making foresight with only one or two scenarios or roadmaps, one of which is a business-as-usual scenario.

The findings in this thesis contribute to the field of sustainability transitions where long-term policy visions, missions, and foresight are investigated by creating possible future pathways (see Mazzucato 2018; Sovacool 2019). Additionally, this thesis has illustrated that the scenarios and transition pathways based on MLP can provide valuable input to strategy processes of regime actors. It helps answer questions about future technologies and their interplay and about how different policies might affect the regime. Strategy proposals were presented to support actors in their planning processes.

9.2 Future research

This work has unveiled several areas for future research. A similar multi-level perspective approach could be taken to a wider Nordic, European and global context in district heating. There are already articles that make use of MLP in assessing DH in Sweden. There are indeed some similarities between Finland and Sweden, but there ought to be several differences, too.

The scenarios from the thesis can work as a medium for new studies. Wind tunneling certain strategic choices across the scenarios could provide information on feasibility of those choices. Another possibility would be to do a Delphi study on the presented scenarios. How the industry, companies and stakeholders would assess the scenarios? Additionally, a longitudinal study could be conducted by interviewing the stakeholders after five, ten and twenty years from the publication of this thesis to follow the evolving field of district heating.

District heating is highly connected to energy sector through CHP production and will probably be even more connected in the future if SMR, hydrogen and energy storage (power/heat to storage to heat) become more mainstream. In addition, use of biomass has been increasing for a long time. Therefore, it would be interesting to consider the interactions between regimes such as district heating, electricity, forestry, traffic and transport, and hydrogen economy.

In such technology-dependent regime as district heating, transition pathways provided to be convenient tools for scenario making. Furthermore, each transition pathway could be created using different technology combinations. What would a transformation pathway look like if small and modular reactors were the symbiotic niche-innovation? How would a technological substitution pathway emerge if burning had a stable ground and was eventually substituted with another technology?

This thesis focused on the Finnish district heating. As several interviewees pointed out, the spatial aspects of district heating need to be considered in transitions. The local nature of district heating creates local innovations and local path-dependencies. As Smith et al. (2010) point out, socio-technical regimes, niches and landscape relate to administrative, territorial and communicative spaces. Even within the territorial space of Finland, sustainability transitions in district heating can play out quite differently. While the local conditions have a significant impact on local transition pathways, contacts and networks across the world can affect the development of different Finnish district heating companies. What is the role of such networks?

District heating as an industry can be both stable and volatile simultaneously. Incumbent actors have significant technology lock-ins and path dependencies. New regulation can disrupt the field radically. These contradictory characteristics promote the need for corporate foresight and the ability to break away from path dependency. Assessing corporate foresight practices with the maturity model for organizational future orientation made known by René Rohrbeck (Rohrbeck 2010; Rohrbeck & Kum 2018) would be an interesting endeavor. How district heating and energy companies are using corporate foresight? Do they think about alternative futures? What kind of impact do their practices have on their success?

Lastly, the interviews took place mostly before the start of Russia’s attack on Ukraine in February 2022. This attack introduced a shock to the energy market with an impact on Finnish district heating. What were the actual effects on Finnish district heating? What kind of changes were made in current operations and related to plans and roadmaps? Have priorities changed? How do the actors think about safety, security, and security of supply? Did the shock trigger a specific scenario introduced in the thesis?

REFERENCES

Bell, W. (1997). The purposes of futures studies. In *Foundations of Futures Studies: Human Science for a New Era*. Transaction Publishers.

Callon, M. (1987). Society in the making: The study of technology as a tool for sociological analysis. *Society in the Making: The Study of Technology as a Tool for Sociological Analysis*, 83–103.

Cassell, C. (2015). *Conducting Research Interviews for Business and Management Students*. Sage.

Coyle, G. (2009). Field Anomaly Relaxation. In J. C. Glenn, T. J. Gordon, & UN Millennium Project, *Futures research methodology*. Millennium Project.

Dator, J. (2019a). Alternative Futures at the Manoa School. In J. Dator, *Jim Dator: A Noticer in Time: Selected Work, 1967-2018*. Springer International Publishing AG.

Dator, J. (2019b). What Futures Studies Is, and Is Not. In J. Dator, *Jim Dator: A Noticer in Time* (Vol. 5, pp. 3–5). Springer International Publishing. https://doi.org/10.1007/978-3-030-17387-6_1

Dzebo, A., & Nykvist, B. (2017). A new regime and then what? Cracks and tensions in the socio-technical regime of the Swedish heat energy system. *Energy Research & Social Science*, *29*, 113–122. https://doi.org/10.1016/j.erss.2017.05.018

Elzen, B., & Hofman, P. (2007). Exploring Future Transition Pathways—The Socio-Technical Scenario approach. *Transforming the Energy System: The Role of Institutions, Interests & Ideas*, 22.

