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To continue to burn something? : Technological, economic and political path dependencies in district heating in Helsinki, Finland

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To continue to burn something? Technological, economic and political path dependencies in district heating in Helsinki, Finland

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Abstract

The transition away from fossil fuel based infrastructure for heating and cooling has to happen on a scale and timetable with no historical precedent. As the systems are large and networked, path-dependencies constrain the transition that is further complicated by the diversity of stakeholders. Here we analyse the case of transitioning the district heating system in the city of Helsinki, Finland, within the target of a carbon neutral metropolitan area. Despite relatively advanced climate policies, path-dependencies on the political, technological-material and economical levels interact in creating a "wicked" problem with no obvious solution and potential for backsliding. It is in this context that a possibility of a green paradox arises: despite the explicit commitment of all stakeholders towards carbon dioxide emission reductions, the combination of the path-dependencies may result in a transition that increases emissions. Our results highlight policy implications of path-dependencies for researchers, government and business.

Keywords

path-dependency; energy transition; district heat; green paradox

Declarations of interest

None

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1 To continue to burn something? Technological, economic and political path 2 dependencies in district heating in Helsinki, Finland

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4

5 **Abstract.**

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7 happen on a scale and timetable with no historical precedent. As the systems are large and
8 networked, path-dependencies constrain the transition that is further complicated by the
9 diversity of stakeholders. Here we analyze the case of transitioning the district heating
10 system in the city of Helsinki, Finland, within the target of a carbon neutral metropolitan area.
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12 technological-material and economical levels interact in creating a "wicked" problem with no
13 obvious solution and potential for backsliding. It is in this context that a possibility of a green
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17 researchers, government and business.

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19 **Keywords**

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22 **Declarations of interest:** none

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25 **1 Introduction**

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27 Transition to low-carbon infrastructure is a key target for economies aiming to mitigate the

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64 28 worst effects of climate change and to achieve the goals of the Paris agreement 2015. The
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66 29 literature on transition emphasizes the need for a deep-seated and wide-ranging transition
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68 30 within three decades [1], [2], [3], while acknowledging that the combination of the needed
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70 31 scale and pace of change has no historical precedent [4], [5].
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74 33 From the perspective of material and energetic conditions of societies, the crucial question is
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76 34 the legacy infrastructure that has been built, maintained and is still run mostly on fossil fuels
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78 35 [6], [7]. The infrastructure includes power plants, energy transmission and storage systems,
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80 36 buildings, transport systems, and city structures, which in Smil's [7] estimate correspond to
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82 37 at least 25 trillion USD (1990 international dollars) in investments during the last century
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84 38 alone.

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88 40 Replacement, early retirement or retrofit of existing infrastructure is constrained by
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90 41 economic, political and technical factors with their own historical trajectories. The interlinked
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92 42 path-dependencies make the problem complicated. There is a diversity of stakeholders, and
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94 43 decisions made now will result in lock-in of development paths and resources for potentially
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96 44 several decades, while every year of inaction necessitates even faster cuts of emissions in
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98 45 the future. Responding to these problems implies using systemic knowledge about the
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100 46 interactions of stocks and resource use at different spatial and temporal scales [8].

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103 48 Here we build on the existing literature of path-dependencies and connect it with the
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105 49 literature on transitions. We then use this general context to frame one recent case in
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107 50 Finland as illustrative of the real-world path-dependencies and their effect on climate action:
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109 51 the role of the district heating (DH) system in the city of Helsinki in the overall goal of carbon
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111 52 neutrality nationally and in the Helsinki metropolitan area.

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115 54 In the literature, energy transition is analyzed from different perspectives, such as social,
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123 55 technological, economical, infrastructural, institutional and political. The so-called multi-level
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125 56 perspective [9], [10], analyses transitions arising from the interplay at three analytical levels:
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127 57 “niches (the locus of radical innovations), socio-technical regimes (the locus of established
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129 58 practices and associated rules that enable and constrain incumbent actors in relation to
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131 59 existing systems), and an exogenous socio-technical landscape” [9]. Here we concentrate
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133 60 on the level of socio-technical regimes as the level where the analyzed constraints and path-
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135 61 dependencies appear, and the analysis will concern the technological, economical and
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137 62 political perspectives. The “wickedness” [11] of the problem of transition is illustrated by the
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139 63 possibility that despite the explicit commitment to the goal of carbon neutrality by all relevant
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141 64 stakeholders, the current trajectory for the system may lead to a “Green Paradox” [12]: due
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143 65 to efforts towards transition, the actual amount of greenhouse gas (GHG) emissions may
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145 66 increase.

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149 68 Overall, the purpose of this study is to show how path-dependencies interact in creating a
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151 69 complicated problem for energy transition with no obvious solution and even potential for
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153 70 backsliding. Furthermore, our analysis offers guidance on how policies may be changed so
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155 71 that the green paradox can be avoided.

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159 73 In this case study our research questions are:

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161 74
- 162 75 1. What are the key path dependencies, constraints and legacy technological solutions
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164 76 in DH in Helsinki, as framed by the need to move to carbon neutral energy provision?
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166 77 2. How do these path-dependencies underlie the wickedness of the problem of
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168 78 transition towards carbon neutral energy, and even point toward a trajectory creating
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170 79 a green paradox?
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172 80 3. What general lessons for policy guidance can be derived from this case study?
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183184 **83 2 Background: Energy transitions, lock-ins, path-dependency and the green paradox**
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188 85 It is abundantly clear that there is a need for massive shift in the way energy is generated
189 86 and used. While there is a constant barrage of news about breakthroughs of renewable
190 87 energy in the markets, and their cost is starting to be competitive [13], past experience of
191 88 energy transitions is worth observing. Historically, transitions have been slow, and the
192 89 evolution of technologies is influenced by problems of scale and previous infrastructure [6],
193 90 [7].
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202 92 Recently, Sovacool [4] suggested that the present transition might be proceeding quicker
203 93 than historical examples. The conventional transition literature, e.g., [14], [7], posits that it
204 94 takes between 50 and 160 years for a total energy transition to occur. Sovacool [4] suggests
205 95 that future energy transitions can be accelerated to the point where they take only a few
206 96 years or decades. On the other hand, Smil [7] and Fouquet [15] argue that scaling issues
207 97 and legacies from previous technology point to a more conservative estimate. Smil [7] offers
208 98 a critique of Sovacool's [4] suggestion, citing evidence suggesting that at a national level
209 99 transition can be fast, but on the global level it is much slower. The slow pace is mainly due
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217 100 to path-dependency and technological lock-ins.
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221 102 Fouquet [15] offers a review of energy path-dependency and lock-in situations. A lock-in
222 103 situation is usually referred to when energy generation is preferential to using a system that
223 104 is either less energy-efficient or is highly energy-intensive compared to best available current
224 105 technologies. Lock-ins happen when there are high infrastructure costs or there exist
225 106 legacies of previous infrastructure that would be expensive to change or retrofit. They can
226 107 also happen through historical trajectories where early-on competition has pushed an energy
227 108 system towards one particular technology, which in turn has increased its likelihood of
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241 109 becoming the dominant technology [16], [15]. There is a wide literature on this issue, usually
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243 110 under the title “history matters” [17], [18], [19].
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247 112 Lock-ins and path-dependencies are not only a matter of infrastructure and technology, but
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249 113 may also arise due to policy decisions. For example, the “green paradox” is an example of
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251 114 adverse policy fueled path-dependency. The concept was coined to illustrate a situation
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253 115 where the announcement of a future climate policy, such as a carbon tax, raises short-term
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255 116 emissions as fossil fuel producers increase their extraction today as a response to an
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257 117 anticipated reduction in future resource rents [20], [21], [12]. Other examples of green
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259 118 paradox include the observations that subsidies for renewable energy can increase
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261 119 emissions through increasing fossil fuel extraction [22] and that giving positive feedback to
262
263 120 citizens on their green choices can lead to less green behavior by the same citizens [23].
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265 121 Following [12], we will use the term in a wide sense to describe unintended negative (for
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267 122 instance, emission increasing) consequences of climate policies.
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271 124 Harjanne & Korhonen [24] have pointed out how the use of the term “renewable energy” to
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273 125 cover a wide variety of very different forms of energy generation is problematic in
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275 126 discussions of transition. They note that the term contains problems with regard to
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277 127 sustainability, incoherence, policy impacts, and bait-and-switch tactics [24]. As an example
278
279 128 of the bait-and-switch tactic, Harjanne & Korhonen [24] discuss the national coal ban in
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281 129 Finland, which is communicated as an accelerated action for climate change mitigation [25].
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283 130 However, the expected outcome is a move towards wood biomass use [26], a renewable
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285 131 source, which, however, produces more end-of-pipe emissions compared to coal.
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289 133 In the current international GHG accounting framework, based on the Kyoto protocol and
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291 134 implemented in the EU Emissions Trading System (ETS), bioenergy is treated as carbon
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293 135 neutral in the energy sector, and any emissions from bioenergy are included in the land
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300 136 sector (LULUCF) accounting. Furthermore, the EU has labeled wood biomass as a
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302 137 renewable energy source [27]. Consequently, fossil fuels are being replaced by wood
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304 138 biomass around Europe, including in Finland [28]. An additional incentive for the energy use
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306 139 of wood in Finland is provided by the government bioeconomy framework [29], [30], that, for
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308 140 instance, subsidizes wood chip production [31]. The problem is that carbon dioxide
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310 141 emissions per produced energy unit are higher from wood biomass than from coal, and the
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312 142 uptake of the “carbon debt” resulting from wood burning is conditional on the dynamics of
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314 143 biomass (re)growth [32]. Consequently, the climate benefits of transitioning from fossil fuels
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316 144 to wood have been contested on the global and European levels [32], [33], [34], [35], as well
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318 145 as in the context of the Finnish bioeconomy framework [36].
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322 147 The life-cycle comparison between coal burning and wood biomass burning contains many
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324 148 variables, including combustion and processing efficiency, carbon intensity of combustion
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326 149 and carbon intensity of supply chain for both fuels, as well as the particulars of the forest
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328 150 type and harvesting methodology [32]. Recent research ([32], for studies using
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330 151 Finnish/Scandinavian forest data see [37], [38], [39]) suggests that repaying the resulting
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332 152 carbon debt from the transition from coal to wood takes several decades, even up to a
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334 153 century, which from the perspective of the needed pace of transition may be too slow. These
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336 154 results suggest that transitioning from coal to wood in energy generation may even increase
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338 155 carbon dioxide emissions within the crucial time frame for transition, rather than diminish
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340 156 them.

