

Article

Business Model Changes in District Heating: The Impact of the Technology Shift from the Third to the Fourth Generation

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Abstract: This paper addresses the implications on the business model of district heating companies of the technology shift targeting lower temperatures in the distribution network. Lower temperatures are valuable, since heat supply to low-energy buildings with low grid losses is facilitated. In addition, low-temperature heat sources can be integrated into an efficient energy system, improving the environmental performance of the industry. This technology shift opens a window of opportunity to update the business logic in the sector, since the lower temperatures allow a diversification of the value proposed to customers and a closer, long-term customer relationship. The extent to which the business model is impacted by the shift is not known. Thus, six cases of low temperature implementation from five European countries have been identified. Interviews with the project managers of the implementations show that the six cases made limited change to the primary business model when making the technological shift. Consequently, there is an unexplored potential for updating the value proposition and the customer relationship.

Keywords: district heating; low temperature; fourth-generation technology; business model change

1. Introduction

1.1. The Technology Shift in District Heating from the Third to the Fourth Generation

Heating and cooling are the largest energy-consuming sectors in the EU, representing half of the final energy use. To date, approximately one-fifth of the fuels used in the sector are renewable [1]. One way to support decarbonization in heating is to increase the share of district heating (currently 9% of the European heat is provided from district heating) [2]. District heating (DH) systems can reduce the usage of fossil fuels, making use of renewable energy sources and waste heat. In Europe, the potential for industrial heat recovery is significant. The potential was quantified for different countries in a survey which showed that the unrestricted EU technical potential, was approximately 2.7 EJ/year [3]. This equals one-quarter of the building heat demand in Europe (approximately 10 EJ/year). [4]. Waste heat from high-temperature, industrial processes is apt for waste heat recovery. It is however possible to use heat pumps to increase the temperature of low temperature heat sources, making low temperature heat sources interesting. In Sweden, heat from sewage water plants has, for example, been utilized since the 1980s. As a result of energy efficiency improvements in buildings, competition from other heating alternatives and the prediction that biofuel is a resource that will become scarce [5] both DH companies and owners of low temperature waste heat sources are becoming interested in using low temperature heat sources. They are often found in urban infrastructure systems (sewage and transportation) or from cooling processes (supermarkets or computer centres). A recent study in a H2020 project, the Reuseheat project, states that the available waste heat potential of sewage water, metro systems, service sector buildings and computer centres is 1.6 EJ/year [6]. It should be



noted that the urban waste heat recovery integrates the use of heat pumps which adds additional complexity to the investment. The close link to the price of electricity has been shown to be a decisive factor for urban waste heat recovery success [7]. The heat pump technology itself is mature but there are few, validated low temperature cases in operation to date [8].

DH technology has gone through technical shifts before. The first generation of this technology was characterized by steam, the second generation resorted to hot water being used as the transport medium for heat and the third generation, still in use today, resorts to hot water in the range of 86 °C (or higher) to transport heat [9]. After sixty years of the third generation it seems that the industry is on the verge of shifting to the fourth generation technology targeting distribution temperatures of 50 °C. The fourth-generation concept was first introduced in a paper "4th Generation District Heating (4GDH). Integrating smart thermal grids into future sustainable energy systems" by Lund et al. [10]. In their paper, it is assumed that the current DH systems need to be developed further to be part of a future, 100% renewable energy system. The writers stated that next (4th) generation of DH must fulfil the following aspects: "be able to: (i) supply low-temperature DH for space heating and domestic hot water to existing buildings, energy-renovated buildings and new low-energy buildings, (ii) distribute heat in networks where the distribution losses are lower (than the conventional 10–30%), (iii) recycle heat from low-temperature heat sources and integrate renewable sources such as solar and geothermal heat, (iv) be a part of an integrated, smart energy system (encompassing electricity, gas, fluid and thermal grids) and (v) ensure planning, cost and motivation structures to develop a future sustainable energy system".

Apart from the phase-out of fossil fuels, urban waste heat recovery is valuable for mitigating the urban heat island problem (e.g., the phenomenon whereby heat generated in urban structures increases the temperatures of urban areas compared to their surroundings) [11,12]. This problem is often most visible in city centres where the increased temperature levels trigger increased use of cooling equipment, whereas the energy consumption in residential areas is lowered; however, there is a benefit from the temperature increase in the cooler periods of the year [13]. These urban heat sources can either be used in existing systems when supported by heat pumps that can elevate the temperature of the heat sources or used as part of new, low temperature solutions. A study made on Denmark and their energy system in 2050 indicates that a shift from the 3rd to 4th generation in DH solutions amounts to 300–350 MEUR/year in savings from "investments and operation of the DH grid and in the production (system costs) due to lower temperature" [14]. Lower temperatures are valuable, since heat supply to low-energy buildings with low grid losses is facilitated. In addition, low-temperature heat can be used in an efficient energy system, improving the environmental performance of the industry. Apart from the reduced climatic impact, the lower distribution temperatures will also enable and improve the utilization of renewables and excess heat sources in general [15].