Finnish Energy. (2022). *Kaukolämpötilasto 2021*. https://energia.fi/uutishuone/materiaalipankki/kaukolampotilasto.html

Finnish Energy. (2020). *Energia-alan vähähiilisyystiekartta*. Energiateollisuus. https://energia.fi/uutishuone/materiaalipankki/energia-alan_vahahiilisyystiekartta.html

Finnish Energy. (2023). *Energiavuosi 2022—Kaukolämpö*. https://energia.fi/uutishuone/materiaalipankki/energiavuosi_2022_-_kaukolampo.html

Ford, R., Maidment, C., Vigurs, C., Fell, M. J., & Morris, M. (2021). Smart local energy systems (SLES): A framework for exploring transition, context, and impacts. *Technological Forecasting and Social Change*, *166*, 120612. https://doi.org/10.1016/j.techfore.2021.120612

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy*, *31*(8), 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy*, *33*(6), 897–920. https://doi.org/10.1016/j.respol.2004.01.015

Geels, F. W. (2014). Regime Resistance against Low-Carbon Transitions: Introducing Politics and Power into the Multi-Level Perspective. *Theory, Culture & Society*, *31*(5), 21–40. https://doi.org/10.1177/0263276414531627

Geels, F. W. (2018). Disruption and low-carbon system transformation: Progress and new challenges in socio-technical transitions research and the Multi-Level Perspective. *Energy Research & Social Science*, *37*, 224–231. https://doi.org/10.1016/j.erss.2017.10.010

Geels, F. W. (2019). Socio-technical transitions to sustainability: A review of criticisms and elaborations of the Multi-Level Perspective. *Current Opinion in Environmental Sustainability*, *39*, 187–201. https://doi.org/10.1016/j.cosust.2019.06.009

Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research Policy*, *36*(3), 399–417. https://doi.org/10.1016/j.respol.2007.01.003

Geels, F. W., & Schot, J. (2010). A multi-level perspective on transitions. In *Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change* (pp. 18–28). Scopus. https://doi.org/10.4324/9780203856598

Geels, F. W., Schwanen, T., Sorrell, S., Jenkins, K., & Sovacool, B. K. (2018). Reducing energy demand through low carbon innovation: A sociotechnical transitions perspective and thirteen research debates. *Energy Research & Social Science*, *40*, 23–35. https://doi.org/10.1016/j.erss.2017.11.003

Geels, F. W., Sovacool, B. K., Schwanen, T., & Sorrell, S. (2017). The Socio-Technical Dynamics of Low-Carbon Transitions. *Joule*, *1*(3), 463–479. https://doi.org/10.1016/j.joule.2017.09.018

Gidley, J. M. (2017a). *The Future: A Very Short Introduction*. Oxford University Press. https://doi.org/10.1093/actrade/9780198735281.003.0003

Gidley, J. M. (2017b). The future multiplied. In J. M. Gidley, *The Future: A Very Short Introduction* (pp. 44–62). Oxford University Press. https://doi.org/10.1093/actrade/9780198735281.003.0003

Glenn, J. C. (2009a). Introduction. In J. C. Glenn, T. J. Gordon, & UN Millennium Project, *Futures Research Methodology* (3.0). The Millenium Project.

Glenn, J. C. (2009b). Scenarios. In J. C. Glenn, T. J. Gordon, & UN Millennium Project, *Futures Research Methodology* (3.0). The Millenium Project.

Glenn, J. C., Gordon, T. J., & UN Millennium Project. (2009). *Futures research methodology*. Millennium Project.

Heinonen, S., & Lauttamäki, V. (2012). Backcasting scenarios for Finland 2050 of low emissions. *Foresight : The Journal of Futures Studies, Strategic Thinking and Policy*, *14*(4), 304–315. https://doi.org/10.1108/14636681211256099

Heiskanen, E., Apajalahti, E.-L., Matschoss, K., & Lovio, R. (2018). Incumbent energy companies navigating energy transitions: Strategic action or bricolage? *Environmental Innovation and Societal Transitions*, *28*, 57–69. https://doi.org/10.1016/j.eist.2018.03.001

Helen Oy. (2023). *Helen Vuosiraportti 2022*. https://www.helen.fi/tietoa-meista/helen-oy/tutustu-meihin/taloudelliset-julkaisut

Hofman, P. S., & Elzen, B. (2010). Exploring system innovation in the electricity system through sociotechnical scenarios. *Technology Analysis & Strategic Management*, *22*(6), 653–670. https://doi.org/10.1080/09537325.2010.496282

Hölscher, K., Wittmayer, J. M., & Loorbach, D. (2018). Transition versus transformation: What's the difference? *Environmental Innovation and Societal Transitions*, *27*, 1–3. https://doi.org/10.1016/j.eist.2017.10.007

Hyppänen, T. (Ed.). (2022). *Kohti hiilineutraalia Suomea—LUT-yliopiston energiaselonteko 5/2022*. https://www.lut.fi/sites/default/files/media/documents/LUT-yliopiston-Energiaselonteko-2022.pdf

