Master Thesis

From Third to Fourth Generation District Heating in Leeuwarden:

An Exploration of Feasibility and Risks

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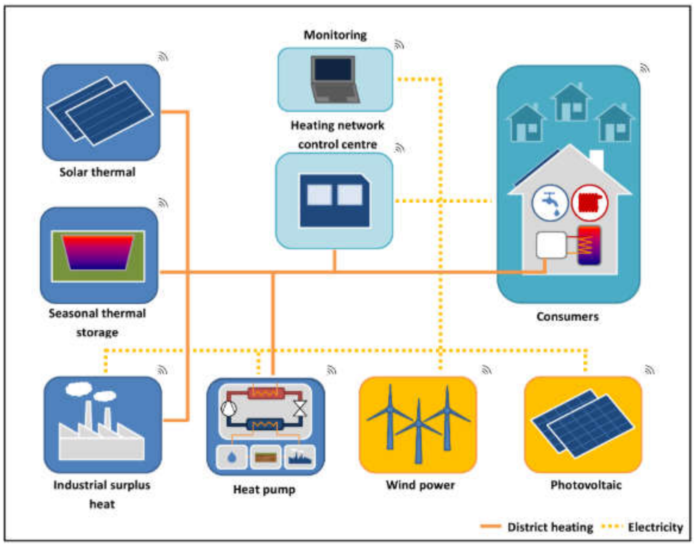

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Summary

The existing district heating system (DHS) in Camminghaburen (Leeuwarden) is dominated by 3rd generation district heating (3GDH) system. This DHS rely on centralized heat producer (Combined Heat and Power plant (CHP)) which consumes natural gas for heat generation. The heat with quite high temperature (75-85 degC) is then distributed by heat networks (water pipes) for customers (heat is used for space heating and domestic hot water (DHW) heating inside buildings). Due to these unique characteristics, the existing DHS can only be supplied with selective heat producers which can produce heat with that specific temperature (or higher). Apart of that, the heat distribution using water with high temperature usually cause large amount of heat loss due to dissipation of heat to surrounding environment.

In order to improve the reliability of existing DHS, the DHS needs to be upgraded to accommodate wider scale of heat producers. These heat producers use more sustainable heat sources (geothermal heat, residual heat and biogas) for heat generation. The utilization of these heat sources can reduce natural gas consumption thus help the energy transition process towards low carbon energy supply. The upgrade also needs to enable utilization of lower temperature heat supply, thus can decrease heat loss during heat distribution. Finally, the upgrade needs to implement smart thermal grid (STG) which is important to enable demand side management of heat consumption. The upgraded DHS that can carry on these tasks is known as 4th generation district heating (4GDH) system.

In order to discover the improvements needed for upgrade of existing DHS to 4GDH system, the concept of 4GDH system, the characteristics of existing 4GDH system in Netherlands (Mijnwater 2.0 in Heerlen) and existing DHS in Camminghaburen (Leeuwarden) are analysed. Based on this analysis, the differences between existing DHS and 4GDH system are highlighted. After that, the necessary changes on the existing DHS in Camminghaburen are proposed. Some of the upgrades include integration of multiple heat sources, replacement of natural gas with geothermal and/or residual heat sources and implementation of STG which needed to establish prosumer system.

Some prominent risks that can occur during upgrades of existing DHS to 4GDH system are identified. Difficulty to form good collaborations between multiple heat producers & DHS company (due to issue with contract of heat supply), lack of collaboration between DHS company & housing corporations to coordinate on buildings refurbishment (that can support utilization of low temperature heat supply) and concern of data privacy to be exposed (due to presence of remote heat measurement) are some risks that can be faced during transition from 3GDH to 4GDH system. In order to mitigate these risks, some potential solutions are recommended which is mostly related to changes in local energy policy along with more leadership from municipality to drive the development of 4GDH system.

Keywords: District heating system, 4th Generation District heating, smart thermal grid, organizational complexity

Acknowledgements

My interest to do this research is mainly originated from the "smart" word. This "smart" word is identical to utilization of ICT to improve the performance of system. In the energy system, this "smart" word is related to deployment of ICT to enable more efficient energy system. One of the most famous smart energy systems is smart electricity system or known as smart grid. The research on this smart grid has been performed by numerous academic to this date. To avoid duplication on previous works, I decided to focus my research related to smart grid for district heating system or known as smart thermal grid. This smart thermal grid is still being researched by experts in thermal energy system especially for its implementation in new generation district heating system or known as 4GDH system. After looking for more information, I decided to do my research on 4GDH system with more focus on the risks related to the upgrades of existing district heating system towards 4GDH system.

During the tenure of my research, I have been supported by some important people. Without their helps, I will not able to finish my research properly. At first, I would like to thanks my direct supervisor, Dr. Maarten Arentsen for his help to crystallize the ideas related to this research along with his great advices to do research and to prepare the report. Great appreciation is also delivered to my second supervisor, Prof. Joy Clancy for her help to review and improve the content of the report. I also would like to send my great appreciation for innovation manager of Mijnwater BV, Mr. Herman Eijdems who had provided numerous information (technical and non-technical) related to development of 4GDH system in Heerlen. I also want to send my gratitude for the energy expert in municipality of Leeuwarden, Mr. Bouwe de Boer for his insight and information related to development of district heating system in Leeuwarden.

Finally, I also want to send my appreciation to my family (my wife and my 2 kids). Without their continuous supports during my master degree, I will not able to accomplish my master thesis.

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List of Acronyms

4GDH = 4th Generation District Heating
CHP = Combined Heat Power (Heat & Electricity)
DHS = District Heating System
DHW = Domestic Water Heating
EU = European Union
ICT = Information & Communication Technology
IOT = Internet of Things
LTDH = Low Temperature District Heating
STG = Smart Thermal Grid
TES = Thermal Energy Storage
TPA = Third Party Access

Chapter 1 – Introduction

1.1 Background

More than half of energy demand in Netherlands comes from heating needed by homes, industries, companies and greenhouse. To this date, this heat is mostly generated by combustion of natural gas. To reduce CO2 emission caused by natural gas consumption for heating, the natural gas needs to be replaced with more sustainable energy resources. Apart of that, it is also necessary to reduce the energy consumption for heating generation. Both approaches can be done by individual measure or collective measure in which collective measure is more cost-effective and more energy efficient than individual measure (Hoogervorst et. al., 2016). The collective measure with district heating has potential to phase out natural gas consumption through utilization of heat from low carbon sources (such as heat from geothermal wells or solar thermal plants).

Although district heating system (DHS) has been known in Netherlands since 1920's when the first DHS was built in Utrecht, DHS penetration is still low in Netherlands (only 5.6% of total heating in residential buildings is provided by DHS in 2017 (CBS, 2019)). One of the main reasons for the low penetration is the low gas price in the past decades which had driven development of national gas infrastructure and heating system based on gas boiler. At the same time, the DHS is only developed minimally due to non-technical factors such as lack of price competitiveness, insufficient investment, lack of interest and inadequate public support. The DHS development is only seriously considered after formulation of regulation by government to tackle on climate change and significant reduction of gas supply from Groningen gas fields.

The current DHS in Netherlands is dominated by specific heat producers (such as heat from power plants or waste incineration) which generate heat with high temperature (> 100 ^{o}C). Heat networks are then used to distribute the heat to buildings for space heating and domestic hot water (DHW) heating. The main limitation of existing DHS is dependency on centralized high temperature heat sources which prevent integration of decentralized low temperature heat sources. The technical characteristics from this existing DHS have slowed down DHS development in Netherlands.

To overcome some of these limitations, the existing DHS need to be upgraded to new district heating system which is known as 4th generation district heating (4GDH). This 4GDH system has ability to integrate centralized & decentralized heat sources and to utilize lower temperature heat sources. Apart of that, the 4GDH system also can use smart thermal grid (STG) to improve energy efficiency through proper monitoring of heat demand and controlling of heat distribution. This STG enable heat consumers to be heat producers (prosumer) at the same time and to allow integration of heat storages (Lund et. al., 2014). Using these features, 4GDH system can enable peak shaving and reduce dependency of gas consumption to meet maximum heat demand (peak load).

As common for development of new energy infrastructure, it is expected that 4GDH development for existing DHS in Netherlands will face some non-technical risks. These risks can be originated from the non-supportive regulation and lack of public support on 4GDH development. The high DHS development cost and organizational complexity (caused by participation of many organizations in 4GDH development) can also bring additional risks. These risks need to be identified properly as the risks can delay the development of 4GDH system. The delay on the development of 4GDH system can slow down the energy transition process for current DHS which is mostly supplied by heat generated using natural gas.

Since experiences is needed to develop 4GDH system and also to identify the risks related to 4GDH development, it is necessary to discover the previous 4GDH system which has been developed in Netherlands. Based on literature review, there are several 4GDH systems that can be identified: Mijnwater 2.0 in Heerlen, STG in TU Delft university and STG in B3-Hoek (Rotterdam). From the scope of implementation, Mijnwater 2.0 is considered more extensive as compared to other 4GDH systems since it has wider heat networks coverage (Heerlen municipality), utilize multiple heat sources for heat supply, provide heat for various types of buildings (houses, offices, supermarket, etc.) and implement STG to enable prosumer system (Verhoeven et. al., 2014). Meanwhile STG in TU Delft university only provide heat for buildings inside the university and STG in B3-Hoek only provide heat for one type of heat customer (greenhouses) (Netherlands Enterprise Agency, 2015; Ende, 2015).

The development of Mijnwater 2.0 in Heerlen also has more experiences to deal with technical and non-technical risks. In order to overcome the risks, Mijnwater BV (DHS company) has collaborated with many organizations through participation in several EU projects. One of the risks is related to development cost (financial risk) which is resolved through utilization of several financial schemes (such as subsidy from municipality and funding from EU) (Eijdems, 2019). Other experience is dealing with social acceptance on 4GDH system which has been done through collaboration of DHS company and municipality (municipality actively promotes 4GDH development through regulation (see section 2.3.2). Based on these experiences, the development of Mijnwater 2.0 can be used as lesson learnt to identify improvements needed for upgrade of previous generations DHS to 4GDH and also to identify risks related to 4GDH system.

1.2 Problem Statement

Currently there are two existing DHS that have been developed in Leeuwarden (located in the north eastern part (Camminghaburen) and southern part of Leeuwarden (Zuidlanden) (Ennatuurlijk, 2019)). This DHS is developed as part of the efforts to reduce dependency on natural gas for heating in built environment. The heat generation using individual gas boiler is one of the main contributors for the fossil fuel consumption in Leeuwarden (klimaatmonitor, 2019). One of the existing DHS in Leeuwarden (Camminghaburen) uses CHP (with natural gas as energy source) for heat generation. Since the DHS needs to utilize high temperature heat supply generated from CHP, it is difficult for the DHS to utilize lower temperature heat from other heat producers (such as residual heat from industries) (ennatuurlijk, 2019). As consequence, a lot of useful heat sources are not utilized (such as residual heat from industries and data centre) and the heat is just dumped to environment. The limitation of existing DHS raises the potential development of 4GDH system that can utilize these low temperature heat sources.

Apart of the existing DHS, the municipality also plans to utilize geothermal heat source for upcoming DHS. Although geothermal heat is considered to be sustainable heat source (geothermal well produce renewable heat which emit close to zero CO2 emission), the development of geothermal wells needs significant investment to fulfil the existing heat demand (Warmte Leeuwarden, 2018). In order to expand the geothermal DHS and also to reduce investment for development of geothermal wells, the geothermal heat source need to be used more efficiently. This objective can be achieved through establishment of prosumer system. In the prosumer system, heat demand for some customers can be supplied using heat surplus from other customers. As consequence, the same number of geothermal wells can supply heat for more customers, thus allow the expansion of heat networks without additional investment to develop new geothermal wells. This prosumer system can only be established through implementation of the STG and the STG is considered as important component in 4GDH system.

Although there are many benefits can be achieved by 4GDH system, currently there is lack of study to analyse the potential for the upgrade of existing DHS to 4GDH system in Leeuwarden. Based on analysis of the characteristics of existing DHS in Leeuwarden along with analysis of 4GDH conceptual characteristics and characteristics of existing 4GDH system in Heerlen (Eijdems, 2019; Ennatuurlijk, 2019), there are some missing characteristics (technology, organization and operation) that required to transform the existing DHS towards 4GDH system. Due to this transition, there are some potential risks that can emerge and these risks has not been fully identified since the potential implementation of 4GDH system in Leeuwarden has not been considered yet at this moment.

To fill in the missing information, the first part of this research will focus on describing the upgrade needed by existing DHS in order to be developed into 4GDH system. Meanwhile, the second part of this research will focus on the risks related to the DHS upgrade to 4GDH system. The risks that will be identified in this research are related to non-technical risks including organizational complexity, social acceptance, development cost and policy.

1.3 Research Objective

The objective of this research is to identify the improvements needed by DHS in Leeuwarden to be upgraded towards 4GDH system. Apart of that, this research also aims to identify the potential risks related to the heating system upgrade along with the potential solutions that can be proposed to overcome the risks.

1.4 Research Question & Sub-Questions

Based on the problem statement and research objective, below research question and sub-questions have been formulated:

The main research questions:

What are the changes needed to transform the existing heating networks in Leeuwarden to 4GDH systems, what are potential risks of such a transformation and how can these potential risks be mitigated?

The research sub-questions:

1. What are the main characteristics of a 4GDH system and how are these characteristics developed in practice?
2. What are the differences in technology, organisation and functioning of the existing heating networks in Leeuwarden and a 4GDH system?
3. Which changes will be needed in technology, organisation and operation of existing heating networks in Leeuwarden to transform them into 4GDH systems?
4. What are potential risks of the transition of the current heating networks in Leeuwarden towards a 4GDH system and what are the potential solutions to mitigate these risks?

1.5. Demarcation

This research focuses on the upgrade of existing district heating system to 4GDH system in more general analysis (technology, organisation and operation). This focus is selected since the 4GDH system in Leeuwarden is not yet implemented, hence the comprehensive analysis of 4GDH development is not available at this moment. Apart of that, the risks caused by the district heating system upgrade are only explored for the organizational complexity, social acceptance, development cost and regulation parts. This selection is deemed adequate for exploration of initial risks that can be further discussed by related organizations for realization of 4GDH system in future. This research has more focus on the risks from supply side and less focus on the risks from demand side due to limited information from heat customers (research data is only acquired from DHS company which also has limited information from the customers). The heat customers mentioned in this research are houses and commercial buildings which utilize heat from district heating for space heating and domestic hot water preparation.

1.6 Research Methodology

The research methodology can be separated in 4 different steps as described in following parts.

Step 1: Description: In this step, the concept of 4GDH is explained through comparison of the 4GDH system with previous generation district heating system and description of the smart thermal grid's features in the 4GDH system. After that, the theories of organizational complexity and social acceptance along with descriptions of development cost and regulation related to DHS are further elaborated. The existing 4GDH system that has been developed in Heerlen is also explained in this part. This theoretical and empirical elaborations are used to describe 4GDH system, its operation and non-technical parts related to its development.

Step 2: Focus: This step focus on detail of existing district heating system in Leeuwarden. This detail description and analysis is required to diagnose the characteristics (technical and non-technical parts) of existing DHS. These characteristics are then compared with characteristics of 4GDH system (explained in Step 1) to acquire overview of their differences.

Step 3: Utilize: This step utilizes the differences of existing DHS in Leeuwarden and 4GDH system to identify and analyse the improvements needed for upgrade of the existing DHS to 4GDH system in Leeuwarden. The improvements/changes related to technical and non-technical parts (technology, organisation and operation) are elaborated in this step.

Step 4: Assess: This last step uses the information of risks from desk research, experts of DHS and energy expert in Leeuwarden municipality to identify potential risks related to transition of existing DHS to 4GDH system in Leeuwarden. After that, the potential solutions to mitigate these potential risks are proposed.

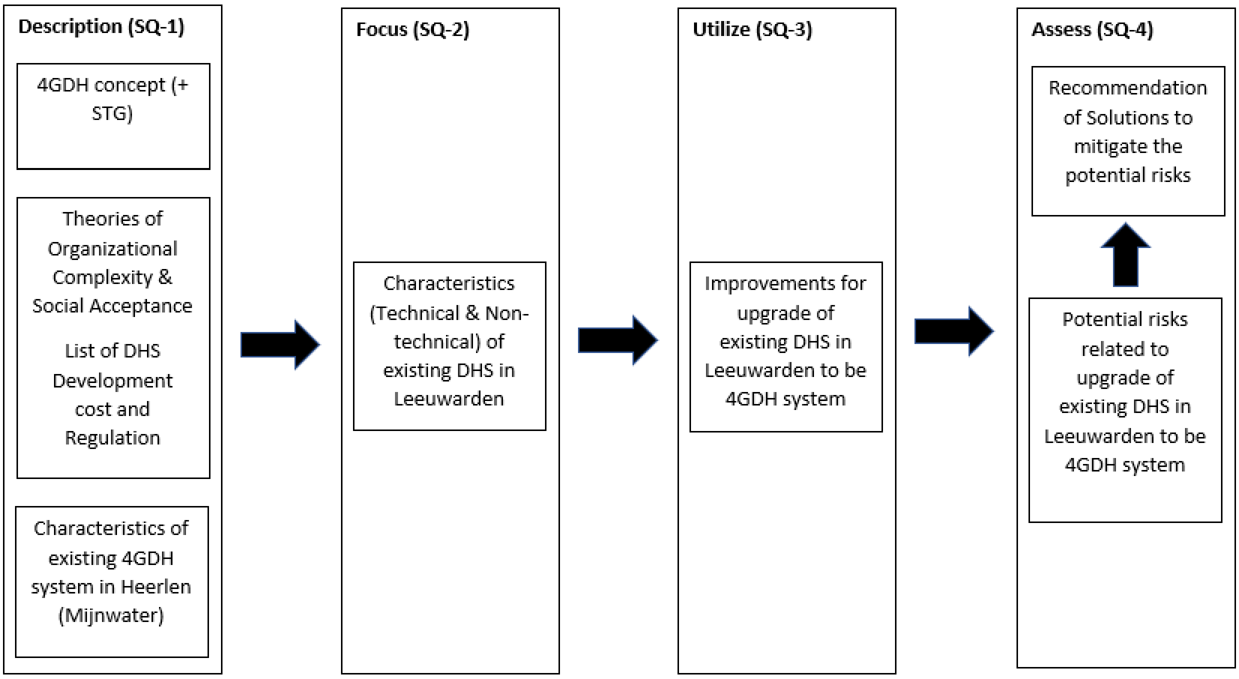

Figure 1. Overview of Research Methodology

1.6.1 Research Strategies

The table below shows the different research strategies, data source and accessing methods that are used in this research.

Table 1. Overview of Research Strategies

Research steps	Research strategies	Data Source	Accessing methods
Description	Desk Research Interviews	Online document Scientific literature Key informants	Search & Content Analysis Questioning & Interviewing
Focus	Desk Research Interviews	Online document Scientific literature Key informants	Search & Content Analysis Questioning & Interviewing
Utilize	Desk Research Interviews	Online document Scientific literature Key informants	Search & Content Analysis Questioning & Interviewing
Assess	Desk Research Interviews	Online document Scientific literature Key informants	Search & Content Analysis Questioning & Interviewing

The in-depth interviews for data gathering are conducted with following informants:

1. Manager from existing 4GDH company (Mijnwater BV)
2. Manager from existing district heating company in Leeuwarden (Ennatuurlijk)
3. Energy manager from Leeuwarden municipality

<u>Content Analysis</u>

The data from first informant is used to acquire information related to characteristics of the 4GDH system that has been developed by Mijnwater BV in municipality of Heerlen (technology & organizations), obstacles that Mijnwater BV faced during development of 4GDH system and their solutions to resolve these obstacles. This information is analysed to identify the practical implementation of 4GDH system which can be compared to conceptual characteristics of 4GDH system.

The data from second & third informants is used to acquire information related to characteristics of existing DHS in Leeuwarden (technology, organizations), obstacles that Ennatuurlijk & municipality faced during the development of existing DHS and their future plans related to development of DHS (mostly focus on development of geothermal DHS and utilization of residual heat from industries). The information from these 2 informants are analysed to show the differences of the existing DHS in Leeuwarden with 4GDH system, to identify the upgrades needed to transform the existing DHS towards 4GDH system and to identify potential risks related to the upgrade.

1.7 Ethical Statement

Since this research requires data gathering through interviews as mentioned above, it can raise ethical issue related to informants' personal information and data privacy (related to information from the informant's). Researcher has to ensure that informants' personal information is not exposed without any agreement with the informants. To acquire this agreement, researcher inform this issue to the informants prior the interview process and the informants are asked to fill in & sign the "Informed Consent" form in which informants can choose to expose their personal information (name and function), to be anonymous or only to be cited for information. Based on the filled "Informed Consent" forms, two informants are willing to expose their personal information, meanwhile one informant (Ennatuurlijk) is not willing to expose the personal information (anonymous). Researcher also ask clarification from the informants' whether the information acquired from them can be shared for public or can only be used for internal publication. To acquire this clarification, researcher will acquire verbal and/or written agreement from the informants. Based on the written agreement from the informants (email), all of the informants have agreed to share the information for public.

1.8 Reading Guide

Chapter 1 give information of research background, problem statement, research objective & research question and research methodology. Chapter 2 answer the first sub-question by describing the concept of 4GDH, theories related to organizational complexity & social acceptance, development cost and regulation related to 4GDH development. This chapter will also describe the existing 4GDH system in Heerlen. Chapter 3 answer the second sub-question by describing the existing DHS in Leeuwarden in term of characteristics (technical & non-technical) and showing the differences of this existing DHS with 4GDH system. Chapter 4 answer the third sub-question by describing and explaining the improvements needed for upgrading existing DHS to 4GDH system in Leeuwarden. Chapter 5 answer the fourth sub-question by utilizing information of risks from desk research and experts' interviews to identify potential risks related to transition of existing DHS to 4GDH system in Leeuwarden. This chapter will also explain the solutions to mitigate these potential risks. Chapter 6 describes the conclusion of this research by summarizing answers for each research sub-question. The recommendation of some possible further works that can be done to improve the research is also explained in this chapter.

Chapter 2. State of the art of 4GDH (4th Generation District Heating)

In order to understand the state of the art of 4GDH system, it is necessary to discover the most relevant concept of 4GDH system. This concept is explained with the main characteristics (technical and non-technical characteristics) of 4GDH system. Additionally, the real development of these characteristics in practice is also shown to emphasize the state of the art of 4GDH system. To serve these purposes, this chapter is separated into two main parts: concept of 4GDH system (describe technical and non-technical characteristics of 4GDH system) and existing 4GDH system in Heerlen (Mijnwater).

2.1. Concept of 4GDH System

DHS can be seen as energy system comprises of heat production, transmission & distribution and consumption. DHS also practically can be seen as network of pipes that distributed heat (in form of steam or hot water) from heat producer/heat source to heat customers.

In typical DHS, the heat with high temperature (130 °C) is delivered through transportation (transmission) network from heat producer to heat substation (using water as heat carrier). In the heat substation, the heat is transferred through heat exchanger in which cold water in heat distribution pipe interacts with hot water in heat transmission pipe. This heat transfer cause hot water in transmission network become cooler (80 °C) and cold water in distribution network become hotter (90 °C). The cooler water in transmission network is then flown back to heat producer for re-heating. The hotter water in distribution network is then delivered to heat customer to be used for heating purpose inside buildings (space heating and DHW). After the heat is consumed, the water in distribution pipe become cooler (70 °C) and it is flown back to heat substation for further heat transfer.

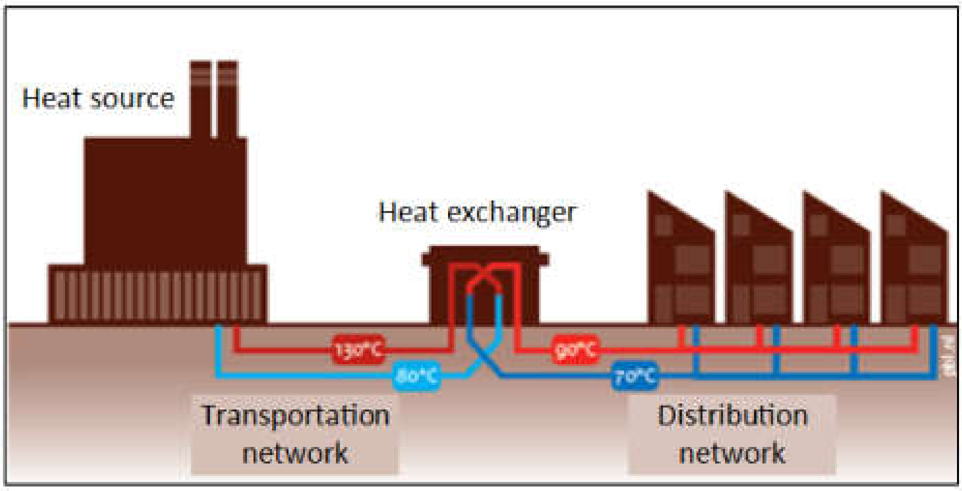

Figure 2. Simple illustration of conventional DHS (Knol, 2018)

2.1.1. Previous Generations DHS

For more than one century since the DHS was widely implemented, there are several generations of DHS that can be identified (Lund et. al., 2014).

