Datacenters as residual heat source for district heating in residential neighbourhoods of Amsterdam

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PREFACE

Dear reader,

This report is the end product of the MSc program Metropolitan Analysis, Design and Engineering at the AMS Institute. The research and report of this thesis concludes my graduation year and I have had a great joy on developing the proposal, execute the research and completing this thesis report. The execution of the research of this has brought me great insights and expertise in district heating due to the interesting interviews with diverse actors from district heating.

I have had the pleasure to fulfil this thesis report with the supervision and help of many valuable persons. First of all, I would like to thank my supervisors from the TU Delft Gijsbert Korevaar and Michiel Fremouw for your time and expertise. Gijsbert, as my first supervisor the regular meetings we had were extremely valuable for me since you offered expertise, insights, guidance and feedback through the thesis process. Your supervision has contributed to the overall consistency and social perspective of this thesis: the institutional feasibility. Michiel, as my second supervisor you have offered me extensive insights on the technical aspects of district heating, specifically on the heat demand for district heating. Your supervision has contributed to the technical perspective of this thesis, specifically the technical feasibility.

Secondly, I would like to thank my supervisors of Accenture Daan van Hameren and Jip Tombrink since I had the pleasure to fulfil my thesis research as internship. Daan, I appreciated your input from your experience in district heating since you have helped me advance my research by helping me get in contact with most actors that I have interviewed and given input from your professional experiences. Jip, I appreciated your input and feedback on the overall process and content of my thesis report.

Last, but certainly not least, I want to thank my family and close friends that have supported me during the process of the execution and writing of my research. You have been a wonderful positive distraction during the evenings and weekends from my full-time dedication to the development of this thesis report.

Marjolein ten Haaft, May 2019

EXECUTIVE SUMMARY

District heating is considered as an alternative heating system for the natural gas heating systems for households. The ability to heat and supply hot water to buildings of households is essential in cities and the transition to an alternative is necessary due to the depletion of fossil fuels and limits on carbon dioxide per country and cities since the Paris Climate Agreement. Fundamental in district heating is the conscious choice for the usage of local heat resources that would otherwise be wasted.

Datacenters are chosen as local heat source to investigate as heat supplying source for district heating due to their constant production of residual heat, which is a result of the operation of the data servers. Datacenters are considered as a sustainable heat source for district heating when the electricity use of the DC is supplied from renewable energy sources.

The relevance of this research on residual heat supply from datacenters for district heating for residential neighbourhoods is based on:

- Amount of heat supply from datacenters for a district heating operator to secure heat supply from the district heating to residential neighbourhoods.
- Datacenters are not necessarily integrated in the energy sector, which will imply a new role and responsibilities for the datacenter operators and for the actors already integrated in district heating.

This has led to the following main research question:

To what extent can heat residual heat from datacenters be integrated in district heating in terms of technical and institutional feasibility and does a framework for institutional mapping contribute to finding the institutional feasibility?

The first part of the research question focuses on finding the extent of residual heat supply from datacenters and the feasibility of district heating systems and the involved actors that encompasses the integration of datacenters with district heating. The second part of the research question focuses on the effectiveness the application of a institutional mapping methodology to assess the institutional feasibility.

The city of Amsterdam is used as case for this research since a high amount of datacenters and are present in Amsterdam. Besides the datacenters, the actors that are involved with district heating are also included in this research. Six actor groups were considered: datacenters, retailers and utility companies, technical consultancy and manufacturers for district heating, municipalities, grid operators, law and policy makers.

EXTENT OF RESIDUAL HEAT SUPPLY FROM DATACENTERS FOR DISTRICT HEATING

The extent of residual heat supply from the 28 considered datacenters in Amsterdam is estimated to be 1,42 PJ. The residential heat demand from the neighbourhoods in Amsterdam is estimated to be 27,04 PJ. As result, and in combination with a CBS validation, the residual heat supply from datacenters for the residential neighbourhoods in Amsterdam is estimated to be between 5.3% and 9.1%.