Hyytinen, K., & Toivonen, M. (2015). Future energy services: Empowering local communities and citizens. *Foresight : The Journal of Futures Studies, Strategic Thinking and Policy*, *17*(4), 349–364. https://doi.org/10.1108/FS-08-2013-0035

Inayatullah, S. (2008). Six pillars: Futures thinking for transforming. *Foresight : The Journal of Futures Studies, Strategic Thinking and Policy*, *10*(1), 4–21. https://doi.org/10.1108/14636680810855991

IPBES. (2019). *Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (Robert T Watson, I. A. Baste, A. Larigauderie, P. Leadley, U. Pascual, B. Baptiste, S. Demissew, L. Dziba, G. Erpul, A. M. Fazel, M. Fischer, A. M. Hernández, M. Karki, V. Mathur, T. Pataridze, I. S. Pinto, M. Stenseke, K. Török, & B. Vilá, Eds.). IPBES secretariat.

Itten, A., Sherry-Brennan, F., Hoppe, T., Sundaram, A., & Devine-Wright, P. (2021). Co-creation as a social process for unlocking sustainable heating transitions in Europe. *Energy Research & Social Science*, *74*, 101956. https://doi.org/10.1016/j.erss.2021.101956

Kemp, R., Schot, J., & Hoogma, R. (1998). Regime Shifts to Sustainability through Processes of Niche Formation: The Approach of Strategic Niche Management. *Technology Analysis and Strategic Management*, *10*(2), 175–195.

Klitkou, A., Bolwig, S., Hansen, T., & Wessberg, N. (2015). The role of lock-in mechanisms in transition processes: The case of energy for road transport. *Environmental Innovation and Societal Transitions*, *16*, 22–37. https://doi.org/10.1016/j.eist.2015.07.005

Lachman, D. A. (2013). A survey and review of approaches to study transitions. *Energy Policy*, *58*, 269–276. https://doi.org/10.1016/j.enpol.2013.03.013

Finlex (2019). Laki hiilen energiakäytön kieltämisestä 416/2019, 416/2019 (2019). https://www.finlex.fi/fi/laki/alkup/2019/20190416

Lang, G. (2018). Urban energy futures: A comparative analysis. *European Journal of Futures Research*, *6*(1), 1–19. https://doi.org/10.1186/s40309-018-0146-8

Latour, B. (1990). Technology is society made durable. *Sociological Review*, *38*(1), 103–131. https://doi.org/10.1111/j.1467-954X.1990.tb03350.x

Lauttamäki, V. (2018). *Geoenergia kiinteistöjen lämmitysratkaisujen markkinoilla Suomessa energiakriisien ajoista 2030-luvulle* [Doctoral thesis, University of Turku]. https://www.utupub.fi/handle/10024/144984

Lauttamäki, V., & Hyysalo, S. (2019). Empirical application of the multi-level perspective: Tracing the history of ground-source heat pumps systems in Finland. *Sustainability: Science, Practice and Policy*, *15*(1), 82–103. https://doi.org/10.1080/15487733.2019.1678372

Majava, A., Vadén, T., Toivanen, T., Järvensivu, P., Lähde, V., & Eronen, J. T. (2022). Sectoral low-carbon roadmaps and the role of forest biomass in Finland's carbon neutrality 2035 target. *Energy Strategy Reviews*, *41*, 100836. https://doi.org/10.1016/j.esr.2022.100836

Mäkelä, V.-M., & Tuunanen, J. (2015). *SUOMALAINEN KAUKOLÄMMITYS*. Mikkelin ammattikorkeakoulu. https://www.theseus.fi/bitstream/handle/10024/97138/urnisbn9789515885074.pdf

Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy*, *41*(6), 955–967. https://doi.org/10.1016/j.respol.2012.02.013

Masini, E. (1993). *Why Futures Studies ?* Grey Seal Books.

Mazzucato, M. (2018). Mission-oriented innovation policies: Challenges and opportunities. *Industrial and Corporate Change*, *27*(5), 803–815. https://doi.org/10.1093/icc/dty034

Meadows, D. H., Meadows, D. L., Randers, J., & Behrens III, W. W. (1972). *The Limits to growth: A report for the Club of Rome's project on the predicament of mankind*. Universe Books.

Meadows, D. H., & Wright, D. (2009). *Thinking in systems: A primer*.

Moradi, A., & Vagnoni, E. (2018). A multi-level perspective analysis of urban mobility system dynamics: What are the future transition pathways? *Technological Forecasting and Social Change*, *126*, 231–243. https://doi.org/10.1016/j.techfore.2017.09.002

Mukherji, A., Thorne, P., Cheung, W. W. L., Connors, S. L., Garschagen, M., Geden, O., Hayward, B., Simpson, N. P., Totin, E., Blok, K., Eriksen, S., Fischer, E., Garner, G., Guivarch, C., Haasnoot, M., Hermans, T., Ley, D., Lewis, J., Nicholls, Z., … Yassaa, N. (2023). *SYNTHESIS REPORT OF THE IPCC SIXTH ASSESSMENT REPORT (AR6)*.