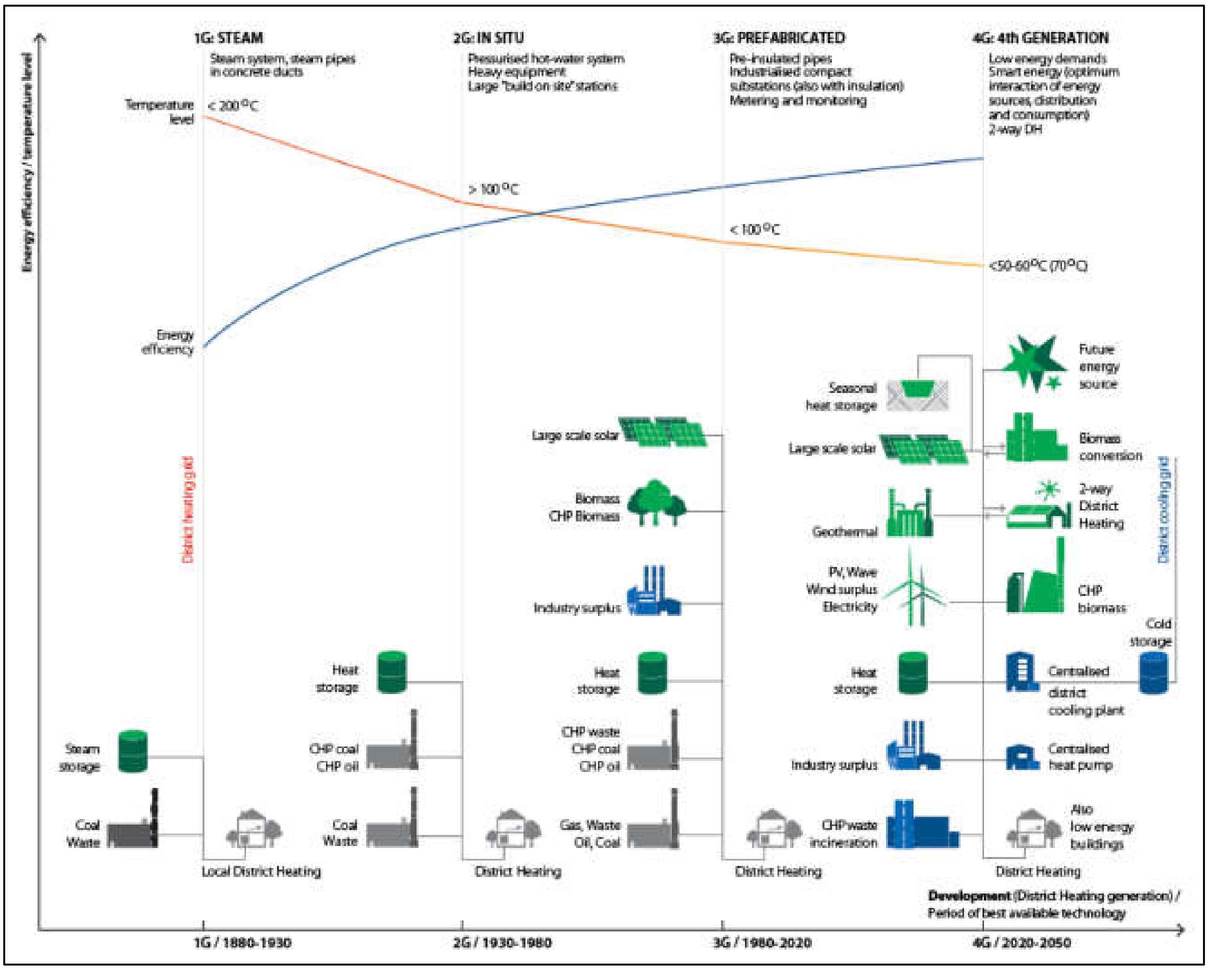

Figure 3. Comparison of 4GDH with previous generations DHS (Lund et. al., 2014)

The 1st generation district heating (1GDH) system was developed between 1880's to 1930's in USA & Europe. This DHS used hot steam as heat carrier. The 1GDH system was mainly developed to replace the individual boilers used in building (to reduce risk of boiler explosion) and to raise comfort. Nowadays, this system is considered to be outdated due to large heat loss during heat distribution and accidents caused by leaking pipes.

The 2nd generation district heating system (2GDH) system was developed between 1930's to 1970's. This DHS used pressurised hot water with temperature > 100 °C as heat carrier. The 2GDH system was mainly developed to achieve fuel savings and to raise comfort through utilization of CHP (combined heat & power) or co-generation plant.

The 3rd generation district heating system (3GDH) is developed from 1970's till present. This DHS uses pressurised hot water with temperature < 100 °C as heat carrier. The 3GDH system is mainly developed to ensure security of energy supply (due to oil price crises happened during 1970's) and to replace oil with cheaper energy sources for heat generation such as biomass, waste, geothermal and solar thermal.

2.1.2. Characteristics of 4GDH system

The 4th generation district heating (4GDH) system is currently being developed in small number of locations (the current 4GDH system is only implemented for few cities in Europe). Large scale development of 4GDH system is expected to be done in 2020 onwards. Several characteristics of 4GDH system are (Lund et. al., 2014):

a. Supply low temperature heat (< 70 °C) for space heating and domestic hot water (DHW) heating in existing buildings, newly retrofitted buildings or new zero carbon buildings
b. Transmit/distribute heat in networks with less heat loss
c. Recycle low temperature heat source (waste heat) and integrate renewable heat sources (geothermal and solar thermal)
d. Integrate heating system with other energy systems (electricity, gas)
e. Support development of institutional framework that can establish suitable planning, cost and motivation structures related to operation and investment strategies for transformation of current energy systems into future sustainable energy systems

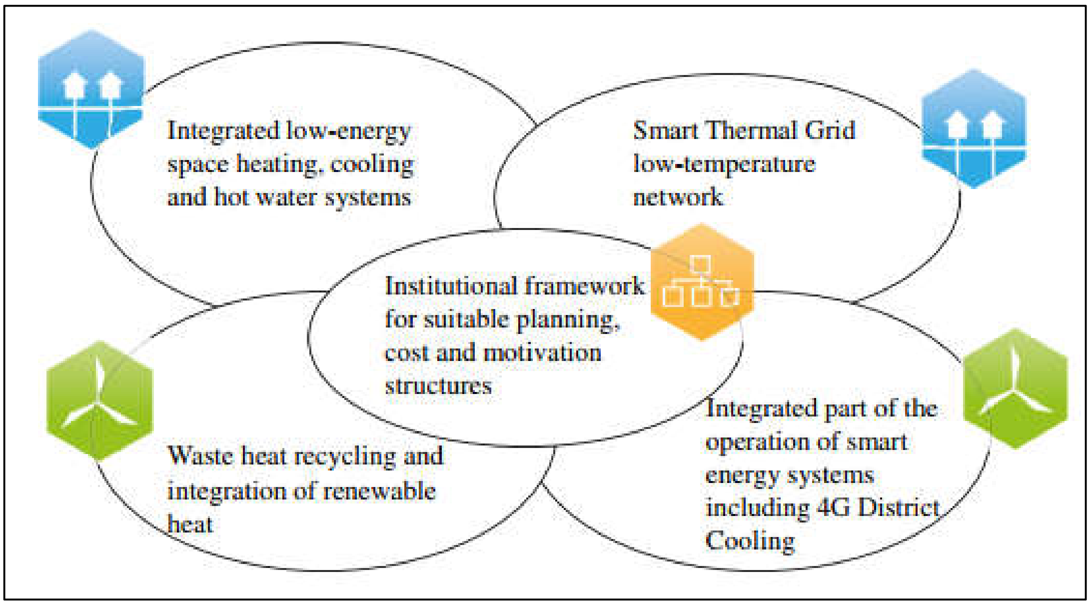

Figure 4. Characteristics of 4GDH system (Lund et. al., 2014)

2.1.3. Features of Smart Thermal Grid (STG) in 4GDH system

In order to transform previous generations DHS into 4GDH system, the STG is utilized to enable following features in the heating system (Lund et al, 2014):

- Intelligent control for heating of buildings and peak shaving. The peak load (maximum heat demand) for space heating can be reduced using peak shaving control system, utilizing buildings with higher thermal capacity and estimating buildings' heat demand based on weather forecast
- Intelligent control of heat network performance and continuous metering. Continuous real-time remote heat measurement and decentralized (close to heat customers) intelligent control can be used to dispatch heat based on demand, minimize loss during heat distribution and establish prosumer system (heat flow in two ways direction)
- Integrate heating system as part of smart energy systems. Intermittency of renewable energy sources can cause difficulty on balancing energy supply & demand. This difficulty can be overcome using integration of different energy systems. One example is the integration of electricity and heat systems. The surplus of electricity during night time can be used for heat generation (using power to heat technology such as heat pump or electric boiler)

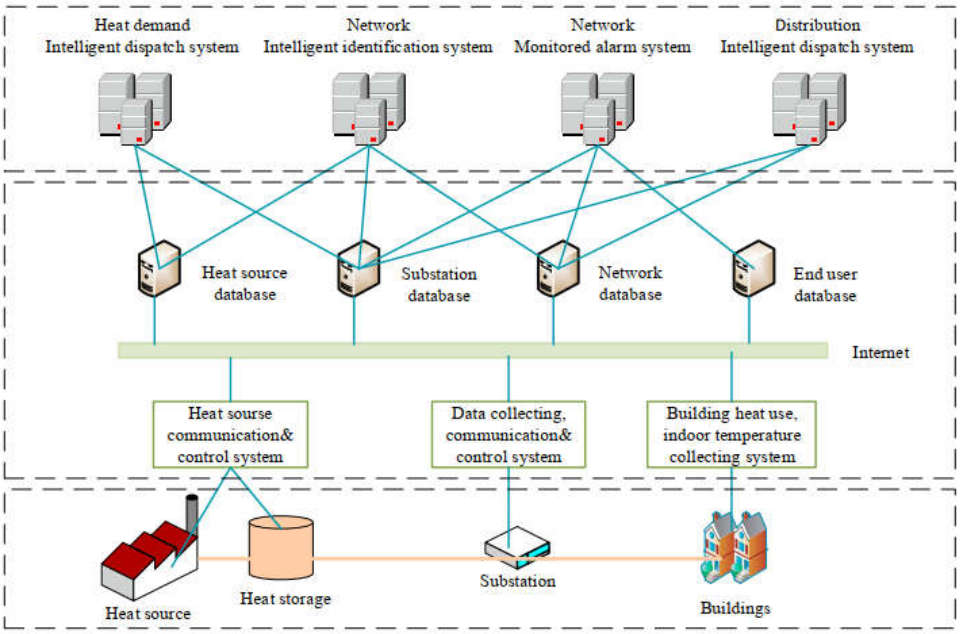

Figure 5. Example of STG model for intelligent control, monitoring and heat (Li et. al., 2018)

2.2. Other Non-Technical Characteristics of 4GDH system

2.2.1. Organizational Complexity in 4GDH system

The shift from centralized to distributed/decentralized decision making (prosumer system), aggregation of distributed energy producers and users, introduction of potential market in energy system can arise organizational complexity during transition from conventional to smart electricity system (Bompard et. al., 2012). Similar complexity can also occur as previous generations DHS are transformed into 4GDH system. This complexity can be illustrated using smart grid architecture model.

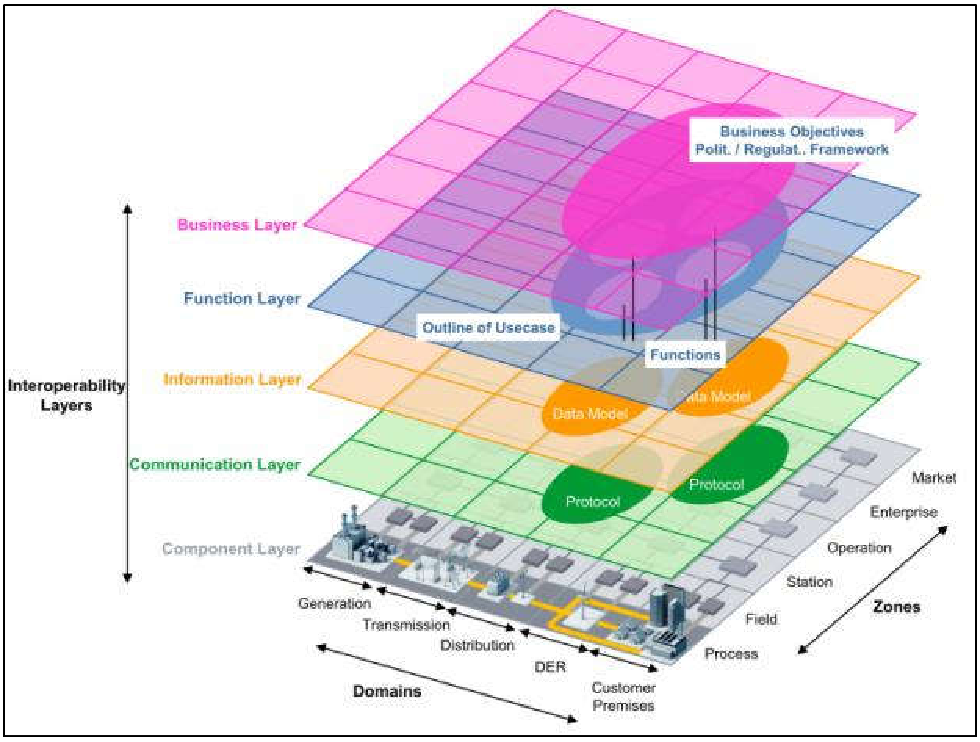

Figure 6. Smart Grid Architecture Model (Retiere, 2017)

There are 3 factors that can contribute to the system complexity in this model (Retiere, 2017):

- Presence of heterogenous components (storage, renewable energy, active demand and other advanced components such as smart meter),
- Presence of multilayered architecture (business layer, function layer, information layer, communication layer and component layer)
- Presence of hierarchical organizations of power systems

Due to presence of multilayered architecture, the interactions of business layer (organizations), which have their own functional (roles), information, communication method and physical component, can cause organizational complexity for development of 4GDH system (Retiere, 2017). Despite of the complexity, the collaborations of organizations are necessary since DHS cannot be developed by only one organization. Since many organizations with different roles can be involved, good collaborations of these organizations are needed to ensure DHS development.

Savage et al. (2011) consider that the collaboration of organisations can be influenced by 3 set of factors: appreciative linkages (e.g. the extent of shared goal), structural features of the collaboration (e.g. power differential among the partners) and processual issues (e.g. degree of trust among partners). Good collaboration (collaboration advantage) can be formed if the organizations have shared value (goal similarity), shared power via joint decision making and mutual trust. Meanwhile collaboration inertia can happen due to divergent aims, lack of trust and inability to handle conflicts associated with power differences (Savage et. al., 2011). One example of the collaboration inertia is the different interests between municipality and DHS company. The interest of DHS company to sell heat to customers (maximize profit) can contradict with interest of municipality (provide affordable heating service to local people).

The collaboration of organizations in 4GDH system is expected to become more complex if there is participation of multiple heat producers. The increasing number of heat producers in 4GDH system needs to be coordinated properly, not only for the technical part but also for the non-technical part (such as establishing contract to ensure security of heat supply from multiple heat producers). In Netherlands, the task to coordinate multiple heat producer is usually only done by single heat supplier (district heating company). This single heat supplier is responsible to purchase heat from these heat producers and distribute the heat to heat customers.

Organizations (Stakeholders)

The main organizations of DHS development are heat producer, transmitter, distributor and customers. Apart of these organizations, there are several additional organizations that can be involved directly (regulator, contractor, controller) or indirectly (investor and academic) on DHS development (Osman, 2017).

Main Organizations:

- Heat producer is responsible for heat production using different technology such as CHP, waste incineration, residual heat from industrial & data center, geothermal heat and solar thermal (Mazhar et. al., 2018)
- Heat transmitter or DHS company (who own & control heat networks) is responsible for heat transmission from heat producer to customer. This stakeholder is also responsible to build heat networks and ensure the heat networks are maintained properly. Many DHS companies in Netherlands are also heat producer and supplier at the same time (Osman, 2017)
- Heat supplier (or heat distributor) is responsible for heat sale from producer to customer. Supplier makes separate contracts with both heat producer and customer for heat trading (heat purchasing from producer & heat selling to customers). Since there is only single heat

supplier exist for many DHS in Netherlands, heat can only be purchased from one company (monopoly on heat supply) (Osman, 2017)

- Heat customer is the stakeholder who consumes heat from producer. In this thesis the customer is either a household or a commercial building. The heat is utilized for space heating and domestic hot water heating in the buildings. The number of heat customers determine heat demand which in turn determine the cost effectiveness to develop heating system in certain location (Osman, 2017)

Additional organizations:

- Regulator (municipality) is responsible for granting permit to develop DHS in the specific location. Apart of that, municipality also can help to provide funding for DHS development (such as SDE+ subsidy) (Osman, 2017). Contractor is hired by DHS owner to help construction & maintenance of heat networks. In the 4GDH system, specific contractor (technology provider) is also required to implement the STG. Controller is required to monitor data acquired & processed by smart system in 4GDH system and provide feedback to DHS owner and/or regulator for transparency purpose. Apart of that, special controller is also needed to control the heat pricing. ACM or Authority of Consumers & Market is the organization who set the annual maximum heat pricing to be charged for heat customers in Netherlands (ACM, 2019)
- Investors are financial institutions who provide funding for DHS development. The common investors are financial institutions who handle long term investment funding such as pension fund. Academic (or knowledge center) has the role to perform research needed to support DHS development (technical and non-technical parts). Academic also has a role to disseminate information about 4GDH systems to inform both the community and the regulator

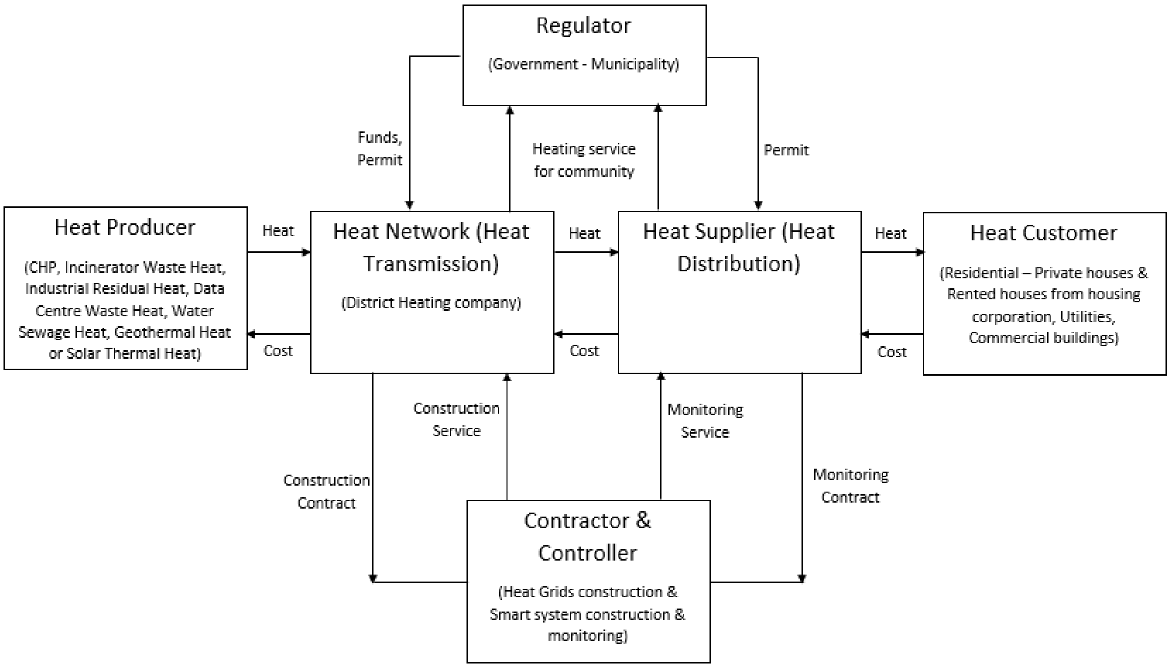

Figure 7. Organizations (stakeholders) of 4GDH system (modified after Osman, 2017)

2.2.2. Social Acceptance of DHS

Experiences on DHS development show that DHS is not always accepted by public in Netherlands (although DHS is known to be environmentally better alternative for heating than individual gas boiler). These facts are related to the social acceptance of DHS development. To understand the concept of social acceptance, 3 dimensions of social acceptance can be distinguished (Wustenhagen et. al., 2007):

- Socio-political acceptance: the acceptance of technology and policies by public, stakeholders and policy makers. The acceptance of STG technology (such as remote heat measurement) by public is one example of socio-political acceptance.
- Community acceptance: acceptance by local stakeholders (local residents and local authorities) on specific energy system deployment in local area close to the stakeholders. The community acceptance has time dimension (acceptance can be different before, during and after the DHS is implemented). Some local people resist development of geothermal wells (especially before the wells are drilled) due to several issues such as concerns of earthquake and groundwater pollution related to drilling of geothermal wells (Dago, 2018). However, this resistance can be reduced if proper communication and action are done to resolve the concerns from local people (Auf, 2010). One example of the communication is done by DHS company in Leeuwarden by arranging several workshops & dialogues with various stakeholders to convince local people to accept the development of geothermal wells (Ennatuurlijk, 2019; Warmte Leeuwarden, 2018).

- Market acceptance: market or customers adoption of particular energy system due to communication process between the adopters and their environments. The market acceptance is not only applicable for customers, but also for investors and inside the organization (intra-firm). The adoption of low temperature heat supply in 4GDH system by the DHS company is one example of market acceptance.

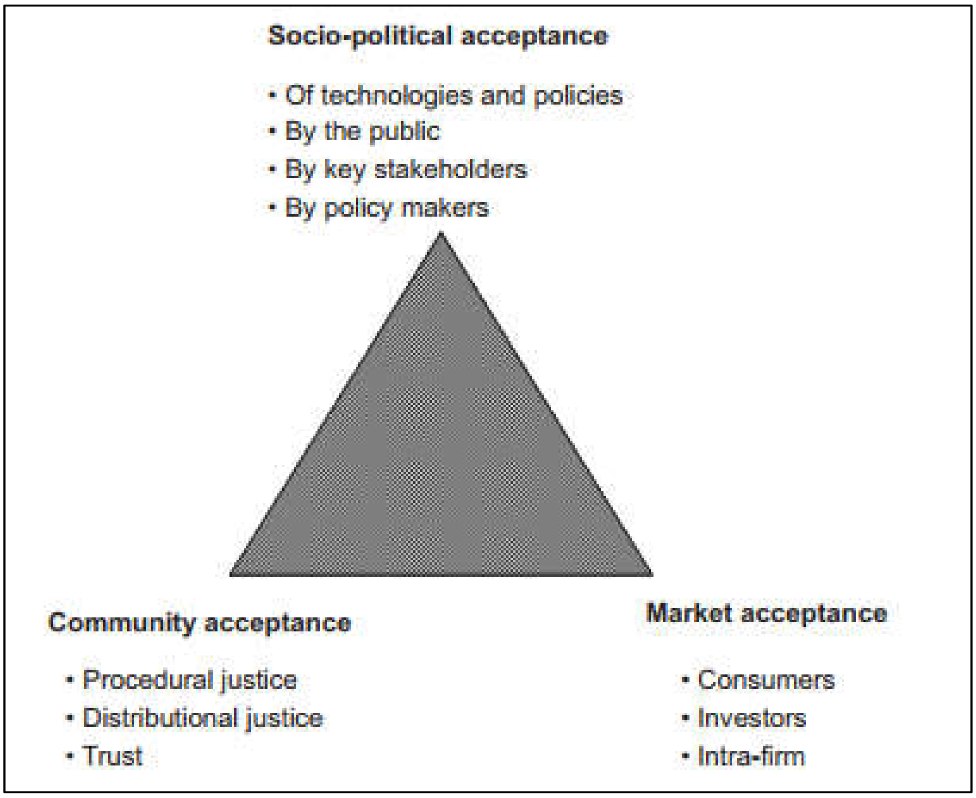

Figure 8. Triangle (3-dimension) of social acceptance (Wustenhagen et. al., 2007)

2.2.3. Development Cost of DHS

The development cost of DHS is mainly comprised of physical cost. The physical cost includes cost to install heat production plants, cost to pay mechanical & civil works to deploy heat networks & storage, cost to perform buildings refurbishment, cost to install equipment for connecting buildings to heat networks and cost to deploy smart system for monitoring & control. Depend on the technology used for heat production, the cost can be significantly different. Meanwhile the cost for deployment of heat networks depends on the location of heat networks and presence of buildings in that location (densely populated location tends to have lower cost as compared sparsely populated location; the cost is higher if the heat networks are connected to existing buildings than connected to new buildings) (Gudmundsson et. al. 2013).

Heat plant type	Specific investment costs	Operating and maintenance cost	Efficiency	Technical lifetime
Centralized gas boiler	0,06-0,12 M€/MW	2-5% of investment costs	97-105%	20
Low temperature geothermal	1,7-1,9 M€/MW	2,5% of investment costs	100%	25
Biomass boiler, wood chips	0,3-0,7 M€/MW	1,8-3% of investment costs	108%	20

Type of area	Linear heat density GJ/m/y	Investment cost, green field area €/house	Investment cost, prebuilt area €/house
Inner city	15	1.400	1.950
Outer city	10	1.600	2.050
Park area	5	2.300	2.650

Figure 9.Heat Plant cost (top) and Heat Network cost (bottom) (Gudmundsson et. al., 2013)

This development cost is recovered by DHS company by charging the heating service cost to heat customers. In Netherlands, the annual heating cost charged to heat customers includes heat consumption cost (fixed cost + amount per GJ), measurement cost and rental of delivery set. Apart the annual heating cost, there is also one-time connection cost that need to be paid by heat customers in order to have the buildings connected to existing heat networks (ACM, 2019). Every year ACM revise the maximum price for heat consumption cost and price for measurement cost in Netherlands. This is necessary since the heat price is still tied to gas price (gas price increases every year).

price	2017 (euros incl. VAT)	2018 (euros incl. VAT)	2019 (euros incl. VAT)
Maximum price	299.16 + 22.69 per GJ	309.52 + 24.05 per GJ	318.95 + 28.47 per gigajoule
Measurement rate	25.02	25.36	25.89
One-time connection fee up to 25 meters	1011.73	1037.78	1038.89
One-time connection fee per meter longer than 25 meters	32.27	33.77	33.91

Figure 10. Annual heating cost set by ACM (ACM, 2019)

Apart of heat pricing regulation, there is also an idea to control price by opening the same heat network for multiple heat suppliers (or known as TPA – Third Party Access). This idea mimics the competition of multiple suppliers in electricity and gas networks which is effective to ensure reasonable pricing charged for customers. This TPA concept is considered to be effective for large heat network, but it is ineffective for small or medium heat network. One of the drawback of the TPA is the high administrative cost that need to be added to stimulate the competition of multiple heat suppliers (Poyry, 2018).