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343 158 The coal ban and the implied move to wood biomass form the immediate background of our
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345 159 case study. Our intention is to analyze the path-dependencies and constraints that lie behind
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347 160 the “bait-and-switch” mentioned by Harjanne & Korhonen [24]. More generally, we use
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349 161 Helsinki district heating system as a case study on how a well-meaning and advanced
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351 162 climate policy can have adverse effects due to not taking fully into account the path-

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359 163 dependencies on various levels, including the material, economical and policy levels. In our
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361 164 analysis, it is the interaction of the path-dependencies on these levels that creates
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363 165 complications for the transition and the potential for a green paradox. Furthermore, we will
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365 166 use the analysis of the path-dependencies in order to evaluate the policy implications of the
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367 167 case.

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371 169 The potential for the green paradox is set by the path-dependent structure of the existing DH
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373 170 system. It is technically built and optimized for a certain temperature and pressure, and
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375 171 needs a wide enough customer base to make economic sense. Under these circumstances,
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377 172 if the decision of replacing existing co-generation plants happens in a moment where
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379 173 emissions from coal are penalized or coal use is outright banned, and emissions from
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381 174 biomass are not, the result may be investment in a fleet of biomass burning plants that lock
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383 175 in years if not decades of increased emissions, even though the explicit goal at the moment
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385 176 of decision is to decrease emissions.

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389 178 Next, in section 3, the methods and data are described. In section 4, the object of our case
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391 179 study, the city of Helsinki district heating system is introduced from the perspective of its
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393 180 historical trajectory, and its main stakeholders. In section 5, the existing situation is briefly
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395 181 described from technical, economical and political perspectives before, in section 6,
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397 182 analyzing the material and policy-related path-dependencies, and showing how they interact
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399 183 in creating a complicated situation with a clear potential for a green paradox. The results are
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401 184 presented in section 7, before a discussion in section 8 and conclusion in section 9.

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404 186 **3 Methods and data**

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408 188 Our approach is exploratory and aims at description and understanding of a case within a
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410 189 larger context [40]. We set out for inductive fact finding without any theoretical

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418 190 preconceptions or hypotheses to test, like in the approaches labeled under grounded theory
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420 191 [41]. The research questions 1-2 are prompted by the problems in transition to low-carbon
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422 192 infrastructure, as articulated by multiple stakeholders. The questions are motivated by the
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424 193 need to find out which factors are stalling transition in the particular case, and the context for
425
426 194 the questions is formed by the existing literature on transition and path-dependencies. They
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428 195 also lead directly to research question 3, as a better understanding of the path-
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430 196 dependencies may inform the practices of the different stakeholders.

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434 198 The research setting is thus case-led rather than theory-led, and consequently the data
435
436 199 gathering relies on methods (document analysis, participant observation) suited for
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438 200 exploratory contexts with low theoretical ambitions [42]. By definition, results from this kind of
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440 201 inductive and exploratory research setting cannot, as such, distinguish between existing
441
442 202 theoretical views and the verification of the results is hard if not impossible. However, the
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444 203 results may be hypothesis confirming or hypothesis generating, like results from grounded
445
446 204 theory approaches, which as [43] notes, have been fruitfully used for various topics in energy
447
448 205 research.

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451 207 For original data gathering, we used document analysis and participant observation.
452
453 208 Document analysis refers to the process of collecting data via analyzing written documents
454
455 209 [44]. The original data on the research questions 1-2 was gathered primarily through
456
457 210 analysis of publicly available documents published by the stakeholders. A comprehensive list
458
459 211 of the documents used is presented in the supplementary material. It contains the websites
460
461 212 of the included stakeholders (national and local administration, the utility company, political
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463 213 parties, NGOs and research organizations), as well as documents from newspapers, web
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465 214 publications and social media. The documents were read, and notes taken on the views
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467 215 presented on the future of DH, the coal ban, use of wood biomass and other relevant issues.
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469 216 The analysis was conducted manually, as it was seen that, e.g., quantitative coding or
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477 217 statistical methods were not needed. Documents were read and notes taken by multiple
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479 218 authors, and the main author independently verified from original sources the views
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481 219 presented here. The main document sources that are available online are referenced within
482
483 220 this article.

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487 222 Participant observation is often used in long-term studies intended for intensive involvement
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489 223 with a group of people, but it can also be used for data-gathering without the goal of deep
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491 224 anthropological or cultural study [45], [46]. Participant observation is recommended for
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493 225 research settings where researchers need to enrich their understanding of what questions to
494
495 226 ask and for gaining an understanding of the meaning and relevance of the data [46]. In this
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497 227 case, participant observation was chosen as a method to facilitate direct contact with
498
499 228 stakeholders in order to validate the data gathered from document review and to widen the
500
501 229 range of what to look for in the data.

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503 230
504
505 231 The authors conducted the observation either as complete participants or as participants-as-
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507 232 observers [45] in 14 different events and discussions on the theme of transition in DH in the
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509 233 Helsinki metropolitan area within the timeframe between September 2018 - January 2019.