Nathan, S., Newman, C., & Lancaster, K. (2018). Qualitative Interviewing. In *Handbook of Research Methods in Health Social Sciences*. Springer Nature Singapore Pte Ltd.

Nelson, R. R. (2008). Bounded rationality, cognitive maps, and trial and error learning. *Journal of Economic Behavior & Organization*, *67*(1), 78–89. https://doi.org/10.1016/j.jebo.2007.06.002

Nilsson, M., Dzebo, A., Savvidou, G., & Axelsson, K. (2020). A bridging framework for studying transition pathways – From systems models to local action in the Swedish heating domain. *Technological Forecasting and Social Change*, *151*, 1. https://doi.org/10.1016/j.techfore.2018.04.003

Normann, H. E. (2017). Policy networks in energy transitions: The cases of carbon capture and storage and offshore wind in Norway. *Technological Forecasting and Social Change, 118*, 80–93. https://doi.org/10.1016/j.techfore.2017.02.004

Nurmeksen Lämpö Oy. (2023a). *Toimintakertomus 2022*. https://www.nurmeksenlampo.fi/documents/55812/0/toimintakertomus+2022.pdf/cbe60c04-5daf-fac4-b24e-a432cc0a01ce

Nurmeksen Lämpö Oy. (2023b). *Vuoden 2021 ja 2022 tilinpäätös*. https://www.nurmeksenlampo.fi/tilinpaatos1

Paiho, S., & Reda, F. (2016). Towards next generation district heating in Finland. *Renewable and Sustainable Energy Reviews*, *65*, 915–924. https://doi.org/10.1016/j.rser.2016.07.049

Paiho, S., & Saastamoinen, H. (2018). How to develop district heating in Finland? *Energy Policy*, *122*, 668–676. https://doi.org/10.1016/j.enpol.2018.08.025

Popper, R. (2008). How are foresight methods selected? *Foresight : The Journal of Futures Studies, Strategic Thinking and Policy*, *10*(6), 62–89. https://doi.org/10.1108/14636680810918586

Proskuryakova, L. (2017). Russia's energy in 2030: Future trends and technology priorities. *Foresight : The Journal of Futures Studies, Strategic Thinking and Policy*, *19*(2), 139–151. https://doi.org/10.1108/FS-07-2016-0034

Raven, R., & Verbong, G. (2007). Multi-Regime Interactions in the Dutch Energy Sector: The Case of Combined Heat and Power Technologies in the Netherlands 1970–2000. *Technology Analysis & Strategic Management*, *19*(4), 491–507. https://doi.org/10.1080/09537320701403441

Raworth, K. (2017). *Doughnut economics: Seven ways to think like a 21st-century economist*. Random House Business Books.

Ritchey, T. (2009). Morphological Analysis. In J. C. Glenn, T. J. Gordon, & UN Millennium Project, *Futures research methodology*. Millennium Project.

Robinson, J. B. (1990). Futures under glass. *Futures*, *22*(8), 820–842. https://doi.org/10.1016/0016-3287(90)90018-D

Rogge, K. S., Pfluger, B., & Geels, F. W. (2020). Transformative policy mixes in socio-technical scenarios: The case of the low-carbon transition of the German electricity system (2010–2050). *Technological Forecasting and Social Change*, *151*, 119259. https://doi.org/10.1016/j.techfore.2018.04.002

Rohrbeck, R. (2010). Towards a Maturity Model for Organizational Future Orientation. *Academy of Management Annual Meeting Proceedings*, *2010*(1), 1–6. https://doi.org/10.5465/AMBPP.2010.54493637

Rohrbeck, R., & Kum, M. E. (2018). Corporate foresight and its impact on firm performance: A longitudinal analysis. *Technological Forecasting and Social Change*, *129*, 105–116. https://doi.org/10.1016/j.techfore.2017.12.013

Røpke, I. (2016). Complementary system perspectives in ecological macroeconomics—The example of transition investments during the crisis. *Ecological Economics*, *121*, 237–245. https://doi.org/10.1016/j.ecolecon.2015.03.018

Sandbag. (2023, June 6). Carbon Price Viewer. *Sandbag Climate Campaign*. https://sandbag.be/index.php/carbon-price-viewer/

Saunders, M. N. K., & Lewis, P. (2018). *Doing research in business and management* (2nd edition). Pearson.

Schot, J., & Geels, F. W. (2008). Strategic niche management and sustainable innovation journeys: Theory, findings, research agenda, and policy. *Technology Analysis & Strategic Management*, *20*(5), 537–554. https://doi.org/10.1080/09537320802292651

Schwartz, P. (2007). *The art of the long view: Planning for the future in an uncertain world* (Repr). Wiley.

Seppälä, Y. (2018). The Futures Table (Morphological Matrix) Method. In O. Kuusi, S. Heinonen, & H. Salminen (Eds.), *How Do We Explore Our Futures? Methods of Futures Research* (pp. 139–155). The Finnish Society for Futures Studies.