An ongoing project for the International Energy Agency has identified over 100 low temperature demonstration sites that have been built worldwide (www.iea-dhc.org/TS2). Low temperature heat sources are either included in the current DH system (3rd generation) by means of heat pumps or directly used in new construction areas. There, the installations are built as islands that are either standalone or connected to the existing DH system. The conventional business logic of DH is based on scale in production and in distribution. The low temperature heat sources are not centrally available in a city. Instead they are spread out in different areas, which necessitates a logic of decentralized, small-scale heat distribution, which is opposite to the logic of the 3rd generation. The logic of 3rd generation is economies of scale (in both production and distribution) whereas the logic of 4th generation is based on the resources available at the district level. The different logics emphasize different gains. The large scale production and distribution benefits from lower distribution costs and the value of recovering a fossil free heat source (e.g., the value of green is pronounced). The tradition of the large scale logic amongst district heating companies can make the introduction of the decentralized heat recovery challenging.

The industry has an engineering tradition which draws attention to technical development and a number of technical generations. This tradition has sustained the industry over time and supported its development for decades. However, to develop further in the context of energy citizens (they are active in making choices related to energy; they can for example choose to invest in renewable energy production or decide to generate and sell energy themselves: becoming prosumers) both business model development and technical development must take place [16,17].

There are generic elements of business models. Customers (value, relationships, segments), resources (infrastructure, activities, partners, logistics) and the cost/income structure are such elements [18–22]. Much has been written about business models but there is not any universal definition of what they are. They can create competitive advantage [23–27] at least before being copied [27]. A business model does not equal product or market strategy [28], they it illustrates the fit of different pieces of a business but does not entail action to offset competition [26]. Business models can reflect strategy [23], but the two are not equivalent [21,24–28]. Business models are also different from products, companies, industries, networks, technology, internal organization and value chains [18].

Business models develop and some find that the development is a tool for corporate renewal [29–32]. It seems as if successful organizations look outward and account for new preconditions by developing their business models. Indeed, long-term competitiveness and survival reflects an efficient business model [22,32–34]. There is no consensus on how business model development unfolds. Some advocate that systematic and structured processes generate business model development [22,35,36]. Trial and error is another pathway [22,29,37]. If business models develop as a response to external pressures, internal changes or a combination of both is not clear [31,35,38,39]. One barrier to business model development is the links between its different parts [21]. Another barrier is the existing business model which hinders the development of a future business model [22,29,40]. A business logic reflecting a past situation is a third barrier. For example, assuming that economies of scale are preferable to other alternatives, even though this assumption is no longer valid, is a hindrance to development [21]. Another hindrance is that information is filtered and only certain information is detected through the lens of the current business logic [38]. Least but not last, a fifth barrier is the uncertainty of the future. It is difficult to assess which business models are suitable for the future if the future strategy is unknown [22].

Firms need to change, adapt and innovate their business models to appropriate value from technological innovation [33,41,42] and to sustain success over time [21,22,43]. Hence, business models mediate firm technology choice. That said, technology development necessitates business model decisions on openness and user engagement [41]. There are some that claim that multiple, parallel and partly even conflicting business models exist in one single company. The coexistence of business models is a method for managing risk and opportunity whilst absorbing technical development [23,24,32]. In contrast, others find that the primary business model shifts continuously to meet demand [29,32,44–46]. It is also known that established firms develop (rather than innovate) business models by making new combinations and architectural changes to the existing value chains, relying on general business knowledge [47,48]. It is concluded that the extent to which technical development spills over to the business model is not clear.

1.2. The Business Model in District Heating

In [49], the features of the DH business, 3rd generation, are presented (resorting to the methodology of the business model canvas developed by [20]). On the customer side of the DH business model, the largest customer segment is professional customers e.g., large building owners. The business logic is based on economies of scale and a strategy of push (heat supply), rather than pull (market demand), towards the customers; the business models are also utility-sided. Regarding the infrastructure, the key resources are production units and distribution networks (they can be owned by one single entity or by different companies). The necessity to cover fixed costs from production and distribution are seen

in the cost and income structures. In terms of key partnerships, fuel providers are crucial to success of DH businesses [50]. The features of the conventional DH business model are summarized in Table 1.

Custom	er Side	In House (DH Company) Side		
1. Customer value	Heat and hot water	1. Key activities	Production Distribution Maintenance	
2. Customer segment	Large building owners	2. Key resources	Production unit Distribution network	
3. Customer relationship	Provider to consumer	3. Key partnerships	Fuel providers	
4. Customer channel	Invoice, Campaigns	-	-	
5. Income structure	Fixed	4. Cost structure	Large fixed costs	

Table 1. The features of the conventional DH business model.