INFLUENCE OF SOCIAL AND SPATIAL VARIABLES ON DISTRICT HEATING

The social and spatial variables that influence the development of a district heating system are divided into three main variables and translated into a model for the development of the system configurations.

- Biophysical conditions
  Physical composition of the district heating system consisting of four subsystems that are supported by various technical components. The estimated extent of residual heat supply from datacenters for district heating of Amsterdam is taken into account.

- Community of Attributes
  One or more actors are responsible for one of the four subsystems from the biophysical conditions, who jointly share a vision of the heat network and an opinion on the laws and regulations that apply for district heating and cooperation between the actors.
- Rules in Use
  The rules that apply to district heating are divided into three subgroups:
  - Constitutional-choice: national legislation and regional and local regulations.
  - Collective: binding partnerships through contracts between the actors of the subsystems.
  - Operational: effect of laws and regulations and contracts on responsibilities for the actor of the subsystem.

CONFIGURATIONS OF DISTRICT HEATING SYSTEMS WITH DATACENTERS

Three system configurations are developed based on a literature review and interviews with the actors from the considered six actor groups. See figure for an overview of the three developed system configurations.

System configuration 'Contemporary situation'

System configuration 'Contemporary situation' corresponds to the current district heating system of Amsterdam with a retailer that is the district heating operator and retailer of the heat where the current and succeeding Heat Act allows the retailer to be active in multiple subsystems of the district heating system.

System configuration 'Open district heating and independent management of infrastructure'

System configuration 'Open district heating and independent management of infrastructure' demonstrates an open district heating and independent management of the infrastructure of the district heating system where the succeeding Heat Act has most impact by allowing only a municipal heat company or grid operator as eligible district heating operator. Additionally, to the second system configuration, multiple retailers are present for the sale of heat to consumers where a market model will be required for.

System configuration 'Experimentation of various district heating systems'

System configuration 'Experimentation of various district heating systems' demonstrates various district heating systems that are allowed to experiment with in ranges of temperature, actors eligible per subsystem and technical components, which is supported by the succeeding Heat Act.

Figure: Overview of three system configurations of district heating with datacenters.

FEASIBILITY OF THE INSTITUTIONAL SYSTEM OF DISTRICT HEATING

A comparison of the three system configurations revealed that they are distinctive in the constitutional-choice rules, in particular the succeeding Heat Act, that enables which actors are eligible to be responsible per subsystem or the option for one or more actors per subsystem. System configuration 'Experimentation of various district heating systems' enlarges the uncertainty that the succeeding Heat Act could give for all interested actors in a district heating system with DC as heat supplying source. In contrast, system configuration 'Open district heating and independent management of infrastructure' minimizes uncertainty and gives certainty by including eligible actors per subsystem in the succeeding Heat Act. System configuration 'Contemporary situation' Furthermore, the heat plans could be used by the municipality to experiment with the system configurations and demonstrate their vision. Through experimentation and demonstration of district heating systems they could give advice to the development of the succeeding Heat Act.

AFFECT OF OR EFFECT ON ACTORS OF DISTRICT HEATING WITH DATACENTERS

Five key components and the options that define distinctively the system configurations are selected and the analysed in terms of their influence on the considered actors. They either can be affected by actors or have effect on the actors from the six actor groups that were considered. An overview is provided in the figure below. The actors that have most influence in affecting the components and their options in the development of new district heating systems or transformation of existing district heating systems are the social actors: law and policy makers and municipalities. The actors that the system configurations have effect on by the effect of the components and their options in the development of new district heating systems or transformation of existing district heating systems are the market and technical actors: DC, grid operators, retailers and utility companies and technical consultancy and manufacturer companies of district heating.