2.2.4. Policy (Regulation) of DHS

The regulation in public energy system is usually formulated to ensure social welfare can be distributed properly for community. The most important social welfare for DHS is related to cost of heating service. The regulation is then needed to set the pricing to be reasonable not only for the customers (affordable) but also for the investors (good business case to get back the investment in reasonable timing) (Deyne, 2016). Due to climate change pressure, the regulation is also formulated to tackle environment issue (such as reduction of greenhouse gases).

Some regulations applicable for 4GDH system in Netherlands are (Interreg Heat Net NWE, 2018):

- Heat Act (2014, latest revision 2016) is regulation to protect heat customers whom connected to heating networks with capacity less than 100 kW. This regulation ensures that the tariffs for heat supplied through district heating cannot be higher than similar heat produced using individual gas boiler (NMDA principle as listed in Article 5 of Heat Act). The article 8 of Heat Act also regulate the remote heat measurement (customers can refuse remote heat measurement unless there is assurance on the data security).
- Heat Plan is policy to enforce buildings to be connected with district heating networks unless the buildings' owners find other alternative and this alternative should be as good as district heating and good for environment. Examples of regional heat plans are Groningen heat plan, Amsterdam city policy (2005) and Utrecht's vision on climate neutral city
- Energy Agreement (2013) is an agreement on measures to achieve 2020 EU targets which set prioritization of using cost effective waste heat and development of regional heat plans
- Energy Agenda (2016) is agenda which formulate law for implementation of heat networks for CO2 emission reduction. This agenda enforces new buildings to have no connection of gas networks and focus on energy connection (electricity & heat networks). The same agenda also gives more responsibility for local authority to prepare regulation for heat networks
- Climate Agreement (2018) is an agreement on measures to achieve reduction of CO2 emission in 2050 by phasing out natural gas usage in built environment

2.3. Existing 4GDH system in Heerlen (Mijnwater)

The development of 4GDH system in Heerlen has been started since 2008 and the system has evolved through different phases till present (Mijnwater 1.0, Mijnwater 2.0 and Mijnwater 3.0). The 4GDH system in Heerlen utilizes geothermal wells (5 geothermal wells) as the source of heat and cool water (Verhoeven et. al., 2014).

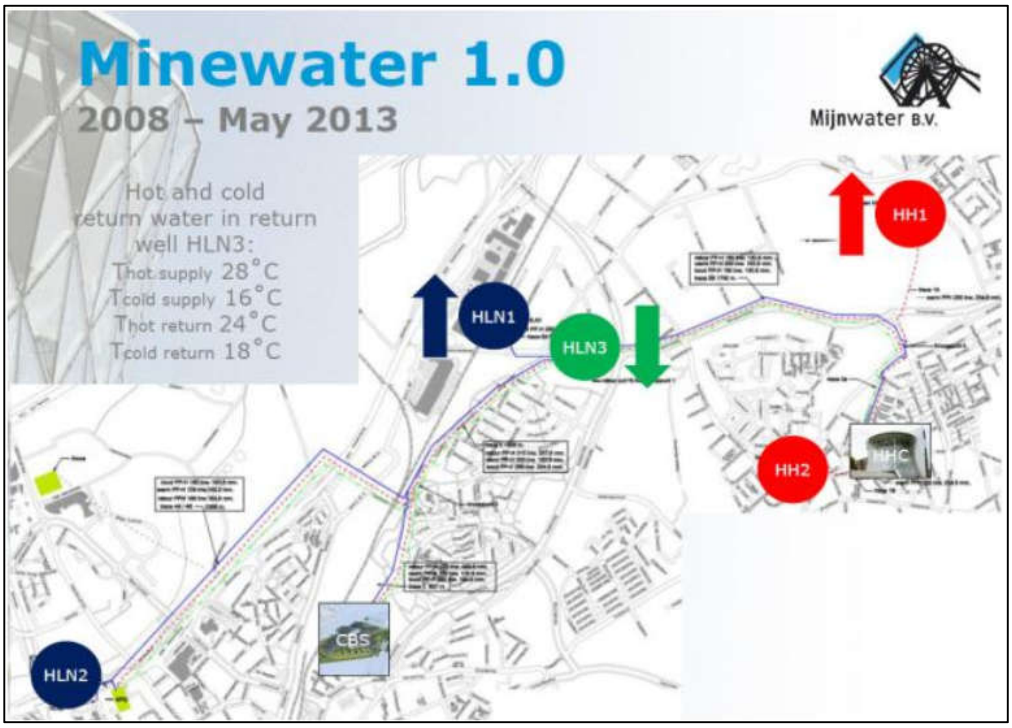

Figure 11. Location of geothermal wells of 4GDH system in Heerlen (Verhoeven et. al, 2014)

2.3.1. 4GDH Development in Heerlen

<u>Mijnwater 1.0 – Pilot system</u>

The Mijnwater 1.0 system in Heerlen was developed from 2008 to 2012. This system used geothermal wells as main part of the heating & cooling infrastructure. 3 geothermal wells are used: HH1 well provides hot water for heating, HLN1 well provides cool water for cooling and HLN3 well is used to dispose water from cooling & heating (Verhoeven et. al., 2014).

The hot water with temperature of 28 ^oC was extracted from HH1 well (HH1 well was drilled down to 700 m depth), meanwhile the cool water with temperature of 16^oC was extracted from HLN1 well (HLN1 well was drilled down to 250 m depth). The heating & cooling networks consisted of 3 main pipelines (1 pipeline for each well) to connect the geothermal wells with buildings (heat customers). The main disadvantages of Mijnwater 1.0 system include limited hydraulic & thermal capacity, not demand-driven system and no exchange of heat energy among buildings. These advantages are the main reasons for the system upgrade to Mijnwater 2.0 (Verhoeven et. al, 2014).

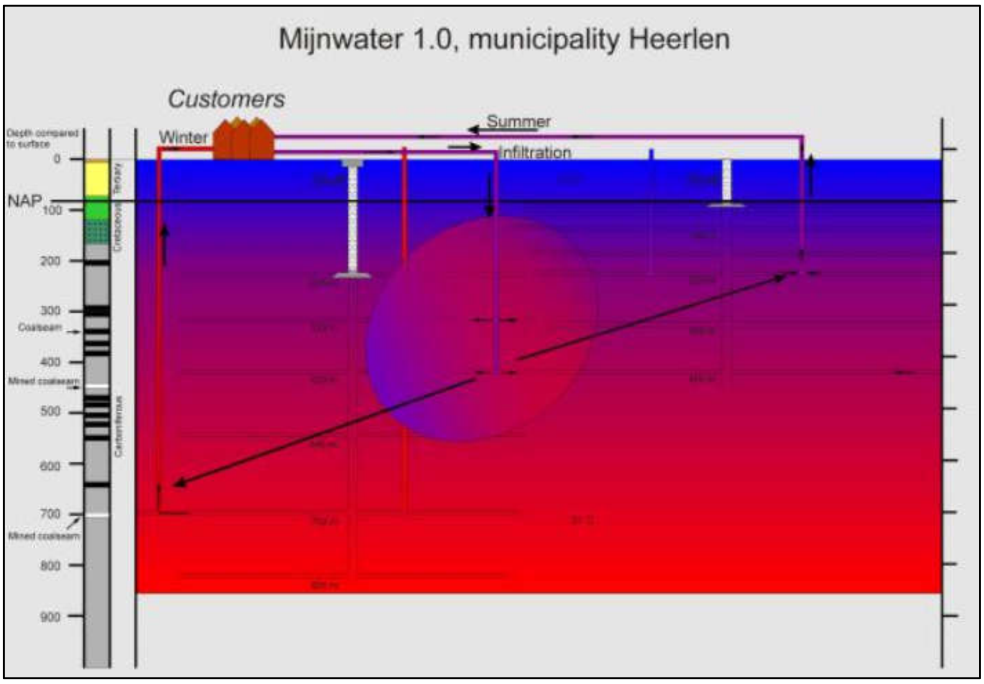

Figure 12. Mijnwater 1.0 utilize geothermal wells as heat source (Verhoeven et. al, 2014)

<u>Mijnwater 2.0 – Full-scale Hybrid Sustainable Energy</u>

The Mijnwater 2.0 system was developed from 2013 till now in order to upgrade the existing Mijnwater 1.0 system. The Mijnwater 2.0 system has capabilities as mentioned in following part (Verhoeven et. al, 2014).

a. Energy exchange instead of energy supply: The system was developed with 3 different levels (buildings, clusters and wells) to enable local energy exchange between buildings, between clusters of buildings and between clusters of buildings with geothermal wells
b. Energy storage and regeneration to prevent well depletion: The energy balance of geothermal wells needs to be maintained on yearly basis through regeneration of mine water in the reservoir. For this purpose, the depletion of mine water in the reservoir (due to unwanted water return temperature from heat networks) is prevented by applying certain criteria on the temperature of water injected into the wells
c. Addition of multiple heat & cold sources to the system: The system became hybrid energy system that can utilize other thermal energy resources (such as additional wasted heat from data centre & industries)
d. Maximizing thermal capacity: This was done through utilization of HLN3 well as heat supply and disposal well for thermal capacity enlargement in the system (this HLN3 well is only used as disposal well in Mijnwater 1.0)
e. Fully automatic controlled and heat demand driven system: The fully automatic and demand driven system are controlled in each level using different parameters: MI-Building – Temperature, MI-Cluster – Flow Rate and MI-Well – Pressure. Using this controller, the decentralized heat

service can be provided only for customers who needed the heat through utilization of separated heat pumps (boiler houses) (Eijdems, 2019). This decentralized heat system increases energy efficiency and reduced energy loss of heat networks.

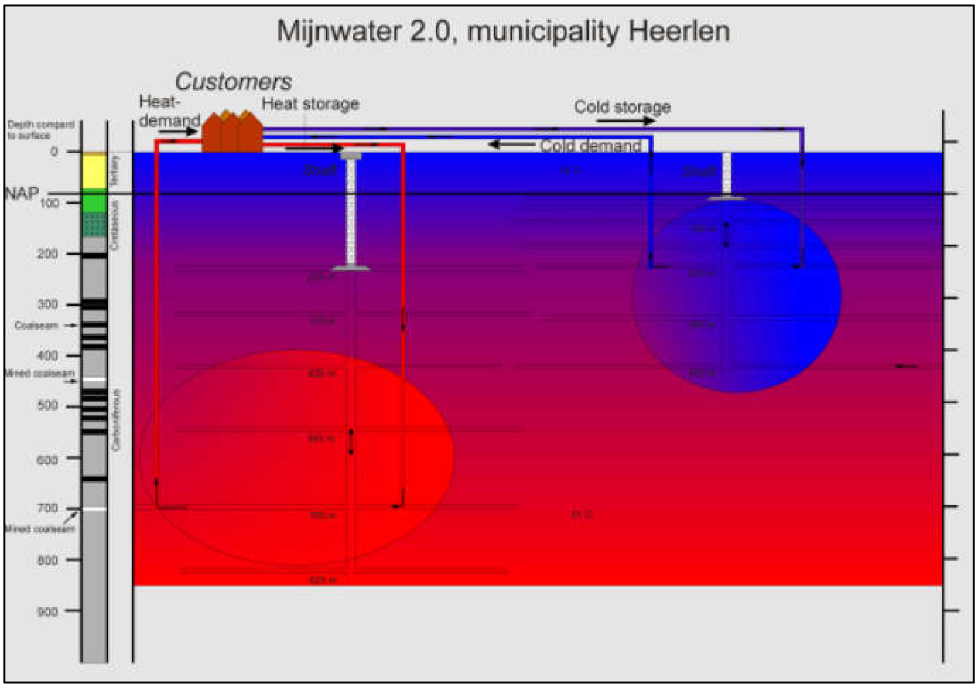

Figure 13. Mijnwater 2.0 utilize geothermal wells as heat storage & heat source (Verhoeven et. al, 2014)

The intelligent controller (as part of STG technology) is used to enable heat demand driven system. This controller is developed through STORM (Self-Organizing Thermal Operation Resource Management) project. The intelligent controller is developed to have capability of self-learning (through analysis of historical data) and to adapt to surrounding conditions (predictive, climate, behavior and customer demand). The heat meters are installed for each heat producers (geothermal wells), distribution networks (node) and heat customers (APG, ARCUS, CBS, etc.). The heat measurements are remotely monitored using wireless heat meter. The data acquired from this monitoring is collected in the database and the database is connected to central control, monitoring and reporting systems.

The main stakeholders for this STORM project are: Mijnwater BV, Noda (Sweden Intelligent system developer), Neber (knowledge development & expansion), SigmaOrionis (ICT knowledge), Veab (Sweden DHS company) and Vito (Belgium sustainable company). The investment for implementation of STG is ~600,000 Euro (out of total cost of ~10 million Euro for development of Mijnwater 2.0). Since the implementation of Mijnwater 2.0, the total asset value has been grown into 30 million Euro from 10 million Euro (Eijdems, 2019).

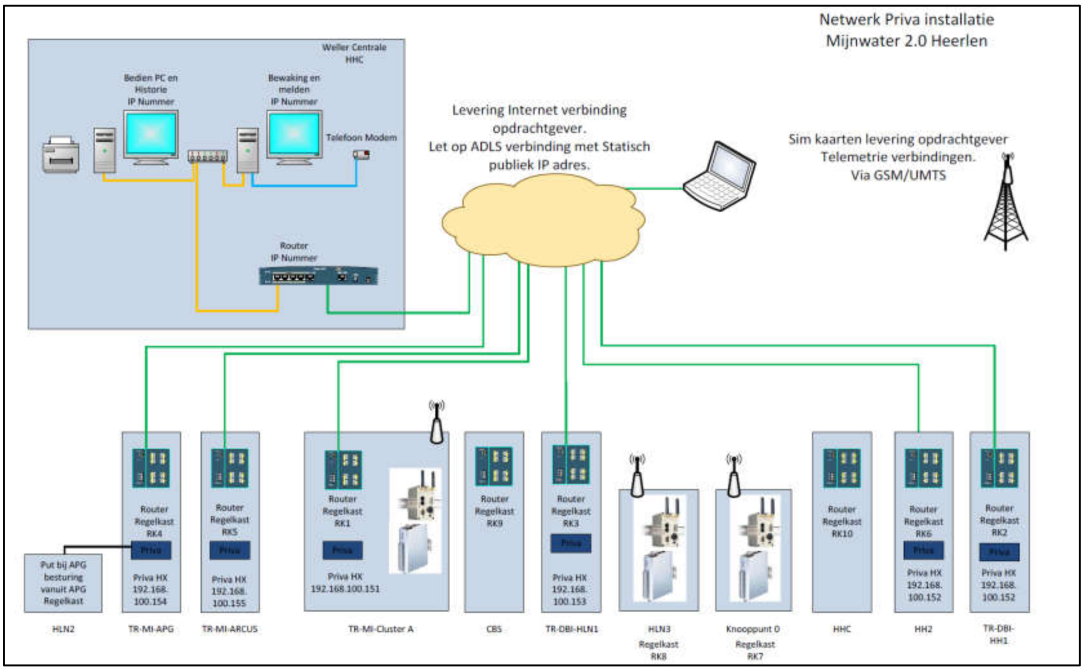

Figure 14. Intelligent Controller for Mijnwater 2.0 (Verhoeven et. al, 2014)

2.3.2. Characteristics of 4GDH system in Heerlen

The technical characteristics of existing 4GDH system in Heerlen are:

- Capability to use water with low temperature heat supply (29 degC)
- Utilize both centralized and decentralized heat producers from multiple heat sources (geothermal and residual heat from industries & data centre)
- Utilize STG technology to monitor & predict heat demand, enable peak shaving & heat exchange between buildings for improvement of energy efficiency
- Enable heat flows in two directions (from heat producer to heat customer and vice versa) and establish heat prosumer system

<u>Non-technical characteristics</u>

In this 4GDH system, DHS company acts as single heat supplier whom can purchase heat from producers and sell heat to customers (monopoly on heat supply). To further prevent monopoly on heat pricing due to presence of single heat supplier in this 4GDH system, the regulator applies annual fixed maximum pricing as set by ACM. The annual heat cost charged to customer by DHS company is approximately 10% less than pricing set by ACM (Eijdems, 2019). The perception of high heat cost can be minimized through establishment of heat prosumer system. The heat prosumer system can reduce cost of heat service since customers can sell the surplus of heat which is produced from individual heating system (such as heat produced using heat pump) (Mijnwater Nieuws, 2018).

The main stakeholders of the 4GDH system are regulator (government), DHS company (Mijnwater BV), heat customers/prosumers, controller, contractor, investors and academic. The roles of each stakeholder are described in the following table (Eijdems, 2019; Mijnwater Nieuws, 2018).

Table 2. Organizations involved in the existing 4GDH system and their roles

Organizations	**Roles**
Mijnwater BV	Centralized heat producer (owner of geothermal wells), owner of heat networks (monitor & maintain heat networks), and heat supplier
Buildings owners (including housing corporation)	Heat customers/prosumers
Local Industries & Data Centre	Distributed / Decentralized heat producers (residual heat)
Heerlen municipality	Regulator (grant permit for DHS development), Investor (provide fund for DHS development)
ACM	Price controller (as regulated in Heat Act)
STORM partner (NODA)	Smart system developer & installer (contractor)
University, STORM partners (Vita, Neber, SigmaOrionis, Veab)	Knowledge providers
European Commission	Investors (provide funding for 4GDH development through several projects: Life4HeatRecovery, STORM-DHC Controller, HeatNet NWE, D2Grids)

Recently the ownership of Mijnwater BV has been sold to other organization (Limburg Energy Fund). Previously the district heating company was owned by municipality of Heerlen with intention to have full support of municipality during the pioneer development of 4GDH system in Heerlen. This transfer of ownership is necessary to increase the financial contribution which is needed to upscale the 4GDH development throughout the province of Limburg (Eijdems, 2019).

Apart of the national regulation of DHS which is formulated by national government, under the Heat Act, there is local energy policy (PALET (Parkstad Limburg Energie Transitie) which support development of 4GDH system in Heerlen. This local energy policy supports utilization of residual heat from industries & geothermal heat in heat networks. This local policy also supports implementation of smart energy system for electricity & heat system with purpose to tackle future capacity issues. PALET policy has main objective to achieve carbon neutral in Parkstad Limburg region in 2040 (PALET 3.0, 2015).

The current PALET 3.0 policy has been modified from previous PALET 1.0 & PALET 2.0. PALET 1.0 is the policy related to ambition/target of energy transition, meanwhile PALET 2.0 has more detail energy plan to answer some more specific questions to achieve the target (such as "what is energy profile per municipality", "how much energy can be saved", "what possibilities to become sustainable energy generator at local level", etc.). The PALET 3.0 is formulated to be the region RES (Regional Energie Strategie) which have concrete choices & objective for short, medium and long term of the energy transition process. The PALET 3.0 will be further revised to PALET 4.0 and PALET 4.0 will include the qualitative and quantitative monitoring of the energy transition process (PALET 3.0, 2015).

In addition to the PALET policy, there is also another policy related to 4GDH system due to implementation of STG. The GDPR (General Data Protection Regulation) or AVG ("*Algemene verordening gegevensbescherming*") is the policy to ensure the data security and data privacy related to personal data. The adherence to GDPR is needed to protect personal data acquired from real time heat measurement using smart heat meter. This GDPR aligns with Heat Act (Article 8) which mention that proper measures in respect of data protection need to be done if a smart meter is utilized for heat measurement in order to prevent the exposure of a customer's data to unauthorized organizations (Autoriteitpersoonsgegevens, 2018; Overheid, 2019).

2.4. Conclusion of Chapter

The state of art of 4GDH is shown by concept of 4GDH system and existing 4GDH system in Heerlen. The concept of 4GDH system shows several main characteristics that district heating system (DHS) should have in order to be classified as 4GDH system. These characteristics include utilization of low temperature heat supply, reduction of heat loss, utilization of recycle heat & renewable heat and integration of heating system into smart energy systems.

In order to develop 4GDH system for the existing DHS, other non-technical characteristics related to development of 4GDH system also need to be considered. Good collaboration of organizations is needed especially collaboration of DHS company with municipality, STG technology provider & knowledge centre. Social acceptance of 4GDH system also need to be strengthened especially acceptance on low temperature heat supply & remote heat measurement. Additional development cost to implement STG also need to be considered since this cost will affect the annual heat cost for customers. The regulation that can support or resist development of 4GDH system also need to be considered (especially local energy policy).

The existing 4GDH system in Heerlen (Mijnwater) shows the characteristics of 4GDH system as described in the 4GDH concept. The utilization of low temperature heat supply (28 ^{o}C), supply heat from multiple heat producers (residual heat and geothermal heat) and integration of heat & electric systems through deployment of smart controller are some characteristics of the 4GDH system.

In order to establish 4GDH system in Heerlen, DHS company has good collaboration with other organizations (mainly specific contractor to develop STG (Noda) and knowledge centre). Apart of that, the DHS company also has experience to make agreement (contract) with multiple heat producers and prosumers and this experience strengthen the community acceptance on the 4GDH system. The DHS company also participates in several EU projects to secure funding that is used to develop STG technology (such as Life4HeatRecovery, STORM DHC-Controller and HeatNet NWE). Through this funding, the development cost of 4GDH system can be managed properly without additional heat service cost need to be charged for the customers. The local energy policy (PALET) also support the development of 4GDH system.

Chapter 3. Existing DHS in Leeuwarden (Ennatuurlijk)

This chapter describes the existing DHS in Leeuwarden in terms of the technical and non-technical characteristics. These characteristics are then compared with the characteristics of 4GDH system which has been explained in previous chapter in order to show differences of existing DHS in Leeuwarden with 4GDH system.

3.1. Existing DHS development in Camminghaburen (Leeuwarden)

There are 2 existing DHS in Leeuwarden which located in the northern part (Camminghaburen – developed in 2015) and southern part (Zuidlanden – developed in 2009) (Ennatuurlijk, 2019).

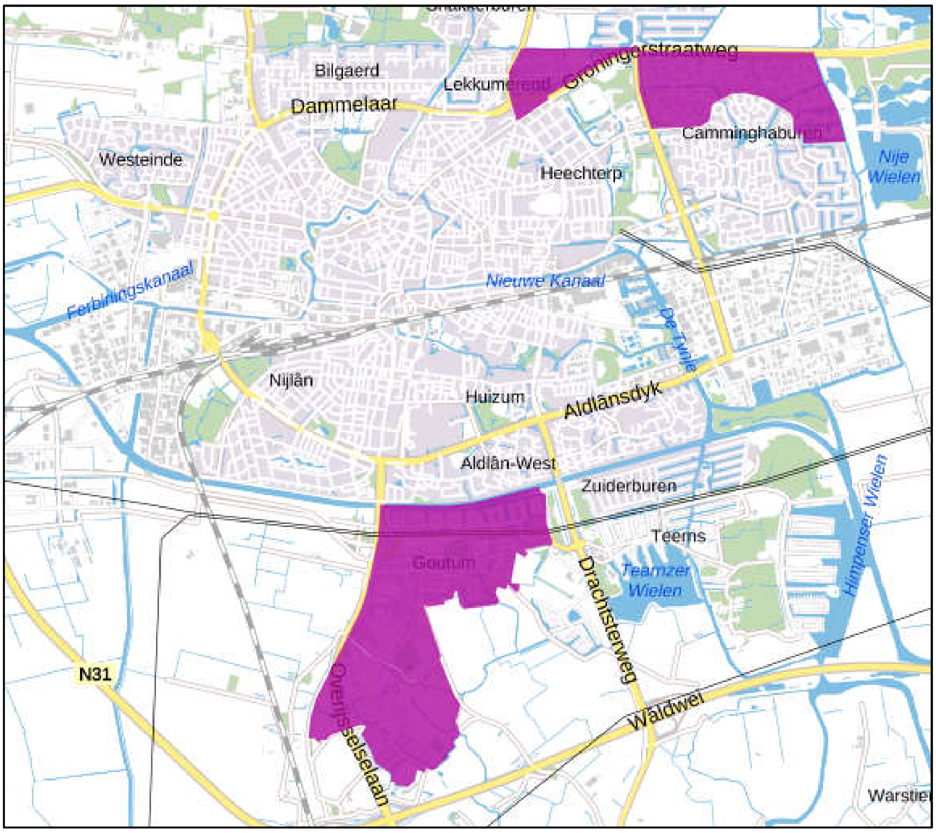

Figure 15.Location of heating networks in Leeuwarden (purple color) (Warmteatalas, 2019)

The heat used to supply heat networks in Camminghaburen is produced from natural gas co-generation plant (CHP). This heat is then distributed to 1500 households in neighbourhoods of Camminghaburen & Indische, flats in Vrijheidswijk, sport complex in Kalverdijkje (sport halls and swimming pools) and 2 companies (ennatuurlijk.nl; Ennatuurlijk, 2019). The co-generation plant produces electricity with capacity of 2 MW (supplied to electricity grid) and heat with capacity of 11 MW (supplied to heat network). Annual heat production is 62,000 GJ and annual electricity production is 11,000 MWh. The total cost for the DHS development is 17 million Euro (Ennatuurlijk, 2019).