There are a few studies on DH business modelling. Two generic models are mentioned in a German study on how energy utilities innovate their business models [51], these are the utility-sided and the customer-sided models. The former provides value by bulk generation of electricity. The latter generates energy in small-scale systems close to the point of consumption (by means of technologies such as solar photovoltaics, micro-wind turbines and micro-combined heat and power systems). Heat entrepreneurs in Finland are addressed in another study. In it, ownership is taken as a proxy for business model determination [52]. Five ownership forms are identified: public company, public-private partnerships, private cooperatives, network model of large enterprise and energy service companies (ESCOs). Linked to each ownership category is a specific earning logic ranging from long-term standard contracts to complimentary partnerships and subcontracting arrangements. In Sweden, solid waste management is common. In a study of relevant business models for such undertakings, three value-creating activities were identified [53]. One activity was to service the public and authorities in their quest to manage waste. Another activity was the actual processing of waste (including environmental concern and recycling). The third activity was marketing activity to arrive at an economic value from the waste processing. Two additional studies from Sweden identify the role of national policymaking in the development of business for DH [1,54]. Both studies recognize the lock-in effect of the current business 'regime.' The lock in sustains heat production rather than supporting a transition towards reduced heat demand.

Köfinger et al. [55], studied four cases of low temperature installations in Austria. They considered investment costs and ecological impact of the investments. They concluded that the local conditions of low temperature DH investments make comparisons and generalizations across investment projects difficult. Dynamic effects will differ from case to case (heat pump effect, supply- and demand-side matching and mixing conditions) and the investment costs will be higher than with conventional installations. The higher investment costs are however, balanced by lower distribution losses and by ecological gains. Another study followed the municipality of Aalborg in Denmark, which decided to become fossil free before the year of 2050 [56]. The results of the study show that usage of low temperature geothermal heat in combination with wind power can cover the municipality's energy needs; biomass is seen as a finite resource and not seen as a long-term solution. It was concluded that the investment cost of the low temperature solution is higher than conventional solutions but has positive effects both in terms of climatic impact and on the number of locally generated jobs since the low-temperature investments are more local-labour intensive. In terms of prosumers (building owners that both consume and generate energy), a simulation was made showing that there is a prosumer potential for small-scale local solar collectors in combination with heat pumps. However, the prosumer element necessitates increased system management and control to handle migratory temperature fronts [57].

It is not easy to know how to balance investments in energy savings with investments in renewable technologies. It is challenging since complex DH system can generate high specific costs at the heat source recovery point and/or at the energy efficiency improvement location. Further complexity is added by the impact of short term policy instruments. This was showcased in a simulation study undertaken to analyse the transition from conventional DH systems towards 4GDH systems [58]. It is also not apparent how to shift the tariff structure in the transition from conventional to 4th-generation DH solutions. Focusing on understanding the part of fuels and "other" aspects in the tariff in isolation from each other it was not possible find any single, "other" factor being decisive for an efficient transition from 3rd to 4th generation tariffs [59]. In a Finnish study [56], a review of existing district operating practices was undertaken to understand how a transformation can be made from current generation of DH. The focus was on innovative technologies and it identified solar thermal collectors, thermal heat storage at the building level (short-term) and at the district level (long-term), and heat pumps are important aspects of the future DH generation. It is also identified that there will be a development towards an increasing number of prosumers, which can facilitate local heat trade. An example of such a heat market place is in Stockholm, where Stockholm Exergy has created a local marketplace for heat (Fortum, Open district heating, 2015). In [60], it is also concluded that the business logic of DH is outside of the scope of the study but that it needs to be carefully addressed in future research.

From business model research it is known that it is difficult to change a business model that is efficient and generating a positive return. Indeed, there are known cases of companies that failed to meet the need for a new business logic before it was too late, resulting in termination of their activity (such as Kodak and Xerox). The DH industry is in a situation where their conventional business logic is becoming outdated. The shifting demand (towards added value of energy efficiency and CO2 efficiency), the shifting fuel mix (from fossil to urban heat sources) and the potential to invest in district level low temperature solutions meeting increasing heat demand (e.g., avoiding reinvestment in the central production unit) challenge the traditional business model configuration. There is a need for modernization of the business model if the industry will survive long term. That said, the challenge to do so is substantial. Low temperature DH solutions necessitate even better optimization of the network than in conventional DH. To be able to use locally available heat sources where they are in supply and to optimize their injection into the wider DH context is a challenge that is linked to choices regarding technology, investments, climate and the local territory. Also, choices and tradeoffs that need to be made are sometimes conflicting. One example can be the tradeoff between the increased dependency of electricity in urban waste heat recovery and the CO₂ savings from resorting to the local heat source. In sum, the challenge is large and will take time. The big advantage of the DH sector, making the necessary business logic shift possible, is that the market is slowly changing and that customer demand only shrinks slowly (at the pace of increased energy efficiency), allowing for a transition from one business logic to another. Installations of low temperature DH solutions in existing DH companies, will for some time, necessitate a co-existence of conventional business logic and new aspects important for low temperature solutions.

