# *Business implications of net-zero targets for district heating and cooling*

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## Abstract

District heating and cooling (DHC) helps valorize energy sources that would otherwise be wasted. Development of DHC has been heterogenous, depending on local opportunities and policy settings. With more ambitious greenhouse gas emission reduction targets, the business model can be expected to change. We use a qualitative System Dynamics approach to map the dynamics of DHC development under net-zero policies and discuss its practical implications.

This analysis provides a coherent mapping of the socio-technical dynamics around DHC. Growth is driven by network effects, within the boundaries set by pre-defined goals. On the flip side, vicious cycles due to lower adoption and building energy efficiency may threaten viability. Business implications of net-zero policies will vary locally, depending on deployable energy potentials. Of note, choices at local level depend on the development of competences and legitimacy nationally.

Recommendations for different actors could be specified. Utilities should place energy efficiency at the center of their business model. Municipalities can guarantee sustainable prospects through adequate strategic planning. This can be strengthened by planning firms with adequate offerings. Finally, higher levels of government can strengthen the legitimacy of desirable technologies, increasing the likelihood that they will be adopted by utilities and municipalities.

## 1. Introduction

As countries, regions and cities commit to reducing their greenhouse gas (GHG) emissions to net-zero by the middle of the century or earlier, a key challenge is to reduce emissions from energy use in the building sector. In this context, district heating and cooling (DHC) is a key technology, as it enables the valorization of localized, low-carbon energy sources. Many of the questions around the roll-out and modernization of DHC call for a technical or techno-economic answer. As a result, decarbonization of heating and cooling is sometimes framed as a purely technological matter (Ayrault, 2022). By contrast, the business model of DHC has long remained unchanged and unchallenged (Knutsson et al., 2021; Lygnerud, 2018). Several recent trends call for a reconfiguration of the business model: some technological innovations imply a different value-creation logic, so that their integration should be accompanied by organizational changes (Lygnerud, 2019; Lygnerud et al., 2023; Williamsson, 2023). Also, the close coupling of DHC business and policy development (Bolton & Hannon, 2016) suggests that increasingly ambitious decarbonization policy goals will impact business. Moreover, the modernization of DHC infrastructure and the integration of new energy sources require new forms of collaboration with customers, building professionals, potential excess heat suppliers, etc. (Leoni et al., 2020; Lygnerud et al., 2023). In this context, socio-technical research should provide DHC industry actors (utilities, municipalities, consultants, policymakers) with a strategic view of the business implications of technological and policy change.

However, from a business perspective, the role of DHC can be somewhat difficult to grasp. On one hand, it addresses an essential need for the functioning and livability of buildings, and thus shares many characteristics with other networked infrastructure types such as electricity or water grids. On the other hand, the need addressed by DHC can often be covered by other means, so that the legitimacy of the infrastructure is not given a priori. A cost advantage is often cited as a motivation to build DHC systems, although this is highly dependent on specific local conditions (Zuberi et al., 2021). Often, the main or secondary motivation for DHC is an expected public benefit, such as energy affordability, air quality improvement, or societal energy efficiency and subsequent robustness against energy price fluctuations. In particular, DHC has become a key instrument to reduce greenhouse gas (GHG) emissions in many countries and cities. With different, and sometimes changing, motivations for the deployment of DHC, its organizational configuration varies between and within countries (Paardekooper et al., 2022), reflecting a path-dependent series of political, technical and managerial decisions (Bolton & Hannon, 2016). This heterogeneity makes it difficult to generalize insights from specific cases. For example, insights from Sweden (Lygnerud, 2018; Sandoff & Williamsson, 2016), where DHC is liberalized, or from Denmark (Johansen & Werner, 2022), where regulation is much stronger, cannot necessarily be transferred to different settings. There is therefore a need for a framework enabling a context-sensitive description of DHC from a business perspective.

This paper aims at addressing this gap by mapping the dynamics that shape the development of DHC under the energy transition. Conceptually, this mapping builds upon a business ecosystem perspective (Kanda et al., 2021; Speich & Ulli-Beer, 2023): the business model of the utility is considered in the context of its interactions with other organizations in a value network, as well as a corresponding resource pool (Ma et al., 2018). An ecosystem perspective enables recommendations not only on the utility's business model, but also on strategic measures to orchestrate its interaction with other organizations. Methodologically, this analysis builds upon System Dynamics (Sterman, 2000). Concretely, formal techniques of qualitative System Dynamics, i.e., subsystem diagrams and causal loop diagrams, are applied here to obtain a coherent picture of the dynamics and challenges of DHC development under the energy transition. We pose the following research questions:

RQ1: What is the business logic of DHC in its dual nature as a competitive business field and an instrument of public policy?

RQ2: What are the implications of more ambitious public decarbonization goals for the business model of DHC and its ecosystem?

Although some insights may be more generally applicable, this analysis focuses on the case of Switzerland. More precisely, we assume the case of public DHC, i.e., DHC is operated by a utility that belongs to the municipality. These choices are reflected in the identified dynamics. The rest of this paper is structured as follows: Section 2 introduces the selected methods and data sources, Section 3 presents the resulting subsystem and causal loop diagrams, Section 4 discusses the implications for research and practice, and Section 5 concludes with actor-specific recommendations as well as an outlook for further research.

## 2. Methods and data

### 2.1. Methods

In this paper, we follow a qualitative System Dynamics approach. A qualitative approach can be an intermediate step towards quantitative simulation, or it can be used for insight (Coyle, 1999). Although this work is part of an ongoing project where quantification is the next step, we focus here on the insights obtained from qualitative analysis. Concretely, we apply two complementary tools of qualitative system dynamics: subsystem diagramming (Morecroft, 1982) for basic conceptualization, and causal loop diagramming for a more detailed mapping of the relevant dynamics.

### 2.2. Data

The dynamics of local DHC systems are identified based on data from several case studies and workshops conducted in the ongoing SWEET-DeCarbCH research project:

- A case study of the business ecosystem around DHC in Switzerland, based on 18 semi-structured interviews of decision-makers in utilities, municipalities, engineering firms and intermediaries.
- A case study of the organizational, regulatory and planning settings around DHC, and their development in the context of the net-zero transition, in the city of Zurich, Switzerland. This study is based on document analysis (proceedings of the municipal council, planning and policy documents, media reports, trade literature, etc.).
- A case study of the decarbonization of DHC since 1990 in the city of Hennigsdorf, Germany, based on document analysis and triangulated with involved actors.
- A workshop on the topic of seasonal thermal energy storage in thermal grids, with 32 participants from industry, administration and research.
- Two workshops on the development of deep geothermal energy in Switzerland, with 18 participants from administration, respectively 24 participants from industry (Sierro et al., 2024).

## 3. Results

### 3.1. Subsystem diagram

Taking a business ecosystem perspective on local DHC systems (Speich & Ulli-Beer, 2023), the subsystem diagram (Figure 1) distinguishes three tiers: the customers represent their own subsystem, nested within the activities of the utility. The utility is in turn embedded in the local ecosystem, consisting of the various actors and activities with which it interacts directly. Additionally, we consider six environmental dimensions which have an exogenous effect on the system.