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511 234 As the time period was limited and researchers from various universities and research
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513 235 groups were and have been involved in the discussions on transition for a long time in visible
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515 236 roles, the potential ethical dilemmas of participant involvement [47] could be kept to a
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517 237 minimum. The events ranged from private discussions and invite-only round-table
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519 238 discussions with less than 10 participants to large public events (see table 1).

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521 239 Representatives from all the analyzed stakeholder groups were present at the same time in
522
523 240 at least three of these events, while participants in some of the events consisted only of one
524
525 241 group of stakeholders.

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Event	Topic	Date	Participant stakeholders
Public seminar	Alternatives to coal in DH	26.9. 2018	Greenpeace Finland, political parties
Private discussion	Technical and economic issues, esp. load and production curves	10.10. 2018	ex-CEO of Helen Ltd
Private discussion	Political issues, views within the city council	26.10. 2018	City councillor (Greens)
Private discussion	Technical and economic issues	2.11. 2018	ex-CEO of Helen Ltd
Private discussion	Technical and economic issues	14.11. 2018	ex-CEO of Helen Ltd
Roundtable discussion	Upcoming motions on DH in the city council	20.11. 2018	City councillor (Greens), city councillor (Pirate Party), city councillor (Left Alliance)
Private discussion	Technical and economic issues	27.11. 2018	ex-CEO of Helen Ltd
Private discussion	City ownership policy	4.12. 2018	Chairman of the Board, Helen Ltd
Public seminar	Roadmap towards carbon neutral DH in Helsinki	11.12. 2018	Representatives from city council groups, Helen Ltd., NGOs
Private discussion	Political issues, views within the city council	11.12. 2018	City councillor (Social Democrats)
Private discussion	Coal ban and DH	12.12. 2018	City council group, Greens
Roundtable discussion	Coal ban and DH	20.12. 2018	Representatives of Greenpeace Finland, FinGo, and The Finnish

			Association for Nature Conservancy
Roundtable discussion	Helen Ltd. existing and future technological plans	20.12. 2018	Representatives of Helen Ltd.
Invite-only researcher meeting	Discussion on the "Clean district heating – how can it work?" report	7.1. 2019	Representatives of Helen Ltd., NGOs

244

245 Table 1. Events of participant observation. Location for all events in Helsinki, Finland.

246

247 The authors participated in the events (all more than once, and none in all of them) and took
 248 notes on their observations. The notes were collected and reviewed by multiple authors. As
 249 the goal was to find data on views that stakeholders explicitly hold and are willing to express,
 250 note-taking was limited to factual statements presented by the participants. For clarity and
 251 brevity, the findings from observations are reported in the article text without referring to
 252 particular events or notes. When the article relies on notes from spoken communications
 253 within the events, the correctness of the presentation has been confirmed with the relevant
 254 stakeholder(s) through subsequent direct communications (e-mail and phone) conducted
 255 during February-March 2019.

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258 **4 District heating infrastructure in the city of Helsinki**

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260 **4.1 Infrastructure**

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262 After WWII, Finland launched a program of reconstruction with rapid increase in energy

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654 263 generation [48]. These efforts, among other factors, brought into focus the need to improve
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656 264 primary energy efficiency and minimize fuel imports, leading to the adoption of DH [49]. The
657
658 265 energy efficiency of energy generation from burning can be substantially increased in
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660 266 combined heat and power (CHP) units, and the DH network, in addition, contributes to
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662 267 improved total energy system efficiency [50]. Consequently, the efficiency of cogeneration is
663
664 268 a key rationale and design constraint for the evolution of the DH system in Helsinki, setting a
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666 269 path-dependency right from the start. Helsinki had some city-block sized and smaller
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668 270 cogeneration units based on burning wood and coal already before the war [51]. However, in
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670 271 the decades after the war, the larger cogeneration plants were designed exclusively for coal
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672 272 burning, which constrains the temperature and pressure of the heat transmission liquid [49],
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674 273 which, in turn, determines, in part, network characteristics and parameters for customer
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676 274 equipment.

677 275
678
679 276 Altogether five big cogeneration plants have been built in Helsinki since the 1950's (see
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681 277 Table 2 and Figure 1). The post-war demand for electricity was first met in 1953 by building
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683 278 the Salmisaari A power plant which uses a coal-powered turbine for electricity generation,
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685 279 and from 1957 on, the excess heat from the unit is captured and used for district heating. In
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687 280 1960, 1974 and 1984 new coal cogeneration plants are built (Hanasaari A and B, Salmisaari
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689 281 B). The first CHP plant using natural gas (Vuosaari A) is taken online in 1991 and a second
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691 282 in 1998 (Vuosaari B) [52].

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695 284 Currently, Hanasaari A has been decommissioned, and Salmisaari A is a reserve unit, with
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697 285 Salmisaari B (electricity capacity 160 MW, heat capacity 300 MW), Hanasaari B (electricity
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699 286 capacity 220 MW, heat capacity 420 MW) and Vuosaari (electricity capacity 650 MW, heat
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701 287 capacity 600 MW) functioning as base load units [53]. In addition, the DH network has seven
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703 288 smaller heating plants around the city area with a total heat power of 2200 MW and a heat-
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705 289 only boiler in Salmisaari, with 170 MW of capacity [54]. Over half of the yearly heat
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290 generation is done by burning coal (with heat generation capacity from coal at 890 MW), the
 291 rest being a combination of natural gas (ca. 30 %), heat pumps (using excess heat from
 292 waste water as a source, ca. 10%), wood biomass and heavy oil [55].

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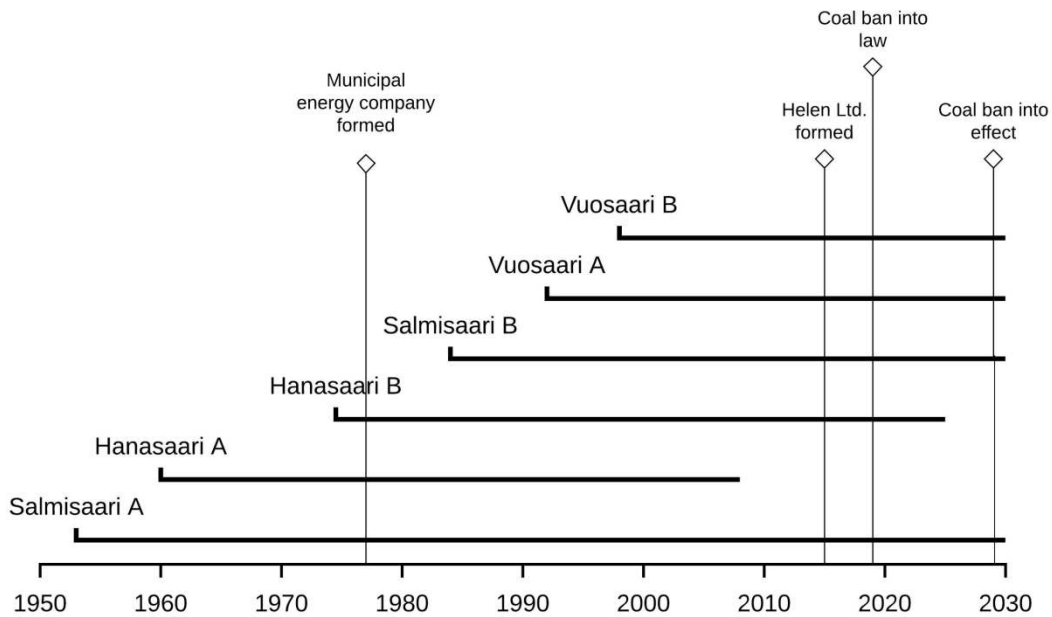
Power plant	Main fuel	Commissioned	Decommissioned	Current role	Heat capacity
Salmisaari A	Coal	1950	?	Reserve	170 MW
Hanasaari A	Coal	1960	2007	-	-
Hanasaari B	Coal	1974	Planned 2024	Base load	420 MW
Salmisaari B	Coal	1981	?	Base load	300 MW
Vuosaari A	Natural gas	1991	?	Base load	165 MW
Vuosaari B	Natural gas	1998	?	Base load	430 MW

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296 Table 2. Helen Ltd. power plants.