Smith, A., Stirling, A., & Berkhout, F. (2005). The governance of sustainable socio-technical transitions. *Research Policy*, *34*(10), 1491–1510. https://doi.org/10.1016/j.respol.2005.07.005

Smith, A., Voß, J.-P., & Grin, J. (2010). Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges. *Research Policy*, *39*(4), 435–448. https://doi.org/10.1016/j.respol.2010.01.023

Sovacool, B. K. (2019). *Visions of Energy Futures: Imagining and Innovating Low-Carbon Transitions*. Routledge.

Sovacool, B. K., & Hess, D. J. (2017). Ordering theories: Typologies and conceptual frameworks for sociotechnical change. *Social Studies of Science*, *47*(5), 703–750. https://doi.org/10.1177/0306312717709363

Statistics Finland. (2022a). *Households' consumption by Heating mode, Year and Information*. https://pxdata.stat.fi/PxWeb/pxweb/en/StatFin/StatFin__ktutk/statfin_ktutk_pxt_13qk.px/table/tableViewLayout1/

Statistics Finland. (2022b). *Production of district heat*. https://pxdata.stat.fi/PxWeb/pxweb/en/StatFin/StatFin__salatuo/statfin_salatuo_pxt_12b7.px/table/tableViewLayout1/

Suarez, F. F., & Oliva, R. (2005). Environmental change and organizational transformation. *Industrial & Corporate Change*, *14*(6), 1017–1041. https://doi.org/10.1093/icc/dth078

Trading Economics. (2023). *Coal—2023 Data—2008-2022 Historical—2024 Forecast—Price—Quote—Chart*. https://tradingeconomics.com/commodity/coal

Vadén, T., Majava, A., Toivanen, T., Järvensivu, P., Hakala, E., & Eronen, J. T. (2019). To continue to burn something? Technological, economic and political path dependencies in district heating in Helsinki, Finland. *Energy Research & Social Science*, *58*, 101270. https://doi.org/10.1016/j.erss.2019.101270

Verbong, G. P. J., & Geels, F. W. (2010). Exploring sustainability transitions in the electricity sector with socio-technical pathways. *Technological Forecasting and Social Change*, *77*(8), 1214–1221. https://doi.org/10.1016/j.techfore.2010.04.008

VUCA-World. (2023, March 15). VUCA, BANI, RUPT or TUNA. *VUCA-WORLD*. https://www.vuca-world.org/vuca-bani-rupt-tuna/

Walker, W. (2000). Entrapment in large technology systems: Institutional commitment and power relations. *Research Policy*, *29*(7), 833–846. https://doi.org/10.1016/S0048-7333(00)00108-6

World Commission on Environment and Development (Ed.). (1987). *Our common future*. Oxford University Press.

Yle Uutiset. (2021, September 25). *Suomessa kehitetään vauhdilla pienydinvoimaloita – Helsinki harkitsee sellaisen tuomista kaupunkiin kymmenessä vuodessa*. Yle Uutiset. https://yle.fi/uutiset/3-12098463

Yle Uutiset. (2022, October 31). *Pienydinvoimalat ovat todellisuutta jo muutaman vuoden päästä – selvitimme, millaisiin paikkoihin niitä voitaisiin Suomessa sijoittaa*. Yle Uutiset. https://yle.fi/uutiset/3-12664757

Yle Uutiset. (2023a, March 23). *ESE tekee jatkossa kaukolämpöä myös halvalla pörssisähköllä – hakkeen hinta on noussut jo kolmanneksella*. Yle Uutiset. https://yle.fi/a/74-20023800

Yle Uutiset. (2023b, April 24). *Suomessa ei synny enää tarpeeksi jätettä, ja siksi meille raahataan nyt tonneittain italialaisten roskia poltettavaksi*. Yle Uutiset. https://yle.fi/a/74-20027904

Yle Uutiset. (2023c, May 29). *Kuopiossa etsitään paikkaa pienydinvoimalalle – pelkkä lupaprosessi voisi kestää kuusi vuotta*. Yle Uutiset. https://yle.fi/a/74-20033490

Yle Uutiset. (2023d, June 22). *Ehdotus raottaa ovea kaupunkien pienydinvoimaloille: Turvaetäisyydet kutistuvat laitosten mukaan*. Yle Uutiset. https://yle.fi/a/74-20037741

APPENDICES

Appendix 1. An interview script (translated from Finnish)

Welcome and thank

Explaining the purpose of the research, anonymity, confidentiality, withdrawal at any timeline

Video and audio recording

Consent form

Setting the scene

1. What is your background in relation to district heating?
2. DH has been in the news recently. Companies are introducing new strategies towards carbon neutrality and some have announced price increases. What do you think of the recent news?
3. (landscape) What are the things that you see affecting district heating on a top level? Something that puts pressure on the system and what the industry can hardly change? (presumably: digitalisation, climate crisis, price demands, increasing fossil fuel prices (Paiho & Saastamoinen 2018))

   Regime
4. (industry) Who are the main actors in the industry at the moment and why? Are they the same in the future?
5. (markets) How are the markets of district heating going to evolve? Are there changes in user preferences? What kinds of effects do those changes have?
6. (markets) How do you see the future effects of market changes like prosumers (consumers acting as producers), household energy self-sufficiency and energy positive neighborhoods? (inspired by Paiho & Saastamoinen 2018)
7. (culture) Do you think that ways of heating and living change in the future, other than what has already been discussed?
8. (markets) Are business models evolving and how could they evolve further? (inspired by Paiho & Saastamoinen 2018)
9. (markets) In a study from 2018, DH experts described a few business challenges: competitiveness, opening of networks, pricing, subsidy and fiscal policy. Do you see these as challenges now and in the future?