Summing up the section on theory, it is concluded that business model innovation can be triggered by different factors. It is, however, difficult to innovate a business model that is still generating positive cash flow, which means that the future is mitigated by the present. Taking the large infrastructure investments of DH into account, it is understandable that the current, conventional DH business model dominates and makes the development of alternatives challenging. Indeed, the primary business model is dominant and based on a logic that is opposite to harvesting local, low temperature heat sources. To make use of multiple, local energy sources there is for example an increased need for efficient system control. It also necessitates a new relationship to customers who can both consume and deliver heat into the DH network (e.g., prosumers). The interaction with the existing DH network is also a challenge, although there are examples of close interaction between the conventional and the low temperature DH grids (using return heat from the conventional distribution network and lowering the temperature level in the existing network) and of decoupled interaction (through the establishment of energy hubs). Other, non-technical aspects are also important to consider, such as the balance between investment capital going to energy savings or to new heating technology and the aspect on how to price heat in the future.

The situation of DH companies provides an opportunity to understand the following research question: **Do district heating companies that implement low temperature solutions develop their business models at the same time as they make the shift in technology?** The main aim of this paper is to understand if a nascent technology shift in an industry spreads to its primary business model. The case for studying this phenomenon is the DH industry, in which there is a nascent technology shift. A case study is made by the aggregation of information from six low temperature implementation cases in the DH industry. The main conclusion is that, when the technology shifts, there is limited development in the primary business models used for 3rd-generation DH. The industry could better exploit the values of the low temperature solution: energy savings, lower distribution losses, capitalize on the value of green (a low CO2 technology), placing a value on the creation of jobs locally (since decentralized heat production is more labour intensive than centralized), avoiding fuel transports (distant fuels are replaced by local heat sources) and a direct and close long-term relationship with their customers (necessitated by the closer collaboration between provider of waste heat, DH company and heat customer).

2. Materials and Methods

Business models are composed of a number of connected parts. To understand the impact of technology shifts on the different parts it is important to collect in-depth information. The technology shift in DH is nascent, and thus there is a limited number of installations made to date. In an ongoing project for the International Energy Association (IEA) work is done to identify existing implementations. By reviewing information on the internet and following up on such information, 131 low temperature installations have been identified to date (more information about the projects can be found at (www.iea-dhc.org/TS2). It was not possible to gather in-depth data from all the implementations made and, hence, a case study was made on six cases. These were chosen based on criteria ascertaining that the aggregation of results from the six sites gives as broad information as possible about 4th-generation implementation. Cases that met these criteria are seen as forerunners in terms of the low temperature technology shift. The cases are interpreted as critical cases from which the DH industry can learn how to maximize the impact of the technology shift from 3rd to 4th-generation DH [61]. The first criterion was that the implementation status was to be implemented before the year end of 2019. The second criterion was that the ownership of the DH company undertaking the case should be a mixture between private and public companies (three companies selected are privately owned and three are publicly owned). The third criterion was that the heat sources in the system have a lower temperature than in conventional, 3rd-generation systems. The fourth criterion was to feature cases from both the frontrunner countries in DH technology and less mature DH markets. Interviews with the project managers for the 6 low temperature implementation projects were made.

2.1. Case Presentation

A short description is provided of each case, including the motivations for undertaking the project. Cases 1 and 2 were located in Germany, a mature DH market where construction companies have the responsibility to install an energy system with a primary energy factor of 0.5 or less. Since electricity has a high primary energy factor, solutions that use other resources for heating are incentivized. The primary energy factor constraint creates a demand from construction companies to engage their local energy companies to find energy solutions with a low primary energy factor, which triggers the energy companies to elaborate innovative solutions that are reflected in both of the German cases.

The case is in Germany. It is a developing area and there are good possibilities to challenge traditional thinking and form an area that addresses changing living behaviour, construction, interaction and energy system innovation. The project aims to focus on energy system innovation and development from an environmental and primary energy perspective, taking advantage of the existing DH network (using the return heat) and locally available heat from the sewage system. The case provides heating and cooling for an area equal to the size of around 28 football fields. The project is a collaboration between the site developer and the local, privately owned, energy company. On-site–produced (from renewable biomethane) electricity, excess heat from the sewage system and from the low temperature return heat in the DH network will be combined. Together with an innovative, 4th-generation DH piping system, the project aims for a low primary energy need by using low system temperatures that decrease energy losses. The heat sources temperatures are in the range of 15 °C (sewage water heat in wintertime) to 40 °C (return temperature of the DH system).

2.1.2. Case 2: Darmstadt, Germany

The case is located at the Lichtwiese campus at the Technical University of Darmstadt. The university wants to contribute to the German energy transition by making use of waste heat from a high performance computing data center located on campus. The project is a collaboration between a research team consisting of architects, electrical engineers and mechanical engineers from the institute of technical thermodynamics as well as the university administration and the local district heating supplier (private company owned by the city of Darmstadt).

The campus is a typical university campus erected in the 1960s and thereafter expanded on several occasions. Currently the university contains heat from three gas engines in combined heat and power plants (total of 7 MWth) and six gas boilers (55.8 MWth). Since 2017, there is a district cooling network on site, supplied by absorption cooling (1 MWth). In addition to the heat and power station a data center will serve as a heat source: the low temperature heat source (supplying 360 kWth, a small fraction of what is needed in total). The heat source temperature is in the range of 40–45 °C coming from high performance computer servers. Since this temperature is too low to be used for heating purposes directly, the temperature of the data center waste heat is upgraded via a heat pump to 60–70 °C and integrated into the return line of the district heating system.