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300 Figure 1. Timeline of Helen Ltd. power plants and main historical events 1950-2030.

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302 In 2017, the district heating network comprised ca. 1300 kilometers and provided heat for ca.
303 90% of the built cubic volume in Helsinki. The company sold 6 606 GWh of DH to 15 289
304 connections, and the connection power (maximum load) was 3 400 MW [55].

305
306 The basis for the current utility company is formed in 1977, when the municipal electricity
307 company and the municipal gas company are combined into the municipal energy company
308 [52]. In 2015 the municipal company is transformed into a private enterprise (Helen Ltd.),
309 with the City of Helsinki as the sole owner [52] (see Figure 1). Currently, the main business
310 sectors of the company are district heating, district cooling and electricity [52]. In the
311 following, we will concentrate on DH, only touching on electricity and district cooling when
312 they relevantly affect the DH transition. In 2017, the company generated a profit of 81 million
313 euros, with a turnover of 805 million [55].

314

315 4.2 Stakeholders

316

317 The stakeholders in the question of DH as a part of energy transition can be identified in
318 different ways. Ultimately, as the issue of GHG emissions affects all life on the planet, the
319 stakeholders involve all humans. More directly, the stakeholders include at least the utility
320 company, its owners and customers, the citizens of the city and the whole metropolitan area,
321 the national government and citizens of Finland, various NGOs and political organizations,
322 researchers, fuel and technology suppliers, and the wider energy sector and its institutions.
323 We will here concentrate on three stakeholders or stakeholder groups: the utility company,
324 the city and NGOs/political organizations, and touch on the national level as a regulatory
325 actor. We believe that the viewpoints presented by these three groups are sufficient to
326 illustrate how the path-dependencies end up hampering intended climate action.

327

328 The main actor is the utility company that owns and runs the DH system. Its views are
329 publicly available on its own website, where it presents both official information and more
330 free-form audience-engaging content such as blog posts. The views of the utility company
331 are also a point of public interest, so that its representatives are often interviewed both for
332 journalistic and research purposes (e.g., [36]).

333

334 The city of Helsinki has a dual stakeholdership: on the one hand it is the owner of the utility
335 company, on the other hand it is a regulator determining policy. Ultimately, the city of
336 Helsinki consists of its citizens that are represented by an elected city council overseeing the
337 executive and regulatory affairs of the city. All major policy changes both with regard to the
338 utility company and climate and energy policy have to pass through the council. The views of
339 the council itself are a matter of public record [56], and its members representing various
340 political parties have their own publications, e.g., on the internet.

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890 342 There is a number of NGOs and NGO-led campaigns advocating ambitious climate action, in
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892 343 general, and active in the discussions around DH, in particular. Three of these, Greenpeace
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894 344 Finland, The Finnish Association for Nature Conservation (Suomen Luonnonsuojeluliitto)
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896 345 and FINGO (a NGO platform for global development), have dedicated staff on climate and/or
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898 346 forest issues, have published position papers on climate and forest issues [57], [58], [59] and
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900 347 have regularly taken part in the discussion on DH. Their views are therefore analysed,
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902 348 below.

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907 908 351 **5 Economical, Technical and Political Operating Environment**

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911 912 353 **5.1 Economical**

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915 355 Economically, the role of the company is to generate revenue for the owner, within the
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917 356 corporate governance guidelines set by the city [60]. Although the DH network is in its area
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919 357 of coverage something of a natural monopoly, at the edges of the network the company
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921 358 faces competition from other smaller providers that offer decentralized heating, e.g., via heat
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923 359 pumps with geothermal wells and ambient air as heat sources. In the densely built city
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925 360 center the monopoly is relatively secure, as alternative modes of heating are either
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927 361 technically not viable (for instance, it is very hard if not impossible to find space for
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929 362 geothermal wells) or much more costly (direct electric heating) [61]. However, investments
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931 363 into energy efficiency, such as insulation and heat pumps, may affect the economic bottom-
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933 364 line also in the city center.

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937 366 As observed in [50], the total competitiveness of DH is a combination of two cost
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939 367 components: first, the cost difference between centralized and decentralized heat supply
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941 368 and, second, the heat distribution cost. If the amount of heat the company generates and

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949 369 sells diminishes, the proportional weight of the distribution cost in the calculation increases.
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951 370 Thus losing sales and customers via increased energy efficiency or transition to other
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953 371 methods of heating affects the bottom line of a DH provider substantially, as decreases in
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955 372 distribution cost are difficult to obtain. However, densification of urban areas may help keep
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957 373 distribution costs down, and modeling in [50] has indicated that in dense areas reduced heat
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959 374 demand is not a barrier to DH. In addition, it has been observed that taxation of competing
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961 375 forms of heating can increase the competitiveness of DH even in areas of low heat density
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963 376 [62].
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967 378 In 2018, due to regulatory and political pressure, Helen Ltd. opened its DH network for other
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969 379 providers of heat, for which it pays a seasonally variable rate [63]. For the reason noted
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971 380 above, the open DH network is also a potential problem for the company. Industrial scale
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973 381 CHP units are economically most effective when they are used for base load capacities with
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975 382 uninterrupted uptimes. Consequently, functioning as a network operator promises less
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977 383 economic return than selling heat produced by the company itself. Furthermore, the pricing
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979 384 models are not developed enough for separating the network operator from the heat
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981 385 producers [64]. The company sees that if the share of the heat produced and sold by the
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983 386 company itself via its network plummets, maintaining the DH network and CHP units may
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985 387 lose commercial viability [65].
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987 388
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989 389 This network characteristic forms an important economic condition. For instance, network
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991 390 load and temperature adjustments and proactive reacting to weather patterns is best done
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993 391 on the system level (even though the development of smart metering and demand flexibility
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995 392 in so-called 4th generation DH systems may in time change the situation, [61], [64]).
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997 393 Likewise, economically the network needs a large enough customer base. From this
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999 394 perspective, there is a critical threshold for both control over the network and the amount of
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1001 395 heat delivered below which the network loses economic competitiveness and loses its
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1008 396 advantage in terms of energy efficiency compared to non-networked heat provision.
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1012 398 The basic economic setting is complicated by the fact that the owner, the city of Helsinki,
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1014 399 also consists mainly of the customers of the company, the citizens of Helsinki. Helsinki
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1016 400 residents are by definition owners of the utility company, and almost always in practice its
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1018 401 customers. The majority of the profit generated by the utility company is included in the
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1020 402 budget of the city. The budget, in turn, is governed by the city council for the benefit of the
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1022 403 residents. The profit also comes out of the pocket of the residents in so far as they generate
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1024 404 the revenue for the company by buying electricity and heat (part of the electricity is sold
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1026 405 outside of Helsinki). Consequently, the customer price for DH is also partly determined by
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1028 406 social factors. If the customers feel that the price is not right, they can vote for
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1030 407 representatives that as the owners of the enterprise do have a say on company policies.
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1032 408 Here the intertwinement of the economical and the political becomes evident: on one hand
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1034 409 the company is statutorily governed to operate as a market actor, on the other hand the
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1036 410 owner does set constraints informed by factors other than market prices.
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1039 412 **5.2 Material and technological**
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1043 414 The company makes agreements with customers, promising to deliver a certain amount of
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1045 415 heat. When added together, the sum of these agreements gives the contractual peak load
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1047 416 that the company is obliged to be able to provide (in 2018, the maximum contractual load
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1049 417 was 3400 MW), even during the coldest periods of the year. Due to seasonal variation, there
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1051 418 is considerable difference between the actual peak thermal load and the base load (around
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1053 419 1500 MW) [66].
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1057 421 From the perspective of the plants generating heat, it makes sense to optimize the plant size
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1059 422 and location for maximum yearly uptimes according to the base loads. Providing for the peak
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1067 423 load, usually necessitated by extended periods of below zero temperatures, creates another
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1069 424 important technical constraint. Even though the peak load is required only for a small
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1071 425 percentage of the year, it is also the time when customers are most reliant on the service.
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1073 426 This necessitates having generating capacity up to double of base loads at the ready for
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1075 427 peak periods.
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1079 429 As noted above, the technical and energetic efficiency of the CHP units is best when they
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1081 430 have long and uninterrupted uptimes. From this perspective, it makes sense to design the
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1083 431 units to correspond to continuous base load use. The existing units have been optimized for
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1085 432 cogeneration, and reach high levels of efficiency, up to 90% [66]. In the past few years, they
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1087 433 have been readjusted to use a small percentage of wood pellets (up to 10 %) mixed with
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1089 434 coal [53].
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1092 436 From the perspective of the network, one crucial factor is the physical location of heat
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1094 437 producing units, constrained by the physical location of the most intensive and consistent
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1096 438 user loads, supply and return temperatures, as well as city zoning and other regulation on
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1098 439 power plant placement. Due to the historical factors discussed in section 3, the network is a
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1100 440 so-called high-temperature network, with heat-exchanging temperatures in the hot loop
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1102 441 between 65 – 120 °C, and during cold periods 80 – 120°C. The heat exchangers that
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1104 442 customers use have been dimensioned for the high-temperature heat exchange liquid.
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1109 445 **5.3 Political**