Component	Option	Datacenters	Retailers and utility companies	Technical consultancy and manu-facturеres	Municipalities	Grid operators	Law and policy makers
Supply temperature	High-temperature	Effect	Effect and/or affect	Effect	Affect	Effect	Affect
	Mid- and low temperature		Effect and/or affect			Effect	
Number of heat sources in district heating system	DC and other heat sources	Effect	Affect	Effect	Effect	Effect	Affect
	One DC		Affect	Effect		Effect	Affect
District heating operator	Retailer	Effect	Effect	Effect	Effect	Effect	Affect
	Municipal heat company	Effect	Effect		Effect	Effect	
	Grid operator	Effect	Effect		Effect	Effect	
Sale of heat	One retailer	Effect	Effect	Effect	Effect	Effect	Affect
	Multiple retailers	Effect	Effect	Effect	Effect	Effect	Affect
Succeeding Heat Act	Monopoly situation for market actors	Effect	Effect	Effect	Effect	Effect	Affect
	Social actors in charge of infrastructure	Effect	Effect		Effect	Effect	Affect
	Heat plans are supported	Effect	Effect	Effect	Affect	Effect	Affect

Figure: Overview of key characteristic components and affect of or effect on actors.

The results are determined by the approach of this research that based on four steps:

1. Extent of residual heat supply of datacenters in Amsterdam for residential neighbourhoods of Amsterdam.
2. The social and spatial variables determining system configurations of district heating.
3. Development of system configurations of district heating where datacenters are included as heat supplying source.
4. Assessment of the feasibility of the institutional system of district heating through the comparison of the system configurations and the affect of or effect on the considered actors.

To achieve a full understanding of the results and the research methods applied to achieve the results this graduation thesis can be viewed on https://repository.tudelft.nl/.

ABBREVIATIONS

ACM	–	Authority for Consumers and Markets
DC	–	Datacenters
DDA	–	Dutch Data Center Association
DHW	–	Domestic Hot Water
GIS	–	Geographical Information Systems
HT	–	High temperature district heating
IADF	–	Institutional Analysis Development Framework
LT	–	Low temperature district heating
MT	–	Mid temperature district heating
PBL	–	PBL Netherlands Environmental Assessment Agency
SH	–	Space Heating
WPW	–	Westpoortwarmte bv.

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1 INTRODUCTION

For many cities the ability to heat and supply hot water to buildings of households is essential. Today, this is an emerging challenge in cities because building spaces and domestic water of households are heated by on site boilers using natural gas. An alternative for natural gas for heating of households is necessary because of the depletion of fossil fuels, including natural gas, and limits on emissions of carbon dioxide that apply for each country since the Paris Climate Agreement. The Netherlands will have to reduce its emissions of carbon dioxide with 40-50% by 2030 and with 85-95% by 2050 to limit global warming with 2 degree Celsius in 2050 (Vuuren, Boot, Ros, Hof, & Elzen, 2016). This goal results in further specified goals per sector, including the residential sector, to reduce emissions of carbon dioxide that the sector is responsible for. The households of the Dutch residential sector are responsible for 10% of the total emitted carbon dioxide of the Netherlands in 2017 (CBS, 2017a). Together with the fact that fossil fuels will deplete, households will have to transform their current heating system based on natural gas into a sustainable heating system. Therefore, municipalities of Dutch cities are obliged to have established a heat plan in 2021 for the districts of their city that includes a planning for the transformation of the heating system based on natural gas into a heating system based on an alternative energy heat source (Ollongren, Wiebes, & Van Zanen, 2018).

One of the solutions for a sustainable heating system for districts in cities is district heating. District heating encompasses a network of pipes containing heated water from centralised heat sources or several distributed heat sources (Lund et al., 2014). This network can connect buildings of neighbourhoods, districts or a whole city to supply their heat demand for space heating (SH) and domestic hot water (DHW). Fundamental in district heating is the conscious choice for the usage of local heat resources that would otherwise be wasted (Werner, 2013). As a result, more sustainable heat sources can be chosen to integrate as heat supply sources in a district heating network. Therefore, district heating provides a substitution of the natural gas as primary energy supply source for residential heat demands, while achieving a lower environmental impact in terms of carbon dioxide emissions (Werner, 2017). Since the fundamental idea of district heating is to use local heat resources that would otherwise be wasted, five suitable strategic energy resources exist for heat generation in the district heating process. The five suitable strategic local energy resources are: heat from thermal power stations, heat obtained from waste incineration, heat from industrial processes, geothermal heat sources and biomass (Werner, 2013).