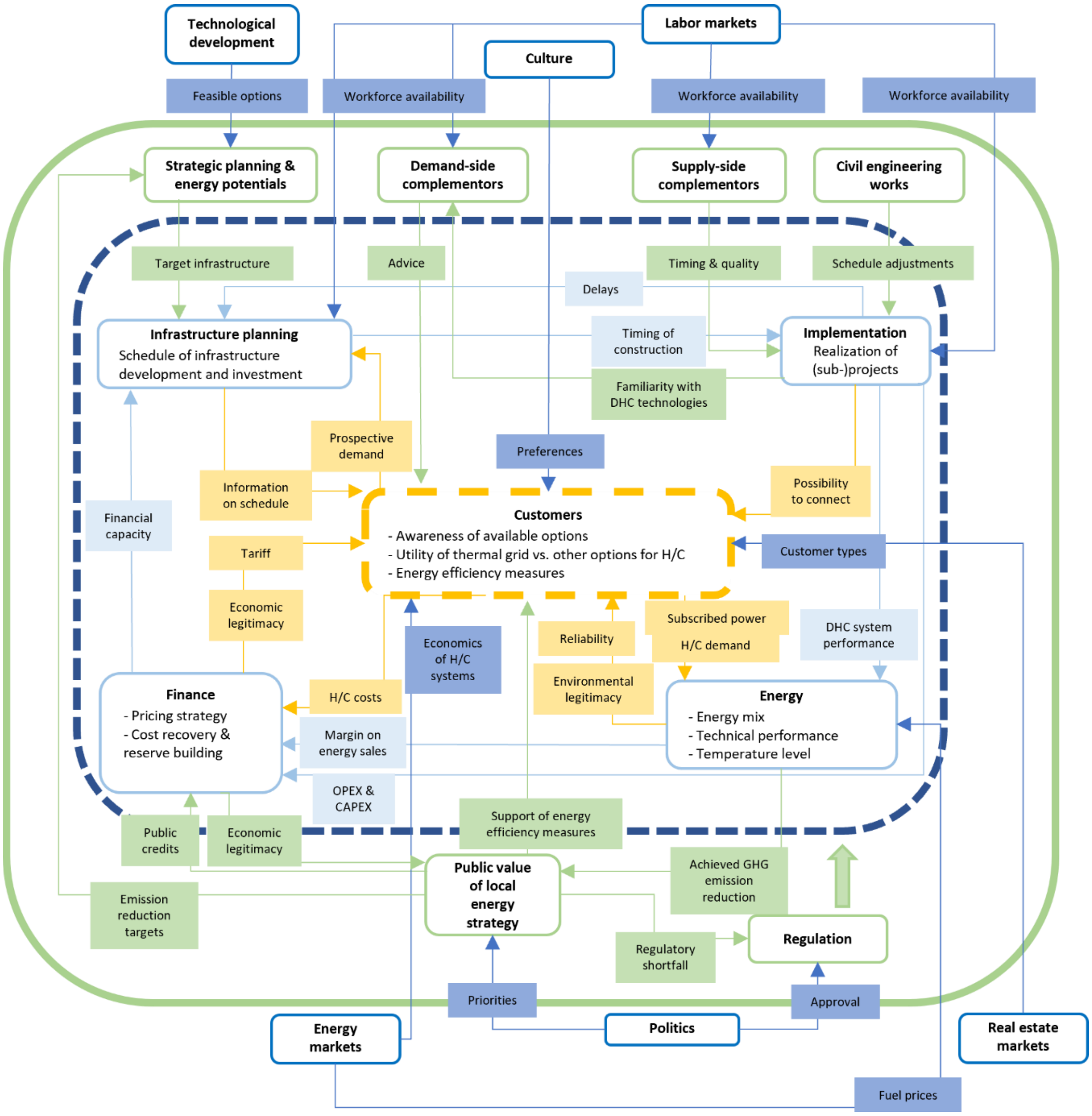

*Figure 1: Subsystem diagram of the local business ecosystem around DHC. Round boxes represent subsystems, and arrows represent flows of information between them. Orange arrows are information flows between the customers and the utility, light blue arrows are internal to the utility, green arrows are information flows within the ecosystem, and dark blue arrows are exogenous inputs.*

The customer subsystem represents the decision-making and behavior of actors on the demand side. Customer decision-making is considered on three points: choice of heating system, decision to carry out building energy retrofits, and acceptance of demand-side management measures. Behavior corresponds to use patterns that may impact energy consumption. For simplicity, this paper does not differentiate between different types of customers and buildings. The utility's internal subsystems cover its finances, i.e., its long-term pricing strategy in the light of future investments; the planning of future investments as well as its implementation, which are linked through potential delays; as well as a simplified representation of DHC as an energy system. The ecosystem contains the municipality, interacting the utility through strategic planning, as well as complementors, i.e., firms on whose contribution the utility depends to realize its value proposition (Adner & Kapoor, 2010). Finally, the ecosystem is embedded in an environment consisting of technology, culture as well as labor, real estate and energy markets.

### 3.2. Strategic energy planning

Infrastructure is planned under the double constraints of economics and GHG emission reduction (Figure 2). On one hand, there is a cost-recovery imperative (B1): For a grid to be profitable, a certain level of energy sales is necessary. If fewer customers than expected join the grid, or demand decreases, the utility must intensify customer acquisition. On the other hand, strategic energy planning aims at transforming the local energy system to reduce GHG emissions. The starting point of strategic energy planning is to compare current GHG emissions with an indicated reduction path compatible with public policy targets. A gap prompts the search for local, low-carbon energy potentials to be deployed in DHC (B2). With sufficient energy potentials identified, an expansion of the DHC infrastructure becomes feasible from a supply-side point of view. The more ambitious the decarbonization goals, the more is invested into identifying energy potentials: potentials that were previously neglected due e.g., to perceived risks and expensive exploration (e.g., deep geothermal energy) or need for inter-organizational coordination (e.g., excess heat utilization) may be considered again if the gap is too large. Spatial matching of identified energy potentials and projected demand is not straightforward and requires expertise. In most cases in Switzerland, spatial energy planning is carried out by a private firm mandated by the municipality. However, such plans are sometimes lacking in quality, so that opportunities to valorize local energy potentials are missed. To close the GHG emissions gap, the municipality may choose to spend more on spatial planning to pay for more hours or hire more experienced planners (B4). The output of strategic energy planning is a plan of infrastructure to be built based on an assessment of economics. Existing DHC infrastructure offers synergies with new developments, so that plans are more likely to be deemed feasible if such synergies can be exploited (R1). While the primary purpose of DHC in the described setting is to reduce GHG emissions by offering building owners a low-carbon option, DHC itself often relies on fossil fuels to cover peak loads. To meet ambitious decarbonization goals, it is therefore necessary to also substitute this use of fossil fuels, which requires further integration of RES and infrastructure improvements (B5). Besides integrating RES, another lever to reduce GHG emissions is to encourage building energy efficiency improvements (B3). This has the effect to reduce energy demand from grid customers, prompting the need for further customer acquisition (B1). The evolution of demand is a key unknown for spatial energy planning: the infrastructure should be planned so that it is neither under- nor overdimensioned under future conditions. However, demand depends on decision-making by building owners, which cannot be controlled by the municipality or utility. Therefore, municipalities must make assumptions about future demand. If a municipality actively supports building energy efficiency, this may factor into its scenarios, so that a lower demand is assumed (B6). Since the economics of DHC depend on energy demand density, lower expected demand reduces the number of neighborhoods for which positive economics are expected. This makes it less likely that local energy potentials can be matched with sufficient demand, so that less distribution infrastructure is planned and built, and the DHC grids that are built are dimensioned for a lower energy supply[1].