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1114 447 The city of Helsinki and the other cities in the Helsinki metropolitan area have committed
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1116 448 themselves to carbon neutrality [67]. The city of Helsinki has its own Carbon Neutral Helsinki
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1118 449 policy program, with the target of reducing emissions generated within the city by 80 percent
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450 and compensating all the rest by 2035 [68]. With regard to this goal, DH is a main concern,
451 as it produces over 40 percent of the yearly emissions of carbon dioxide equivalent GHG
452 gasses [69].

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454 The biggest political groups in the city council for the current term in office (2017-2021) are
455 the Greens and the right-wing National Coalition Party. For the Greens, climate action has
456 been a major goal, and for them the CHP units with their open air coal storage areas and
457 power plant chimneys very visible in the cityscape have been a sore point [70], [71]. The
458 views of the Greens have been supported by NGOs such as Greenpeace, which during
459 2018 collected a list of over 8000 signatures supporting rapid transition to a coal free
460 Helsinki [72] and published a Gallup poll according to which two thirds of Finns support an
461 end to coal in energy generation by 2025 [73]. Consequently, the 2018 decision [74] by the
462 City Council to explore ways of providing heating without coal and to obligate Helen Ltd. to
463 find ways of providing fossil free DH were presented as important achievement by the
464 Greens [75], [70]. Most of the other groups in the council supported the motion.

465

466 As part of its EU climate agreements, Finland has committed to increasing the share of
467 renewable energy sources to 50 percent by the year 2030 [76]. In 2015, the government of
468 PM Juha Sipilä, representing the Centre Party, launched a bioeconomy program, where
469 renewable products based on wood and other biomass, including energy from wood, figure
470 centrally [29]. The bioeconomy program supports even non-renewable peat as a domestic
471 energy source, both for DH and decentralized heating solutions. Toward this goal, the
472 program includes the use of taxation so that peat is more competitive than coal, but more
473 expensive than wood [77]. Major interest groups, such as The Central Union of Agricultural
474 Producers and Forest Owners, which is closely aligned with the Centre Party, are strong
475 supporters of the bioeconomy program and wood biomass as energy source.

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1185 477 The political constraints on DH have been recently brought to limelight with a national ban on
1186 478 coal burning by 2029 [25]. The year is earlier than the economical end-of-cycle for the
1187 479 existing CHP plants (estimated to be in the mid-2030's). The Centre Party has presented the
1190 480 coal ban as the major climate action accomplishment by the government of PM Sipilä, with
1191 481 his Centre Party colleague Kimmo Tiilikainen as the Minister for Environment [78]. The other
1194 482 parties in government, the National Coalition and Blue Reform, supported the ban, as do
1196 483 majorities in the opposition parties.
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1201 485 Concern over and opposition to the ban did not follow party lines. The opponents and
1202 486 skeptics that represent almost all of the major parties, have raised three kinds of concerns
1203 487 [79]. First, there are concerns over the effects on DH prices and the competitiveness of the
1206 488 companies. Second, opponents of the ban pointed out that, for instance, the Helsinki power
1208 489 plants can convert over ninety percent of the fuel energy into electricity and heat, while coal
1210 490 burning plants in Europe often operate on energy efficiency that is much lower, down to
1212 491 40%. This means that when the more effective coal burning plants are scrapped and their
1214 492 emission allowances released, carbon dioxide emissions in the EU may rise. Of course, this
1216 493 green paradox can be avoided if the state or another actor buys the released allowances, as
1218 494 suggested, for instance, by Helen Ltd. and The Finnish Innovation Fund Sitra [80], [81]. The
1219 495 third concern, one to which we will return below, is that given the current availability and
1220 496 pricing of heat sources, the most likely replacement for coal is biomass, with problems of its
1222 497 own.
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1228 499 The analyzed environmental NGOs (Greenpeace, The Finnish Association for Nature
1229 500 Conservation and FINGO) recognize the possibility of a "green paradox" due to the coal ban
1230 501 and move to wood biomass. However, in their view the coal ban is necessary for a variety of
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1244 503 something".¹ The NGOs have been frustrated by what they perceive as foot-dragging by the
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1246 504 utility company. In their view, the company has been aware of the need to transition away
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1248 505 from fossil fuels for three decades but has done little and found excuses for continuing coal
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1250 506 burning. Second, the coal ban is needed as a signal of ambitious work against climate
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1252 507 change. The argument goes that a developed country like Finland can help international
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1254 508 efforts by setting an example. Third, the NGOs emphasize the role of research and
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1256 509 development. Even if at the moment there is no realistic scenario for providing for the peak
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1258 510 load with non-burning heat sources, new technologies can advance rapidly. Thus the
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1260 511 representatives of the NGOs see that the utility company should launch ambitious R&D
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1262 512 efforts, preferably in an open manner that could involve a wider community. Furthermore, the
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1264 513 NGOs see that the coal ban is just one step on a long road. The issue of emissions (and
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1266 514 other potential ecological damage, such as biodiversity loss) from burning wood biomass
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1268 515 can and should, in their view, be tackled separately.

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1271 517 From the perspective of the city, the possible increase in emissions is a more troubling
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1273 518 issue, even though it, like the utility company, may under the current regulatory regime
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1275 519 report diminishing emissions when transitioning from coal to wood. The city mayor, Jan
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1277 520 Vapaavuori representing the National Coalition Party, has repeatedly maintained that
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1279 521 economically the utilization of biomass benefits mainly other areas in Finland, and is not the
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1281 522 best solution for the city, either economically or ecologically [82]. The city would prefer that
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1283 523 Helen Ltd. runs the DH network on non-burning base load technologies. However, the city
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1285 524 also requires that the company has to be competitive. In the current technological
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1287 525 landscape, the company can not fulfill both demands from its owner at once.