The five local energy sources serve as heat sources due to their operations that take place within or around cities that can serve as input for district heating. This corresponds to the theory of Urban Symbiosis, where the use of by-products from operations in cities or urban areas is seen as an opportunity to serve as an alternative raw material for potential users in geographic proximity (Chertow, 2000). As a result, the operations of the five local energy sources become related to the process of district heating in the exchange of heat. The exchange according to Chertow (2000) takes place in mutually beneficial manner in terms of economic and environmental benefits. Therefore, the choice for one or multiple of the five local energy sources and their heat output that otherwise would be wasted is very important in achieving a sustainable residential heating system.

A potential heat source from industrial processes for district heating are datacenters (DC). DC can be considered as a sustainable heat source for district heating when the electricity use of the DC is supplied from renewable energy sources where residual heat is the result of the DC industrial process. The district heating network operator and DC operator can benefit each other in the utilization of residual heat from DC for district heating (Wahlroos, Pärssinen, Manner, & Syri, 2017; Wahlroos, Pärssinen, Rinne, Syri, & Manner, 2018). A major benefit for district heating operators is that DC are a reliable local heat source because of the continuous output of residual heat that is equally spread across each hour of the day. Major benefits for a DC operator are the improvement of the energy efficiency as residual heat is a by-product of the operation of a DC that can be managed by the use in district heating and the use of the returned water of district heating for cooling of DC. However, the companies that own DC typically do not act in the energy sector and lack the know-how on residual heat utilization and the associated technical opportunities and business models (Wahlroos et al., 2018). When DC would integrate as a new heat source in district heating, this not only entails technological changes for district heating but also substantial changes in the existing organisations and the institutional system they operate in (Ajah, Patil, Herder, & Grievink, 2007; Lund et al., 2014).

1.1 Case study Amsterdam

The city of Amsterdam includes a total of 467.606 households and aims to no longer make use of natural gas in 2040 (CBS, 2018; Municipality of Amsterdam, 2016). The municipality of Amsterdam has therefore set the goal to connect 230.000 households with district heating in 2040 in order to transform the current residential heating system based on natural gas (Municipality of Amsterdam, 2016).

A district heating network already exists in Amsterdam that supplies households with heated water from two centralised heat sources. The two heat sources that are currently used are from a power plant located in the east of Amsterdam and a waste incineration plant located in the west of Amsterdam (NUON, n.d.). The district heating system in Amsterdam is owned by Westpoortwarmte bv. (WPW) and is established and in ownership of energy supplier NUON and heat producer AEB. WPW has the natural monopoly in sale of heat and operating of the district heating system in Amsterdam.

The city of Amsterdam forms the digital gateway to Europe with the AMS-IX internet exchange point, which is one of the biggest internet exchange points of the world. As a result, the Metropolitan Region of Amsterdam forms the Dutch datahub with DC located in Science Park, Amsterdam South-East, Schiphol & Amsterdam West (Dutch Data Center Association, n.d.). The Dutch Data Center Association (DDA), representing the Dutch DC, recognizes the extensive output of residual heat and, to accelerate the transformation of the Dutch residential heating system, offered the residual heat from DC as heat source for district heating without demanding for financial benefits for DC. Moreover, in light of the usage of sustainable heat sources for district heating the DDA claims that over 80% of the Dutch DC are powered by renewable energy (Dutch Data Center Association, 2018).

1.2 Research objective

The transformation of the residential heating system of Amsterdam into a sustainable heating system that no longer makes use of natural gas in 2050, of which 230.000 households will be heated with district heating, demands an exploration of sustainable local heat sources to use for district heating in Amsterdam. This aligns with the fundamentals of Urban Symbiosis and district heating where the conscious choice is made for the use of local heat sources and their by-products to serve as heat input for the district heating system when the heat source is in geographic proximity. Since a high amount of DC and production of residual heat output are present in Amsterdam, which are recommended as suitable heat sources for district heating but not yet investigated, the use of DC as sustainable local heat source is chosen in this thesis to explore as supplying heat source for district heating to fulfil the heat demand of residential neighbourhoods in Amsterdam.