The heat in the heating networks is distributed using hot water with average supply temperature of 75-85 °C (with temperature deviation of 25 °C depend on the seasons) and average return temperature of 40 °C. The heating networks is mainly made of steel pipe with PUR foam insulation and PE cover which is used to reduce the heat loss. Using the same heat network, it is possible to reduce the supply water temperature to 40-50 °C for heat distribution to the new houses. The total length of heat networks is 12.5 km. Heat storage (hot water tank) is used in DHS for peak shaving to reduce the gas consumption. Apart of heat storage, smart ICT system is also employed to monitor the heat production and distribution to ensure adequate heat supply produced and to detect faulty on heat networks. The remote measurement of heat consumption is only applicable for large companies (Ennatuurlijk, 2019).

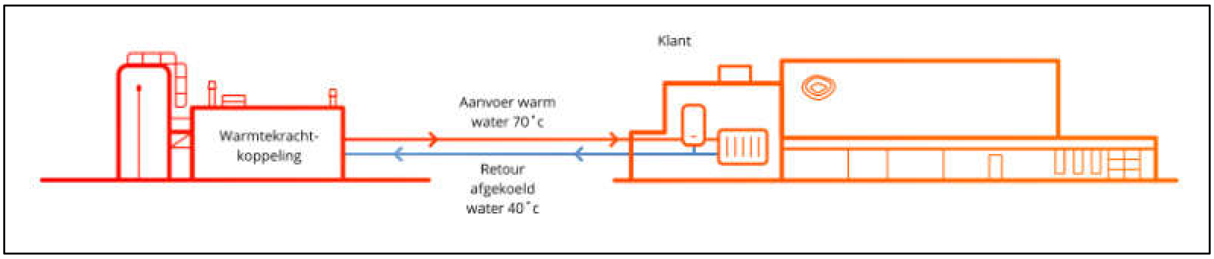

Figure 16. Schematic of heating networks in Camminghaburen (ennatuurlijk.nl, 2019)

There is plan to develop geothermal well to supply heat in DHS in the west of Leeuwarden municipality (Geothermie Leeuwarden 2). The main funding for this geothermal DHS development is acquired from government subsidy (SDE+) with total amount of 72 million Euro (Ennatuurlijk, 2019). The main stakeholders for the upcoming geothermal DHS are:

- ECW (geothermal well owner, developer & operator)
- Ennatuurlijk (DHS company as the heat networks' owner & developer; heat supplier)
- Dijkstra Raisma (housing corporation as heat customer)
- Leeuwarden municipality (ensure geothermal DHS development following regulation; issue permit in collaboration with ministry and provincial government)

Apart of this project, there is also another potential geothermal DHS (Geothermie Leeuwarden 3) which is planned to be developed by collaboration of Ennatuurlijk and Friesland Campina (a dairy company based in the east of Leeuwarden) . The geothermal heat is planned to be used by Friesland Campina for its industrial process heating (drying process). However, the development progress for this geothermal DHS is currently on hold due to lack of interest from Friesland Campina. In the past, there was also plan to utilize industrial residual heat from Friesland Campina to supply heat in the heat network of Camminghaburen. The plan is not executed until now due to poor business case

(Ennatuurlijk want to have guarantee of heat supply for 15 years, meanwhile Friesland Campina only can guarantee to provide heat supply for 5 years) (Ennatuurlijk, 2019).

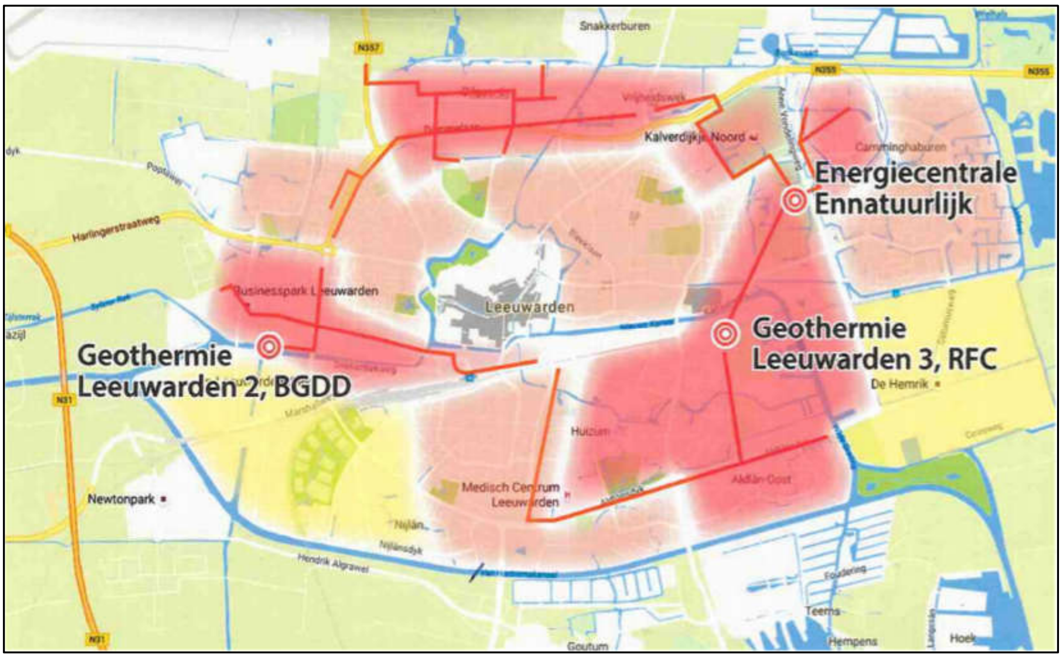

Figure 17.Location of planned geothermal wells (red circle) and heat networks (red line)

3.1.1. Characteristics of DHS in Leeuwarden (Camminghaburen)

The technical characteristics of existing DHS in Camminghaburen are:

- Utilize water with medium temperature (75-85 ^{o}C) to supply heat
- Reliance on centralized heat producer (CHP with natural gas) for heat production
- No integration of DHS with other distributed heat producers (such as residual heat from industries & data centre)
- Heat only flow in one direction (from heat producer to heat customer)

Due to these characteristics, the heating networks in Leeuwarden can be considered as 3rd generation district heating system (3GDH).

Non-technical characteristics

The reliance on single & centralized heat producer cause monopoly on the local heat market (customers can only acquire heat from one supplier). In this monopoly condition, the heat pricing is controlled by regulator by implementation of annual maximum heat pricing. This annual maximum heat pricing is regulated in Heat Act ("Not More Than Else" (or NMDA in Dutch) principle) (tariff ennatuurlijk.nl, 2019).

The main stakeholders of the DHS development & operation are regulator (government), DHS company (Ennatuurlijk), heat customers, gas & water providers, controller and contractor. The roles of each stakeholder are described in the following table (Ennatuurlijk, 2019).

Table 3. Organizations involved in the existing heating networks in Camminghaburen and their roles

Organizations	Roles
DHS company (Ennatuurlijk)	Heat producer, distributor & supplier; Investor on DHS development
Buildings owners (including housing corporation)	Heat customers
Leeuwarden municipality	Regulator (grant permit for DHS development)
Gas provider (natural gas providers)	Gas providers for co-generation plants (CHP)
ACM	Price control (as regulated in Heat Act)
Vitens	Water provider used in heat network & heat storage
Veolia	Contractor (installer & maintenance of heat networks)

As part of the national Heat Act, there is also Leeuwarden Energy Agenda (2016-2020) which applicable for DHS development in Leeuwarden. This local energy policy promotes the DHS development using residual heat from industries and geothermal heat. This policy has objective to have at least 1 geothermal DHS in 2020 with an annual total heat supply of 0.28 PJ (PetaJoule) and saved heat supply of 0.032 PJ by 2020 (as compared to heat supply in 2010) through utilization of residual heat in heat networks (replace current heat generation using natural gas) (Leeuwarden Energy Agenda, 2018).

As part of the sustainable collective heating using DHS, the policy also supports (Leeuwarden Energy Agenda, 2018):

- Implementation of sustainable individual heating (such as utilization of electric heat pump for heat generation)
- Energy conservation related to heat consumption through continuous (annual) project of houses insulation. This houses insulation project is done through collaboration of municipality (subsidy provider) and housing corporations
- Implementation of smart living in houses for energy conservation (such as installation of smart controller to reduce energy consumption)
- Development of smart electricity grids in North of Leeuwarden as part of Leeuwarden contribution to national SWITCH project
- Development of future Energiecampus with expectation for the institution to contribute on sustainable energy supply development in Leeuwarden (Gemeente Leeuwarden, 2018)

3.2. Differences between existing DHS in Leeuwarden and 4GDH system

There are several differences that can be observed from both technical and non-technical characteristics of existing DHS in Camminghaburen (Leeuwarden) and 4GDH system.

Technical Characteristics (Technology & Operation)

The heat supply for DHS in Camminghaburen is generated by single heat producer (CHP with natural gas as primary energy source). Since this CHP is the only centralized heat producer (centralized) for the DHS, the heat customers rely on this heat producer without alternative to utilize other heat sources. On the contrary to existing DHS in Camminghaburen, the heat supply for 4GDH system is generated by multiple heat producers (such as combination of geothermal heat and residual heat from industries for 4GDH system in Heerlen).

The heat is distributed for existing DHS in Camminghaburen using water with temperature of 75-85^{o}C. This temperature is considered higher than temperature required by 4GDH system (< 70^{o}C) such as supply temperature of 29^{o}C for 4GDH system in Heerlen so measures to reduce the temperature need to be implemented. The DHS in Camminghaburen uses specific thermal energy storage (TES) such as water tank to store heat. Meanwhile the 4GDH system can also use buildings as a virtual heat storage as part of the specific TES (such as water tank or geothermal wells in Heerlen).

The heat only flows in one direction for DHS in Camminghaburen (from heat producer to heat customers), meanwhile the heat flows in two directions for 4GDH system. This bi-directional heat flow establishes heat prosumer system (heat customer can sell heat surplus to the heat supplier). One example is the supermarket in Heerlen which consumes heat from heat networks for space heating during part of the year (seasonal), but also sells surplus heat (from refrigeration system) to the heat supplier at a profit. In the 4GDH system, heat for production, distribution and consumption is remotely monitored using heat meter. On the contrary, the heat consumption is only measured periodically for most of heat customers in Camminghaburen (remote heat measurement is only done for large companies).

Most of the buildings in Camminghaburen can only use a higher supply temperature (> 70 ^{o}C) for space heating and DHW. These buildings are still using radiator for space heating instead of underfloor heating which can utilize supply temperature of 40^{o}C for space heating leading to a more energy efficient system (Rama et. al., 2017). Most buildings in Camminghaburen have energy label of “B” or worse due to poor buildings insulation. Meanwhile buildings connected to 4GDH system have used underfloor heating and have better buildings insulation to enable utilization of lower temperature heat supply (buildings connected to 4GDH system in Heerlen can utilize heat with supply temperature less than 50^{o}C).

One of the most important operational differences between DHS in Camminghaburen and 4GDH system is the decentralization of heat production and heat distribution. In 4GDH system, the heat is generated and distributed only based on demand. The 4GDH system in Heerlen only provides heat with higher temperature (60^{o}C) if there is demand for DHW and maintains a lower temperature (29^{o}C) in heat networks if there is no demand for DHW. This heat demand-based management system is supported through deployment of heat substations close to heat customers and these heat substations can adjust water temperature automatically. Meanwhile the DHS in Camminghaburen maintains high temperature in the heat networks (75-85^{o}C) for all of the time (regardless if there is less heat demand for DHW) due to implementation of centralized heat production. The decentralized heat production of 4GDH system in Heerlen can be enabled by deployment of power to heat technology (such as electric heat pumps in the heat substations which is controlled by a smart system that enables integration of heating and electricity systems. The integration of energy systems is still not available for existing DHS in Camminghaburen (the heat is only generated using gas boilers).

Non-technical characteristic (Organizations)

There is only one heat producer for DHS in Camminghaburen (CHP) as compared to multiple heat producers for 4GDH system in Heerlen (geothermal heat, residual heat from industries and heat prosumers). There is no necessity to have collaboration between heat producer and heat supplier since both roles are handled by the same DHS company (Ennatuurlijk). On the contrary, there is necessity to have collaboration between multiple heat producers or heat prosumers and heat supplier in 4GDH system. Although DHS company in Heerlen (Mijnwater) owns geothermal wells and also acts as single heat supplier, there is necessity to collaborate with industries, data center and supermarket which also supply heat to the heat network.

STG contractor (smart system technology developer) is mandatory to be involved during the development of 4GDH system (such as NODA which developed smart controller & monitoring system for 4GDH system in Heerlen). Since there is no implementation of STG in Camminghaburen, no specific STG contractor is involved in the DHS development. Due to the nature of 4GDH system as niche development at this moment, it is necessary for the knowledge center and municipality to support the development of 4GDH system. The participation of a knowledge center in Heerlen is also needed to to disseminate information of 4GDH system for the community and municipality. On the other hand, there is lack of academic involvement for DHS development in Camminghaburen since the technology which is utilized for the DHS is quite mature (3GDH technology used in Camminghaburen has been developed since 1980's).

Funding for DHS development in Camminghaburen is only provided by DHS company (Ennatuurlijk). Meanwhile funding for development of 4GDH system in Heerlen is provided by municipality and EU (through collaboration of Mijnwater in several EU projects: Life4HeaRecovery, HeatNet NWE, STORM-DHC controller). Since municipality in Heerlen acts as owner of the DHS company (Mijnwater), the municipality has great influence on the DHS operation. On contrary, the DHS in Camminghaburen is owned by private sector (Ennatuurlijk). As consequence, municipality in Leeuwarden has less influence on the DHS development and DHS company control everything (heat production, transmission and supply).

3.3. Conclusion of Chapter

The DHS in Camminghaburen (Leeuwarden) can be classified as 3GDH system based on its characteristics. These characteristics include utilization of heat supply with temperature > 70 ^{o}C, reliance on centralized heat producer (CHP), flow of heat only in one direction (from producer to customers) and no integration of heat system with other energy systems. The DHS in Camminghaburen has less organizational complexity since DHS company acts as heat producer, transmitter and supplier. The DHS development is only funded by DHS company. The local energy policy (Leeuwarden Energy Agenda) only has objective to replace/reduce natural gas consumption for DHS with residual heat and geothermal heat.

Based on the analysis of characteristics of existing DHS in Camminghaburen and existing 4GDH system in Heerlen, there are several differences that can be summarized in the table below. These differences are used to analyze the upgrades which are needed to transform the existing DHS in Camminghaburen to 4GDH system.

Table 4. Differences between existing 3GDH system in Camminghaburen and 4GDH system in Heerlen

Existing DHS in Camminghaburen (3GDH)	**4GDH system in Heerlen**
Technical	
Single & centralized heat producer (CHP)	Multiple & centralized + distribute heat producers (geothermal, residual heat)
Utilize heat supply with medium temperature (75-85 ^{o}C) for heat distribution	Utilize heat supply with low temperature (29 ^{o}C) for heat distribution

Heat flow in one direction (from heat producer to customers); no STG is implemented	Heat flow in two directions which enable prosumer system; STG is implemented
No integration of heat system with other energy systems	Integration of heat system with electricity system
Non-technical (organization, development cost & policy)	
No collaboration between heat producer & heat supplier	Collaboration between DHS company (as heat supplier) with multiple heat producers / prosumers; collaboration between DHS company with STG contractor & knowledge center
Financing for DHS development is provided only by DHS company; DHS is owned by private sector	Financing for 4GDH development is provided by municipality and EU (through participation of DHS company in several EU projects); DHS is owned by municipality
Local energy policy (Leeuwarden Energy Agenda) support replacement of natural gas with more sustainable heat sources (geothermal and residual heat)	Local energy policy (PALET) support replacement of natural gas with sustainable heat sources, development of STG & 4GDH system

Chapter 4. Upgrade Existing DHS in Leeuwarden to 4GDH System

4.1. Upgrades of Technology & Operation

The upgrade that need to be done for heat production is replacement of natural gas (which is currently used for heat generation) with more sustainable heat source. There are 3 different options that can be used to replace the natural gas in Leeuwarden: residual heat from industries, geothermal heat and biogas (for heat generation using CHP) (klimaatmonitor rapport, 2019).

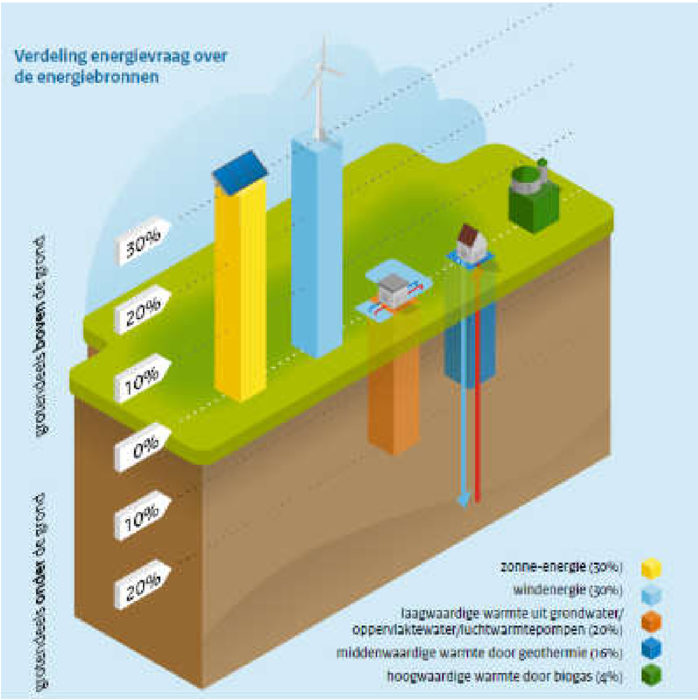

Figure 18. Scenario of sustainable heat utilization in Leeuwarden (klimaatmonitor rapport, 2019)

The residual heat is the most abundant heat sources, however the proximity of the heat sources and temperature of residual heat determines its reliability and cost. Some industries are located far from the customers and some industries produce residual heat with low temperature (30°C or less) which is not suitable to be used in the heat networks. In order to utilize this residual heat, the required technology includes heat exchanger which is used to recover residual heat and heat pump which is used to adjust temperature of heat supply (Jouhara et. al., 2018).

The geothermal heat is the most sustainable heat source since geothermal well can produce continuous and adequate amount of renewable heat. There is approximately 100 TJ of heat that can be generated annually by 1 geothermal doublet (1 production + 1 injection geothermal wells). This amount of heat is enough to heat 5500-6000 houses (warmtevanleeuwarden, 2018). However, the development of geothermal well is considered as the most expensive heat source compared to the other two options. The upcoming geothermal DHS that will be developed in south and west parts of Leeuwarden require big investment (approximately 72 million Euro of funding has been granted by

SDE+ for this project (Boer, 2019)). In order to utilize geothermal heat, the required technology includes heat exchanger which is used to recover heat from geothermal wells and hydraulic unit which is used to separate water from geothermal wells with water in the heat networks (warmtevanleeuwarden, 2018).

The natural gas for heat generation by CHP can be replaced with biogas. However, an additional cost to the biogas utilization is the necessity to purchase a Guarantee of Origin (GO) certificate to certify that the gas acquired from the gas networks is green gas (biogas) (Groen Gas, 2014). This GO is a one off payment. It is needed since the biogas is partly sold through the existing natural gas networks (Boer, 2019).

Instead of using only single heat producer (CHP), it is necessary to utilize combination of multiple heat producers (CHP + geothermal heat + residual heat). This upgrade is necessary to reduce dependency on single heat producer and to ensure the security of heat supply. In the 4GDH system, the residual heat, geothermal heat and biogas CHP can be utilized optimally as base load of heat demand. Meanwhile thermal heat storage and heat pump can be used to cover for peak load of heat demand (without any utilization of peak gas boilers) (Mazhar et. al., 2018). The distributed heat source from prosumer system (such as residual heat from supermarket) can also be utilized as base load. The STG technology (smart control and smart heat meter) is then required to continuously monitor temperature and volume of heat produced from these sources and continuously dispatch heat based on heat demand monitoring and forecasting.

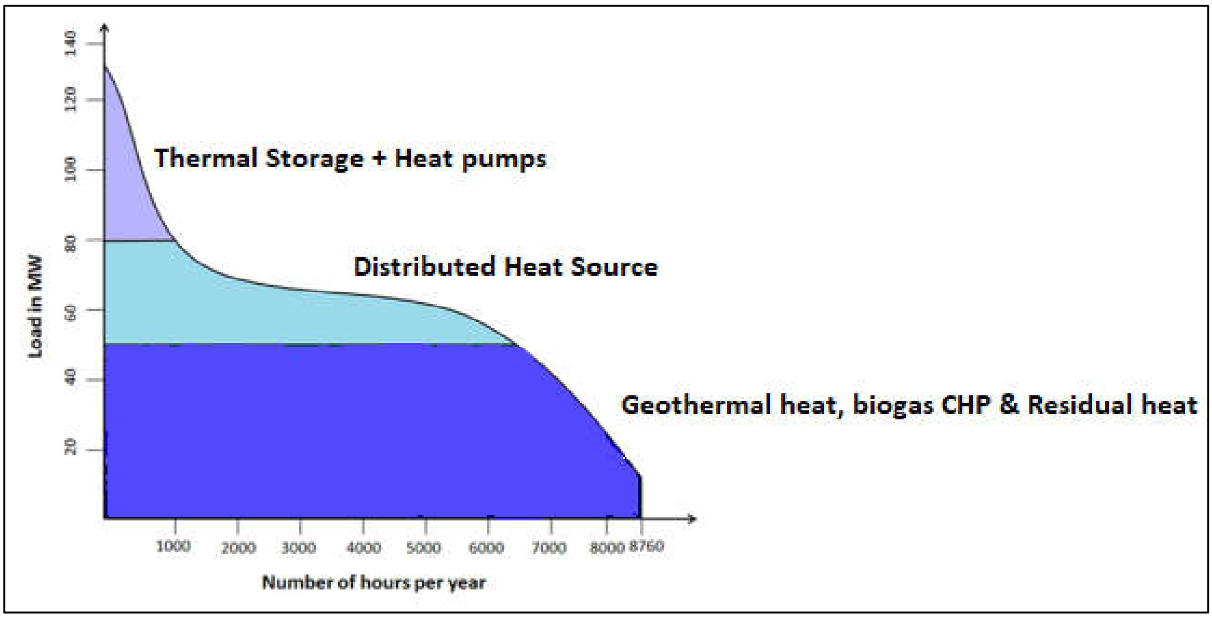

Figure 19. Utilization of multiple heat sources for base load & peak load (modified after Mazhar et. al., 2018)

The heat supply temperature in the heat network needs to be decreased from currently 75-85°C to < 70°C (Lund et. al., 2014). Since the existing heat networks are already made of steel pipe with foam insulation, the pipes can be used to distribute low temperature heat supply (40-50°C) (Ennatuurlijk, 2019).

The existing buildings in Camminghaburen, which mostly have energy label "B", "C" and "D" (klimaatmonitor buurten, 2019), need to be upgraded to have energy label "A" or better in order to utilize low temperature heat supply. This upgrade can be done through improvement of buildings insulation and replacement of radiator heaters inside buildings with new radiator heaters or underfloor heating (Averfalk et. al., 2017).

Woningen met geldig energielabel 2017 - Buurten 2018			
	Camminghaburen-Noord	Camminghaburen-Midden	Camminghaburen-Zuid
A	6	6	19
B	163	199	97
C	279	471	107
D	148	63	1
E	13	2	?
F	?	?	?
G	?	?	?

Figure 20. Energy labels of registered buildings in Camminghaburen (klimaatmonitor buurten, 2019)

If the heat supply temperature is decreased to < 60 °C, the legionella bacteria can grow and affect the water quality (Karlsson et. al., 2018). To prevent growth of bacteria, the heat supply temperature can be increased to 60 °C using decentralized heating system. To enable this decentralized heating system, heat substations (which is equipped with heat exchanger, heat pump and smart controller) need to be installed close to heat customers. This heat substations can be used to dispatch heat based on demand. This heat demand is continuously monitored using smart heat meter (which installed for each heat customer). This decentralized heating system imitates the operation of existing 4GDH system in Heerlen.

The STG technology needs to be implemented to enable heat flow in two directions (bi-directional) and heat prosumer system. Using this prosumer system, heat customers can sell the heat surplus to heat supplier (such as supermarket in Camminghaburen can sell the heat surplus which is generated from refrigeration system). The STG technology also need to enable utilization of excess electricity generated during night time for heat generation, thus enable integration of heat and electricity systems.

4.2. Upgrades of Organizations

Since multiple heat producers need to be involved in the 4GDH system, the DHS company need to collaborate with different organizations. Operator of geothermal heat, some companies that potentially can provide residual heat (such as Friesland Campina), biogas provider (Biogas Leeuwarden) and other prosumers (such as supermarket) are some heat producers that need to be involved by DHS company. Contract needs to be established between DHS company & heat producers to ensure continuous delivery of heat supply.

In order to implement STG technology, DHS company need to collaborate with technology provider that has capability to install hardware and software related to smart system (such as NODA from Sweden). Knowledge centre (university) also need to be involved to develop the suitable STG system specific to existing DHS in Camminghaburen. Special contractor is needed for insulation of buildings and replacement of radiator heater with underfloor heating system. This buildings refurbishment is needed to maintain or improve comfort level of space using low temperature heat supply.

Since development of 4GDH system in the existing DHS will require additional investment, municipality need to be involved to secure funding. Municipality need to provide subsidy to heat customers for buildings refurbishment. DHS company and municipality need to work together for socialization of the upgrade project to heat customers, including the socialization of civil work (which required to replace the existing heat pipes and to add additional heat substations) and utilization of smart heat meter for remote heat measurement (which need to be approved by heat customers).