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1294 1 The views summarised in this paragraph are gathered through participant observation, and
1295 their validity confirmed in subsequent communication. See section 3.
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13041305 **528 6 Path dependency and its role in complicating transition**
13061307 529
13081309 530 Given the political goal of carbon neutrality and the ban on coal use, the most urgent
13101311 531 challenge for the DH system, and its operator, Helen Ltd., is replacing the existing coal-
13121313 532 powered CHP plants, Salmisaari B and Hanasaari B, with total heat capacity of 870 MW.
13141315 533 Even though natural gas produces much less carbon dioxide than coal, also the natural gas
13161317 534 powered plants Vuosaari A and B will need either replacement or carbon capture technology
13181319 535 to become carbon neutral. In addition, natural gas is more expensive than coal and Finnish
13201321 536 energy companies see low security of supply (with Russia as the only provider) as a barrier
13221323 537 for increasing the role of natural gas [83]. The timeline of the coal ban, 2029, means that if
13241325 538 scrapped, the plants will not reach the end of their planned lifecycle. As the company loses
13261327 539 not only the heat generation from these plants but also the electricity generation, it loses
13281329 540 some of its revenue and, consequently, means of investment.
13301331 541
13321333 542 Currently, according to the utility company itself and confirmed by studies by research
13341335 543 organizations, no economically competitive non-burning technology exists that could provide
13361337 544 the needed amount of heat load for the peak periods [84], [61]. This is also the view held by
13381339 545 city officials [85]. The only possible alternative would be the utilization of direct electricity-to-
13401341 546 heat boilers [61] but this alternative presupposes a massive increase in electricity availability
13421343 547 and grid upgrades – matters that are not in the hands of the utility company. If the transition
13441345 548 would happen in terms of boilers used within individual houses or blocks, a big part of the
13461347 549 rationale for DH network would disappear. On the other hand, done in a centralized manner,
13481349 550 the move to electricity-to-heat might use the DH network as a regulator of intermittent
13501351 551 electricity generation. However, due to the technological constraints mentioned above, these
13521353 552 options are not on the table. As the CEO of Helen Ltd., Pekka Manninen, has pointed out,
13541355 553 this means that the decision over which technology replaces coal burning depends on when
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1362 554 the decision is made: in the future new non-burning alternatives, such as small modular
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1364 555 nuclear reactors, may become available, but with currently available technology, the
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1366 556 transition will result in wood biomass burning [86].
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1370 558 The utility company emphasizes that it has to operate within the current regulatory and
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1372 559 contractual framework. Given the need to provide for the peak load and to operate with an
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1374 560 acceptable profit margin, providing heat through burning is the best option for the company.
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1376 561 As head of corporate responsibility for Helen Ltd., Maiju Westergren, puts it: “The fastest
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1378 562 route away from coal and fossil fuels is via biofuels and via accepting the fact that we
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1380 563 continue to burn something” [87]. With the end of coal use on the horizon, market conditions
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1382 564 suggest biomass as fuel, as also pointed out by independent research [84]. In sum, the
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1384 565 choice that fits the existing legacy parameters is to burn biomass instead of fossil fuel in the
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1386 566 base load units that need to be constructed to replace the existing CHP units.
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1390 568 As noted above, there is a list of concerns about the trajectory of replacing coal burning with
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1392 569 biomass burning. These concerns are voiced, for instance, in the statements on the coal
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1394 570 plan that stakeholders have left in the official governmental service collecting statements on
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1396 571 new legislation [79]. The concerns with regard to a move to biomass expressed, for instance,
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1398 572 by Helen Ltd. and other energy companies, include questions of availability, price, GHG
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1400 573 emissions, small particle emissions, logistics and effects on biodiversity and other ecological
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1402 574 effects.
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1406 576 The official evaluation on the coal ban legislation concludes, based on a review of the views
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1408 577 of current coal users, that the most likely outcome of the ban is that coal is replaced by wood
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1410 578 biomass [26]. More strikingly, the evaluation also states that because of this replacement the
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1412 579 ban will not likely reduce Finnish carbon dioxide emissions [26]. The statement is quite
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1414 580 stunning, when we remember that the legislation is intended and celebrated as a major
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1421 581 climate action. However, there is no reason to suspect its validity. As Sterman et al. [32]
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1423 582 observe, while the combustion effect of wood pellets is lower than coal and the wood supply
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1425 583 chain has higher procession emissions, “wood-fired power plants generate more CO2 per
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1427 584 kWh than coal.”

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1431 586 With regard to the main goal of the transition, reducing GHG emissions in the name of
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1433 587 climate action, the result of this path of least resistance is paradoxical. However, the
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1435 588 increase in carbon dioxide emissions would be politically acceptable, since current GHG
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1437 589 accounting in the EU includes wood felling in the LULUCF sector, and biofuels are deemed
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1439 590 to be carbon-neutral [27]. Thus, even if the physical end-of-pipe emissions compared to coal
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1441 591 burning increase, in the current regulatory framework the emissions are not penalized. This
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1443 592 situation is, of course, not particular to Helsinki or even Finland; rather the accounting of
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1445 593 LULUCF sector emissions, especially biomass burning, is a contentious issue worldwide
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1447 594 [88], and researchers have warned that the new European Union renewable energy directive
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1449 595 (RED), aimed at reaching higher renewable energy targets, could result in a situation where
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1451 596 energy generation “consume[s] quantities of wood equal to all Europe’s wood harvests,
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1453 597 greatly increase[s] carbon in the air for decades, and set[s] a dangerous global example.”
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1455 598 [34].

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1458 600 The outcome is also closely linked to the use of the term “renewable”. As Harjanne &
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1460 601 Korhonen [24] point out, the term “renewable” contains many ambiguities and is therefore a
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1462 602 poor indicator for successful energy policy. In this case, energy from burning wood biomass
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1464 603 is renewable, but not emissionless and not, without further qualifications, sustainable. Most
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1466 604 damagingly, the concept enables bait-and switch schemes that seem to address climate
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1468 605 change, but in reality serve other interests [24]. In the case of Helsinki DH, these interests
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1470 606 include the economical goal of forest owners and bionenergy providers to have lucrative
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1472 607 markets and the interest of politicians to promote domestic renewable energy. These
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1480 608 interests combined with the economic and technical path-dependency according to which “to
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1482 609 burn something” is the most competitive available technology, are on the trajectory of locking
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1484 610 in yet another decades long increase in carbon dioxide emissions from DH.
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1488 612 This potential new lock-in also introduces a new risk. It is possible that the international GHG
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1490 613 accounting regulations and ETS are changed over time, so that the end-of-pipe emissions of
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1492 614 wood burning have an economic effect, for instance, through inclusion in the ETS or through
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1494 615 a price on natural carbon sinks, in which case wood biomass price is bound to increase.
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1496 616 These worries have registered within the stakeholders, as, for instance, the chairman of the
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1498 617 board for Helen Ltd., Osmo Soininvaara, representing the Green Party, has predicted that by
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1500 618 2030 at least a part of wood burning emissions will be included in the ETS [89].
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1504 621 **7 Results**

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1508 623 The first research question was to identify the key path dependencies, constraints and
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1510 624 legacy technological solutions in DH in Helsinki, given the goal of rapid transition. In view of
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1512 625 the above, the path dependencies and constraints can be listed as follows:
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1517 628 ● The company is committed and contractually bound (economic constraint)

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1519 629 ● to reliable service (socio-economic path-dependence)

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1521 630 ● during peak load periods (material constraint).

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1523 631 ● This together with the high-temperature nature (material path-dependence) of the
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1525 632 network means that no non-burning technology currently exists to replace coal.