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[1] Recall that this study focuses on high-temperature grids. Technologies to valorize low-grade energy potentials, such as 4th and 5th generation DHC, are more suitable for districts with a lower energy demand. However, these technologies entail specific costs and barriers, which will be considered in a future study.

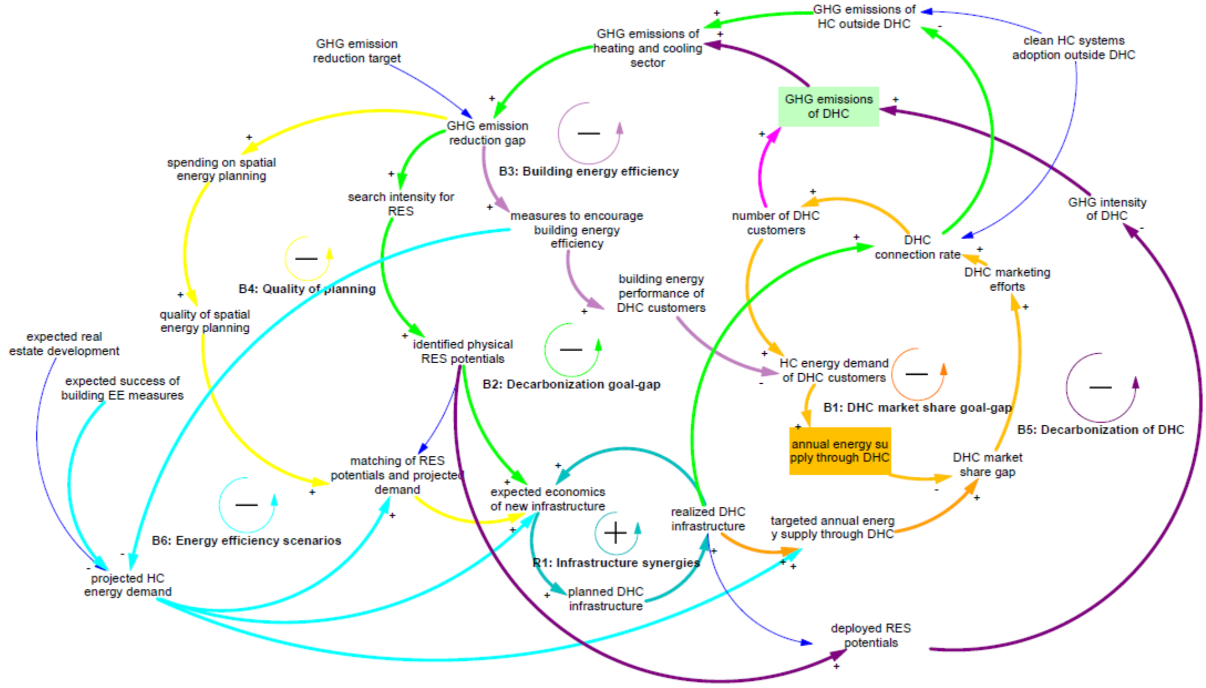

*Figure 2: Causal loop diagram from the perspective of strategic energy planning*

### 3.3. Decision-making by building owners

Building owners are represented as a series of stocks (Figure 3), building upon Kubli & Ulli-Beer (2016). Each stock represents the buildings with a distinct status regarding heating systems[2]. Three of the stocks contain the buildings where heating system replacement is not imminent, and correspond to the three heating systems represented in the model: fossil-fueled boilers, DHC and decentral heat pumps. Here, we assume a situation where fossil-fueled systems are still prevalent, but new installations are prohibited by law. Customers can therefore choose between connecting to a grid and installing a decentral, renewables-based system, represented here by building-level heat pumps (HPs). Heating system replacement is represented as a process (Hecher et al., 2017): when the need arises to consider a replacement, the building owner starts considering and comparing various options, and finally decides on one solution. This is represented by an additional stock, to which customers move towards the end of their H/C system's lifetime. Unless there is a policy to accelerate H/C system replacement, the flow towards this stock depends on the lifetime of an H/C system.

Customers' decision for or against connecting to the DHC grid depends on whether this option is available to them, whether they are willing to consider it, and how attractive it is to them compared to the alternative. Availability is expressed here as the number of years before a connection is possible, which depends on the construction status of infrastructure. Customers may commit to a grid connection before it is physically available (this process can be supported by the utility or municipality by offering temporary heating solutions to replace old systems). Therefore, we distinguish two stocks: customers that have committed to a connection, and customers that are physically connected. The size of the first stock determines the likelihood that a planned grid will be realized: to minimize risks, utilities begin construction only if enough demand has been secured through binding contracts. If this threshold is not reached, the project may be delayed or abandoned. The number of committed

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[2] For simplicity, we equate buildings, building owners and heating systems in this discussion, i.e., we do not explicitly consider the cases of building portfolios belonging to the same owner, or heating systems shared by a cluster of buildings.

customers thus increases the likelihood that a grid will be available and reduces the waiting time (R2). Even if a grid is available, building owners may rule out this option without further comparison. Building owners often rely on external advice on the choice of heating systems (Lehmann et al., 2017): this advice can come from qualified (e.g., engineering firms, architects), but also less qualified actors (e.g., HVAC installers, technology providers, real estate managers). In both cases, we assume that the likelihood of advisers to recommend a certain option depends on the alignment of that technology with their business model. We define alignment both in technological and financial terms: technological alignment is given when the advisers are familiar with an option and incorporate it in their routines, whereas financial alignment depends on the incentives of the adviser to recommend one option over another. As DHC grids are being rolled out, local advisers become more familiar with the technology and are more likely to consider it as an option to be potentially recommended to customers (R6).