4.3. Conclusion of Chapter

Based on differences of existing DHS in Camminghaburen and 4GDH system which are explained in previous chapter (Chapter 3), there are several upgrades that is needed to transform existing DHS in Camminghaburen to be 4GDH system:

- Replacement of natural gas which is used for heat generation by CHP with residual heat, geothermal heat and biogas. Additional technology that is needed to utilize residual heat and geothermal heat are heat exchanger and heat pump
- Utilization of heat sources from multiple heat producers instead of using only one heat source. Additional technology that is needed to utilize multiple heat sources is STG technology (smart controller and smart heat meter)
- Reduction of the existing heat supply temperature to lower temperature (< 70 ^{o}C)

- Upgrade buildings to have energy label of “A” or better. The upgrade can be done through improvement of buildings’ insulation and replacement of radiator heater with underfloor heating system
- Implement STG to enable bi-directional heat flow and heat prosumer system
- Establish collaboration between DHS company and multiple heat producers through contract that can ensure security of heat supply
- Establish collaboration between DHS company with specific contractors (such as STG technology provider) and knowledge center
- More participation of municipality to provide subsidy for development of STG technology, buildings refurbishment and socialization of the DHS upgrade to local community (such as utilization of smart heat meter for remote heat measurement)

Chapter 5. Risks Analysis & Potential Solutions related to DHS upgrade

5.1. Risk Analysis

Risk analysis is process of identifying and analyzing potential issues that could negatively impact business initiatives or critical projects in order to help organizations to avoid or mitigate those risks. An important part of risk analysis is identifying the potential for harm of the risks and likelihood that the risks can happen (Rouse, 2014). The risk itself can be defined as the possibility of an unfortunate occurrence; the potential for realization of unwanted, negative consequences of an event; or the occurrences of some consequences of the activity (Society for Risk Analysis, 2015). There are two main approaches in risk analysis: qualitative and quantitative. Qualitative risk analysis assesses the likelihood of the risk to happen and the impact of the risks using predefined ranking scales (low, medium or high). Meanwhile quantitative risk analysis attempts to assign quantitative value to adverse events (such as financial amount) which represent the potential cost to an organization if that even actually occurs (Rouse, 2014).

Risk analysis is used to manage different elements of risks properly that can be arisen due to development of new energy system such as new 4GDH system. The generic process that can be used for risk analysis usually have several steps (Michelez et. al., 2011):

- Project definition & requirements: acquire detailed description of the context in which the risk analysis is carried out
- Risk identification: identify risks using workshop and/or “risks library” from past experiences
- Risk evaluation: analyze outcomes from previous development and use them to understand the possible outcomes for future DHS development
- Risk control & risk follow up: uses formal control procedure to assign responsibility for action
- Risk feedback: compares the real outcomes of the real development with the development plan and the results are put in the “risks library” for future analysis

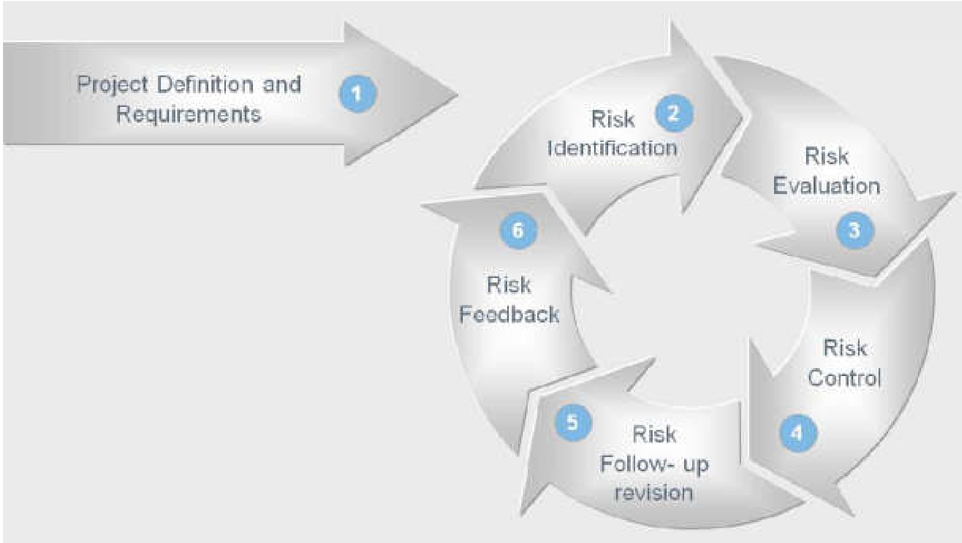

Figure 21. Steps of Risk Analysis (Michelez et. al., 2011)

In this report, the risk management for 4GDH development focus on the risk identification (to develop "risks library"). The risk evaluation, control, follow up and feedback are not performed due to no real 4GDH development at this moment.

5.2. Risks for development of 4GDH system in Leeuwarden

The risk of heat production is related to the difficulty of DHS in Camminghaburen to acquire heat from geothermal wells. This difficulty is considered as risk since it can limit the availability of sustainable heat source to meet heat demand in long term and can discourage the replacement of natural gas CHP with low carbon heat source. The current development plan of geothermal wells will only provide heat to DHS in the south & west of Leeuwarden (and will not supply heat to DHS in Camminghaburen). This plan is considered as the first phase of geothermal DHS in Leeuwarden, which is expected to start by mid of 2020 and will finish by 2023 or 2024. Although there was plan to develop next phase geothermal DHS in east part of Leeuwarden (which heat can be supplied to DHS in Camminghaburen), this plan is not moving forward at the moment due to lack of interest from the key stakeholder (Friesland Campina) at this moment (Friesland Campina suffer economy setback in the past few years due to competition of dairy products from China) (Ennatuurlijk, 2019; Boer, 2019). Furthermore, the development of next phase geothermal DHS has been hindered by limitation of funding, uncertainty on the first phase development of geothermal wells and concern of earthquake by local people (warmtevanleeuwarden, 2018).

Another risk of heat production is related to the difficulty of DHS in Camminghaburen to acquire residual heat from industries. This difficulty is considered as risk since it can limit the availability of low-cost residual heat source that is needed to replace natural gas. At this moment, there is no urgency for industries to utilize the residual heat. Most of residual heat from industries is only disposed to surrounding environment (water or air). The initiative to utilize the residual heat has been hindered by the difficulty to create long term heat supply contract. This difficulty is caused by different interests between DHS company and industries (DHS company usually want to have security of heat supply in long term, meanwhile industries can only agree to have shorter heat supply contract). There was plan to utilize residual heat from Friesland Campina few years ago, but this plan was not realized since Friesland Campina only agreed to supply heat for 5 years contract, meanwhile DHS company want to have supply heat for 15 years (Boer, 2019). Apart of that, there are limited numbers of big industries in Leeuwarden which can produce residual heat with high temperature. The residual heat from medium and small sized industries mostly have lower temperature than the temperature of heat supply required by heat networks.

Another risk of heat production is related to difficulty to replace natural gas with biogas for CHP heat generation due to limitation of biogas produced by DairyCampus & Biogas Leeuwarden (the existing biogas can generate heat to supply 700 houses and generate electricity to supply 1600 houses) (Biogas Leeuwarden.nl, 2016). This difficulty is considered as risk since biogas is the best fuel alternative to replace natural gas for CHP heat generation. Without sufficient biogas supply, the transition from natural gas to low carbon heat source will take longer time. As natural gas will be phased out gradually in future, the industries will also need large amount of biogas for heating process. Apart of that, the price of biogas is expected to increase annually, hence it will not be economic to utilize biogas for CHP (without any incentive).

The risk of heat distribution & consumption is related to incompatibility of low temperature heat supply to meet heat demand of existing buildings due to limitation of buildings' insulation and inadequacy of internal heating system in the buildings. The buildings incompatibility is considered as risks since most buildings in Camminghaburen has energy label of "B" or worse (klimaatmonitor buurten, 2019). Without proper buildings insulation and internal heating system, it is impossible for the existing DHS to be upgraded to 4GDH system. During DHS development in Camminghaburen, there was no proper coordination between DHS company and housing corporation to design buildings refurbishment plan for existing buildings that can meet low temperature heat supply (Ennatuurlijk, 2019). As consequence, the buildings refurbishment only follows the national target (improvement of existing buildings is only done up to energy label "B") which is still inadequate to utilize low temperature heat supply. This target is set based on the research which inform that the upgrade of buildings from energy label "B" to "A" (or better) will not decrease CO2 emission significantly (DNV GL et. al., 2018). Apart of that, currently there is lack of funding to perform necessary building refurbishment. The subsidy is only provided for 250 houses annually in Leeuwarden (Leeuwarden Energy Agenda, 2018). In short to medium timing duration (<10 years), this amount of subsidy is not enough to refurbish all of the existing buildings connected to DHS in Camminghaburen. There is also no local energy policy that can enforce utilization of low temperature heat supply, hence there is no urgency for DHS company to utilize low temperature heat supply.

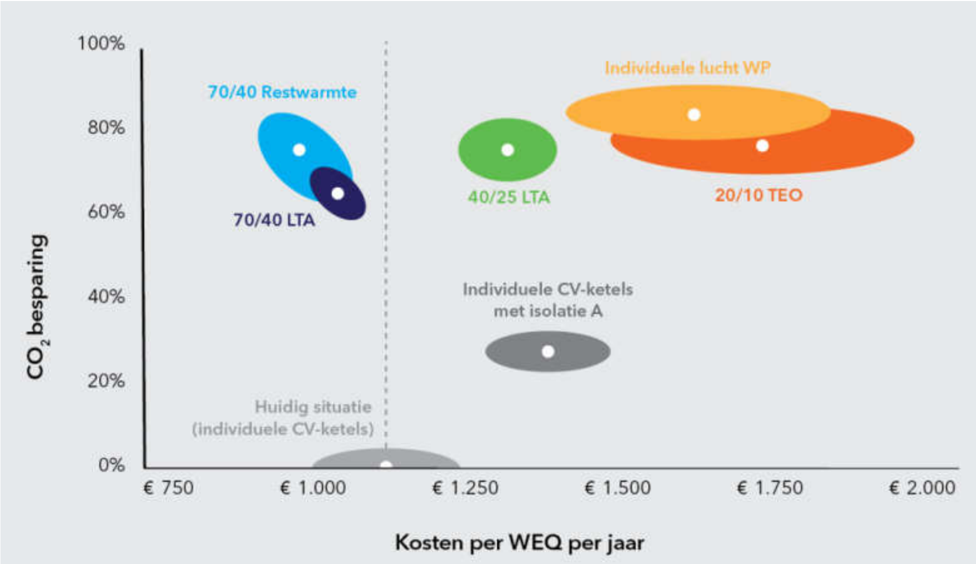

Figure 22. Comparison of CO2 emission reduction and cost for refurbishment (DNV GL et. al., 2018)

The risk of social acceptance related to acceptance of STG technology by both DHS company and community. The acceptance of STG technology is considered as risk since the implementation of STG cannot be done properly without initiative of DHS company to develop the STG technology in the existing DHS and willingness of local community (heat customers) to provide approval on the remote heat measurement. Currently the STG technology is still being tested by DHS company (such as STG pilot test in Eindhoven which is done through collaboration of Ennatuurlijk and NODA (energyville, 2019)). Before successful pilot test is performed, the DHS company will not have adequate knowledge on STG technology, hence DHS company will have difficulty to develop smart system that can enable prosumer system, bi-directional heat flow and heat exchange between buildings. The utilization of remote heat measurement (as part of STG technology) also can cause concern on the data privacy and data security for existing heat customers. The heat consumption data acquired by continuous remote measurement can reveal daily activity of people lives in buildings (similar to electricity consumption data acquired by remote measurement (Weaver, 2014)) and this information can be exposed to unauthorized person/organization.

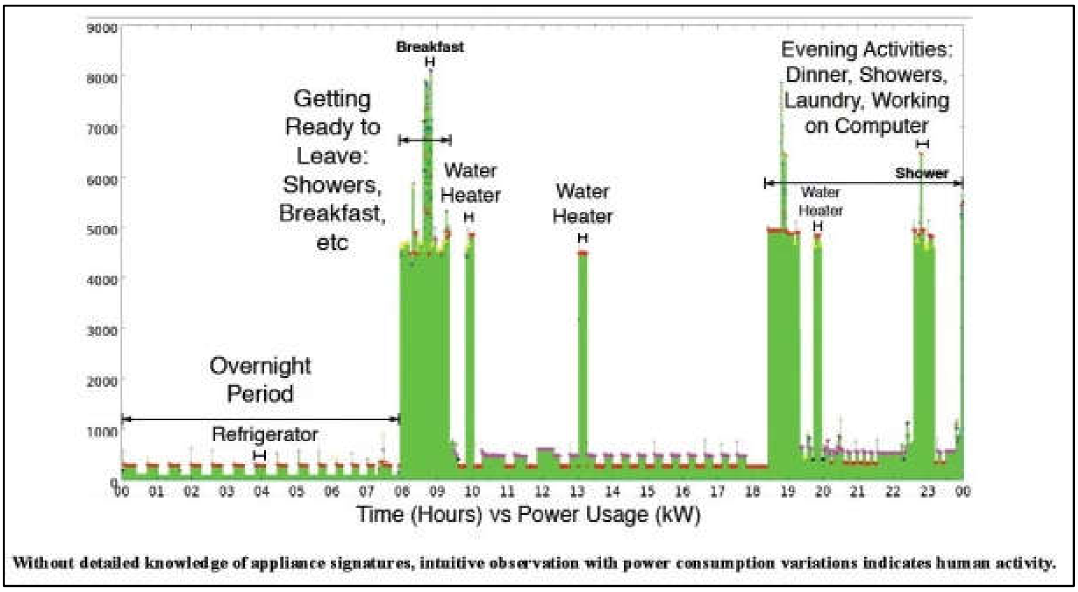

Figure 23. Example of daily activities interpreted based on electric smart meter data (Weaver, 2014)

The risk of development cost is related to additional cost that is needed to implement 4GDH system for existing DHS in Camminghaburen. The additional cost is considered as risk since inadequacy of funding can delay the upgrades of existing DHS to 4GDH system. The existing DHS has inadequate funding for the upgrade since the existing DHS is already well functioned and further development will be discouraged if there is no additional benefit that can be acquired by the DHS company (as the owner of the heat networks). Apart of that, the heat pricing (that can be charged to heat customers) is limited by regulation (Heat Act), hence any additional investment on the existing DHS can only be recovered in longer duration. This is further complicated by the fact that the investment on existing DHS in Camminghaburen has not yet been recovered since its commissioning in 2013 (Ennatuurlijk, 2019).

The risk of organizational complexity is related to the fact that the DHS company in Leeuwarden is not owned by municipality but it is owned by private sector (ennatuurlijk.nl, 2019). This issue of ownership is considered as risk since DHS company can decide to keep the existing 3GDH system without intervention by municipality. As the owner of the heat networks, DHS company has more power than municipality in term of funding, knowledge and practical experience to manage heat networks. DHS company can make decision to rely only on existing centralized heat producer (CHP) which is owned by the DHS company. This decision will limit the participation of other potential heat producers and will delay the transition of existing DHS to 4GDH system.

Another risk of organizational complexity is related to the lack participation of local academic center (university) for development of 4GDH system (local academic center is expected to be more aware of local issues and more embedded in the local community). The lack of participation from the local academic center is considered as risk since it can limit dissemination to local stakeholders of knowledge and experiences which are needed to implement STG technology. In the current situation, most of the planning related to energy system are done by energy experts which are located in municipality, province or national organization of energy experts. These energy experts are quite limited in number and knowledge especially related to experiences on new energy system (Boer, 2019). As consequence, the municipality has limited development on smart energy system (only smart electricity grid has been planned in north of Leeuwarden which is also part of national SWITCH project (Leeuwarden Energy Agenda, 2018)).

5.3. Potential solutions for risks mitigation

In order to mitigate the risk related to heat production & development cost, it is necessary for the municipality to accelerate the utilization of residual heat to be supplied in the heat networks. The acceleration can be done by formulation of local energy policy which prohibit the disposal of residual heat to surrounding environment (this policy can imitate the policy that has been implemented in Denmark (Hoogervorst et. al., 2016)). Due to the pressure of the policy, industries are forced to work together with municipality to establish technology that can recover & utilize residual heat (and prevent disposal of residual heat). Municipality can then help industries & DHS company to acquire subsidy from government (such as SDE+ or EIA / Energy Investment Allowance) or international body (such as subsidy from EU) that will be used to develop necessary technology for residual heat recovery. Municipality also can help industries to establish heat supply contract with DHS company which can ensure security of residual heat supply from industries and this contract also will not become burden for industries. This can be done through establishment of contract with shorter duration. The advantage of 4GDH system which utilize multiple heat sources can further enable contract with shorter duration since contract can be established with multiple heat producers and the aggregation of these multiple heat sources can cover lack of heat supply from only centralized heat source. Apart of relying on the residual heat from industries, district heating company can also put effort to recover the residual heat from the water sewage system. This effort adds more heat source that can be supplied in the heat network. The heat recovery from sewage system can be done through collaboration between district heating company, municipality and local waste water treatment company.

In order to mitigate risk related to heat distribution & consumption, municipality can formulate policy which support development of low temperature district heating (LTDH). The policy should integrate LTDH development with buildings refurbishment. Improvement of buildings insulation and upgrade of internal heating system need to be supported to achieve energy label "A" or better. Apart of that, the policy should be established to enhance collaboration between DHS company and housing corporations for development of buildings refurbishment plan that can support energy saving and utilization of low temperature heat supply.

In order to mitigate risk related to social acceptance on STG technology & lack participation of knowledge center, DHS company can develop STG "living lab" in Leeuwarden. This "living lab" can be used to show the benefits of STG. One of the possible "living lab" that can be established is the upcoming geothermal DHS which will be connected to 3000 households in "Middelsee" using low temperature heat supply (50 degC) (Ennatuurlijk, 2019). This "living lab" can be used as lesson learnt for DHS company to check the implementation of STG technology in Leeuwarden. Collaboration can then be established between DHS company and knowledge center to develop the STG technology (such as collaboration between DHS company and upcoming Energie Campus or recently developed Campus Fryslan). DHS company can work together with municipality to persuade local community to participate on this "living lab" (municipality can attract local people to participate by providing subsidy to refurbish their houses), hence local people will see the benefits of STG technology and has less resistance to this new technology. The data security and data privacy issues related to remote heat measurement also need to be tackled by collaboration between DHS company and specific technology provider (such as organization with expertise in cybersecurity). Another solution to mitigate risk related to social acceptance on STG technology can be done through formulation of local energy policy which support development of smart energy system. The current policy needs to be updated to not only support development of smart electricity grid (Leeuwarden Energy Agenda, 2018), but also support smart thermal grid.

A workshop on district heating held under the auspices of an EU project, recommended that in order to mitigate risk related to ownership of DHS, it is necessary for municipality to have ownership on the existing DHS or upcoming geothermal DHS (such as by enforcing DHS company to sell part of the share to municipality) (Interreg HeatNet NWE – Remunicipalisation, 2018). This ownership can give municipality more control on the future DHS development (Lysias, 2017). Through the DHS ownership, municipality can force the development of 4GDH system for the existing DHS. By participation of municipality in the development of DHS, the municipality also can get more experience on the development of 4GDH system which can support further upscaling of 4GDH system in Leeuwarden.

5.4. Feasibility for upgrade for existing DHS to 4GDH system in Camminghaburen

Considering the situation of existing DHS in Camminghaburen, changes needed for upgrade to 4GDH system and the risks associated with 4GDH development (restriction of policy, limitation of funding, social acceptance of 4GDH system, more organizational complexity), the upgrade of the existing DHS to 4GDH system is not feasible to be realized without support of municipality, changes of policy and good collaborations of the stakeholders. By implementing the recommended potential solutions, it is more feasible to develop 4GDH system for existing DHS but the development still requires longer duration.

The upgrade of existing DHS towards 4GDH system requires several criteria to be fulfilled: utilization of residual heat and/or geothermal heat sources to replace existing natural gas CHP, utilization of STG technology, utilization of low temperature heat supply and integration of heating system with other energy systems. Since the first phase development of geothermal DHS will be finished by 2024, the second phase development of geothermal DHS can only be realized at least 5 years after 2024 (or 2029). The utilization of residual heat can be done faster if there is more push from municipality, hence it can be done in 5 years from now.

The utilization of low temperature heat supply depends on the time duration needed to refurbish all of the buildings in Camminghaburen to have energy label of “A” or better. Since the current pace of refurbishment is 250 houses annually and by assuming that 150 houses’ refurbishment will be done only in Camminghaburen, then it will take at least 10 years to finish the refurbishment (there are approximately 1500 houses which are connected to existing DHS in Camminghaburen which connected to existing DHS and most of them have energy label of “B” or worse at this moment (Ennatuurlijk, 2019; klimaatmonitor buurten, 2019)). The assumption for refurbishment of 150 houses only for houses in Camminghaburen can only be done by support of local energy policy which prioritize refurbishment for buildings connected to heat networks.

Since the STG technology is still being tested by DHS company (Ennatuurlijk) at this moment, the STG technology is expected to be implemented in Leeuwarden at least 5 years from now. As the STG is the key technology to enable integration of heating system with other energy systems, the integration of smart energy systems can only be realistically implemented by at least 10 years from now (the time duration is expected to be > 5 years due to limited development on smart electricity grid at this moment). Considering the timeframe needed for each criteria mentioned previously, it is expected that the transition from existing DHS to 4GDH system in Camminghaburen will take at least 10 years.

5.5. Conclusion of Chapter

There are several risks that can be identified to upgrade the existing DHS in Camminghaburen to 4GDH system as summarized in table below.

Table 5. Risks of district heating company to upgrade of existing DHS in Camminghaburen to 4GDH system

Risks	**Reason to be risks**
Difficulty to supply heat from geothermal wells for heat networks due to lack of funding to develop next phase geothermal DHS, uncertainty on the development of first phase geothermal DHS and concern of earthquake by local community	Lack of geothermal heat can limit the replacement of natural gas with more sustainable low carbon heat that can fulfil long term heat demand of 4GDH system
Difficulty to supply heat from industries' residual heat due to no urgency for industries to utilize residual heat, issue with long term heat supply contract and temperature of residual heat supply	Lack of residual heat can delay the replacement of natural gas with low cost heat source
Difficulty to supply biogas to replace natural gas for heat generation by CHP due to limited availability of biogas and additional cost needed to purchase biogas	Lack of biogas can delay the replacement of natural gas which is needed to transform the existing DHS to 4GDH system
Incompatibility of low temperature heat supply to meet heat demand for the existing buildings due to limitation of buildings' insulation and inadequacy of internal heating system in the buildings	Without improvement on buildings' insulation and internal heating system, it is impossible to transform existing DHS to 4GDH system which require utilization of low temperature heat supply
Low acceptance of STG technology by DHS company due to inadequate knowledge on STG. Low social acceptance by local people due to concern on the data privacy & data security that can be exposed by remote heat measurement	Without initiative by DHS company to implement STG technology and without approval of local people on remote heat measurement, it is difficult to develop STG which is key component of 4GDH system
Inadequate funding to develop 4GDH system due to lack of interest of DHS company to invest on well functioned system without additional benefits for the DHS company	Lack of funding can delay the upgrades of existing DHS to 4GDH system
Existing DHS is owned & operated by DHS company (without participation by municipality) which cause dependency of municipality on DHS company for development of 4GDH system	The ownership of DHS company on the existing heat networks can give the right for DHS company to delay the upgrade of existing DHS to 4GDH system (without intervention by powerless municipality)
Lack of participation by local knowledge centre (university)	The lack of participation can limit dissemination of knowledge and experiences related to 4GDH system and STG technology

Several potential solutions have been proposed by different stakeholders to mitigate several risks which are mentioned previously.

1. Municipality accelerate the utilization of residual heat from industries through formulation of local energy policy which prohibit disposal of residual heat to surrounding environment, support for industries & DHS company to secure subsidy to develop technology for recovery of residual heat and support for industries to establish contract of heat supply with DHS company (proposed by national government)
2. Municipality formulate local policy that support development of low temperature district heating (LTDH) and enhance collaboration between DHS company & housing corporations to develop buildings refurbishment plan which is adequate for utilization of low temperature heat supply (proposed based on experience of DHS company)
3. DHS company develop “living lab” of STG technology which can be used by DHS company to learn the STG implementation, show benefits of STG & reduce resistance of local people on deployment of STG technology. Municipality also can formulate local policy that can support development of smart energy systems to integrate heating system with other energy systems (proposed based on experience of DHS company)
4. Municipality take ownership on the existing DHS which can give municipality more control on the future development of DHS and give more experience for municipality on the development of 4GDH system which support the upscaling of 4GDH system in Leeuwarden (proposed by EU)

If these potential solutions are implemented to mitigate the risks, the existing DHS in Camminghaburen is feasible to be upgraded to 4GDH system although this may take at least 10 years. This longer duration is required to develop sustainable low carbon heat sources (geothermal), to refurbish the existing buildings so that the buildings can utilize low temperature heat supply and to acquire adequate experience on the STG by the local district heating company.

Chapter 6 Conclusions and Recommendations

6.1. Conclusions

The objective of this research (as mentioned in the first chapter of this report) is to identify the improvements that are needed to upgrade existing DHS in Leeuwarden to 4GDH system, risks related to the upgrade and potential solutions that can be recommended to mitigate these risks. This objective has been translated into 4 different research sub-questions and the answer for each research sub-questions are summarized here.

What are the main characteristics of a 4GDH system and how are these characteristics developed in practice?

4GDH system is new DHS which has several main characteristics that differentiate it with previous generations DHS: utilization of low temperature heat supply, reduction of heat loss, utilization of recycle heat & renewable heat and integration of heating system into smart energy systems. Additionally, there are several non-technical characteristics that need to be considered in 4GDH system: collaboration of more organizations (DHS company, municipality, STG technology provider & knowledge centre) which increase the organizational complexity, social acceptance on STG technology & low temperature heat supply, additional cost incurred to develop STG technology and regulation which support or resist development of 4GDH system.