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1527 633 ● In current GHG accounting frameworks, emissions from wood burning are calculated
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1529 634 on the LULUCF sector (political path-dependency), which means that from the
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1539 634 emission accounting perspective, the move from coal to wood is possible.
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1541 635 • In addition, the bioeconomy framework of the current government supports wood
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1543 636 biomass by subsidies and taxation (political constraint) and
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1545 637 • coal use in energy generation is banned by 2029 (political constraint).
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1549 639 The second research question concerned the role of these path-dependencies in
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1551 640 complicating the transition towards carbon-free energy. Due to the material path-
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1553 641 dependency, government supported market environment and regulatory framework, the
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1555 642 trajectory for DH in Helsinki produces a green paradox if coal is replaced by wood biomass:
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1557 643 even if all stakeholders are committed to reducing GHG emissions and act on their
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1559 644 commitment, physical emissions may grow. Moreover, this green paradox may be enforced
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1561 645 by a future lock-in. For the utility company and its owner, investments into heat producing
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1563 646 units are long-term affairs, with pay-back times extending well over a decade. Thus
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1565 647 investing, for instance, in wood biomass burning base load units means, other things being
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1567 648 equal, that biomass will be burned for decades, so that the increase in carbon dioxide
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1569 649 emissions is perpetuated.

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1572 651 This is the crux of the path-dependent nature of the green paradox at hand. The need (and,
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1574 652 from the company's contractual and commercial perspectives, responsibility) to do long-term
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1576 653 investments in industrial-scale infrastructure locks in future emissions for decades. If the
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1578 654 decision happens at a moment when coal emissions are penalized but biomass emissions
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1580 655 are not, the result may be an increase in emissions even though the explicitly expressed
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1582 656 reason for infrastructure overhaul is to decrease emissions.
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1586 658 The third research question was the policy implications to be drawn from the case. As noted
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1588 659 above, coal emissions from energy use are included in the ETS, while wood biomass

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1598 660 emissions are included in the accounting of the LULUCF sector when the timber is felled (not
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1600 661 when it is burned). Clearly, a more uniform accounting would level the field. For instance, a
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1602 662 regime where carbon dioxide emissions would have a price, regardless of the fuel burned,
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1604 663 and coal sinks would be compensated, would create a uniform price mechanism, where coal
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1606 664 and wood biomass would compete on an equal footing with regard to their contribution to
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1608 665 actual atmospheric carbon dioxide emissions. These policy issues are, for the most part,
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1610 666 outside the purview of local and national legislation, so any initiative for change most likely
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1612 667 needs to happen through attention to the more general level danger that the inconsistent
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1614 668 accounting and directives pose, as pointed out in [34].
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1616 669
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1618 670 Likewise, as argued in [24], the notion of “renewable energy” functions as a term that
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1620 671 somewhat obscures the fact that wood biomass is not a carbon free fuel. A more nuanced
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1622 672 research and public discourse is needed, such that combustible and non-combustible forms
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1624 673 of energy generation, and carbon-intensive, low-carbon and carbon-free energy systems can
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1626 674 be distinguished and discussed in policy settings unambiguously. Our case study
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1628 675 corroborates the hypothesis in [24] that the ambiguity of the term “renewable”, as it appears
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1630 676 both on the national and EU level discussions, contributes to the potential green paradox.
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1632 677
1633 678 The DH network itself, with the power plants, pipe networks and consumer equipment, is a
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1635 679 massive and expensive piece of infrastructure, where major changes are expensive and
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1637 680 slow. If, indeed, it is the case, first, that currently no non-burning technology exists for
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1639 681 provisioning for the peak loads, and, second, that transition to a wood biomass base load
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1641 682 means a commitment to decades of increased carbon dioxide emissions, then it would make
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1643 683 sense to reconsider the social and economic constraints that are behind the need for the
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1645 684 peak load. For instance, the need for the peak load could be alleviated by reformulating the
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1647 685 contracts between the company and its clients so that the company could provide a lower
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1649 686 temperature for some customers during cold periods. It is obvious that such a decrease in
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1657 687 the comfort level provided by the service would not be totally welcome by the customers.
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1659 688 This brings up the cultural aspect of energy transitions [90] and underlines that a more
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1661 689 realistic and detailed understanding of the material path-dependencies and constraints of the
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1663 690 legacy infrastructure might help to further the needed steps of transition in terms of social
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1665 691 acceptability.
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1667 692
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1669 693 The last point also touches on the role of the city. The city obligates the company, Helen
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1671 694 Ltd., to competitive market performance. At the same time, it has set itself the goal of being
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1673 695 carbon neutral by 2035. These goals are, to some extent, at cross purposes, in so far as no
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1675 696 non-burning technology exists for provisioning for current DH needs at competitive prices.
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1677 697 Thus a more realistic and detailed knowledge of the existing DH infrastructure and its
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1679 698 constraints would help the city place more realistic demands on the company and itself. If it
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1681 699 prioritizes the goal of being carbon free, as it given the current knowledge on climate change
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1683 700 and its effects should, it should relax the economic constraints on the company so that it has
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1685 701 more leeway in terms of investment and operational costs. If more costly technologies were
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1687 702 an option, the green paradox could be easier to avert.
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1689 703
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1692 705 **8 Discussion**

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1694 706
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1696 707 In so far as there are other DH systems with similar path-dependencies and constraints, the
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1698 708 lessons from the case study may apply. This is most likely the case in (Northern) European
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1700 709 countries that share the relevant EU regulations and goals, including the ETS system and
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1702 710 the RED directive, as well as climatic conditions. This gives grounds to generate a
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1704 711 hypothesis on the basis of the case study: in Northern European DH systems that transition
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1706 712 away from fossil fuels, especially coal, the path of least resistance points towards burning
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1708 713 wood biomass, thus implying a green paradox. This is because the transition to a non-

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1716 714 burning alternative implies larger systemic changes (for instance, re-dimensioning of
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1718 715 network, reformulating contractual obligations, changing customer expectations, etc.) that
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1720 716 are likely to be also more costly.
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1722 717
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1724 718 However, the lessons from the case study are obviously limited by particular constraints in
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1726 719 the DH system in Helsinki. First is the bioeconomy framework strongly pushed by the
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1728 720 government of PM Sipilä. The bioeconomy framework has helped create a situation
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1730 721 favorable to transition to wood biomass, through both direct economic subsidies for wood
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1732 722 energy and through encouraging public perception of the benefits of wood biomass use.
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1734 723 Here the ambiguity of the term “renewable” has been consequential, not the least by uniting
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1736 724 the goals of forest owners and the analyzed NGOs in supporting banning coal, with the
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1738 725 expected replacement of coal by wood biomass.
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1740 726
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1742 727 As noted above, the bioeconomy framework has been questioned and criticized by
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1744 728 researchers and politicians. It is possible that a future national government may formulate a
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1746 729 different strategy, especially if it prioritizes rapid transition, and wood biomass may lose
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1748 730 some of its advantage. However, given the weight of the forest sector in Finnish economy, it
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1750 731 is unlikely that any national government would set climate or sustainability criteria for wood
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1752 732 energy that would be more ambitious than those on the EU level. Consequently, a definitive
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1754 733 dismantling of the potential for green paradox in cases like Helsinki DH would most likely
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1756 734 demand a change in how GHG emissions from wood burning are included in emission
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1758 735 accounting and target setting on the EU and/or global level.
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1762 737 Second, the city as the sole owner of the utility company has created goals that are at cross-
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1764 738 purposes: to generate revenue and to transition to carbon neutrality. The city could prioritize
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1766 739 carbon neutrality and relax the demand for revenue. Due to the loss of revenue, this would
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1768 740 mean increased costs for its citizens. Depending on structures of ownership, this option may
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1775 741 not be available in other cases.
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1779 743 Third, the DH network in Helsinki is exceptionally reliable and prepared for undiminished
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1781 744 service also during prolonged cold spells. If a DH provider and its customers would be willing
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1783 745 to use less heat during cold spells, the peak load demanded from the system would be
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1785 746 lower, and consequently provisioning with non-burning alternatives would be easier.
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1789 748 Due to the use of participant observation as a method, some of the results are tied to
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1791 749 particular events happening within a given time frame. For instance, the views of the
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1793 750 stakeholders, the utility company, politicians and NGOs, are likely to evolve in time, so that a
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1795 751 return back to the views present at the time of observation is not possible. Thus the
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1797 752 independent verifiability of these observations is necessarily limited. However, the limitation
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1799 753 seems acceptable, especially given the fact that the answers to the three research questions
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1801 754 rely mostly on publicly available records. The data from participant observation has helped in
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1803 755 confirming that the facts presented in the publicly available materials are, indeed, facts on
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1805 756 which the stakeholders rely in their views and actions, and in focusing on crucial facts that
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1807 757 underlie the positions of the stakeholders.
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1811 759 For instance, the importance of reliability of service and contractual obligations is mentioned
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1813 760 in the materials published by Helen Ltd., but observing the argumentation by current and
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1815 761 previous representatives of Helen Ltd. helped drive home the centrality of these constraints
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1817 762 in the reasoning done in the company. Likewise, discussions with local politicians and
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1819 763 representatives of NGOs focused attention to the factors enabling the potential green
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1821 764 paradox: in their perspective the potential is an unfortunate side effect of, on one hand,
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1823 765 existing international regulation, and, on the other hand, need for rapid and visible action.
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1834 **768 9 Conclusion**