   Technologies
10. (technology) Are there technologies that are coming to their end? When? Why?

11. (technology) How would you describe the future success and relevance of the following technologies?

    - Hydrogen, synthetic fuels, small modular nuclear reactors, waste and excess heat, geothermal energy and ground sourced heat, biofuels, solar heat, photovoltaics and solar panels, heat storages, heat pumps, electric boilers, biomass, BECCS, other?
12. (science, niche) Are there expectations to science and scientific research to discover new solutions?
13. (technology) Do you think the technological solutions in use will be the same in Finland as in the rest of the world?
14. (markets, technology) How do you see district cooling?
15. (technology) What is the share of renewable energy in district heating in 2050 (2020: 54%)?

Regime continues (30 minutes marker)

16. (policy) How would you describe the influence of policies and regulations on the developments of district heating currently and in the future?
17. (policy) What kind of policies would be needed to foster a sustainability transition in district heating?
18. (policy) What kind of policies would you rather not see implemented in the future?

Niche and weak signals

19. Is there something that is an early sign or rarely talked about in district heating?

Transitions

20. (general) What is sustainable district heating to you? Is Finnish district heating sustainable?
21. (transition) How could it become sustainable?
22. (Smith et al. 2010) What do you think of a sustainability transition in district heating?
23. Does it flow bottom-up or top-down? Is it innovation-driven or driven by policy or by incumbent actors?
24. (Geels and Schot) Will there be a total transformation, gradual reconfiguration or substitution of existing solutions with new solutions, or is it more of a crisis situation whose outcome is currently unclear?
25. (if time) How can companies make the most out of current and future opportunities?

Time travel

26. Let’s take a moment and breathe a few deep calm breaths.

27. Now look back from the present moment and think about how district heating has changed and evolved during the last 30 years. What comes to your mind?
28. Now travel forward to the year 2050 where district heating is carbon neutral and sustainable. What has changed and how in 30 years?
    - luring topics: decentralisation, renewables, multiple production means, prosumers, energy storage

Thanks and farewells

Appendix 2. The complete futures table.

Classification	Variable title	Value 1	Value 2	Value 3	Value 4	Value 5	Value 6	Value 7	Value 8	Value 9	Value 10	Value 11	Value 12
MLP technology	Dominant DH heat production technology	Cheap and energy-efficient hydrogen production (A, B, C, D, F, G)	SMR easy and cheap (A, B, C, E, F, G)	Heat pumps (A, B, C, D, F, G, H)	Burning bio-based fuels (A)	Electric boilers (C, D, H)	Solar (G)	Electrification of DH production (D, F, H)	Synthetic fuels (A, H)	Hybrid systems (B, E)			
MLP technology	Other technological aspects	DH networks upgraded	Energy storage (B, E, F, G, H)	CCS (A, D)	**Virtual power plants**	*Waste heat*							
MLP Market and user preferences	Competition and demand	Declining demand due to energy efficiency and property solutions like HP, GSH, Solar thermal, Biomass	Increasing demand due to urbanization	Shifting customer preferences: bi-directional prosumers (A)	Shifting customer preferences: district cold and air conditioning, indoor air quality and other services	No prosumers (H)							
MLP Market and user preferences	**Energy market regulations**	Deregulation of energy markets	Competition policy (A)	Security of supply regulations	**Energy market integration**	Improved status of prosumers and households							
MLP Science	Most prominent scientific and technological advancements	Technological breakthrough: fusion or other significant excess power	Systemic design with data, AI and monitoring	No major breakthroughs	Energy storage enables long-term storing, making use of intermittent	SMR (A)	Ground sourced heat (A, H)	*Social engineering breakthrough*	**Quantum computing**	**Nanotechnologies**	**Artificial intelligence**	**Materials science**	

		source			nature of renewable energy								
MLP Industry	Operating principle	Collaboration among DH industry: research, pilot projects, joint investments, joint ventures (A, ChatGPT)	International big money ownership (A), diluted business operating district borders, increased rivalry	City-ownership and public-private partnerships (A)	Separation of business areas (A, B, H)								
MLP Industry	**Business models**	**Peer-to-peer energy trading**	**Demand response management services**	**Energy as a service**	*Traditional*								
MLP Policy	Impactful national and EU policy and legislation	Opening of networks (B)	Forest biomass restricted or limited (A, E)	Taxonomy (A)	Electricity taxation changes (H)	Emission trading (H) and carbon pricing	Property solution incentives (A)	**Energy efficiency regulation and targets**	**European standards for DH system design and operation (opening?)**	**Renewable energy mandates**	**Feed-in tariffs**	**Priority access to energy markets**	Eased regulation for SMR
MLP Policy	Impactful local policy	**Support for DH expansion**	**Zoning and building codes (D, G)**										
MLP Culture	Cultural influence	Compensation services (A)	Negative perception, media trumps DH (A)	DIY, prosumers, energy awareness, smart home	Green transition, environmental aspects	Engineering people (A)	Positive perception, acceptance of DH as best solution	Opposition to SMR – NIMBY					