2.1.3. Case 3: Albertslund, Denmark

Albertslund is a town west of Copenhagen in Denmark that invested in DH in 1964. Denmark is a mature DH market and 97% of the heat demand in Alberslund is covered by DH. Within the next 10 years, depending on the willingness and speed amongst building owners to refurbish, approximately 5000 dwellings are foreseen to be renovated in a city of 28,000 inhabitants.

The heat is purchased from a district heating transmission company and then distributed through the locally owned DH distribution network (owned and operated by the municipality). The heat purchased is manly generated CHP on biomass and from waste incineration but also waste heat through a heat pump from a computer centre is included in the distribution system. The city has ambitious environmental goals and annually presents its green accounts (where CO_2 neutral heat and electricity by 2025 and 100% reduction of CO_2 emissions by 2050 are important targets). One measure to reach the goals is to lower temperatures in the DH distribution network. The target was launched in 2016, and by January 2026 the temperature level in the system should be 60 °C. The target will be met by energy savings in buildings, adjustment of buildings for low temperature DH and the distribution system will be updated to allow for lower temperatures.

Work to partition the distribution system up into low temperature systems has been initiated. There are today five islands locally where a shunt to mix hot and cold water for the area has been installed. The buildings in these areas have been new construction or social housing where there have been substantial refurbishment efforts. Currently, more than 1000 households are supplied with low temperature district heating. The project is a collaboration between the municipal DH network operator and the building owners in the city. There is a dialogue forum called "the User Council" with representatives from above 50 different housing areas. In this council all aspects related to the local supply of heat, water, sewage, outdoor lighting, garbage and re-use" are discussed the suggestions from the council are addressed by the local politicians. In the User Council low temperature in DH has been agreed upon, and a low temperature action plan is updated annually. The interest from the house owner side to make preparatory work for the low temperature installations has increased over time. The Albertslund district heating supply is offering the end users the option to rent a new heating unit with service. All 7500 heat meters have been changed to smart meters, and for the coming years, focus with be on big data analysis of meter and weather data, to provide the end users with a more exact consultation for preparing the house owners for lower temperatures.

2.1.4. Case 4: Vallda Heberg, Sweden

This case is located in Vallda Heberg, a residential area in the city of Kungsbacka south of Göteborg in Sweden. The area is newly built and was completed in 2013. The houses are passive energy houses and encompass a retirement home, service sector (gym and offices), single family houses and apartment buildings. The installation was made by the local energy company EKSTA Bostads AB, owned by the city itself. This company not only provides energy but is also engaged in construction of buildings. The company is a forerunner in Sweden, in that they use solar in DH whenever possible. Since the company both owns the buildings and provides them with heat, they understood that lower temperatures in the network would make the usage of solar energy more efficient and they decided to make a test in the Vallda Heberg area (the heat source is solar with temperature in the range of 70–80 °C). The company has considered the whole area rather than the building level when setting the system boundary of the implementation. One way to secure a good summer load is that the buildings have the washing machines and dishwashers connected to the heating system. The heat is delivered to the heat exchanger of the building, e.g., no apartment switches were installed. The project is the result of the company being able to both impact the energy system and the construction of the buildings in the area. All customers in the area chose to connect to the DH network. The installation is a small network that will not be connected to the large-scale DH network in the locality.

2.1.5. Case 5: Nottingham, United Kingdom

The fifth case is in the city of Nottingham in the UK. It is the first low temperature DH network installed in the UK. There is an existing, 3rd-generation DH network in the city where the heat sources are waste incineration in combination with gas boilers. The DH market in the UK is fragmented but entering a growth phase. The heat source feeding the low temperature DH island is the return heat from the DH system (with a temperature of 60–65 °C). The local DH company is municipally owned, this is also the case of the Nottingham City Homes. The scheme implemented is that Nottingham city homes has its own ESCO for the low temperature area. NCH is a separate company that owns 30,000 homes in Nottingham and it is owned by the local council. An area of 94 flats belonging to Nottingham city homes was substantially refurbished and attached to a newly built low temperature grid (also owned by the housing company). The work was done within the realms of the REnovation MOdel for URBAN regeneration (REMOURBAN) project (H2020 financing) as part of EU Smart Cities and Communities grant and the installation was completed in March 2019. The local university has been actively engaged in the energy installation, providing knowledge and installation advice as well as monitoring of the installations made.

The consumption is measured per apartment and the gas boilers that were previously in the apartments have been substituted with an apartment switch. The small volumes of water standing still in the heat exchangers do not allow for the growth of legionella bacteria, and is therefore not a problem.