Two aspects define the focus of this research upon when DC are considered for the supply of heat for district heating. First, the amount of heat supply from DC is important for a district heating operator to secure heat supply from the district heating to residential neighbourhoods. The investigation of the technical feasibility of DC as heat source for district heating is therefore vital in the addition of new and more sustainable local heat sources to a district heating network. Secondly, DC are not necessarily integrated in the energy sector and therefore the integration of DC as new heat supplying actor in a district heating system implies a new role and responsibilities for the supplying DC actors and for the actors already integrated in the district heating institutional system to cooperate with. The investigation on the realization of an institutional system of district heating where DC as supplying heat source are integrated would be even more significant, compared to the technical feasibility, as this will cause substantial changes and requirements from DC operators and the current actors operating in the district heating system of Amsterdam.

The overall research objective is based on the two aspects of the problem definition. The research will search via a socio-technical perspective the technical feasibility of DC as heat source for district heating networks by estimating the extent of residual heat supply from the DC for residential neighbourhoods of Amsterdam. Furthermore, this thesis will search the social feasibility of the current institutional system of district heating with the addition of DC as heat supplying actor by mapping this as system configurations, since DC are not integrated yet in the district heating energy sector as heat supplying actor. The findings of this thesis will generate an insight of the elements of the current institutional system of district heating that facilitate or form a barrier for the integration of DC as heat supplying actor, while taking into consideration the technical feasibility of heat supply from DC for district heating. The research objective of this thesis therefore is:

Derive insight in the technical and social feasibility of a district heating network for the residential sector with DC as heat supplying actor, based on the estimated extent of residual heat supply for demand of district heating and the mapped configurations of institutional systems of district heating with DC for the case of Amsterdam.

1.3 SCOPE OF THESIS

To execute a concrete investigation for this thesis four boundaries are set up to create a clear research scope.

- District heating
- Residential sector
- Datacenters as local heat source
- Geographic area of Amsterdam

This thesis aims to investigate district heating, since this is a major solution for the heating system in the transformation towards a sustainable heating system. Specifically, the focus will be on the application of district heating for the residential sector as one of the major contributors to CO2 emissions with the current heating system. Next to this, various local heat sources can be considered in the setup of a new district heating network or as additional heat source for an existing district heating network. Due to the emerged recommendation of DC as heat source for district heating, this will limit the investigation of this thesis to DC as local heat source for district heating. The geographical scope will be limited to the case of Amsterdam in the investigation of DC as local heat source of district heating for the residential sector.

Out of scope:

- Technical applicability of residential neighbourhoods in Amsterdam to supply heat with district heating, use of results of research on district heating in Amsterdam.
- Share of renewable energy used for DC in Amsterdam.

1.4 RESEARCH QUESTIONS

A socio-technical perspective will be used in this thesis. On the one hand this thesis will investigate the technical feasibility of residual heat supply from DC as local heat sources for district heating. On the other hand, this thesis will investigate the actions and decisions that are required to be taken from the institutional system of district heating when DC are considered as new heat supplying actor. Therefore, the following main research question is formulated:

To what extent can heat residual heat *from datacenters be integrated in district heating in terms of technical and institutional feasibility and does a framework for institutional mapping contribute to finding the institutional feasibility?*

In order to answer the main research question the following elements are required to obtain:

- Estimation of residual heat supply from DC with the demand of neighbourhoods of Amsterdam for district heating
- Mapping of system configurations of district heating systems where DC are integrated as heat source
- Alternative courses of actions and decisions by the institutional system based on the system configurations of district heating where DC are integrated as heat source

To obtain the abovementioned elements, four sub research questions are developed:

1. *What is the extent of residual heat supply of datacenters for district heating for residential neighbourhoods in Amsterdam?*
2. *What are the spatial and social variables that influence the district heating system?*
3. *What district heating system configurations where DC are integrated as heat source of spatial and social variables influences the decisions and actions of the actors?*
4. *What is the feasibility of the district heating system when influenced by the system configurations where datacenters are taken into account as heat supplying source in Amsterdam?*

1.5 SCIENTIFIC RELEVANCE

In literature, most studies on DC and energy efficiency are related to efficient cooling systems, electricity consumption and usage of renewable electricity by either locally produced or bought from a renewable energy provider (Davies, Maidment, & Tozer, 2016; Ebrahimi, Jones, & Fleischer, 2014; Wahlroos et al., 2017). Wahlroos et al., 2018 recommends creating a sense of urgency by developing possible future scenarios, as part of the change process, on how to include DC in district heating networks and stresses the importance of a transparent process when DC are taken into consideration for district heating.