MLP Niche	Niche	Building automation systems	Elasticity of demand and demand response systems (B, E)	Hydrogen (G)	Peak production capacity (H)	Energy poverty (A)	*Increased availability of renewable heating technologies*						
MLP Landscape	Dominant megatrend	***Urbanization and demographic changes***	Energy poverty (A)	***Green transition: increasing demand for renewable energy sources***	Russo-Ukrainian war aftermath and political stability, effects to energy supply	**Global energy and climate trends: International agreements to reduce greenhouse gas emissions**	**Technological innovation and disruption**						
Speed	Speeding or slowing	Old DH network infrastructure completely transformed and upgraded(A)	Support and incentives for energy renovations										
Specific shock	Specific shock	Demand for 100% renewable	Fossil fuel supply errors	Actor with endless demand for energy, always ready to buy excess energy	Cannibal subsidies (A)	***Changes in energy prices, taxes on fossil fuels***	**Economic recession or rapid growth**						
Realised weak signal	Realised weak signal	Cooling services (F, H)	Burning restricted, ie. only with CCS (A, B, C, E,	Business outside network area (B)	Biodiversity (C)	Replacing DH with property solutions (A)	*Quantum and super computer waste heat*						

			Н)										

Appendix 3. Original exerpts from interviews.

“jos se tähtäin seuraavassa 30 vuodessa, niin ehkä rupeen olemaan jo vanha ja kyyninen, että ne kerkeis kaupalliseen skaalautumisvaiheeseen ja vaikuttamaan tässä aikajänteessä, mitä me ei nyt tiedetä eikä oo tutkaruudulla, niin epäilen. että sillä tavalla niinku paino on näissä asioissa mitä nyt tehdään.” [eng. If the target is in the next 30 years, perhaps I’m starting to feel old and cynical, that they would achieve market scalability and be effective within the time period, what we don’t know and is not within the radar, I highly doubt it. Thus the weight lays on these current affairs.]

“-- on varmaan vähän erilaisia tilanteita vähä eri puolilla Suomee eri paikkakunnilla, mut jos ajattelee sen lämmitysmarkkinan näkökulmasta niin kyllä meillä siellä se muutos on käynnissä.” [eng. There must be differing situations around Finland in each town, but if we think about it from heating market’s perspective, we do have the change in effect.”

“Joo siis kyllähän se markkina koko ajan muuttuu ja, itsessäänhän kaukolämpö tuotteena muuttuu, jo se tuotantotavat siellä taustallahan, sehän on ollu hirvittävän nopeeta et miten tota nopeesti esimerkiksi kuvitellaan tällä hetkellä jo että lämpökin, tai niinku kaukolämpökin muuttuu hiilineutraaliksi ja se itsessään se muutos jo on niinku, se on se varmaan se kaikkein suurin muutos siellä, se, tavallaan se päästöttömyys siellä taustalla, itsessään sen tuotteen osalta.” [eng. Yeah the market is constantly changing, and the district heat itself as a product is changing, even the means of production in the background, it has been extremely fast, for example think about the heat is turning into carbon neutral and that is the greatest change of all there, in essence being emission free in the background, around the product itself.]

“Must tuntuu että toi kaukolämpöala on vähä semmosta konservatiivista. Et ne on ehkä semmosia aika hitaita ne muutokset. Ehkä just meilläki sitte ku päädyttiin tohon noin nopeeta hiilestä luopumiseen niin se on sit buustannu tän homman nopeemmin liikkeelle. Mut jos ei ois ollu niin tuskinpa.” [eng. I think district heating industry is rather conservative. That they are perhaps a bit slow, the changes. Perhaps that’s why when we [in Finland] decided to ban coal so fast, it has boosted this change further. But if no [ban was set], I doubt it.]