2.1.6. Case 6: Wörgl, Austria

The city of Wörgl in Austria has a local district heating company which is new to the DH market (it was installed in 2013). The heat is generated by biomass and industrial waste/residual heat from a dairy factory (with waste/residual heat flows at a temperature of 45–80 °C). The DH system is in growth and one strategy for growth is to build small heat islands that are connected to the large network. The city has been building an area of social housing targeting young families. Building the houses, the city decided to go for low temperature heating which is well suited for floor heating, primarily using the waste heat from the dairy factory. The city engaged a team including city planner, developer, architect and pipe manufacturer at an early stage to identify an efficient solution for the area. As a result, a prefabricated pipe solution was designed to save on piping costs and space used in the area. The Legionella aspect is treated locally with booster heat pumps for heating the water used.

In Table 2, a presentation of the companies of the case study is provided. The respondents in the cases are the project managers of the low temperature implementations. This target group was deemed most apt for providing an understanding of the implementation as a whole, from the purpose of implementation to the technical constraints. The interviews were semi-structured, and the questions were elaborated based on the business model canvas components. The relevance of the questions was tested with practitioners from three DH companies in three countries (Italy, France and Germany) and their input was incorporated in the interview guide. The interviews lasted between 45 minutes and 1 hour. During the interviews, notes were taken and the interviews were documented in conjunction to each interview occasion. The model of analysis applied is the "business model canvas", [58]. The analysis conducted identified if/where development in the business models could be detected in the cases where the technology shift occurred, compared with the conventional DH business models.

Respondent Company	Implementation Status	Ownership Structure of DH Company	Heat Sources and Their Temperatures	Mature Heat Market (Y/N)
1	Feasibility completed	Private	Sewage water (15 °C in Winter) and return of DH (40 °C)	Y
2	In progress	Private	Waste heat from high performance computer (40–45 °C)	Y
3	In progress	Public	DH network (60 °C)	Y
4	Complete	Private	Solar (70–80 °C)	Y
5	Complete	Public	DH network return (60 °C)	Ν
6	Complete	Public	DH network using different heat sources (45–80 °C)	N *

Table 2. The companies included in the case study.

* The Austrian DH market is developed, but not the Tyrol region where the demo site is located.

2.2. The Model of Analysis

The business model canvas [58] is the analytical framework applied. It was co-developed by academics and practitioners and is built around a structure that is easily conveyed to a broad audience (DH researchers, policymakers and practitioners). The framework was deemed apt as it addresses all the relevant components for understanding change in the DH business.

Shown in Table 1, the canvas contains nine parts. Four of them focus on the customer side. Three of them address the delivery of value, resources needed and important partnerships. The last two reflect the cost and income structure of the model.

3. Results

Results are provided on the customer side (Section 3.1) and on the resource side (Section 3.2).

3.1. Results of the Customer-Oriented Activities

The parts addressing the customer are linked to the value, segment, relationship and communication channel. In the six case companies, no shift is identified from the conventional customer segment. The professional customer segment is still the dominant one. Regarding customer value, it was identified that it was the customers in five out of the six cases who demanded a greener DH solution and thereby triggered the technological shift. In all three cases where the DH company is publicly owned (Wörgl, Albertslund and Nottingham), the city has requested that the municipally owned DH company undertake the low temperature solution, thereby supporting the city in its work to achieve environmental goals. In the two German cases (both operated by privately owned DH companies), the regulated primary energy factor creates a demand from the customer of an energy system in line with the regulation. The German legislation appears to have efficiently created a demand for green solutions amongst building owners. In the Swedish privately owned company it was the operational efficiency gain when using solar as heat source that triggered the installation. None of the six cases changes the product offered to the customer: it is still heat and hot water rather than a green, indoor climate service built on a strong customer: it and relationship.

Two of the studied companies explicitly address that the value of saving space in newly built areas is important to the customers. In the construction process the fact that the DH system can be placed under ground, including the operational rooms needed for controlling the systems, created a competitive advantage compared to other heating solutions. In one of the cases (Wörgl) no basements were installed in the building, forcing the full DH solution below ground, under the buildings.

Regarding the customer relationship, the project managers in all six cases found that the success of the installation was that it was tailor-made. The usage of the low temperature heat sources is a technical challenge that is new to the DH operators and is one that must be met by the installation of heat pumps in different locations. Heat pump technology is not new but the combination, using low temperature heat sources in DH, is. The low temperature heat solution does not allow the conventional provider/purchaser relationship, built on the business logic of scale and the 'push' of products/services towards the customers. In the low temperature case, the relationship with the customer is characterized by intensive dialogue. In three of the cases, the local university provided direct support to facilitate the low temperature installation. In one of the cases, (Darmstadt) the university is the customer of the DH company and the knowledge at the university triggered it to demand the low temperature heat solution as part of the university's environmental work. In the other case, (Nottingham) the university is part of a research project implementing the low temperature solution. In the third case (Vallda), leadership in DH research at the local university has resulted in an understanding about the synergies between solar heat recovery and low temperature solutions. In one of the cases (Wörgl), there was early collaboration between representatives from the city (the customer), the architect, the DH company and the provider of the piping solution. This kind of collaboration was new to the parties involved but proved important for the successful implementation.