In practice, the characteristics of 4GDH system has been developed for DHS in Heerlen (Mijnwater 2.0). Mijnwater 2.0 has several characteristics which classified it as 4GDH system: utilization of low temperature heat supply (28^{o}C), supply heat from multiple heat producers (geothermal heat & residual heat from data centre) and integration of heat with electricity systems (utilize electric heat pump to meet higher temperature heat demand). Additionally, there are several non-technical characteristics that have been implemented to develop this 4GDH system: good collaboration is formed by municipality (as the owner of DHS company) with STG technology provider (NODA) & knowledge centre (university) through several EU projects in order to implement STG technology and to acquire subsidy to cover the development cost; social acceptance is improved through establishment of contract for multiple heat producers & enable prosumer system and local policy (PALET) is formulated to support development of 4GDH system.

What are the differences in technology, organisation and functioning of the existing heating networks in Leeuwarden and a 4GDH system?

Based on the characteristics of existing DHS in Camminghaburen (Leeuwarden) and existing 4GDH system in Heerlen, there are several differences in technology, organization and functioning which can be identified:

Existing DHS in Camminghaburen	**4GDH system in Heerlen**
Technology & Functioning	
Single heat producer (CHP)	Multiple heat sources (geothermal wells & residual heat from data center)
Utilize heat supply with medium temperature (75-85 °C) for heat distribution	Utilize heat supply with low temperature (29 °C) for heat distribution
No STG technology is implemented (remote heat measurement is only used for large company)	STG technology is implemented (smart heat meter for remote heat measurement)
Heat flow in one direction (from heat producer to customers)	Heat flow in two directions which enable prosumer system
No integration of heat system with other energy systems	Integration of heat system with electricity system (utilize electric heat pump to enable decentralized heat production)
Organization	
No collaboration between DHS company with heat producer since DHS company hold the roles of heat producer, heat transmitter & heat supplier	Collaboration between DHS company (as heat supplier) with multiple heat producers / prosumers;
No collaboration for DHS company with knowledge center (university) & specific contractor to implement STG technology	Collaboration exist for DHS company with STG contractor & knowledge center to implement STG technology
No collaboration between DHS company and other funding organization since the funding for DHS development is only provided by DHS company	Collaboration exist for DHS company with municipality, national government & EU to acquire funding (subsidy) to develop 4GDH system

Which changes will be needed in technology, organisation and operation of existing heating networks in Leeuwarden to transform them into 4GDH systems?

Based on the differences mentioned in previous research sub-question, some upgrades are needed to transform the existing DHS in Camminghaburen to 4GDH system:

Technology & Operation:

- Replacement of natural gas which is used for heat generation by CHP with residual heat, geothermal heat and biogas. Additional technology that is needed to utilize residual heat and geothermal heat are heat exchanger and heat pump
- Utilization of heat sources from multiple heat producers instead of using only one heat source. Additional technology that is needed to utilize multiple heat sources is STG technology (smart controller and smart heat meter).
- Reduction of the existing heat supply temperature to lower temperature (< 70 °C)

- Upgrade buildings to have energy label of "A" or better. The upgrade can be done through improvement of buildings' insulation and replacement of radiator heater with underfloor heating system
- Implement STG to enable bi-directional heat flow and heat prosumer system

Organization:

- Establish collaboration between DHS company and multiple heat producers through contract that can ensure security of heat supply
- Establish collaboration between DHS company with specific contractors (such as STG technology provider) and knowledge center
- More participation of municipality to provide subsidy for development of STG technology, buildings refurbishment and socialization of the DHS upgrade to local community (such as utilization of smart heat meter for remote heat measurement)

What are potential risks of the transition of the current heating networks in Leeuwarden towards a 4GDH system and what are the potential solutions to mitigate these risks?

There are several potential risks that can happen due to transition of current heating networks in Camminghaburen (Leeuwarden) towards 4GDH system:

Risks	**Reason to be risks**
Difficulty to supply heat from geothermal wells for heat networks due to lack of funding to develop next phase geothermal DHS, uncertainty on the development of first phase geothermal DHS and concern of earthquake by local community	Lack of geothermal heat can limit the replacement of natural gas with more sustainable low carbon heat that can fulfil long term heat demand of 4GDH system
Difficulty to supply heat from industries' residual heat due to no urgency for industries to utilize residual heat, issue with long term heat supply contract and temperature of residual heat supply	Lack of residual heat can delay the replacement of natural gas with low cost heat source
Difficulty to supply biogas to replace natural gas for heat generation by CHP due to limited availability of biogas and additional cost needed to purchase biogas	Lack of biogas can delay the replacement of natural gas which is needed to transform the existing DHS to 4GDH system
Incompatibility of low temperature heat supply to meet heat demand for the existing buildings due to limitation of buildings' insulation and inadequacy of internal heating system in the buildings	Without improvement on buildings' insulation and internal heating system, it is impossible to transform existing DHS to 4GDH system which require utilization of low temperature heat supply
Low acceptance of STG technology by DHS company due to inadequate knowledge on STG. Low social acceptance by local people due to	Without initiative by DHS company to implement STG technology and without approval of local people on remote heat

concern on the data privacy & data security that can be exposed by remote heat measurement	measurement, it is difficult to develop STG which is key component of 4GDH system
Inadequate funding to develop 4GDH system due to lack of interest of DHS company to invest on well functioned system without additional benefits for the DHS company	Lack of funding can delay the upgrades of existing DHS to 4GDH system
Existing DHS is owned & operated by DHS company (without participation by municipality) which cause dependency of municipality on DHS company for development of 4GDH system	The ownership of DHS company on the existing heat networks can give the right for DHS company to delay the upgrade of existing DHS to 4GDH system (without intervention by powerless municipality)
Lack of participation by local knowledge centre (university)	The lack of participation can limit dissemination of knowledge and experiences related to 4GDH system and STG technology

These risks can be mitigated using several potential solutions:

1. Municipality accelerate the utilization of residual heat from industries through formulation of local energy policy which prohibit disposal of residual heat to surrounding environment, support for industries & DHS company to secure subsidy to develop technology for recovery of residual heat and support for industries to establish contract of heat supply with DHS company
2. Municipality formulate local policy that support development of low temperature district heating (LTDH) and enhance collaboration between DHS company & housing corporations to develop buildings refurbishment plan which is adequate for utilization of low temperature heat supply
3. DHS company develop "living lab" of STG technology which can be used by DHS company to learn the STG implementation, show benefits of STG & reduce resistance of local people on deployment of STG technology. Municipality also can formulate local policy that can support development of smart energy systems to integrate heating system with other energy systems
4. Municipality take ownership on the existing DHS which can give municipality more control on the future development of DHS and give more experience for municipality on the development of 4GDH system which support the upscaling of 4GDH system in Leeuwarden

6.2. Recommendations

In order to better identify the improvements for upgrade the existing DHS to 4GDH system, it is recommended to have workshop with all stakeholders in Leeuwarden (municipality, DHS company, community, academic). The result of the workshop can produce more comprehensive information related to the changes needed for DHS upgrade along with the identification & evaluation of the risks associated to the system upgrade. The more comprehensive technical analysis on the existing DHS can be acquired through internship in the DHS company. This is necessary to capture all technical limitations that can obstruct development of 4GDH system. Separate workshop can also be done with major district heating companies in Netherlands which are currently developing 4GDH system in other locations. This workshop can be used to share experiences among the experts in DHS and to promote best practices of 4GDH development.

Since the feasibility of the DHS upgrade is only based on risks impact on duration for 4GDH development at this moment, it is also necessary to do more comprehensive feasibility study based on cost. Using the cost and duration information, the risks can be better evaluated to identify the potential risks. The stakeholders can then put more effort to resolve these potential risks. Apart of that, the heat customers can be involved to provide more information of their concerns related to the upgrade of existing DHS to 4GDH system (such as their concerns related to buildings refurbishment). This information will be used to analyse the risks from the demand side which is still not explained in the current research.

6.3. Reflections

Most of the data utilized in this thesis has been acquired from the district heating companies. As consequence, the analysis is focused more on the supply side point of view and not from the demand side point of view. This analysis has potentially caused imbalance on the potential upgrade and risks that can be identified to transform the existing heating system to 4GDH system. In order to have more balanced analysis, this research can be expanded to include information from the heat customers.

There are two examples of imbalance that can be identified from this thesis. The first example is the potential risk related to development cost of geothermal heat. From the supply side point of view, the geothermal well which need to be developed can incur high development cost for district heating company. Meanwhile from the demand side point of view, the geothermal heating has long life cycle thus it can provide affordable heating in the long term. The second example is the potential upgrade related to buildings refurbishment which is necessary to utilize low temperature heat supply. From the supply side point of view, the buildings refurbishment is necessary to be done to enable the connection of heat networks to those buildings in 4GDH system. Meanwhile from the demand side point of view, the buildings refurbishment can cause more risks to the buildings’ owners (or tenants) due to the unease caused during the refurbishment and danger of fire caused by material used in the refurbishment.

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Appendix

As complementary for the main chapters of this thesis, this appendix chapter will describe some technology which is typically used in district heating system. Apart of that, the European Union (EU) projects and the national subsidy that support the development of district heating system are also explained. The personal communication (interviews & questioning) from several informants are also included at the end of this appendix chapter.

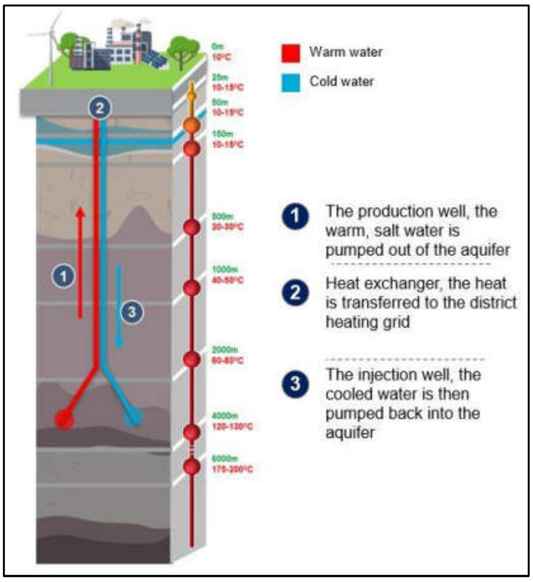
Appendix 1. Technology in District Heating

In this section, the heat source (and heat production technologies) are explained along with other technologies related to district heating system.

- Geothermal heat

  Geothermal heat is sustainable heat source that has almost no CO2 emissions. This heat source is not dependent on weather condition, day/night or seasonal cycles. The heat is extracted from warm water which located in the porous sandstone and limestone rocks and the rocks are typically located below the surface of earth with depth of 500 metres to more than 4000 metres.

  To extract heat from the ground, wells are drilled to reach the aquifer rocks that contain the required warm water. The warm water from producer well is then pumped to the surface and the heat is transferred to heat networks via heat exchanger (the water from the well is separated from the water in the heat networks). The cooled water is then injected back to the well (injector well) to be re-heated by earth. These 2 wells (producer and injector) form the core of geothermal wells or typically is known as doublet. The technical lifespan of a doublet is around 30 years (DAGO, 2018).



Illustrative geothermal wells as heat source for district heating system (DAGO, 2018)

Development of geothermal wells can bring positive and negative impacts and these impacts are summarized in figure below (Shortall et. al., 2015).

Theme	Positive impacts	Negative impacts
Poverty	– Increased per capita income – Increase in salaries – Social development initiatives – Affordable energy supply – Higher living standards – Improved food security – Access to drinking water	– Rising property prices – Community displacement
Health	– Improved sanitation – Improved medical facilities – Lower indoor air pollution – Therapeutic uses	– Odor nuisance – Toxic gas emissions – Water contamination risk – Noise pollution
Education	– Improved education facilities – Improved school attendance	– Sudden or unprecedented cultural change
Natural hazards		– Induced seismicity – Subsidence – Hydrothermal eruptions
Demographics	– Positive social change – Increased tourism	– Negative cultural impacts – Resettlement – Livelihood displacement
Atmosphere	– Displacement of greenhouse gas emissions from other energy sources	– Greenhouse gas emissions – H_2S pollution – Toxic gas emissions
Land	– Small land requirements relative to other energy sources	– Habitat loss – Soil compaction – Conflict with other land uses
Forests	– Replacement of traditional biomass	– Deforestation – Ecosystem loss
Freshwater	– Low lifecycle water consumption relative to other energy sources	– Conflict with other energy uses – Contamination of shallow aquifers and other water bodies
Biodiversity		– Habitat loss or disturbance – Loss of rare geothermal ecosystems
Economic development	– Increased energy security – Low climate dependence – High capacity factor – Direct, indirect and induced economic activity and employment	– Few direct long-term jobs
Consumption and production patterns	– Waste heat can be cascaded or recaptured	– Waste may cause environmental contamination – Risk of overexploitation – High cost of turbines may compromise efficiency

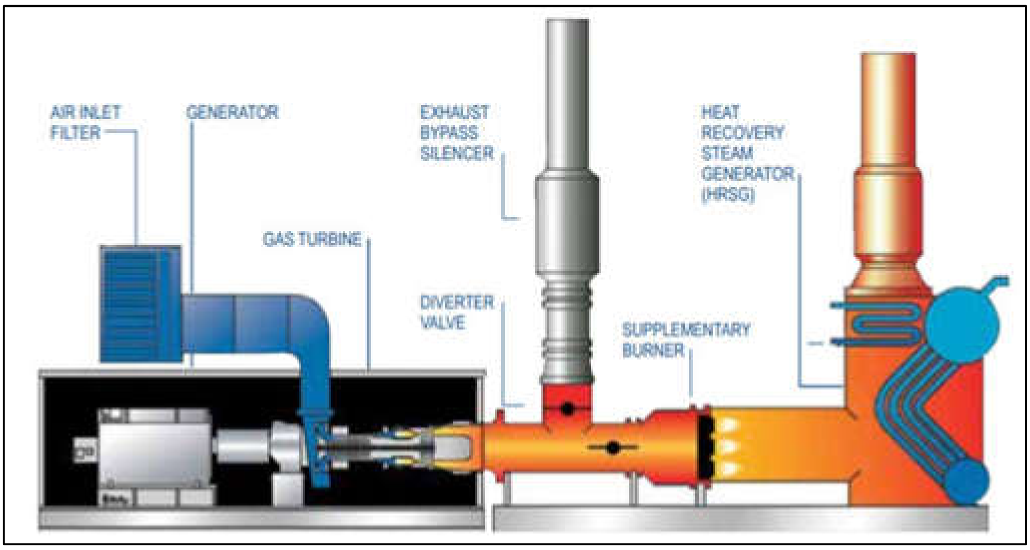
Positive and negative impacts of geothermal wells

- CHP (combined heat & power)

  Thermal energy in CHP system is produced as a by-product of electricity generation (the waste heat is generated from fuel combustion to produce electricity). The co-generation of heat and electricity is more efficient than the gas boiler system which is used to generate heat only. The theoretical efficiency of CHP energy conversion (both electricity & heat) is between 60% to 80%, however the practical efficiency depends on the demand of both heat & electricity. The energy conversion has lower efficiency if the main goal is electricity production, meanwhile the energy conversion has higher efficiency if the main goal is heat production. CHP for district heating are typically adjusted to provide approximately half of peak load (peak is provided by boiler system) (Related, 2018).

Some technologies of power generation for CHP are gas turbines, combined gas-steam turbines and gas engines (Sayegh et. al., 2017).

- The gas turbines consist of electricity generator, gas turbine, compressors and combustion chamber. The electrical efficiency usually has range between 0.35 – 0.42. The ratio of power to heat has range of 0.5 – 2, which is one of the highest ratios compared to other technologies
- The gas-steam turbines consist of heat recovery steam generator, steam turbine and condenser. The gas-steam turbines have higher electrical efficiency (0.59) than gas turbines due to the capability to reuse the waste heat for electricity generation. The heat supply for heat network is produced by condenser, waste heat exchanger and exhaust gas boiler
- The gas engines have electrical efficiency between 0.2 – 0.4 and power to heat ratio has range of 0.5 – 1. The internal heat recovery system uses the temperature of exhaust gases to supply heat for small district heating and individual buildings.

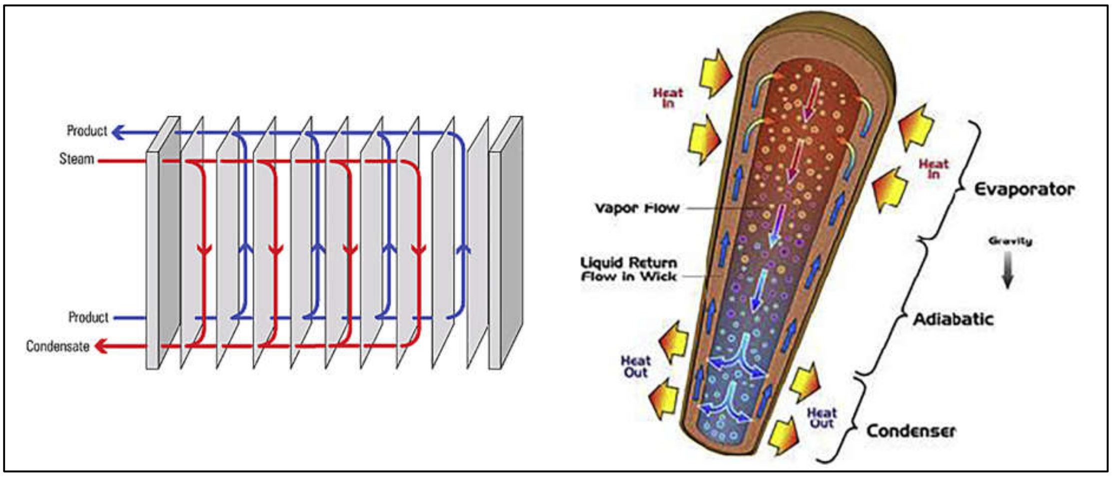


Gas turbine with heat recovery steam generator (US Department of Energy, 2016)

- Residual heat from industries

Residual heat from industries is energy that is generated from industrial process and is wasted or dumped in the environment (the residual heat carriers can be in form of liquid or gas). The sources of residual heat are heat loss that happen due to conduction, convection and radiation from industrial products, equipment & process or heat discharged directly from combustion process. The residual heat can be classified into high temperature (> 400 ^{o}C), medium temperature (100-400 ^{o}C) and low temperature grades (< 100 ^{o}C). The residual heat can be recovered using Waste Heat Recovery (WHR) technologies (such as plate heat exchangers & heat pipe systems) (Jouhara et. al., 2018).

- Plate heat exchangers transfer heat from one fluid to another without cross contamination between fluids. The plate heat exchanger is typically stacked of several thin metal plates in parallel to each other. Each plate consists of different patterns which are surrounded with gaskets to control fluid flow and produce turbulence for better heat transfer. The gaskets are arranged to allow only one type of fluid through one gap and other fluid flow through the adjacent gap. In this arrangement, the hot and cold fluids pass through each section of the heat exchanger and exchange heat without getting contaminated with each other.
- Heat pipe system is a device that transfer heat from one place to another with help of condensation & vaporisation of working fluid. A heat pipe consists of a sealed container, wick structure and small amount of working fluid (such as water, methanol or ammonia). When heat is applied to one end of the pipe, the heat is conducted through the pipe wall and wick structure which cause the evaporation of working fluid inside the pipe. The vapour is then pushed to other end of the pipe and release heat through the wick structure & wall of the pipe (the released heat is transferred to the heat sink). After that, the vapour condenses (and absorbed by the wick structure) and the liquid form of the working fluid is then driven back to the hot end of the pipe.



Schematic of plate heat exchanger (left) and heat pipe system (right) (Jouhara et. al., 2018)

- Heat Storage

  Heat storage is technology which store heat energy by heating storage medium and the heat energy can be used later for heating and conversion into other energy products. The heat storage can help to offset the mismatch between periods heat energy is available and in demand (for example heat storage can be used to store heat generated in summer season to be used in winter season). The heat storage is used in district heating system to enable integration of heat & electricity systems (heat can be generated using electricity during off-peak time of electricity demand) (Rosen, 2008).

There are 2 main types of heat storage: sensible heat storage and latent heat storage. The sensible heat storage store heat energy by elevating the temperature of substance inside the storage medium, meanwhile the latent heat storage store heat energy by changing the phase of substance. Some common types of sensible heat storage are water tank, underground aquifer and wells. Meanwhile some types of latent storage medium are inorganic & organic materials, acids & aromatics and paraffin waxes. The technology of sensible heat storage is more mature than latent heat storage, hence the cost to deploy this type of storage is cheaper. However, the latent heat storage has higher storage density than sensible heat storage (Rosen, 2008).

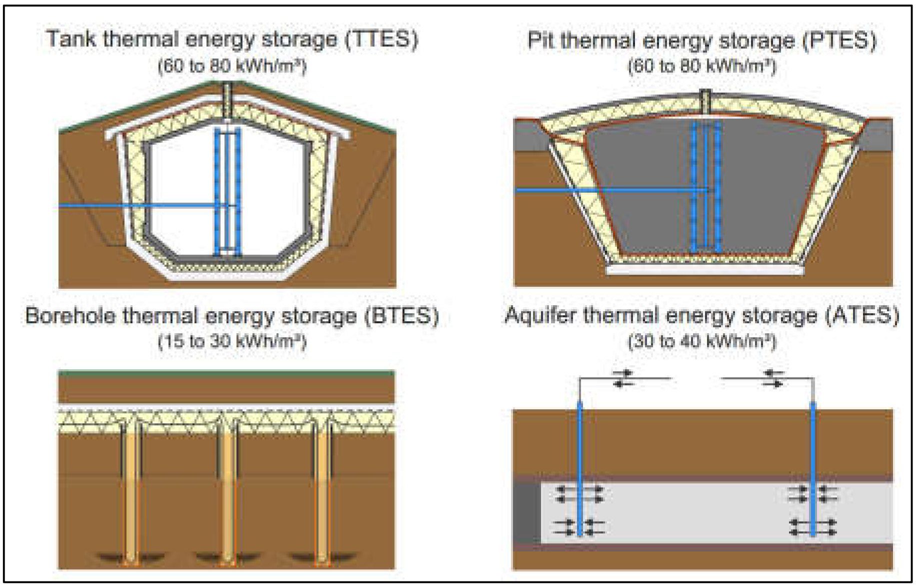


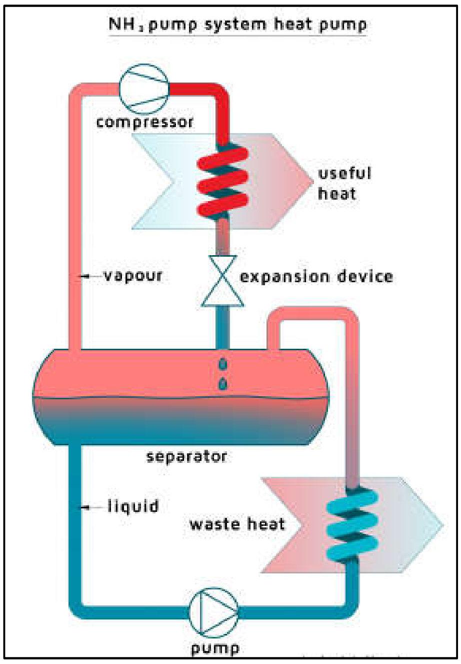
Illustration of some common types of sensible heat storage (BEIS, 2016)

- Heat Pump

  Heat pump is a technology that can be used to adjust the temperature of water before it is supplied to heat networks. For conventional district heating, the heat pump is also used to increase the water temperature to 50 °C for space heating and to 65 °C for domestic hot water heating inside buildings (Zieler, 2017). The main components of heat pump are evaporator, compressor, condenser, expansion valve and refrigerant fluid such Ammonia.

  There are several types of heat pumps that are currently available in the market and they can be categorized based on the operating principle and energy used to drive the heat upgrading process. The heat pump types include: mechanical heat pump, gas engine heat pump, absorption heat pump, adsorption heat pump, trans-critical CO2 heat pump, hybrid heat pump and thermo-acoustic heat pump (industrialheatpumps.nl). The mechanical heat pump is the most common heat pump used nowadays and it can be operated using different mediums of energy sources: air source, geothermal source and water source. The efficiency of mechanical heat pump is known as Coefficient of Performance (COP) which is the ratio of heat generated to the input of electricity (power).

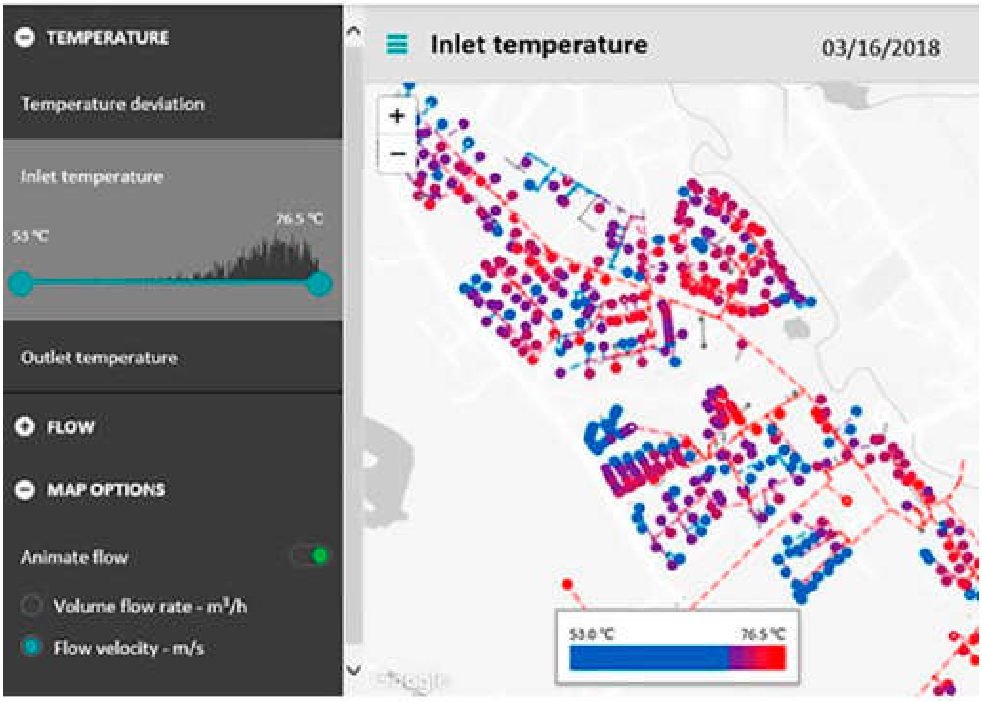
The working principle of heat pump is based on the evaporation & condensation of the refrigerant fluid. At low temperature & pressure, the refrigerant fluid is evaporated as the heat energy is driven into the heat pump. The compressor then increases the pressure of refrigerant vapor (compressor is operated using electricity). After that, the high pressure & temperature of refrigerant vapor is condensed inside the condenser which release useful heat. Finally, the refrigerant liquid is transported to expansion valve which decreases the pressure of refrigerant liquid and the refrigerant liquid is feeds into the evaporator to start new cycle of heat pump operation (industrialheatpumps.nl).