“siis jos nyt itte miettii että mä olen tätä nyt seurannut tässä ehkä sen 25 vuotta niin ihan valtavastihan tässä on niinku tapahtunu asioita mitä ei ois osannu ajatellakaan sillon 25 vuotta sitte et kaikkee tällasta. Vaikka sanotaan että kaukolämpö on niinku, [naurahtelua] ehkä vähän vanhoillinen toimiala mut et kylhän sielki, sielläkin niinku esimerkiksi lämpö, lämpöpumppujen ja sen, erilaisten lämpöpumpputeknologioitten kautta niin, on niinku menny ihan valtavasti tullu uusia asioita ja ja totaa..” [eng. When I think about I’ve been following this for about 25 years, a whole lot has happened that I could not have thought of 25 years back. Even if they say that district heating is like, [laughter] a bit conservative industry but indeed, for example, heat and heat pumps and heat pump technologies have resulted in many new things…]

“kyllä se näkyy tulevien kymmenen vuoden aikana niin tapahtuu todella paljon. Kaukolämmön sähköistyminen ja nää sektori-integraatiot niin ne on nyt niin vahvasti käynnissä, että uskon, että me näemme seuraavan 10 vuoden aikana nää vanhat perinteiset [tuotantotavat] on otettu kuviosta pois, ja siinä on sit tullu nää uudet tuotantomahdollisuudet ja varastointimahdollisuudet.” [eng. Yes it will show in the next ten years will happen a lot. Electrification of district heat and these sector integrations are now on so strongly, that I believe that we’ll see within ten years that these traditional old [ways of production] are taken down, and there are then these new production possibilities and storage possibilities.]

“kyllä näkisin että nämä yhtiöt jotka panostavat vahvasti siihen kaukolämmön kehitykseen, innovointiin, esimerkiksi vetytalouteen liittyviin ratkasuihin, niin ovat niitä suurimpia vaikuttajia tällä hetkellä” [eng. I’d say that these companies that are investing heavily on developing district heating, innovation, for example hydrogen economy related solutions, they are the biggest influencers at the moment.]

“Kyl mä tunnen tän alan aika hyvin näin nää yritykset, niin siellä on sopivan nuorta porukkaa, siellä on tämmöset vanhat jäärät laitettu jo pois. Et siellä ei oo niinku sitä jarrua siel johtopäässä enää, et kyl siellä semmoset ihmiset jotka haluu ettii sitä muutosta niin ne on tekemässä tosissaan töitä sen eteen.” [eng. I do know this field quite well these companies, they have proper young people, they have thrown such old people out already. That they don’t have [old] people [slowing down change] in the management, that there are people that thrive to look for change and they are really working for it.]

“iso osa sitä ratkasua Suomessa tää ratkasu, koko Suomen niinku kestävyyssiirtymän osalta, että Suomessa tää niinku näyttelee suurta osaa tää kaukolämpö siinä kokonaisuudessa. Että mää nostasin sen ehkä niin päin että meillä on niinku valtava etu verrattuna vaikka muuhun Eurooppaan siinä, että miten me pystytään niinku tätä kestävyyssiirtymää tekemään, ja siinä niin yks iso tekijä on meillä kaukolämpö ja sen iso rooli täs meijän energiajärjestelmässä.” [eng. Big part of this solution in Finland, in relation to Finland’s sustainability transition, is that district heating plays a big role in the whole. I’d say it this way that we have a huge advantage compared to other Europe that how we can do the sustainability transition, and a big factor in that is district heating and its big role in our energy system.]

“PH: Niin varmaan kuitenki tällanen imagoisku on osittain tullu tässä.
F: Tulee koko ajan. Nyt ku tuolla ihmiset katsoo puol ysin uutisia, niin siellä sanotaan että kaukolämpö kallistuu joka paikassa, niin mikä käsitys siitä sitte jää.” [eng. PH: Yeah there has been a partial hit on the image [of district heating]. F: Incoming all the time. Now that people out there are watching the half past eight news, they say [in the news] that district heating is becoming more expensive everywhere, so what is the image that remains.]”

“Ja se että Helsinki joutuu nostamaan hintoja, niin sehän on koko alalle ihan katastrofi, ku varsinki Yleisradio ja kumppanit toitottaa tuolla että kaukolämmön hinta on kallistunu, ja tulee semmonen kuva että on tapahtunu joka puolella ja täysin väärillä mielikuvilla mennään liikkeelle tai mennään eteenpäin asian suhteen. Sit ku vielä media tätä toitottaa.” [eng. And that Helsinki has to increase prices, well that’s a catastrophy for the whole industry, especially when the Finnish Broadcasting Company and others deliver a message that price of district heating has increased, and one receives an image that it has happened everywhere and with false mental images you start going forward with it. And then the media repeats this.]

“[energiavarasto] antaa helvetinmoinen määrän joustavuutta siihen tuotantopuolelle. -- pannaan vanha CHP-laitos, jos siinä ei sähkön hinnat oo tarpeeksi hyvät, niin ei oo tarvetta ajaa sitä vaan lämmön takia, mikä aikaisemmin on ollut, että pitää pitää koko laitosta käynnistä, että saadaan lämpöä koko kaupungille. Mutta nyt sen lämmön voi ottaa sieltä varastosta. Se on todella hyvä.” [eng. [energy storage] gives a hell lot of flexibility to production. -- take an old CHP plant, if electricity prices are not good enough, then there’s not need to run it only for heat, which has been the case earlier, that you need to run the whole plant, to get heat for the city. But now you can take the heat from the storage. That’s very good.]