Almost no research has been executed on the investigation of the use of residual heat for another process such as district heating by mapping the heat supply and demand geographically and use this in mapping of the institutional system to explore the feasibility of the current institutions in place for district heating. The research of this thesis contributes therefore to the combination of the technical and institutional feasibility and the application of the corresponding research methodologies for geographic and institutional mapping.

2 THEORETICAL FRAMEWORK

2.1 RESIDENTIAL HEAT CONSUMPTION

In the residential sector the energy that is consumed by households supports the living standards of the occupants of the household. The heat consumption for the end use groups in the residential sector is produced by the dominant use of on-site boilers that use fossil fuels (Connolly et al., 2014). Three end use groups exist for the consumed energy of a household of which two relate to the heat consumption of a household (Swan & Ugursal, 2009). For the residential sector the two end-use groups for heating are:

- Space heating — heating of the living space with radiators or floor heating to maintain a comfortable temperature of the living space
- Domestic hot water — supply of water to an appropriate temperature for the occupant to use for various needs such as shower water, cooking and other household applications that demand hot water.

2.2 RESIDUAL HEAT

The supply of heat for district heating originates from heat sources that can supply heat due to their production of heat via industrial processes, thermal power stations, waste incineration, geothermal heat sources and biomass (Werner, 2013). A definition is required to define the heat of DC from industrial processes to use as term in this research. The term that is simply used in most literature on the use of heat from DC for district heating is “waste heat” (Ajah et al., 2007; Davies et al., 2016; Ebrahimi et al., 2014; Wahlroos et al., 2017, 2018). However, the heat of DC originates from the industrial process of data processing, data storage systems and digital telecommunications. This process has as result that the technology that is currently used in DC releases heat in order to operate for data processing, storage and digital communications. Therefore, the definition used in this research for heat of DC will be defined in relation to an industrial process. Bendig, Maréchal, & Favrat (2013) used heat cascading of the heat above ambient temperature and based on this have defined the heat that is released by a process as either avoidable and residual heat that is unavoidable. The business of a DC depends on the operation of the contemporary existing technology of data servers which makes the heat that is produced due to the operation unavoidable and can be defined as residual heat. This aligns with the characteristic of residual heat that it is the unavoidable amount of heat that a process should produce. In addition, residual heat is characterized as heat that can be used for any purpose without affecting the energy bill of the process (Bendig et al., 2013).

2.3 INSTITUTIONS

Institutions are the prescriptions that humans use to organize all forms of repetitive and structured interactions including those within families, neighbourhoods, markets, firms, sports leagues, churches, private associations, and governments at all scales. Individuals interacting within rule-structured situations face choices regarding the actions and strategies they take, leading to consequences for themselves and for others (Crawford & Ostrom, 2005).

2.4 DISTRICT HEATING

District heating are divided into four generations of district heating systems (Lund et al., 2014; Werner, 2013). District heating was introduced in 1880s in North American cities and the primary motivation for the introduction of the first generation of district heating system was to replace individual boilers to reduce the risk of boiler explosions and to increase comfort. Components of the first generation of district heating systems were pipes with steam as heat carrier with as fuel source steam coal. As this district heating system generation was characterized by substantial heat losses and severe accidents from steam explosions due to the high steam pressures a new district heating system generation was introduced. The second generation emerged in the

1930s until the 1970s with pipes with pressurised hot water as heat carrier with supply temperatures over 100 degree Celsius. The third generation of district heating systems were introduced in the 1970s and used also pressurised water as heat carrier, although the supply temperatures are often below 100 degree Celsius. This district heating system replaced all existing district heating systems and was used in extensions and new district heating systems. Two trends can be identified in these three generations of district heating systems (Lund et al., 2014). First, the primary motivation of the introduction of these district heating systems is the security of heat supply by the replacement of oil. Secondly, the heat supply temperatures become lower with the introduction of each generation of district heating system.