If customers consider DHC, the likelihood to choose this option depends on the relative utility of DHC versus a decentral HP. We define five criteria that influence the perceived utility of a DHC connection from a customer's perspective: economics, size of investment, convenience, economic legitimacy and environmental legitimacy. Economics are determined by variable and annual fixed costs (energy and power price components for DHC and electricity cost and O&M for decentral HP), direct investment costs (connection fee and installation costs of the substation for DHC, material and installation costs of HP) and indirect investment costs (e.g., a retrofit of the building envelope may be needed to make a variant economically viable). The economics of DHC versus decentral HP vary greatly with characteristics of grids and of buildings. Assuming that the DHC utility sets the tariff as low as possible to remain financially self-sustainable (see below), a self-reinforcing loop exists: the more customers are connected, the greater the profits of the utility and the scope for tariff reductions (R3). It should be noted, however, that this presupposes a selection of customers by the utility. In some cases, it may be desirable to connect customers that are less profitable (e.g., small buildings or buildings where the connection is technically challenging) as part of a decarbonization strategy. Such a policy would weaken this reinforcing loop and may lower the economic utility of a DHC connection. In addition to economics, the size of the required investment may lower the attractivity of an option, even if the business case is favorable. Convenience depends on the level of effort required from the building owner to operate and maintain their heating system. This is frequently cited as an advantage of DHC, since very little effort is typically required from owners after installation. While convenience could not be assigned to a feedback loop, we note that this value dimension can be influenced for both DHC and decentral solutions through specific offerings (e.g., energy service contracting). Whereas the first three value dimensions concern the currently expected benefits, the last two refer to the trust that DHC will remain attractive in the future. Indeed, long contract durations and physical installations make it difficult to move away from DHC. The perceived risk of less satisfactory performance in the future may therefore keep building owners from connecting to a DHC grid. To represent these considerations, we use the concept of legitimacy, defined following Schoon (2022) as the conformity of an object to the audience's expectations. Economic legitimacy refers to the expectation that price levels will not substantially rise. Past financial performance gives an indication of this: a utility that has been performing well over years can be expected to keep its prices stable, whereas unsatisfactory performance (i.e., low profits or losses) may indicate the need to adjust prices (R5). Another potential factor are planned developments: ambitious investment and growth plans may increase the need for economic legitimation, i.e., building owners may require additional guarantees for satisfactory future performance. The last value dimension accounts for the fact that the utilization of local RES is perceived as valuable by building owners[3]. Recall that the fundamental benefit of DHC is to valorize energy sources that would otherwise be lost (Werner, 2017). Therefore, infrastructure development increases the utilization of such sources and thus the environmental value of DHC. Since infrastructure development depends on customer acquisition, there is a positive feedback loop between new connections and the environmental value of DHC (R5).

The loops R2-R6 are self-reinforcing loops that support the development of DHC. They are counteracted by R7: as more building owners choose a decentral solution, this decreases the likelihood that new projects are realized as planned (R2), worsens the economics of the grid and thus the scope to keep prices low (R3), which threatens long-term financial stability (R4) and the opportunity to valorize local RES potentials (R5). Furthermore, as DHC is less common, local HVAC installers and engineering firms are less familiar with it, and thus less likely to consider this option when advising customers (R6). This lock-in is problematic not only from the utility's point of view, but also regarding the municipality's net-zero goals (cf. Section 3.2): although only renewables-based heating systems are considered, it may not be possible to meet demand with building-level HPs only: available energy potentials may not match demand spatially, or non-energy related constraints may prevent the installation of decentral HPs (e.g. space, noise, heritage protection requirements). The lock-in created by R7 may therefore result in a situation where future H/C demand cannot be fully met by either decentral solutions or DHC.

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[3] While this entails both environmental and economic considerations (in terms of strengthening the local economy) by building owners, use the terms "environmental value" and "environmental legitimacy" for simplicity.

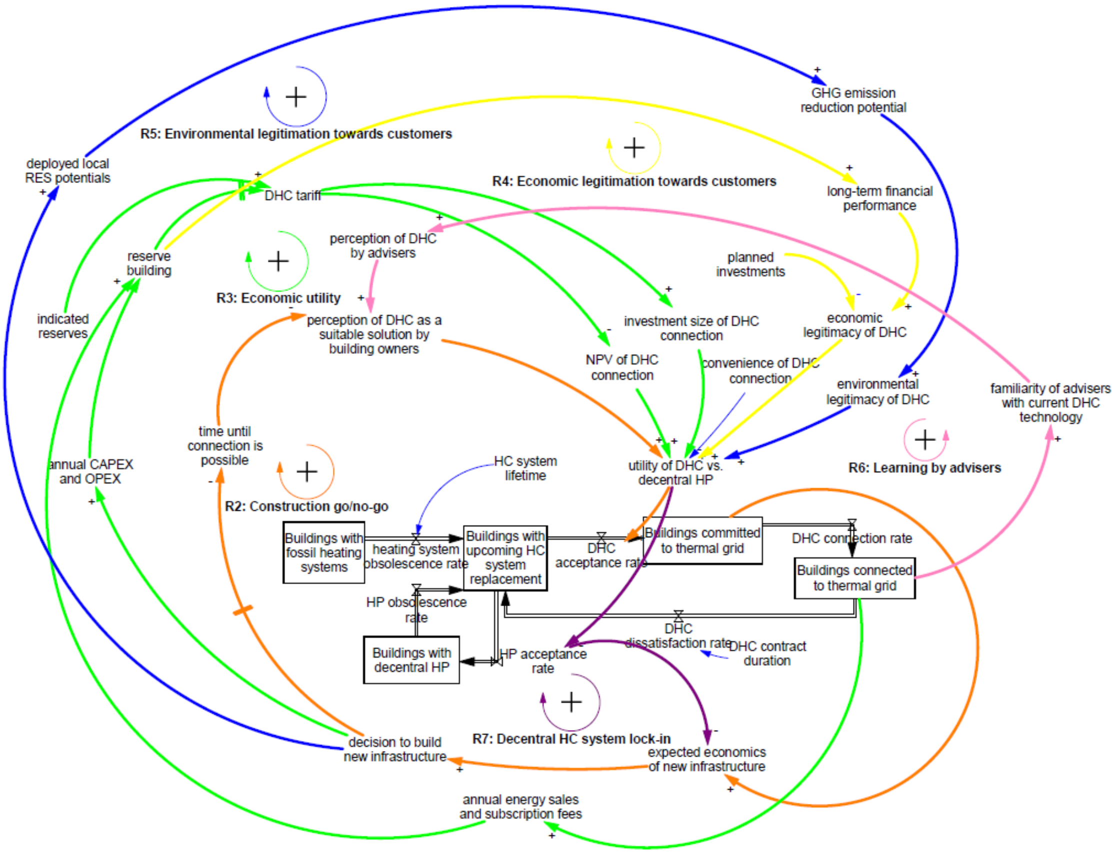

*Figure 3: Causal loop diagram from the perspective of customer decision-making on H/C systems*

## 3.4. Finance

Various pricing mechanisms can be applied to DHC, reflecting the business logic as well as the regulatory conditions (Li et al., 2015). In the case considered here (public DHC in Switzerland), there is no regulation at national level that dictates a certain pricing mechanism. Rather, public DHC is governed at local level. In various municipalities (e.g., in the cities of Zurich and Winterthur), DHC is operated by a dedicated business unit (BU) of the municipal utility. This BU is required to operate in a financial self-sustainable way, in accordance with the principles of cost-recovery and user-pays. Therefore, we assume a cost-plus mechanism (Dholakia, 2018), where the price of a product is set depending on total costs and a markup. We further assume that the price includes an energy-dependent and a power-dependent component, as is practiced in most grids in Switzerland (Preisüberwacher, 2023).