The usage of the low temperature heat sources is decentralized and of varying temperatures and volumes, which necessitates more advanced control systems than in the 3rd-generation setting. Such a development does not only place larger emphasis on efficient control and digitalization but can also empower the customers to make choices and to impact their heat and hot water consumption in an unprecedented way. Only one of the cases, (Albertslund), made direct use of the possibility to offer additional services when the control system is improved, extending its range of energy services, offering the customers advice on how to optimize their heat usage. However, this case did see limited interest in the work of lowering the DH temperatures in the networks even though it is a city target that is updated and communicated to use councils (associations of building owners who discuss the operation, e.g., waste management, heating, lightning and other of their buildings, with the city on an annual basis) every year.

The customer channel in these low temperature schemes displays a more active communication than the conventional communication through invoicing and occasional campaigns. The dialogue around the solution is important in the five cases where the demand for the low temperature solution was triggered by the customers. In the 6th case, using solar as heat source, the installation was not the result of much dialogue with the building owners but placed close to the users, creating an unprecedented visibility of the heating system to the residents/people populating the area.

3.2. Results on the Use of Resources

In four of the six cases, the low temperature DH networks are built in islands that are linked to the existing system by means of a switch mechanism. In one case (Darmstadt), the heat recovered is inserted into the existing DH system directly by means of a transfer pipeline, and in another case (Albertslund) there is work underway to section the current system into parts connected to the distribution network by switches. Over time, the piping of the parts will be shifted to low temperature piping, which in practice means that the system will consist of heat islands that are joined into a citywide system, accounting for the temperatures of the locally available heat sources. The key resources for the low temperature solutions appear to be heat pumps for making use of the local, low temperature heat sources in the DH system (applied in all six cases) and low temperature distribution networks. The increased usage of heat pumps creates a new dependence to electricity making the price level of electricity an impactful factor on the DH business profitability. Three of the companies (the "German city", Vallda and Wörgl) point out that the construction of adjacent low temperature islands, to the existing DH network, is an alternative way to extend heat capacity without enlarging the central production unit in the conventional DH system. All six project managers point to the importance of skilled people to assess potential, derive solutions for the integration of the low temperature heat sources and to monitor the performance of the cases. The skillset of the people is important, since the combination of the low temperature heat sources with heat pump technology to energy efficient buildings is a solution without much empirical evidence to date.

In the business model canvas of the 3rd-generation DH business, fuel providers are the most important partners for DH companies. In the low temperature DH context, a number of new key partnerships are formed with: (i) local heat source providers, (ii) electricity providers and (iii) the customers. To extract the low temperature heat efficiently, a dialogue is needed to determine when that source of heat is most cost efficient and how stable the heat delivery is (in terms of volumes and temperature ranges). The operation of the heat pumps is directly linked to the electricity price and, especially in Germany where the primary energy factor of electricity is high, the greenness of the electricity is important to consider. A study on Swedish industrial waste heat recoveries (high temperatures) considering all industrial waste heat recoveries in the country for the time frame of 1974–2014 shows that the inclusion of electricity in the fuel mix of DH companies to recover waste heat increases the risk of the recoveries being shut down if the price of electricity rises. This should also be applicable to the low temperature heat recovery context, as it necessitates more electricity usage than higher temperature industrial waste heat recovery does relative the heat volumes recovered. Regarding the customer relationship, the close dialogue and tailor-made solutions to meet the customer demand for a green solution can shift to make the customer loyal long term.

Considering the cost and income structure of the installations, they are all associated with fixed costs for equipment and piping as well as with development costs of the new technical interface between the low temperature heat source and a heat pump. Five of the six cases are linked to the existing DH distribution network whereas one case (Vallda) is a standalone low temperature network. The link to the existing DH network creates a safety backup in that if the low temperature system would fail there is a possibility to heat the buildings using heat from the conventional system. This tendency for caution is not only reflected in the technical solution chosen for the low temperature installations. It is also reflected in that the companies keep the price of the low temperature heat at the same level as the conventional DH price.

4. Discussion

In five of the six cases the low temperature installation is primarily a technical test installation. This is reflected by additional key resources such as heat pumps, low temperature heat sources and new skillsets amongst technical staff to install, monitor and operate the urban waste heat recovery. Technical development for sustained development is characteristic of the DH industry but to remain competitive there is a need to also develop the business side. E.g., the different business logics of the 3rd generation and 4th generation and the shifting customer value from 3rd to 4th generation necessitate that an adjustment is made beyond technology. The shift in the value generated for the customer, the value of green energy, is therefore important. The value of green is however not currently exploited by the six case companies. The companies could, for example, as a result of the green value differentiate their offer with different degrees of green allowing for a price differentiation. Also, the proximity between customer and heat provider in the low temperature heat context is not captured in the low temperature heat installation offer.