Lund et al. (2014) have developed a concept of the fourth generation of district heating system that should follow up the previous generations and include current challenges in the development of district heating technologies and a sustainable district heating system. The five capabilities that the fourth generation of district heating system should entail are:

- Ability to supply low-temperature district heating for space heating and domestic hot water to existing buildings, energy-renovated existing buildings and new low-energy buildings.
- Ability to distribute heat in networks with low grid losses.
- Ability to recycle heat from low-temperature sources and integrate renewable heat sources such as solar and geothermal heat.
- Ability to be an integrated part of smart energy systems (i.e. integrated smart electricity, gas, fluid and thermal grids) including being an integrated part of 4th Generation District Cooling systems.
- Ability to ensure suitable planning, cost and motivation structures in relation to the operation as well as to strategic investments related to the transformation into future sustainable energy systems.

2.4.1 Technical design and components

The technical design and components of a district heating system can be divided into three main process steps: from heat generation to heat distribution to consumption within the residential sector (Schmidt, 2018). The obtained heat from a local energy resource will be distributed via an underground distribution network of pipes. Hereafter, the heat is transferred from the network to the distribution systems of the two end-use groups, space heating and domestic hot water, that are located within the building of the household.

The temperatures for district heating vary and this results in solutions for DHW to secure thermal disinfection. Substations can be used along the district heating network or in households to secure the temperature to 60 degrees to prevent legionella (Brand & Svendsen, 2013).

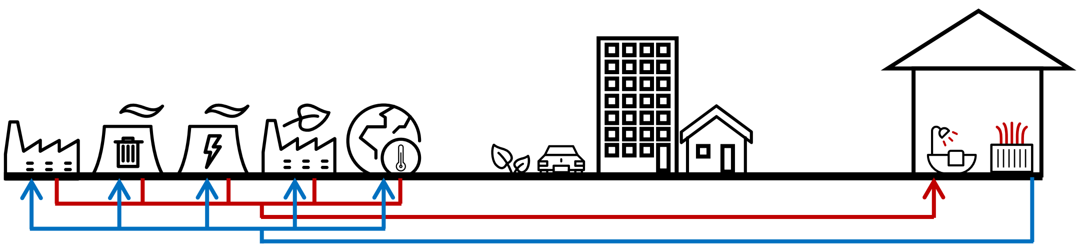

Figure 1: District Heating system based on Schmidt (2018) and Werner (2013).

2.5 Research concepts & tools

2.5.1 Urban symbiosis

The term Urban Symbiosis was first introduced by Van Berkel et al. (2009) as an extension in the field of industrial ecology and industrial symbiosis, which is well-defined by the research of Chertow (2000). Urban Symbiosis refers to the synergistic opportunity of the use of by-products from industrial operations in cities or urban areas as alternative raw materials for potential users in geographic proximity. As a result of the transfer and use of the by-products environmental and economic disadvantages can be avoided to achieve instead environmental and economic benefits.

Since Urban Symbiosis serves as an extension of industrial ecology in an urban context, the fundamentals of industrial ecology and industrial symbiosis are applicable to Urban Symbiosis when applied in an urban context. The underlying concept of industrial symbiosis is that it mimics a natural ecosystem, in which at least two unrelated species exchange materials, energy or information in mutually beneficial manner (Chertow, 2000). In an urban context, this would mean that two or multiple unrelated industrial operations in a city could exchange by-products for their mutual benefit and environmental benefit. In other words, the consumption of energy and materials of one process and the effluents or by-products that is produces can be used as raw material for another process. This results in that separately operating entities within an urban context will be working together to exchange their by-products. The level wherein Industrial Symbiosis, and thus Urban Symbiosis, operates is called the inter-firm level because it includes exchange of waste products among several actors (Chertow, 2000).