Since the goal of the BU is self-sustainability rather than profitability, we assume that the markup is set according to the need to finance future investments. This creates a balancing loop (B7): the difference between currently available reserves and the reserves estimated to be necessary to cover future investments determines the size on the markup, and thus the unit price (i.e., CHF per MWh). Ceteris paribus, increasing the markup on the unit cost leads to more reserves and thus more scope to finance future investments. However, increasing the price also worsens the economics for prospective customers, who may opt for a decentral solution instead (cf. Section 3.3). This creates a self-reinforcing loop (R8): with lower energy sales, the unit cost, and therefore also the indicated price, increase. Although total costs decrease when energy sales decrease (due to lower primary energy needs), the unit cost often still increases since fixed costs will react much slower.

Pricing also involves weighting the fixed and variable parts of the costs. It is generally said that the power-dependent price component should cover fixed costs, and the energy-dependent price component should cover variable costs. However, the weight of these components varies greatly across DHC systems (Preisüberwacher, 2023), so that it can be assumed that actual practice differs. With a greater weighting of the power-dependent component, customers are incentivized to reduce their subscribed power, reducing the associated revenues for the utility (B8). Nevertheless, a reduction of subscribed power per customer may be desired by the utility since it allows more connected buildings for the same heat generation and transport capacity (B9). With a greater weighting of the energy-dependent component, customers are incentivized to reduce energy use, again decreasing the utility's revenues (B10). It should also be noted that a tariff model with more weight on fixed costs carries the promise of greater price stability, which may increase the economic legitimacy of DHC in the eyes of building owners if proven effective during energy price fluctuations.

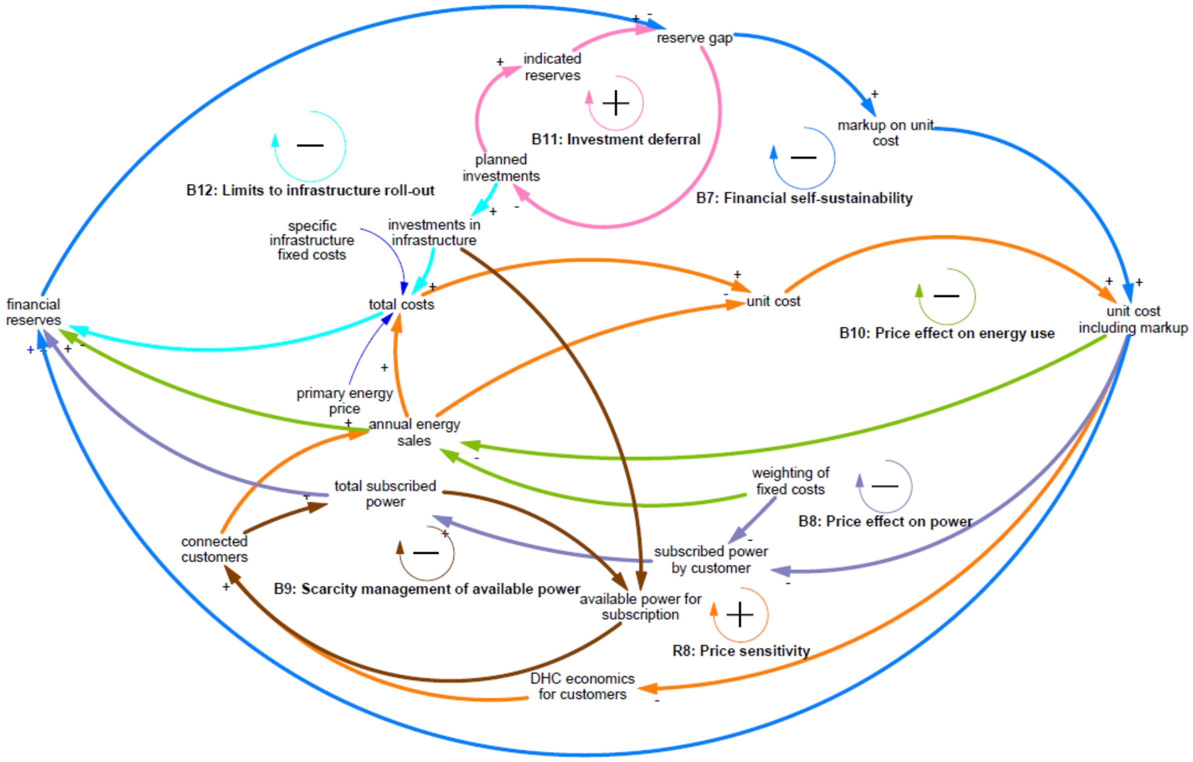

*Figure 4: Causal loop diagram from the perspective of long-term investment planning and pricing strategies*

If the reserves are not sufficient, planned investments may be delayed, reduced or canceled. This is one possibility to reduce the need for reserves and lower prices (B11). Finally, it should be noted that realized investments generate costs, which in turn reduce the capacity to build reserves (B12). The model, as presented so far, rests on the implicit assumption that the utility performs a forward-looking analysis to estimate the costs of future investments. However, if this analysis underestimates the costs, this may limit the capacity for further investments. In addition, such unexpected losses may undermine the economic legitimacy of DHC in the eyes of customers (cf. R4). While utilities apply various risk-mitigating strategies for the construction and expansion of DHC grids (e.g., phased expansion, construction only with enough secured demand), this risk is particularly salient with large investments with high uncertainty. For example, integrating large-scale thermal energy storage may carry important techno-economic risks, so that extensive planning is required (Berberich & Mangold, 2020).

## 3.5. Energy

For the net-zero transition, a key challenge is to integrate RES into extant DHC grids. In Switzerland, existing large-scale grids often operate at high temperature (≥ 100°C), which limits the potential for integration of various RES sources: since those usually have lower temperature levels, it is necessary to raise their temperature to integrate them into the grid. The viability of such options depends on the temperature difference between the source and the grid, so that lowering the grid's temperature becomes a prerequisite for integration.