The conventional DH business model is built on the logic of scale (in both production and distribution). The low temperature DH solution is based on a different logic with decentralized heat sources of small volumes that can be assimilated locally. In all six cases, the primary DH business model for the 3rd-generation DH solutions is applied also to the low temperature installation. As a result, the district heating companies will consider the low temperature installations as less profitable than the 3rd-generation installation. If the value of green were fully explored, e.g., the gain from the heat portfolio being diversified, the lower distribution costs, energy savings, the creation of jobs (regarding job creation, the jobs will materialize both on the equipment provider side and in the DH companies. In a recent stakeholder study on urban waste heat recovery installations (from the Reuseheat project: www.reuseheat.eu, deliverable 2.1), it is identified that heat pump technology is not new, but combining it with urban heat flows is a new concept and necessitates a new skillset amongst equipment installers. Also, the DH companies interviewed identified that the low temperature installations necessitate new skills amongst staff: both on the customer side (to engage in long term relationship and tailor made solutions) and on the technical side (operation of the low temperature systems). Hence, it can be argued that the jobs created will be long term, local and qualified), avoidance of transport of fuel to the central heating unit (transports generate CO_2 emissions and erode the green value of the DH installation) and lower grid cost since low temperatures support the use of pre-fabricated pipes that necessitate a shorter installation period and less civil works, then the value of the low temperature heat recovery investment could make this a better business case than 3rd-generation installations.

The six cases confirm that it is difficult to switch from an existing and profit-generating business model to something new. The tendency to combine components of the value chain in new ways instead of completely reconfiguring it is also identifiable. Theory implies that technology is mediated through the business model but that it also necessitates decisions on openness and user engagement. The potential for a prosumer development is apparent with the local and low temperature heat sources. However, in none of the six cases such a development is talked about or the case constructed in such a way that prosumer monitoring was facilitated or encouraged. Hence, the decision on user engagement and on how open and closed the dialogue should be with the customers does not yet appear to have been a conscious decision. In the six cases, the customer dialogue has been undertaken about the technical solution. The situation provides a window of opportunity to build a closer relationship overall between the DH company and the building owner. In the long run, a close dialogue leads to loyal customers. Loyal customers in combination with the value of green and the potential to save space in newly built areas increases the competitive advantage of the low temperature DH solution.

It is the customer demand that triggered five out of the six installations. This indicates that the customer side is increasingly ready for this kind of solution something that the DH companies need to prepare for to be able to meet the demand as it grows. Half of the respondents found that the low temperature addition to the existing DH business is a cost-efficient way to extend capacity without

investing in a larger, central production unit. Hence, the low temperature systems can be an efficient reinvestment strategy.

In the low temperature context, the synergies of the heat recovery are smaller than in conventional 3rd-generation solutions. This is the result of the volumes being limited and local, necessitating more equipment cost per unit heat recovered than compared with the large-scale production and distribution installations. Even so, the aggregated value of the low temperature installations provides a sufficient synergy to make the investments a relevant development pathway in future DH systems.

5 of the 6 cases are installations that are linked to an existing DH network (the island approach). In future systems, it is probable that this development is further solidified and that the 3rd-generation solution is complemented by the 4th-generation solution, a circumstance that should improve the resilience of the future DH system. With heat generated locally in some parts of the system and centrally in other parts there is a win-win solution in that if the central heat source is lost there is a local supply and if the local supply fails there is a central supply. This kind of combined energy systems are increasingly important in future, smart cities.

It must be recognized that the heat markets are organized differently under different national legislation. The heat market aspect of a country will impact the possibility for entrepreneurs in the energy sector to engage in urban waste heat recovery investments (low temperature). In a recent study of stakeholders related to urban waste heat recovery solutions (in the H2020 project Reuseheat, www.reuseheat.eu, Deliverable 2.1) it is identified that the market for urban waste heat recovery is still unregulated. The absence of a specific low temperature legal framework can be a hindrance to the development of the technology. It is also identified in the report that the extensive support in Europe towards renewables leads to a situation where RES are favoured above low temperature heat recovery. In this paper, the focus is to showcase how the business logic needs to change to manage with the more challenging (multifactor situation) if DH companies are to gain the full benefit from the low temperature installation. The necessary adjustment of the business model to the existing market conditions is out of scope of this paper but is an important area to generate knowledge about in future research.

Returning to the question of research of this paper: Do district heating companies that implement low temperature solutions develop their business models at the same time as they make the shift in technology? The results confirm that yes, there is a shift in the key resources and key activities undertaken. However, the shift generates additional values to the value of the 3rd-generation solution: both in terms of the green value and of a closer customer relationship. None of the cases studied expressed a strategy for materializing both technical and business value of the technology shift. Instead the primary 3rd-generation business model is maintained, and the level of openness and user engagement is kept at the 3rd-generation level. It is concluded that there is an unexplored potential for district heating companies to capitalize on the low temperature technological shift. Both the value proposition and the customer relationship in low temperature district heating installations can be strengthened compared to the business model of 3rd generation installations.

With regards to the limitations of this study, it provides limited information on a technology shift that is nascent in an industry. The results are not possible to generalize for the entire population of DH companies. It is interesting to understand how the full value (technical and business) can materialize. The pathway from a successful technical implementation to the full value being capitalized is important to follow.

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