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1836 **769**

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1838 **770** The DH system in Helsinki has evolved on the basis of cogeneration of heat and electricity

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1840 **771** from coal burning. The company operating the system is contractually obligated to a given

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1842 **772** peak load, even during prolonged periods of cold weather, and its customers are

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1844 **773** accustomed to reliable service. In addition, the owner of the company, the city of Helsinki,

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1846 **774** expects the company both to be commercially viable in terms of returning a profit to the

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1848 **775** owner and to provision DH in a carbon neutral manner in line with the goals set by the city

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1850 **776** and the wider metropolitan area. This, together with a new national legislation banning the

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1852 **777** burning of coal for energy generation by 2029 means that, at the moment, the most

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1854 **778** economic and technically reliable option for the company is to start burning wood biomass.

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1856 **779**

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1858 **780** The outcome is unfortunate, as research has shown that GHG emissions from burning wood

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1860 **781** are higher than from burning coal, at least for a period of several decades, before the

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1862 **782** “carbon debt” from loggings may be repaid by regenerated woodland. However, this fact,

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1864 **783** even if observed, is not seen as reason not to use wood biomass by the company, as

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1866 **784** burning wood biomass is excluded from the EU emission trading system and thus does not,

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1868 **785** unlike coal, appear in the emission accounting of the company or the city.

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1870 **786**

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1872 **787** In sum, it seems that as hypothesized in the literature, green paradoxes, in the sense of

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1874 **788** unintended negative consequences of climate policies, are indeed possible, as evidenced by

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1876 **789** the situation created in Helsinki DH, where regulation aimed at diminishing GHG emissions

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1878 **790** together with the economic-technological path dependencies of the DH system drive a

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1880 **791** transition from coal to wood biomass, with the possible effect of increasing atmospheric

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1882 **792** GHG emissions.

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1884 **793**

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1886 **794** The possibility for the paradox could be undermined by a form of international GHG

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1893 795 accounting, for instance on the EU level, that would better unify the accounting of the
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1895 796 LULUCF sector (loss of sinks via logging, existing sinks in forests) and the ETS sector.
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1897 797 Also, a different ownership policy by the city could provide more economical leeway for the
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1899 798 company, so that a more intensive and costly transition would become an option. Third, the
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1901 799 task of transition could be made easier if the customers adjusted their levels of expectations
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1903 800 on the service, and if this was also reflected in the contracts between the company and its
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1905 801 customers.
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1909 804 **10 References**

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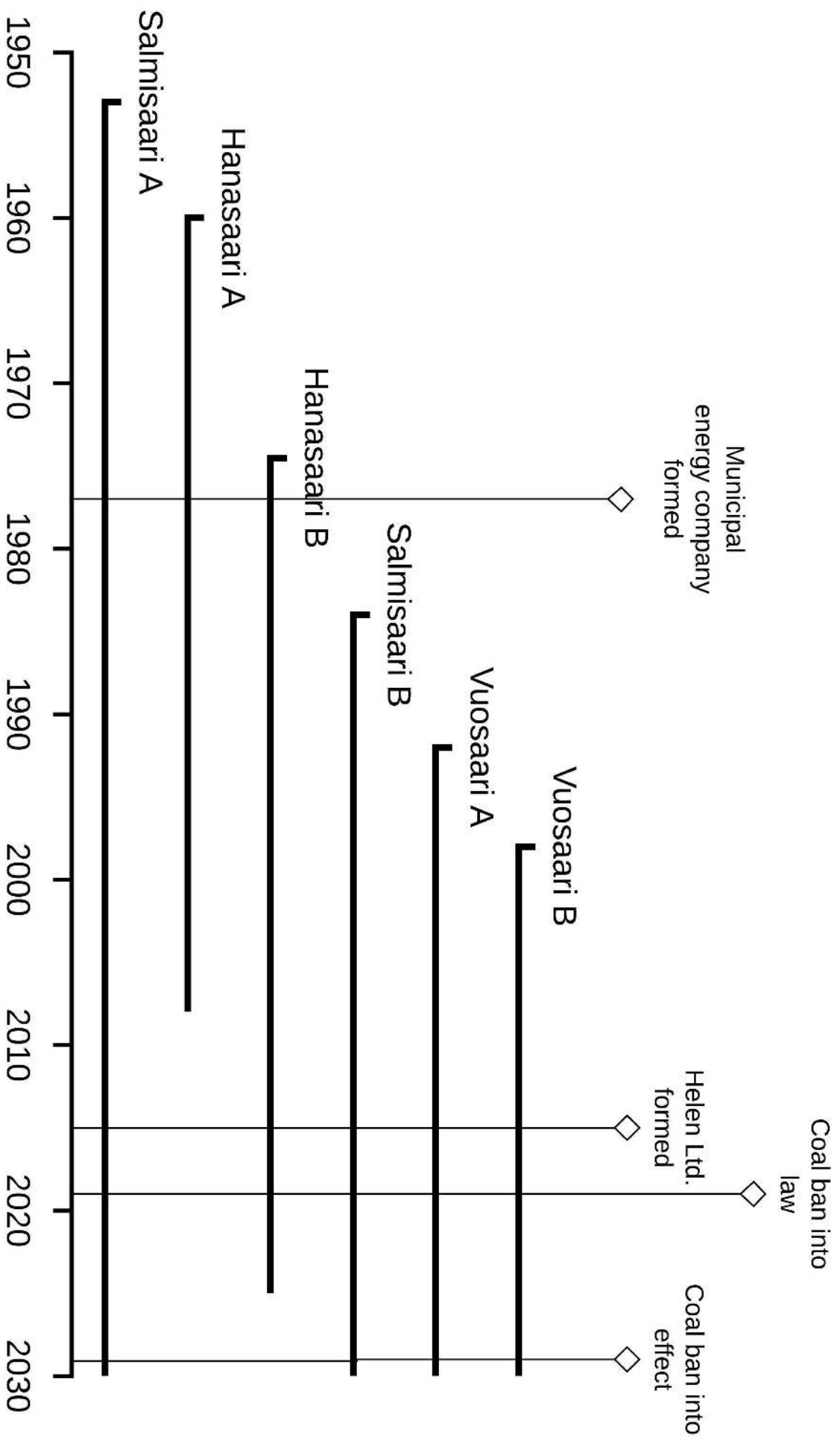
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To continue to burn something? Technological, economic and political path dependencies in district heating in Helsinki, Finland

Supplementary material

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