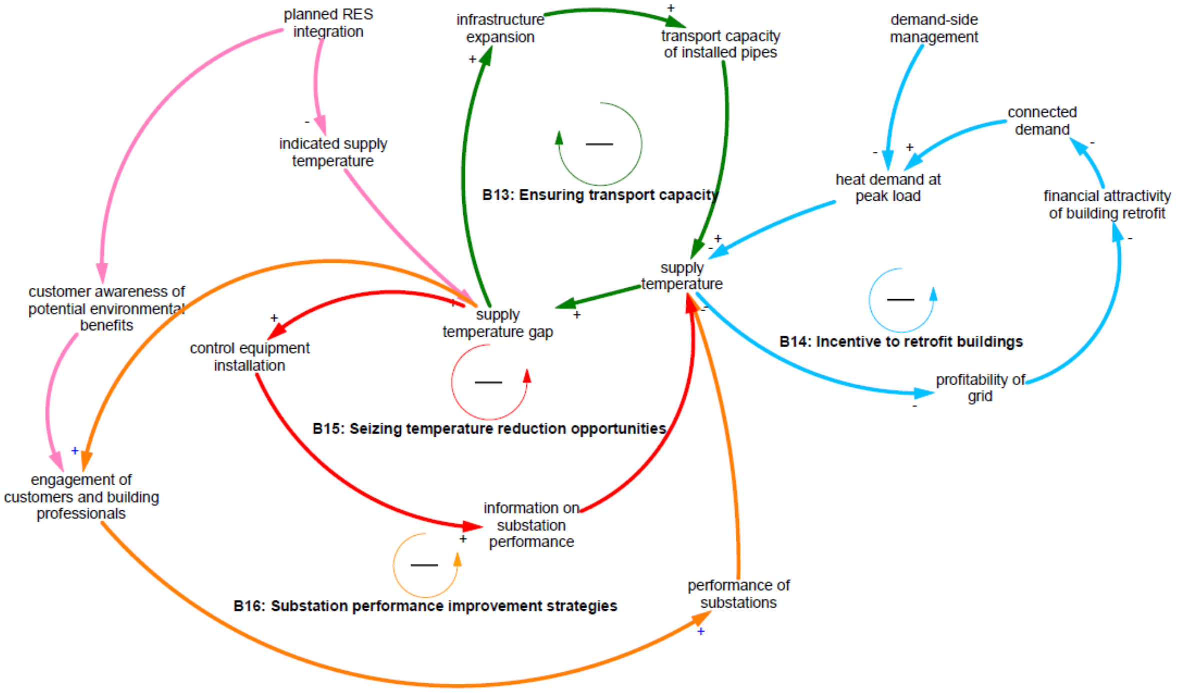

*Figure 5: Causal loop diagram from the energy perspective.*

From a technical perspective, the key variable of influence is the grid's supply temperature, which is controlled directly by the utility. Utilities have an interest in setting the supply temperature as low as possible, since higher temperature levels worsen the grid's economics. Figure 5 shows the factors that constrain the utility's choice (following Quiquerez, 2017): heat demand at peak load, grid transport capacity and the performance of substations and secondary installations in buildings[4]. The first two factors interact: the supply temperature must be set so that all connected buildings receive enough energy in times of peak demand (e.g., cold winter days). The properties of the installed infrastructure determine the temperature level necessary to satisfy this condition: a greater transport capacity (e.g., larger pipes, or several parallel pipes) enables lower temperature levels. On the demand side, the performance of substations and secondary installations constrains the scope to lower temperatures, as there are thresholds for the temperature levels that they must receive to guarantee thermal comfort. In practice, these installations are often not optimized for various reasons: for example, heat exchangers may be under-dimensioned, the building may use inefficient radiators, or substation malfunction may remain undetected due to the absence of a monitoring process.

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[4] In this discussion, we make two simplifying assumptions: first, we do not consider new connections or grid expansions. Such developments also impact the grid's temperature requirements, e.g., by affecting the distance over which energy must be transported. Second, we define supply and return temperatures as long-term quantities, although supply temperature is typically regulated in the short-term depending on weather conditions. Since the aim of temperature reduction is to integrate additional sources, it is sensible to consider the temperature level applied when the energy demand is greatest, i.e., the maximum temperature.

The necessity to integrate RES into the grid creates a gap between the current supply temperature and what is indicated in the future. This gap is location-specific: some municipalities find that they can cover their demand with high-temperature energy sources and/or decentral solutions, so that no effort to lower temperatures is deemed necessary. In other municipalities, however, temperature reduction is a key component of the long-term energy strategy. Several options exist to address this gap. The utility may expand the infrastructure to increase transport capacity (B13). On the demand-side, a price-related feedback loop can be expected: since high temperature levels worsen the grid's economics (due e.g., to higher energy losses), they may incentivize energy retrofits by building owners. With increasing retrofit rate, the peak load, and thus the required temperature level decrease (B14). The effect of this loop may be strengthened by various demand-side management measures to reduce or shift demand at building level. Another option is the installation of monitoring and control equipment (B15): assuming that the utility optimizes supply temperature based on available information, more information on substations and building installations may increase the scope for temperature reduction, by taking advantage of oversized network components and devices (Guelpa et al., 2023). Finally, various interventions are possible to increase the performance of substations in the network (subsumed under B16): for example, establishing procedures for fault detection, targeted replacement of inefficient substations, or encouraging the diffusion of efficient substation architectures (Callegari et al., 2023; Guelpa et al., 2023; Leoni et al., 2020). Since these options require the involvement of additional actors, such as building owners, building professionals or investors, they entail additional transaction costs on the part of the utility.

### 3.6. Interactions of local and national levels

The business ecosystem perspective that underlies this analysis assumes that ecosystems are nested: typically, the local ecosystem around the development of DHC (including the local utility, municipality, customers, building professionals, energy providers, etc.) belongs to a larger ecosystem at national scale. Besides the aforementioned actors at local level, this national ecosystem includes energy service companies as well as engineering and management consulting firms active throughout the country, DHC technology providers, providers of enabling technologies (e.g., control or monitoring systems, or digital planning tools), industry associations, research institutions, regulators and policymakers at national level, etc.