Schematic of mechanical heat pump with ammonia (NH3) as refrigerant fluid (industrialheatpumps.nl)

- Smart Heat Meter

  Smart heat meter is part of smart thermal grid (STG) technology which can provide remote heat measurement data. The smart heat meter uses the heat measurement data to optimize energy efficiency of heat supply using intelligent valve control (such as adjust the water flow rate according to the heat demand). The smart heat meter also can provide accurate heat billing to heat customers and heat suppliers, thus can improve the customer satisfaction and reduce the heat suppliers' cost for regular heat metering. The continuous remote heat measurement data can provide the information of heat networks' performance, hence can reduce the loss of water & energy due to leakage of pipes (leak detection). Other benefits that can be achieved through installation of smart heat meter are identification of faulty or misadjusted heat substations, monitoring temperature of water in the heat networks and modelling of buildings (such as monitoring the heat performance of buildings which information can be used to suggest the need for buildings' renovation) (Kamstrup, 2019).

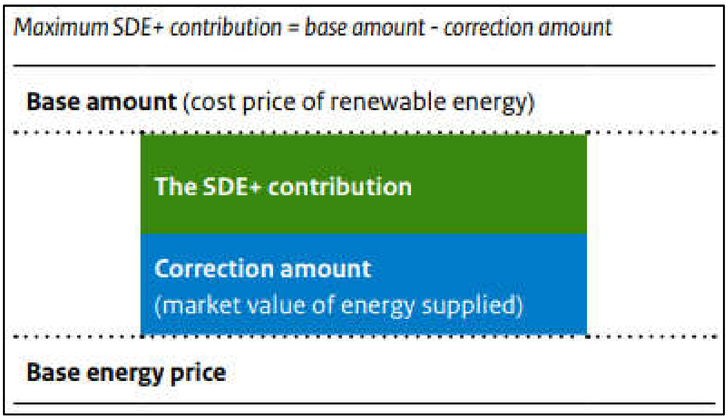


Example of remote heat measurement of smart heat meter (Kampstrup Analytics, 2019)

Appendix 2. National funding related to District Heating System

SDE+

The SDE+ (or Stimulering Duurzame Energieproductie in Dutch) is grant/subsidy from national government that is provided for renewable energy producers. This subsidy is used to cover the unprofitable component of renewable energy generation due to the higher cost of renewable energy production than the market price. The amount of subsidy payments is calculated every year based on the amount of energy produced and the actual energy price (Ministry of Economic Affairs and Climate Policy, 2019).



Calculation of maximum SDE+ contribution (Ministry of Economic Affairs and Climate Policy, 2019)

This subsidy is applicable for several heat production schemes: geothermal heat, solar thermal and renewable CHP. In order to qualify for the subsidy scheme, the geothermal heat needs to be produced from wells with depth at least 500 meters or at least 4000 meters. The geological survey and exploration permit of geothermal wells are the necessary documents to apply for the subsidy. For the solar thermal, it is necessary that the solar collectors to have thermal capacity > 140 kW in order to qualify as the subsidy recipient. The environmental permit of solar installation is then needed to be submitted for the subsidy application (Ministry of Economic Affairs and Climate Policy, 2019).

EIA

The EIA (or Energy Investment Allowance) is the government tax deduction scheme which is applicable for companies invest in energy-saving technology and sustainable energy (the tax deduction is 13.5% in average). Apart of deduction on depreciation, this scheme allows to deduct 45% of the investment cost for energy saving equipment from the taxable profit (Ministry of Economic Affairs and Climate Policy - EIA, 2019).

Example of a calculation

The taxable profit for 2019 is € 500,000. Corporation tax is 19% for the first tax bracket up to € 200,000 and 25% above € 200,000.

You make new energy investments amounting to € 300,000. The EIA is 45% of € 300,000, i.e. € 135,000.

Your taxable profit is now € 365,000 (€ 500,000 - € 135,000).

Without the EIA you would be liable for corporation tax of € 113,000. By making use of the EIA you pay corporation tax of only € 79,250. Your tax benefit is € 33,750.

The net EIA benefit is about 11% of the investment cost.

Example of tax deduction calculation (Ministry of Economic Affairs and Climate Policy - EIA, 2019)

There are some eligible heating technologies that can apply for the tax deduction scheme and support the development of district heating system (Ministry of Economic Affairs and Climate Policy - EIA, 2019):

- Insulation of commercial buildings, installation of heat pump, utilisation of waste heat, heat recovery system, installation of heat exchanger,
- Solar thermal collector system, geothermal heat, boiler with biomass
- Power to heat technologies, storage of sustainably produced heat & intelligent local energy network

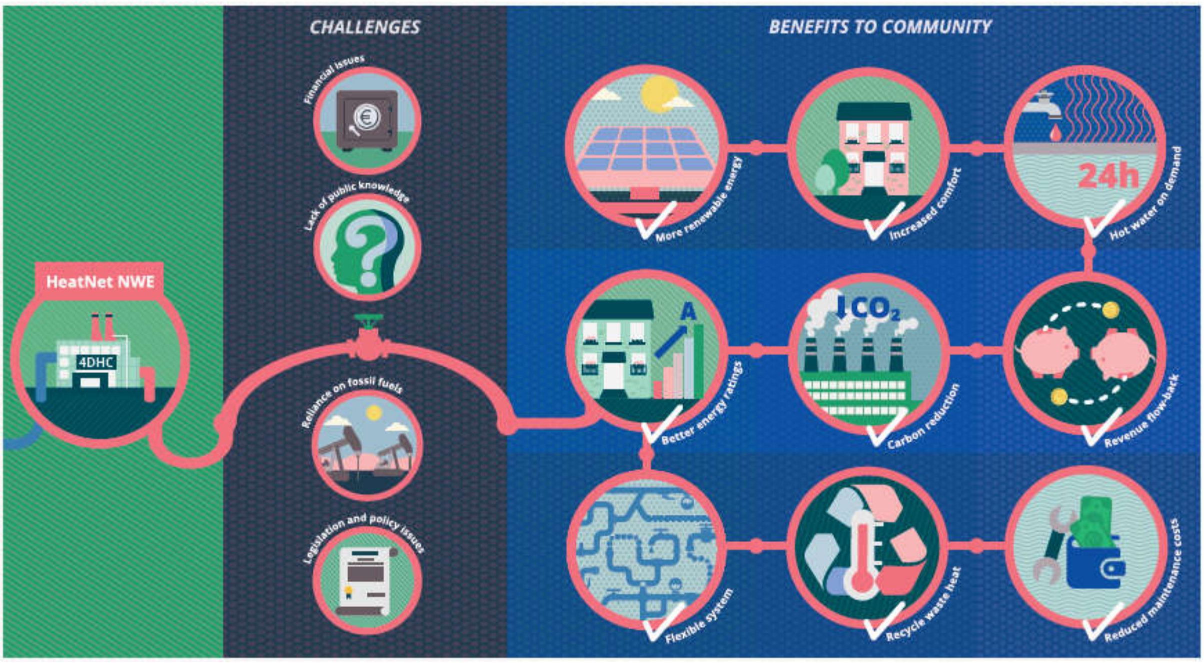
Appendix 3. European Union (EU) projects related to District Heating System

<u>HeatNet NWE</u>

The HeatNet NEW project address challenge of reducing CO2 emissions in North West Europe (NWE) by creating integrated transnational NWE approach to the supply of renewable & low carbon heat to residential & commercial buildings. The objective of this project is to introduce & demonstrate the 4th generation district heating & cooling (4DHC) in North West Europe. The main outputs of this project are (Interreg HeatNet NWE, 2019):

- A replicable model for implementation of 4DHC in North West Europe,
- Living labs to test & demonstrate the robustness of the model,
- Transitional roadmap plan to roll out technical, institutional & organizational arrangement in living labs
- Promotion & fostering of the model in North West Europe through transition roadmap to secure long-term impact of the project

To this date, this project has managed to formulate new guideline to enhance the development of district heating in North West Europe and formulate recommendations of policy that can foster DHC in European cities including the concept of remunicipalisation to support development of 4DHC (Interreg HeatNet NWE, 2019).

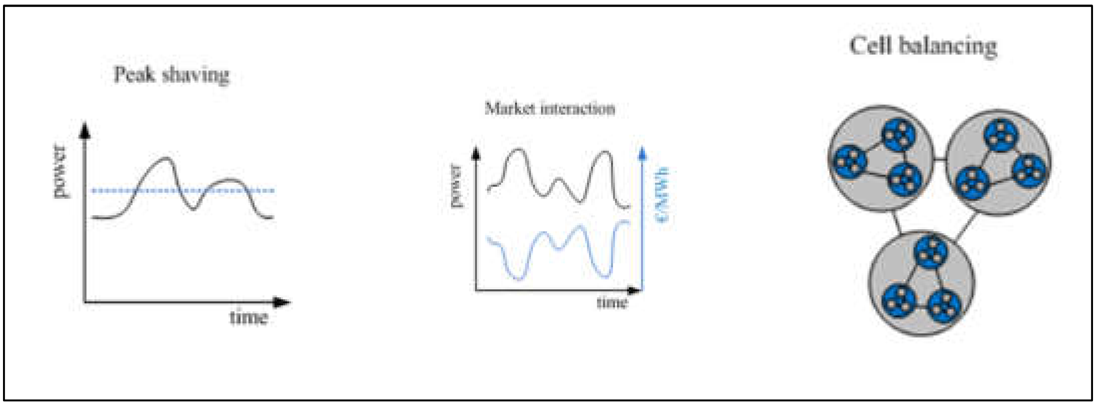


HeatNet NWE Project challenges & benefits (Interreg HeatNet NWE, 2019)

STORM (Self Organising Thermal Operation Resource Management)

The STORM-DHC Controller is EU-funded project (H2020 programme) which tackle energy efficiency at district level by developing innovative district heating & cooling (DHC) network controller. This project supports the research that can develop innovative controller for DHC networks, demonstration of benefits of smart control system (energy, economy & environmental benefits) and development of innovative business models for the large scale roll out of the controller (STORM objectives, 2019). 3 main modules of the STORM controller are the Energy Forecaster ("What will the energy consumption of the networks in the next 24 hours?"), Operational Optimisation Planner ("Which optimal cluster consumption profile can be achieved by taking into account the energy forecast?") and Demand Side Management Tracker ("Which individual control signals are necessary to follow the optimal consumption profile?") (STORM modules, 2019).

The controller has self-learning algorithm that can balance supply & demand in a cluster of heat/cold producers & customers, integration of multiple efficient generation sources (renewable energy, residual heat & storage) and implement 3 control strategies (peak shaving, market interaction & cell balancing). The peak shaving can be used to reduce the use of primary energy to meet the peak load demand (such as gas which is used for peak boilers). The market interaction enables the smart controller to deploy the heat pumps or CHP systems at interesting power prices. The cell balancing enables the supply & demand of heat & cold in a cluster to be optimally balanced in order to increase the energy efficiency (STORM controller, 2019).

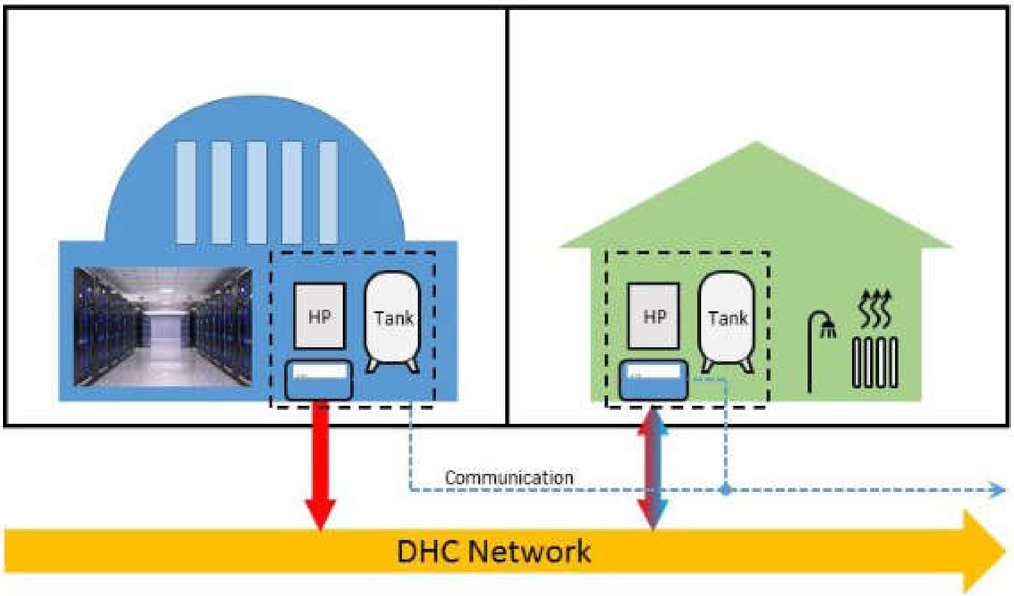


3 control strategies of the STORM smart controller (STORM controller, 2019)

Life4HeatRecovery

The Life4HeatRecovery project focuses on the reuse and recovery of residual heat from urban facilities which is available at low temperature (< 40 °C) in district heating networks. The residual heat can be acquired from thermal energy which is released by cooling systems in industrial process (such as dry cooler), chillers of refrigeration systems (such as chillers of data centre & refrigeration cabinets of supermarket) and services facilities (such as sewer pipes). The objectives of this project are reduction of primary energy use & greenhouse gas emissions, prevention of pollutants emitted from single boilers (gas) and reduction of heat accumulation in specific location due to released heat from human activities (life4heatrecovery, 2019).

The Life4HeatRecovery project supports the reuse of low temperature residual heat from multiple sources. If the temperature of residual heat is lower than required by heat networks, heat pump can be used to rise the residual heat temperature. Meanwhile, if the temperature of residual heat is higher than required by heat networks, the residual heat can be directly distributed to customers. In order to reuse the residual heat from multiple sources, this project supports development of smart thermal grid in 4GDH system. Using the capability of smart thermal grid, different temperature of multiple residual heat sources can be managed, thermal balance can be assured through energy systems integration & utilization of energy storage and heat exchange can be established between heat networks & buildings. Apart of that, this project also supports the elaboration of innovative financing mechanism based on public private partnership (life4heatrecovery, 2019).



Representation of heat exchange between heat networks & buildings (life4heatrecovery, 2019)

Appendix 4. Interview Summaries & Questioning Results

4.1 Interview & Questioning Result: Mijnwater BV (Herman Eijdems – Innovation Manager)

Interview Summary (Eijdems, 2019):

There are lots of obstacles experienced during implementation of DHC in Heerlen by Mijnwater related to financial, cooperation (such as obstacles between end users & Energy company due to mistrust of consumer), technical, economical and legal.

Obstacles related to financial issues:

- Building new infrastructure like a thermal grid needs large investments from financial institutes. Coming 5 years the implementation of the district heating project in Park Stad Limburg would cost about M€ 300. However, those financers (such as the big pension funds & banks) don't know the district heating system (hence don't know the business)
- The return on investment for DHC can generate money only starting after 3-5 years (as compared to investment in wind power which can generate money after ½ - 1 year). As consequence, investors need to wait a longer time to get interest on their investment. Most of the available fundings have a high interest on the loan/investment. That is killing the DHC business before it has even properly started.

Mijnwater Solution/ lesson learnt related to financial issues:

- Perform in very small steps to convince financial institutes and show results from every step. Mijnwater BV has 200,000 m2 of building connected to DHC already and as such can show good example that the DHC system works with a viable business case (established “living lab” in Heerlen)
- Acquire funding and loans (from government and EU) with interest close to 0%. This funding is taking out the startup risks and as such enabling the participation of investors for a larger amount.

  In the past, Mijnwater was owned by Heerlen municipality, however it was recently sold to province of Limburg (Limburg energy fund). This decision was needed to secure more investment to upscale the DHC system.

In the beginning of the Mijnwater project, a large funding was received and the municipality provided loans for 10 million. The Mijnwater system has grown to an asset value of 30 million in nearly 10 years (2008-2018). To fulfil the energy ambition of the region the DHC system must be upscaled in periods of 5 times 5 years having all buildings connected. A five year period requires an additional investment of 150 million. The idea is that Limburg Energy Fund might be able to invest 10-100 million, which means that additional (commercial) investors must be found to invest an additional 50-140 million.

<u>Obstacles related to social issues</u>:

- Bad reputation of District Heating (failures in the past)
- Dependency of customer on heat provider (monopoly) which cause customers' mistrust
- Limited experience of data privacy due to utilization of smart control system
- Some companies have confidential processes and they fear to share data

<u>Mijnwater solution / lesson learnt related to social issues</u>:

- Convince customers in slow process by starting installation of DHC for 400 households. The positive experience from these households are used for communication with other customers (for instance: interview the customers and publish customers' experiences in newspaper). Mijnwater also works with social housing companies for upscaling the DHC to cover additional 3000-4000 households. With good experience of existing households and social housing collaboration, Mijnwater then approach private house owners to convince them for installation of DHC
- Discuss the issue with the customers and make deal they can't refuse with them (such as the case with supermarket in which the supermarket becomes a heat producer and gets a payment/compensation). Consumers (prosumers), like supermarket and other organization (social housing) can be offered to get a share (ownership) of the DHC system to give them influence in the DHC provider. Actually, we see the reverse: the share has been sold back to Mijnwater (since these companies/organizations don't have advanced knowledge on this DHC system)
- Follow requirement of the companies (such as regulation from APC), implement proper data protection (ensure data are save) and establish system to protect them

<u>Organizations & their collaborations (along with their obstacles):</u>

Mijnwater was a pilot in the STORM-DHC project (Horizon2020 program). The aim was to build framework control for the DHC smart system. This framework controller implements self-learning and adaptive algorithms based on up to date software technology for energy equations. Good results are found for peak shaving, which can reduce costs substantially and also avoid fossil peak provisions (and as such save CO_2). Partners in the STORM-DHC project are Swedish company (NODA) and Belgium (VITO)

The upscaling of DHC means to transport more energy. This can be done either by instlling bigger pipes (or higher temperatures) or by increasing the number of load hours. If the grid is used for more hours high investments to increase the DHC grid capacity are avoided. In conventional DHC systems (without smart control) the grid peak capacity is only needed 1000 hours/year (for full capacity/peak loading). A doubling of investment is needed to serve the double area. With the existing infrastructure though, the additional capacity can be transported using it for 2000 hours/year. Strategis to do so are for instance manipulating the heating hours of buildings (shut them of for several hours, utilizing the thermal mass of the building) or adding buffers at building site. By using smart systems, better business case can be established (reduce the additional capacity that need to be added).

The collaboration between NODA and Mijnwater was only the first step. This step deploys cell-balancing, which enables 2 buildings to exchange heat & cold simultaneously without the necessity to supply energy from outside to these 2 buildings. Apart of cell-balancing, peak shaving is also implemented to enable usage of buildings as heat storage to reduce the peak loads. Timed-utilization is also implemented to reduce the heat demand (for example: heating in office can done for 2 hours earlier than 7 am and the heating is then turned off temporarily at 7 am to allow the heating of domestic hot water in households for shower purpose). In Heerlen these strategies are supported by the DHC system, operating at ultra low temperatures and decentral energy plants. The central provision is a large storage in the former mining galleries, which consists of 8 million m3 of mine water. IN the buildings additional buffers are installed like the Maankwartier which has a local storage of70 m3 (filled with exchange heat and operation of the heat pumps).

In future, the system can improve the control on several spatial levels (city, district & building levels) and can forecast energy flows to deliver energy more efficiently. In this partnership NODA acts as consultant/supplier of software and Mijnwater BV as buyer/operator.
The main components of the Mijnwater DHC system are: geothermal water from mine, heat exchanger, heat pump (operated using green electricity from electricity grid + electricity generated by PV). The third-party heat sources include surplus waste heat from industry, data centers, supermarkets and brewery. By connecting to DHC system, endconsumers can save 10% cost for energy. The supermarket and brewery acquire comfortable heating & cooling from Mijnwater as compensation for providing the waste heat to the DHC system.

An important third-party heat source is APG (data center). Mijnwater currently only provides cooling for APG, as such gaining 45 °C heat at the backside of the heat pumps. First this heat is used for heating demand of APG internally. The surplus is used for heating a nearby school building. Mijnwater is operating the energy plant at the APG site.

Another client (CBS) is also connected to the DHC grid, but operates their own internal heating & cooling system. CBS has problems because they are not very well equipped to optimize the operation of the plant. For instance, if heating & cooling are needed at the same time. CBS regards Mijnwater BV as an outsider, which they do not trust to operate their systems. Mijnwater is not yet allowed to offer an agreement for operating (as an ESCO) the CBS internal system. Often time is needed (a few years) to build more trust with CBS (and other clients) to allow Mijnwater to run their internal systems. CBS still utilize gas boiler for their heating system.

Most conventional energy companies are interested in selling more energy in order to increase their income. On the contrary, Mijnwater encourages customers to reduce energy consumption. This is due to the fact that the main costs are CAPEX (investments in infrastructure) and only a small part for buying fuels (OPEX). Moreover, the amount of available (green) energy is limited. In order to expand the number of connections to more customers (buildings) Mijnwater wants to sell as little energy as possible. This asks for a shift from variable tariff to fix fees. More connections will result in a better business model for the customers (more customers will reduce the fee for DHC connection since the same infrastructure can serve more customers without necessity to build new infrastructure which need more investment).

Conventional district heating system mostly only operate the central plants and grids. They have less/no knowledge on buildings. Mijnwater utilizes a demand-driven concept based on good knowledge of buildings. For example, the district heating in Utrecht & Amsterdam need to maintain high grid temperatures for the whole system which causes large heat losses (approximately up to 35%). The central system needs to adapt its conditions to the weakest spot in the city. By running decentral energy plants, Mijnwater only generates higher temperature for those buildings who need it (locally and at the time and as long as demanded) which substantially decreases the total heat losses (to about 5%).

Obstacle with regulation:

- Dutch heat law and building code are still based on the world of fossils (natural gas) which encourage the consumption of gas (gas is cheaper & better). This is considered as unlogical starting point to serve decarbonization and degassing of the society. New options as all-electric, solar, biomass and Geo/DHC should be compared to find the optimal solution for the future and not to the fossil past. Customers, who consider district heating as a more expensive system, will stick to fossils like natural gas for their heating.

Dutch government is currently reviewing the heat act. Mijnwater is also involved for providing advices to director general of internal affairs (ministry).

Mijnwater solution/ lesson learnt related to regulation:

- The regulation barriers can be eliminated with insight from EU for regulation adaptation (and also for acquiring understanding for the sustainable development roadmap)
- A local or regional "Heat plan" can be used to phase out gas and forcing customers to connect to district heating (ot they must proof to have a better solution than district heating). Unfortunately, a "heat plan" is yet not available in Heerlen ("heat plan" is still in progress to be formulated)

Other obstacle:

- Lack of understanding of the technology complexity (TU Delft university which has discussed about the technology with Mijnwater in order to acquire awareness of the technology, still has difficulty to explain the technology to industry & government related to the technology advantage & disadvantage)

Main obstacles to develop smart thermal grid & 4GDHC/5GDHC:

- No/ lack of knowledge from the end customers point of view: most energy companies only focus to prevent complaint from customers & if customers keep paying the energy bill; they are not highly interested in optimization on the grid (designs based on peak loads which need high investments); utilize (HT) heat sources and not (LT) multi-source (as done by Mijnwater)
- Need considerable new investments (financial support) which is not in the interest of existing energy companies (with high investment in conventional infrastructure) and political parties (through lobby of fossil fuel companies).

Questioning Result (Eijdems, 2019)

The conventional district heating system usually has limited number of heat producers and many heat consumers. But Mijnwater smart heating system can have many heat producers since heat consumers can be heat producers (prosumers) and renewable heat technology can also be integrated in the heating system.

1. Any criteria for heat producer to join this heating system?

   Answer: They need to connect to Mijnwater 5GDHC and close a contract for heating and cooling

2. Any criteria for heat consumer to join this heating system?
   Answer: Yes the buildings must be adapted to Low temperature heating (Tsupply < 50 dgC)

3. Any criteria for heat consumer to be heat prosumer?
   Answer: No, but typically Mijnwater will operate as an ESCO and organize the process

4. How the information of heat produced & consumed can be known by heat prosumer?
   Answer: This is done by Mijnwater framework control. Maybe in future based on block chain technology. We are applying for an Interreg project on that issue together with Brightland Smart Campus

5. How is the coordination between Mijnwater and buildings management to enable the connection & monitoring of this heating system?
   Answer: We discuss the opportunities with potential consumers and conclude the appointments in an agreement

6. Who is responsible for inside buildings system that need to be connected to this heating system?
   Answer: That depends on the type of contract. If needed we take full responsibility for output specs.