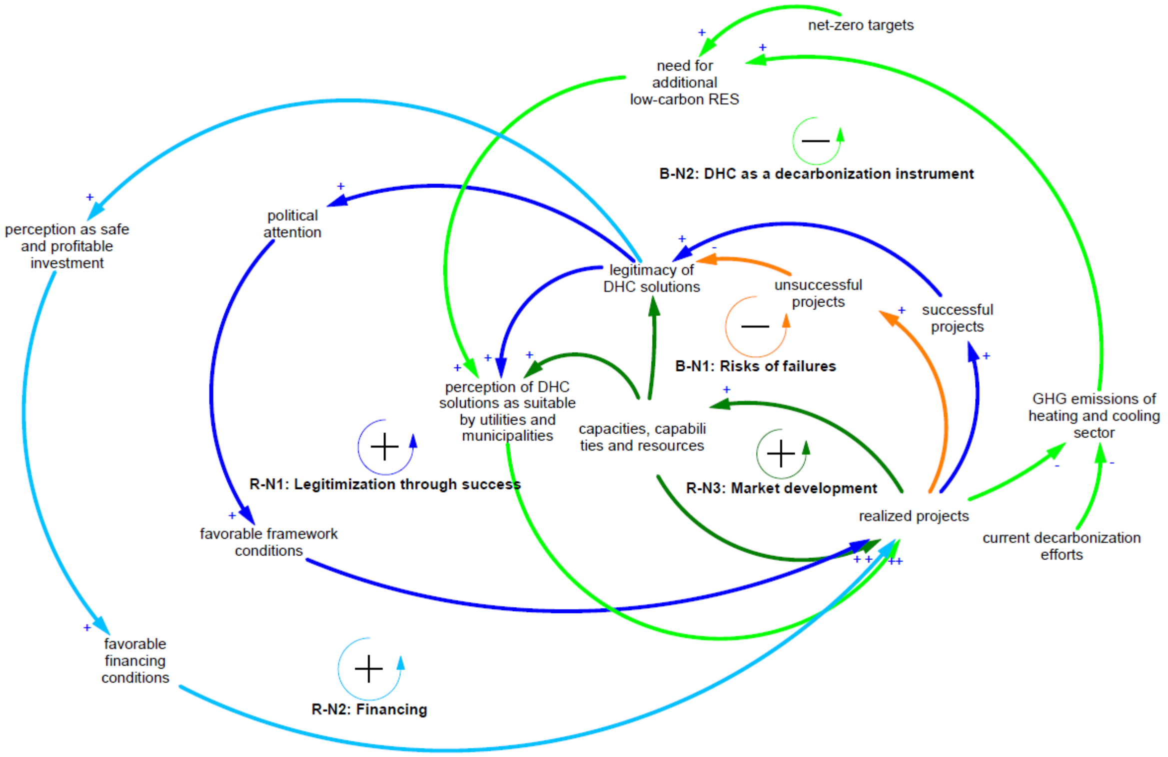

*Figure 6: Causal loop diagram on the diffusion dynamics of DHC solutions at national level*

The dynamics at national level (Figure 6) are shown here as a generic model of the diffusion of DHC solutions. This may refer to DHC itself, to specific technologies (e.g., low-temperature grids, large-scale thermal energy storage, deep geothermal energy), supply concepts (e.g., integrated district heating and cooling) or business model variants (e.g., variants of tariff models). As a solution is implemented with success locally, legitimacy is created for this solution in the eyes of diverse actors. As policymakers and regulators become more convinced of a solution, they are more likely to account for this solution and set frame conditions that favor its implementation (R-N1). This drives the realization of new projects. Similarly, increased legitimacy leads to a solution as being perceived as a safer investment opportunity, so that more favorable financing conditions can be obtained for new projects (R-N2). By contrast, less successful applications undermine the legitimacy of successful solutions, thwarting these self-reinforcing dynamics (B-N1). Here, “unsuccessful” does not necessarily mean that a project was not implemented, but also covers cases where performance or costs were substantially worse than expected. With an increasing number of projects, more and more firms (e.g., technology providers, engineering firms, building professionals) build capabilities and capacities aligned with the new solution, so that more projects can be launched (R-N3). This development can be further strengthened by creating common resources, such as guidelines, standards or specific decision-support tools. The final loop (B-N2) is related to the pressure for decarbonization at local level (B2). Here, utilities and municipalities are in the role of adopters of new solutions: as they need to find new ways to bring local GHG emissions to net-zero, they increasingly consider solutions that were not considered before. Since both utilities and municipalities are limited by a skills shortage (compounded, in the case of municipalities, by a lack of specific expertise), it can be assumed that legitimacy is an important factor in decision-making, rather than (or before) detailed assessments in the specific local context.

## 4. Discussion

### 4.1. Implications for research and practice

This paper aims at understanding the business implications of municipal net-zero policies on DHC utilities and their ecosystem. Through the formal techniques of subsystem and causal loop diagramming, we constructed a coherent map of the dynamics that impact the development of DHC in a municipality. This map allows us to answer the two research question: "*What is the business logic of DHC in its dual nature as a competitive business field and an instrument of public policy*?", and "*What are the implications of technological change and more ambitious public decarbonization goals for the business model of DHC and its ecosystem?*"

As evidenced by the feedback loop B1 (DHC market share goal-gap), DHC by itself follows a conservative logic, in which a specific goal is set a priori. To realize the economies of scale underlying DHC (Sandoff & Williamsson, 2016), the utility depends on high capacity utilization to recover the high investment costs. This creates a pressure to acquire new customers until enough sales are secured, or if sales decrease due to demand-side energy efficiency measures. Customer decision-making and behavior is driven by a series of self-reinforcing loops: a DHC connection becomes more attractive with increasing numbers of customers through better economics, and greater economic and environmental legitimacy, as well as greater alignment of demand-side complementors with DHC. By contrast, greater adoption of competing decentral systems undermines these value dimensions and make DHC less attractive. Therefore, DHC utilities strive to grow as fast as possible (considering the long investment cycles of building owners) within the areas where DHC was conservatively deemed feasible.

Municipal decarbonization policies impact these developments in various ways. First, by pushing the development of new infrastructure, they raise the targets for customer acquisition. These are further raised by measures to encourage building energy efficiency. Second, through the integration of local RES, the energy mix of DHC becomes more attractive to customers. Third, however, new investments raise prices for customers: as the integration of local RES requires additional infrastructure, such as storage, DHC grids tend to become more asset-heavy and prices tend to increase (Kolb, 2022). Fourth, the need to integrate additional energy sources requires a modernization of existing infrastructure and demand-side installations. Since the effect of decarbonization targets is a balancing loop with a goal-gap mechanism (B2, B-N2), it can be expected that the depth and nature of future changes will vary locally, depending on which RES potentials are available and perceived as more easily deployable.

Although societal energy efficiency is at the core of DHC's value proposition, the identified dynamics show that efficiency within the DHC system is not necessarily aligned with the business model. For example, building energy efficiency measures lead to lower revenues, forcing the utility to intensify customer acquisition – or to increase prices, at the risk of triggering a self-reinforcing loop of customer dissatisfaction. Also, the fact that the scope for temperature reduction has often not yet been used, despite efficiency benefits, suggests that the pressure to increase systemic efficiency has been low so far, compared to other driving factors (e.g., need to acquire customers fast; limiting the risk of user discomfort). Nevertheless, the transition to net-zero requires these efficiency potentials to be realized. We note that several substantial barriers exist: the utility may see little incentive for optimization, and coordination with customers and building professionals entails transaction costs. In line with previous research (Lygnerud et al., 2023; Sandoff & Williamsson, 2016), we argue that these changes require a reconfiguration of the DHC business model. For the concrete case of public DHC in Switzerland, we suggest that integrating energy efficiency more strongly in the business model will be necessary under net-zero goals.