7. Who is responsible for monitoring heat consumed (and produced) inside buildings system?
   Answer: We measure the amount of heat delivered. Some contracts are based on needed heating and/or cooling (as much as you want) at fixed price per m2

8. What is the role of municipality in this smart heating system?
   Answer: Municipality needs to provide permits, founded and was former owner of the Mijnwater company. The energy ambition is formulated by the regional cooperation network and confirmed in the councils. The Municipality must set up a Heatplan in which forced connections and monopoly position are regulated.

As far as I know, the district heating in Netherlands is regulated by national government through Heat Act. The Heat Act requires heat producers to ensure security of heat energy supply. The Heat Act also set the tariff of heating system which cannot be more than the similar heat energy generated by natural gas (or known as NMDA in Dutch).

9. During development of Mijnwater smart heating system, is there any barriers due to this Heat Act regulation?

Answer: Not really, but in the ambition of phasing out natural gas the starting points of the law are outdated. There will be low densed area's to connect which cannot be done within the constraints of NMDA

10. Do Mijnwater heating system use the tariff scheme set by Heat Act?

    Answer: Yes (if applicable) but not for cooling and for commercial clients

11. If no, how is the tariff is set?

    Answer: 10 % less than conventional energy bill

12. If yes, is the tariff scheme causing any funding problem during the development & operation of this heating system?

    Answer: No, the investment space for connections however is limited (between € 15.000 and € 20.000 per dwelling)

13. Are the existing consumers (CBS, HHC, etc.) forced to be connected to this heating system by regulation or these consumers do it willingly?

    Answer: Nobody was forced, we made them an offer they couldn't refuse

14. Is there any other policy applicable for the development of this heating system?

    Answer: Yes, PALET regional energy transition plan

15. Is there any barrier from this other policy?

    Answer: No

16. Does policy from province or municipality support development of this heating system?

    Answer: Yes

17. Can you explain the cost structure for development of this heating system and its difference compared to conventional district heating system? (such as cost for hardware, smart system, licensing/permit, lease land, construction, drilling wells, etc.)

Answer: The difference with conventional is that we work demand driven. We discuss best building measures with the end consumer to get optimum between building and grid investments. Due to peak management, investments are 20 to 50 % below conventional design. In operation losses are < 5 % compared to 30-35 % in conventional systems.

18. During development of heating system, do the whole existing infrastructure need to be changed or some part of the infrastructure still can be used?
    Answer: For a transition strategy a large part of the conventional set up can be used as backbone and for peak demand, also utilizing cascading.

19. What is the funding or subside scheme applicable for the development of this heating system?
    Answer: We are supported by European (50%) and National (50%) programs, to overcome innovation and startup costs, in total now M€ 12, formally M€ 10-15

20. Did any funding problem happen during development of this heating system and what is the solution for the problem?
    Answer: The main problem is that DHC does not bring short term revenues. So, it needs investors who are served by long term profits. Problem is that the concept is not known to large investors.

21. Based on information from Mijnwater website, the similar heating system will be developed in Brunssum. What are the biggest challenges for the development of smart heating system in Brunssum as compared to Heerlen?
    Answer: In Brunssum there will be no Mijnwater reservoir (at least from the start), so we are even more dependent on 5GDHC principles.

The district heating development for some places in Netherlands face resistance from the local people. The local people concern about the less comfort of heating from district heating system as compared to heating from gas boiler. Some people concern about the cost of connection to the district heating system and tariff need to be paid.

22. Do you have any problems related to similar social acceptance during the development and operation of this smart heating system?
    Answer: Not too much, but we didn't approach individual owners yet
23. Is there any customer satisfaction survey that has been done to acquire information of customer satisfaction? If yes, how is the satisfaction rate?

Answer: I don't know

24. Is there any concern from local people during the construction phase (drilling geothermal well, laying down the pipe, etc.)?

    Answer: No not much, the resistance is more from political point of view.

4.2. Interview & Questioning Result: Ennatuurlijk

Interview Summary (Ennatuurlijk, 2019)

About their collaboration with FrieslandCampina (FC):

- FC consumes 13 mln m3 natural gas a year, to produce 1.2 mln GJ energy (which is their yearly energy demand)
- A collaboration on residual heat was initiated in 2017 (between Ennatuurlijk (Enn.) and FC), but was canceled at the last moment
- To use the residual heat for district heating from the steam produced by FC when burning natural gas. Potential: 1.6 MW energy in the form of smoke from the steam and gas turbine. This smoke is hot enough to heat up water to 90 degrees Celsius, when put in a heat exchanger. This potential is based only on the residual stream of steam generated by burning natural gas. The potential can be increased when residual heat streams from the production process are included
- Technical design for heat exchangers and infrastructure is completed by Enn. This connects a heat outlet of FC with the existing district heating network of Enn in the North of Leeuwarden, Cammingaburen
- The expectation is that the residual heat from FC can be used directly for the district heating network. No upgrading of the temperature is needed
- The residual heat stream, district heating water and household water are all hydraulically separated in different streams. This is needed to ensure the water quality in the network (treated with chemicals, demineralized and anaerobic, to make sure the water doesn't damage the piping infrastructure). This ensuring low maintenance of the infrastructure
- Financing will cost around 2.2 mln euros to build the infrastructure and will be paid by Enn. Ideally, the infrastructure is owned and managed by Enn (infrastructure from the heat outlet to the existing network) and FC makes sure all residual heat flows through a heat exchanger that is connected to the heat outlet. -> 600,000 eu for the heat exchanger, rest for infrastructure
- Project was declined in the last minute, because FC didn't want to commit to the project for more than 5 years, where Enn needed 15 years to build their business case. Also, the initial potential was estimated at 3.2 MW, which turned out to be half. Third, FC failed to guarantee some of

Enn's requests. This meant that there was too much risk involved for Enn, while FC would carry no risk and no financial obligations. This skewed distribution resulted in a stop of the project, before it even started

- Research on Deep Geothermal from FC, Enn again shows willingness to cooperate and use the residual heat from the Geothermal installation to use in the district heating system.
- FC and Enn did sign a letter of intent, but at the moment, no progress is made. Enn still wants to proceed, but FC is non-respondent at the moment (also because some of the responsible people retired in the last two years: Anne Zuidema and Geert Kooiker)
- Project did not include Enn paying FC for the heat.
- FC is also experimenting with pyrolysis oil as an alternative fuel. this is done in the Enschede/Zwolle area, together with a company called BTG.

About the existing heat network

- There are currently 2 district heating networks in Leeuwarden. Cammingaburen and Zuidlanden.
- Cammingaburen is a district heating network in the north of Leeuwarden. There is a natural gas fired cogeneration power station that provides warm water to 1500 households. Furthermore, an additional 200 houses are under reconstruction to be added to the the network.
- Zuidlanden is a network of 750 households. The district heat is fuelled by the biogas from the dairy campus.
- Besides these two networks, Enn also provides heat to a swimming pool and a gym.
- The water distributed in the network has a temperature of 75-85 degrees celsius (with a deviation of 25 degrees). The returned water has a residual temperature of around 40 degrees celsius.
- The average households consume 30-35 GJ energy from the district heating network
- All in all, there is around 4-5 km infrastructure of pipes in the network (this is a rough estimation, which does not correspond with the numbers in the table below). The pipes are made of steel, with a pure foam insulation and a PPE cover.
- When new houses are built, it is also possible to use low temperature residual heat (40-50 degrees). This is possible, because the design of the energy system can be adjusted (not possible for existing housing). These new built houses need an internal installation for upgrading the temperature in the water (also obliged because of legionella prevention).
- Enn's main collaboration partners and stakeholders are:
    - Municipality
    - Housing Corporations
    - Geothermal Consortium (Enn, Dijkstra Raisma, ECW)

- 'Smaller' partners/stakeholders are: the water board, provicial government, existing customers (both private and b2b)

__About Ennatuurlijk's plan with geothermal energy__

- Enn works on two potential geothermal projects.
- First, they are exploring the potential using cascaded residual geothermal heat, after FC used ultradeep geothermal energy for their industrial processes. The effects of this technology however are unknown. This plan is part of a national plan, lead by Dutch government. By the end of this year, nationally, 3 projects are chosen as pilot sites to test the possibilities of ultra deep geothermal energy. (Geothermie Leeuwarden 3)
- Second, Enn is planning to use geothermal energy from a potential well in the west of leeuwarden to heat the 750 houses in the existing southern heat network. this network will receive 80% of its heat from the geothermal source. Also, the Leeuwarden WTC and MCL will be connected to this heat network. (Geothermie Leeuwarden 2)
- Since all water streams are already hydraulically separated, adding a new separate geothermal fluid stream does not affect the current network substantially.
- Enn is planning to create a heat network through the whole city (red lines in the figure are the main infrastructure, from where heat is distributed to consumers). This plan will be executed in phases. First, from GL2 to the south will be realized. Then hopefully the line from GL3 to the energiecentrale Enn. After that, the other infrastructure will connect the current heat networks. Resources for this network are geothermal heat, biogas and residual heat from industry.

Bron	Leeuwarden 2 DIEPE GEOTHERMIE	Leeuwarden 3 ULTRADIEP GEOTHERMIE	Energiecentrale Camminghaburen/ Vrijheidswijk RESTWARMTE EN WKK
Initiatiefnemers	Bron: DD Geothermie, onderdeel van Bouwgroep Dijkstra Draisma Warmtenet en afzet: Ennatuurlijk	Bron: Friesland Campina Warmtenet en afzet: Ennatuurlijk	Ennatuurlijk
Diepte	2.500 meter	5.000 meter	
Vermogen	15 MW thermisch, 1 MW elektrisch	36 MW thermisch, 1 MW elektrisch	11 MW thermisch en 2 MW elektrisch
Levering warmte per jaar	200.000 GJ warmte en elektriciteit	900.000 GJ warmte en elektriciteit	62.000 GJ warmte en 11.000 MWh elektriciteit
Dit staat gelijk aan	8.000 huishoudens	36.000 huishoudens	2.000 huishoudens
Verwachte start levering	2019	2021	Bestaand
Lengte warmtenet totaal	7 kilometer	15 kilometer	12,5 kilometer
Investering	€ 35 miljoen	€ 85 miljoen	€ 17 miljoen

^^ Translation of the rows in column 1: Source, initiators, depth, power, heat generation per year, which equals #households, expected start of operation, total length of heat network, total investment costs.

__Questioning Result (Ennatuurlijk, 2019)__

Based on available information, there are 2 heating networks available in Leeuwarden: Camminghaburen and Zuidlanden. The heat in Camminghaburen is provided by natural gas cogeneration plant and the heat is distributed to 1500 households. The heat in Zuidlanden is provided by biogas cogeneration plant and the heat is distributed to 750 households.

1. Based on this information, below tables shows the stakeholders of both of these heating networks. Can you please help to fill in the missing information in the tables below (if no information available, please leave it blank)?

Camminghaburen:

Roles	**Stakeholders**	**Company name**
Natural gas provider	Gas company	-
Heat production	Cogeneration plant	Ennaturlijk
Heat distribution & supply	Heating networks	Ennatuurlijk
Heat consumption	Households	Housing corporation
Regulator	Municipality, provincial government	Leeuwarden municipality & Friesland government
Water provider	Water board	Vitens
Other roles??		

Zuidlanden:

Roles	**Stakeholders**	**Company name**
Biogas provider	Biogas company	Biogas Leeuwarden
Heat production	Cogeneration plant	Ennatuurlijk
Heat distribution & supply	Heating networks	Ennatuurlijk
Heat consumption	Households	Housing corporation
Regulator	Municipality, provincial government	Leeuwarden municipality & Friesland government
Water provider	Water board	Vitens
Other roles??		

2. During the development & operation of the heating networks, is there any problem between heat producer and heat distributor/supplier (such as less heat produced caused less heat supplied to consumer)? If yes, is there any solution provided?
   Answer: Yes, but in general its very stable and all systems are monitored from distance. Our service partner Veolia stands for solutions whenever a disruption is caused and will restore the heat delivery as soon as possible.

3. During the operation of the heating networks, is there any problem between heat distributor and consumer (such as faulty of heating networks caused no/less heat supplied to consumer or difficulty to cooperate with consumer)? If yes, is there any solution provided?
   Answer: Same as to answer 2.

4. During development & operation of the heating networks, is there any problem between heat distributor and regulator (such as difficulty to obtain permit for development & operation)? If yes, is there any solution provided?
   Answer: Sometimes it is difficult to obtain a permit from the municipality. But with good cooperation there is most of the time a solution available.

5. Is there any public resistance during the development & operation of heating networks (such as local people resistance on heating networks because of heat pricing or noise caused by construction of heating networks)? If yes, is there any solution provided?
   Answer: Most of the time not but there are projects for example geothermal that causes reactions. But we always get in contact with people and provide them with information so their concerns are withdrawn.

6. Is there any financial problem during development & operation of heating networks (such as lack of funding caused delay on construction or lack of heat demand caused long payback period for the heating networks)? If yes, is there any solution provided?
   Answer: Most of the time not. Sometimes there is a construction delay because of the economy. People buy less houses en the number of connections to the heating grid goes slower.

7. Is there any funding (subsidy or grant) provided by government during the development of heating networks (such as SDE+)? If yes, how much (percentage) of funding covered the total cost? If possible, can you please inform the total development cost of both heating networks in Leeuwarden?
   Answer: There is SDE+, EIA you can look on the site of RVO (government). It is not possible to inform you about the total costs of both heating networks.

8. There is regulation of district heating in Heat Act which set the maximum heat tariff cannot be higher than price of similar heat generated by individual gas boiler (NMDA). Is this regulation cause any problem during development & operation of heating networks (such as maximum heat tariff is very close to actual operation cost which cause long payback period for the heating networks)? If yes, is there any solution provided?
   Answer: Yes, there is much discussion about it because it delays the energy transitions. It's a matter of time. In the meantime the development is stimulated by the government by subsidies

9. What are the main obstacles to expand the heating networks in Leeuwarden (lack of heat producer, lack of funding, lack of heat demand, etc.)?
   Answer: To get all parties along including the local government and the housing corporations

10. Is Ennatuurlijk use smart ICT and/or smart meter for monitoring the heat production, heat distribution and/or heat demand? Is Ennatuurlijk use heat storage for heating networks in Leeuwarden?
    Answer: Yes all our production locations are “”smart” monitored and from a distance accessible. The heating grid and distribution is also monitored. In both we store heat in large buffer tanks to shave the peak in heat demand so less gas capacity is needed.

Additional Questioning Result (Ennatuurlijk, 2019)

I am currently researching the possibility to upgrade existing district heating in Leeuwarden from current district heating system to 4GDH (Fourth Generation District Heating) system. To explain better on the 4GDH system, there are 5 points that can be achieved in 4GDH system:

- Utilization of low temperature heat supply (< 70 degC) in heat networks,
- Utilization of non-fossil fuel for heat production (such as geothermal heat),
- Utilization of smart system to monitor heat production, heat distribution & heat consumption (using remote/wireless measurement)
- Enable prosumer system (example: supermarket get heat from heat network for space heating and supermarket also can sell heat from refrigerator back to heat network)
- Integration of heat system with other energy systems (electricity, gas)

For the research purpose, I still have some questions related to existing district heating (and upcoming geothermal district heating in Leeuwarden).

1. Does Ennatuurlijk has plan to develop the 4GDH system in Leeuwarden?
   If yes, can you please give information on which location (the existing heat networks in Camminghaburen or Zuidlanden or future geothermal heat networks)?
   If no, can you please inform the reason why the 4GDH system will not be developed in Leeuwarden (such as cost problem or other reason)?
   Answer: Yes. Actually we already developing it now. At the south part of Leeuwarden we are planning to drill for geothermal heath in 2020. As part of that plan our existing heating grid Zuidlanden will be connected to it in 2021. More information (in dutch) can be found on the location: https://warmtevanleeuwarden.nl/

2. I read one article related to 4GDH system and I found that Ennatuurlijk has plan to develop 4GDH system in Bilgaard. In this article, it is mentioned that geothermal heat will be used for district heating in Bilgaard. The information can be found in page 10 of following article: (https://projecten.topsectorenergie.nl/storage/app/uploads/public/5c4/1ad/223/5c41ad223cb0c766060240.pdf)
Can you please share information the update for this project plan? Is the geothermal district heating in Bilgaard is part of the upcoming geothermal district heating that will be developed in Leeuwarden?
Answer: Yes, it is part of that plan but not until phase 1 of the project is finalized. That will be not until 2023/2024.

3. Is it possible for Ennatuurlijk to utilize low temperature heat supply (< 70 degC) for heat networks in Leeuwarden?
If yes, what kind of technical improvement can be done (such as using better insulation on heat pipes or better insulation on buildings that will be connected to heat networks)?
If no, is it because most of buildings in Leeuwarden have no good insulation and heating system (such as underfloor heating or wall heating) or other reason?
Answer: Yes, especially with new buildings. We are planning to connect a big part of the new house building project "Middelsee" (3000 househelds) to the geothermal heating grid. We want to connect them to the return pipe (50 degC) of the heating grid.

4. I read one article related to smart system which is currently being tested by Ennatuurlijk in Eindhoven (https://www.energyville.be/en/news-events/ennatuurlijk-and-energyvillevito-launch-district-heating-network-smart-self-learning).
Is this smart system will be used for district heating in Leeuwarden in future (such as for future geothermal district heating)?
Answer: Maybe and I think parts (new insights) of it. As mentioned, it's a pilot project for smarter use of district heating grids.

5. During the connection of heat networks to buildings in Leeuwarden, is the buildings need to have specific insulation? Is there any coordination with housing corporation to do the buildings insulation before connected the buildings to heat networks?

Answer: No not necessarily although it is always better do decrease the demand for heath/energy.

6. Is there any consideration to purchase heat from customer(s) which produce extra heat (such as supermarket which produce heat from the refrigerator)?
   Answer: Yes, most important is the temperature of the (residual) heath being produced and the availability (certainty) of it.

7. For your previous answer related to main obstacles/risks of district heating development in Leeuwarden, you mentioned about the difficulty to "get all parties including local government and housing corporations". Can you please explain more on this? (such as difficulty to get permit from municipality? Or difficulty to cooperate with housing corporations to get permission for connection of heat networks or other things??)
   Answer: Permission is one thing but the corporations have to switch from gas to heath or electricity and this comparison have to be made every time to make decisions based on total cost of ownership. This is often a time-consuming process.

8. For your previous answer related to smart system implementation for district heating in Leeuwarden, you mentioned about the utilization of "smart system" to monitor heat production and heat distribution. Is there any monitoring on heat consumption too (such as using remote/wireless heat measurement)?
   Answer: Yes, for business to business connections (large consumers) there is real time on an hour basis monitoring on heat consumption. For smaller business to consumers there is only periodic monitoring.

4.3 Interview: Municipality of Leeuwarden (Bouwe de Boer – Energy Expert)

<u>Interview Summary (Boer, 2019)</u>

There are companies (operated in Leeuwarden) tried to use residual heat for their internal usage and also for residential heating, but the usage of residual heat is not done in big scale. Friesland Campina (the biggest company in Leeuwarden) has plan to use/sell residual heat for residential heating (Camminghaburen) and swimming pool heating (Kalverdijkje), but this plan has not been executed yet due to issue with long-term contract. For this plan, Friesland Campina worked together with Ennatuurlijk (heat networks provider) in which Ennatuurlijk did some investigations on how to utilize the residual heat and also communicated the plans to nearby housing companies.

Friesland Campina want to sell the residual heat, but does not want to sign long term contract (15 years) and only want to sign shorter term contract (5 years). The long-term contract is required by customers and heat network provider (Ennatuurlijk), but Friesland Campina cannot guarantee that their residual heat can meet the heating demand for long term. Friesland Campina recently has big problem with their business due to competition (3-4 years ago, Friesland Campina planned to build new factory to fulfil demand of milk powder from China (producing milk in bigger quantity and cheaper price) but this development has not been finished due to competition from local milk powder companies in China which affect Friesland Campina's production plan).

In other word, usage of residual heat requires good business case (price, volume of heat, contract, etc.) and will depend on many situations. Currently, there is no specific law or plan from municipality to force usage of residual heat. There is also no big problem at the moment that can force companies to use/sell the residual heat. And there is not common to use residual heat as heating source since there is not many big companies in Leeuwarden.

The municipality has contact with lot of companies in order to ensure that the environmental law is adhered properly. However, municipality does not always have control on the energy initiative done by the companies (especially companies which already have their own energy manager such as Koopmans). Municipality only has control for project that municipality participate (such as project related to energy saving on transportation sector or using residual heat from ice hall (from ice production process) for restaurant).

The responsibility on the inspection of environmental law's implementation is shared between province and municipality. The sharing of responsibility depends on the size of companies in which big companies (such as Friesland Campina) is inspected by province, meanwhile medium to small companies (such as Koopmans and Grain Plastics) is inspected by municipality. This environmental law force companies to implement initiative for CO_2 emission reduction if the payback period for the initiative is <= 5 years.

In the past, there was good inspection done for the lighting system in which companies were required to change the old lamps with LED lamps for energy saving purpose. However, the inspection on heating system was not done properly due to system complexity (such as drying system in Koopmans or extrusion system in Grain Plastics). The province and municipality sometimes didn't have competent energy specialist that can analyse the companies' production process comprehensively. There were reports produced in the past by energy specialist from municipality (for energy usage and payback period of energy initiative), however the analysis was only validated by municipality (and not by the companies). In near future (July 2019 onwards), the new law will require companies to perform analysis on their own system (together with municipality) and put the analysis result on the report. Due to recent climate change pressure, the government also put more effort to do better inspection and force companies to implement energy initiative if the payback period <= 5 years (such as installation of solar PV which can save 20-30% of energy usage).

Although there is no specific plan on energy in Leeuwarden, there is policy from 20 years ago which has energy as part of the policy. This policy is applied for medium and smaller size companies (MKB in Dutch). However, the implementation of this policy was not done properly due to improper inspection by municipality along with lack of willingness for companies to implement (companies can keep asking for implementation's delay such as delay for 2 years and can be extended for unlimited delay). The companies also tend to give reasons that they are busy with their own daily business and if additional measures need to be done for energy part, then the companies will require more financial support from municipality. In this case, local government (municipality) can only request financial support from national government (which has objectives on the energy national plan) but national government cannot give this financial support.

Municipality can have their own energy program which not following national plan. In 2021, municipality need to make their own energy plan (as required in RES – Regional Energy Strategy) which focus on 7 different sectors (industry, household, mobility, electricity, etc.). This energy plan is needed to achieve national target on CO2 emission reduction of 49% by 2030 and 100% in 2050. During implementation, municipality can either meet this target by their own effort, or bargain with other provinces to get help for achieving this target (such as first province only can achieve 38% instead of 49%, then the first province can collaborate with second province in which second province need to reduce CO2 emission by 60% and then the average CO2 emission reduction from these 2 provinces can meet the target).

Although municipality can have their own energy program, national government still has specific policy (with energy part) that apply to specific type of industry (such as for food industry). Last year, there was more year agreement (MJA in Dutch) which required food industry to reduce energy consumption by 30%. Apart of policy for industrial sector, there is also policy established for residential. This policy forced the new developed houses to have no gas installation and only served by electricity.

Apart of performing inspection of energy usage and developing energy program, municipality also has role to grant permission on piping underground for heating network development (such as permission granted to Ennatuurlijk). After granting the permission, municipality also need to develop agreement with heat network provider in order to protect customer from high price of heating. This is necessary since municipality has interest to focus more on people welfare, meanwhile heat network provider want to control everything (including pricing). This conflict of interest in the past had caused the case to be brought on trial and judge decided on the final arrangement. In future, it is recommended to have municipality controlling the heat networks to avoid any conflict of interest.

The challenges on using residual heat is not only due to long term contract, inspection problem and willingness of companies; but there is also challenges on the current gas price (gas price is cheaper if gas consumption is higher). As example: the single household need to pay 63 cent/m3 of gas, meanwhile greenhouse only need to pay 22 cent/m3. However, new (upcoming) law will impose tax for CO2 emission and will affect the gas price, hence this challenge can be overcome.

There are few schemes of financial support that can facilitate the usage of residual heat. One of the schemes is to find new working way (idea) that has good business case for using residual heat and this idea can be used to request for funding and help from municipality. Another scheme is tax advantage that companies can acquire through installation of energy instrument (such as companies which pay less for purchasing LED lamps).

From municipality point of view, heat from geothermal is more interesting and more logical to be applied in Leeuwarden than residual heat from industrial sector. Recently around 71 million euro subsidy (SDE+) has been prepared to develop this system (in order to qualify for this subsidy, companies need to start the development in 3 years from now and subsidy only granted if companies manage to produce heat from geothermal source).

Since there is lot of energy sources apart of geothermal and residual heat (such as solar park, wind farm, biogas, natural gas, hydrogen, energy storage), municipality also want to look for possibilities for using this energy sources. Although municipality want to focus on everything, municipality will try to look for business in which good business case will be prioritized. Apart of business case, municipality also need to consider on more situations (such as house condition whether it is insulated or not in which well insulated house can use electricity only as energy source; price of electricity and heat, etc.).

<u>Illustration of the diversity of energy sources along with their challenges/problems in Leeuwarden</u>: Dairy campus started to supply biogas to residential area (1000 houses) 8 years ago and there is nearby residential area (with 2000 houses built) that need to be supplied. Due to bad experience of biogas usage (including expensive connection to system due to monopoly and people are frustrated due to heating system which only rely on one source), this new residential area prefers to rely on electricity (which supplied by wind farm and solar park). At the same time, Ennatuurlijk also developed geothermal and want to sell heat to another developed residential area (2400 houses) and there is competition between electricity and heating from geothermal.

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