This suggests that the current business model for DHC will be challenged in various ways. Using the parsimonious framework of Demil & Lecocq (2010), we discuss the implications of net-zero targets on three aspects of the DHC business model: value proposition, resources & competences, and organization. The **value proposition** for DHC focuses on reasonable pricing, convenience and environmental/social benefits through the valorization of local RES. For a stronger integration of energy efficiency in the value proposition, utilities may capitalize on the environmental and social value dimension: previous experience and studies (Lygnerud, 2019) found that integrating local RES is perceived positively, factoring into building owners' decision-making and willingness-to-pay. A stronger focus on energy efficiency strengthens this argument, potentially helping drive the positive feedback loop between environmental legitimacy and customer acceptance. Some aspects of the net-zero transition may be perceived negatively by building owners: capital-intensive infrastructure investments, such as the integration of large-scale energy storage, may raise skepticism about the utility's capacity to finance itself without raising prices, whereas the use of monitoring and control strategies may face acceptance issues due to privacy concerns. To communicate the costs and benefits of the envisioned transition, concepts that highlight DHC's role for societal energy efficiency, such as the "heat hub" concept (Jeremias et al., 2017) may be helpful. This is in line with the suggestion of Ayrault (2022) to explore values of DHC beyond decarbonization. The **resources and competences** to realize these changes and operate DHC grids in the future partly depend on the energy sources used locally: for example, different technical skills are required for the operation of low-temperature and high-temperature grids. Furthermore, the ability to implement and operate digital technologies, such as monitoring and control infrastructure, may be more critical where substantial efficiency improvements are necessary (Williamsson, 2023). We note two challenges: first, the build-up of new competences may be costly for the utility, who may not be able to properly estimate these costs. Second, one of the main barriers for a timely energy transition in Switzerland is a shortage of qualified workforce. These challenges call for a strategic approach to the net-zero transition by DHC utilities: technical analyses should be combined with an assessment of workforce requirements over time, as well as the associated costs. To connect the technical and organizational levels of analysis, a focus on technological complementarities (Zapata Riveros et al., 2024) may be helpful. Ideally, such an analysis is integrated with municipal strategic planning. Finally, the **organization**, i.e., the distribution of activities in the value network, may be less impacted, since there are few key activities in DHC that may be split between organizations. Nevertheless, there is scope for complementary offers, such as energy services on the demand side. The decision to allow such complementary offers, or to build such offerings in-house, becomes a make-or-buy decision for utilities, depending on their ability and willingness to integrate digital solutions (Williamsson, 2023). Also, to ensure that complementors have the right incentives to help with temperature reduction efforts, win-win solutions should be aimed for, considering the business logic of business professionals (the elaboration of such solutions is left for further research).

An ecosystem perspective enables a broader view of problems and solutions in situations where the actions of multiple actors require coordination (Kanda et al., 2021). Complementing insights on the DHC business model, this analysis offers lessons for orchestration of the transition of DHC to net-zero. As noted previously (Speich & Ulli-Beer, 2023), municipal energy planning is a key measure for orchestration: by providing clarity on future developments, it informs building owners on the options available to them, which helps DHC customer acquisition. Net-zero goals call for greater efforts in the identification of localized RES (TEP Energy & ECOPLAN, 2020). Our analysis offers three lessons on how to put this into practice. First, with greater quality of energy planning, local RES can be identified and matched with demand more easily. Therefore, allocating more budget to strategic energy planning is potentially a powerful lever for municipalities to realize their energy transition. Second, the evolution of demand and the potential for future infrastructure development are interlinked through the utility's finances. To further reduce risks, an integrated assessment of the evolution of demand and infrastructure development should be undertaken. Since this is currently not standard practice, there is scope for planning firms to elaborate such innovative offers. Third, the perceived suitability of a technology depends on its legitimacy established through successful applications, as well as the capabilities and capacities to realize projects. To encourage adoption of desirable technologies, their legitimacy should therefore be strengthened by adequately communicating successes and potentials. Research may help the establishment of technology-based business ecosystems by learning from the development of more mature ecosystems.

## 5. Conclusion and Outlook

### 5.1. Key insights

This analysis provides a coherent map of the socio-technical dynamics around DHC grids. Growth is driven by positive feedback loops of customer acquisition, i.e., network effects, within the boundaries set by pre-defined goals. On the flip side, vicious cycles due to lower adoption and building energy efficiency may threaten the long-term viability of DHC. The business implications of net-zero policies will likely vary locally, depending on which energy potentials must be deployed to close the decarbonization gap, starting with those perceived as easiest to deploy by utilities and municipalities. Of note, the choices at local level also depend on the development of competences and legitimacy at national level.

### 5.2. Actor-specific recommendations

Based on the described dynamics and their discussions, distinct recommendations can be formulated to different actors:

Utilities should put a greater focus on energy efficiency throughout their business model, particularly regarding building energy efficiency and temperature reduction. Key measures to achieve this are: 1) the build-up of new competences in accordance with the energy potentials that will need to be deployed in the future. A particularly salient measure is the integration of digital technology in the operation of DHC grids, either by the utility or by complementary organizations, and 2) the inclusion of these energy efficiency dimensions into the value proposition of DHC, possibly as part of a vision of DHC as a platform for societal energy efficiency. To cope with the ongoing skills shortage, a strategic planning of required (human) resources over time is helpful.

Municipalities have a potentially powerful lever for the success of the net-zero transition in the funding for strategic energy planning: allocating more funds to this instrument may enable a better utilization of local energy potentials. Furthermore, an integrated planning of demand-side and infrastructure developments assists the utility in assessing the prospects for further DHC development and setting adequate pricing models.

At higher levels of government (federal and cantonal), authorities can encourage the development of competences and legitimacy of desirable technologies, possibly through targeted funding of technology development and knowledge diffusion. In this context, a roadmap for technology development and commercialization support may be useful.

Firms that offer strategic energy planning as a service to municipalities face higher requirements, as net-zero targets call for more effort in the identification of local energy potentials. It is crucial to ensure adequate quality standards in this context. Furthermore, a temporal analysis of demand and infrastructure development may be an additional, valuable offering.

Finally, this analysis has also identified further opportunities for research. To facilitate collaboration between utilities and building professionals in temperature reduction, blueprints for such collaborations may be useful. Since technical and organizational aspects are closely linked, an interdisciplinary approach is indicated. Also, research may accelerate the establishment of future technology-based business ecosystems by identifying concrete measures supporting their development.

### 5.3. Limitations and outlook

A limitation of the presented analysis lies in its qualitative nature. Indeed, to assess the strength of the discussed dynamics, quantitative simulation is essential (Sterman, 2000). This would allow a prioritization of the suggested measures in a specific local context. Also, a simulation model may address some of the gaps identified in this paper: it can be a suitable tool to produce a roadmap of required (human) resources over time, or to jointly analyze the parallel dynamics of demand and infrastructure development.

Another limitation of the model is that it represents the simplest case of DHC applications in Switzerland from an inter-organizational point of view: in public DHC, the coordination between the municipality and its utility is well established. Further inter-organizational challenges may appear in cases where the utility is independent from the municipality, or when third-party heat providers are considered.

Finally, the results presented here are based on a limited number of case studies. Although stakeholders were engaged in the case studies upon which it is based, further validation by stakeholders will be beneficial to further develop the qualitative model, as well as quantitative models building upon it.

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