Useful approaches are introduced in the analysis of various Industrial Symbiosis projects by Chertow (2000) to examine Industrial Symbiosis projects. Three of these approaches focus on both the technical options in the amount and location of input and output and the collaboration options in multi-party relationships. The three approaches are as followed:

- Input Output matching: by collecting input and output data of local industries matches or links can be made between the industries for participation in industrial symbiosis projects.
- Materials budgeting: by mapping of the amount of materials and the by-products, where it is stored and the amount of material and by-product leaving per unit time the material and by-product flows of a chosen system can be identified.
- Stakeholder processes: by community involvement techniques and methods the commitment of the actors in an Industrial Symbiosis project can be achieved. This is important, since the complexity of the development of multi-party relationships is easily underestimated.

2.5.2 Institutional mapping

Institutional mapping can be used as a strategic research instrument to achieve an understanding of potential roles of involved actors, for identifying potential coalitions of support for a project, scenario and strategy building and to assess the relative risks entailed (Aligica, 2006). This type of mapping is characterized by the reflection of the so-called social reality of institutions that leads to actions and decision making. The Institutional Analysis and Development Framework (IADF) is a well-known and applied framework to understand the ways in which institutional systems and the actors they include operate and change over time (McGinnis, 2011).

The Institutional Analysis Development Framework (IADF) developed by Polski and Ostrom (1999) helps to analyse the mechanisms, so called institutions, that guide and adjust the behaviour in a situation that requires coordination among two or more participants or groups of participants of that situation. The participants must interact across multiple action situations because they have a common set of goals or purposes. Since institutional systems are highly abstract, IADF is a systematic method to identify the action situation and by what variables the participants of the action situation are influenced by and the resulting patterns of interactions, outcomes and evaluation of the outcomes of the action situation (Ostrom, 2011). The action situation can be analysed by the "*rules participants use to order their relationships, about attributes of the biophysical world, and about the nature of the community within which the action situation occurs.*". (Crawford & Ostrom, 2005, p. 16)

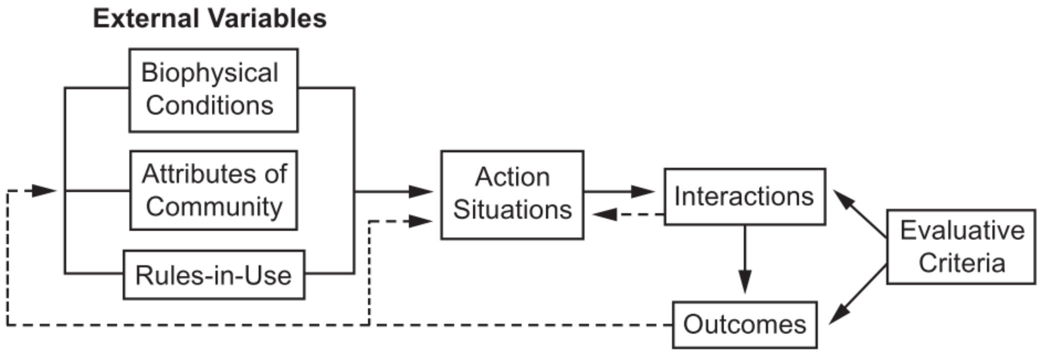

Figure 2: Institutional Analysis and Development Framework (Ostrom, 2011)

2.6 Research methodology

An integrated conceptual approach is developed that considers both the technical and institutional design of district heating with DC as supplying heat source that relates to the context and research objective of this research. The IADF is used as main input for the conceptual model of this research with two additional variables (see figure 3). Since this research focuses on the use of DC for district heating, the first variable that is added influences the biophysical conditions of IADF. The variable 'technical feasibility district heating with DC' aims to identify and map the physical capability to provide residual heat from DC for district heating. The second variable that is added is placed after the spatial and social variables that normally influence directly the action situation. The variable 'system configuration' aims to form a subset of the three spatial and social variables to limit the analysis of the action situation to only the actions and decisions that are required, and influenced by the subset, when a new heat supplying source is taken in consideration for district heating.

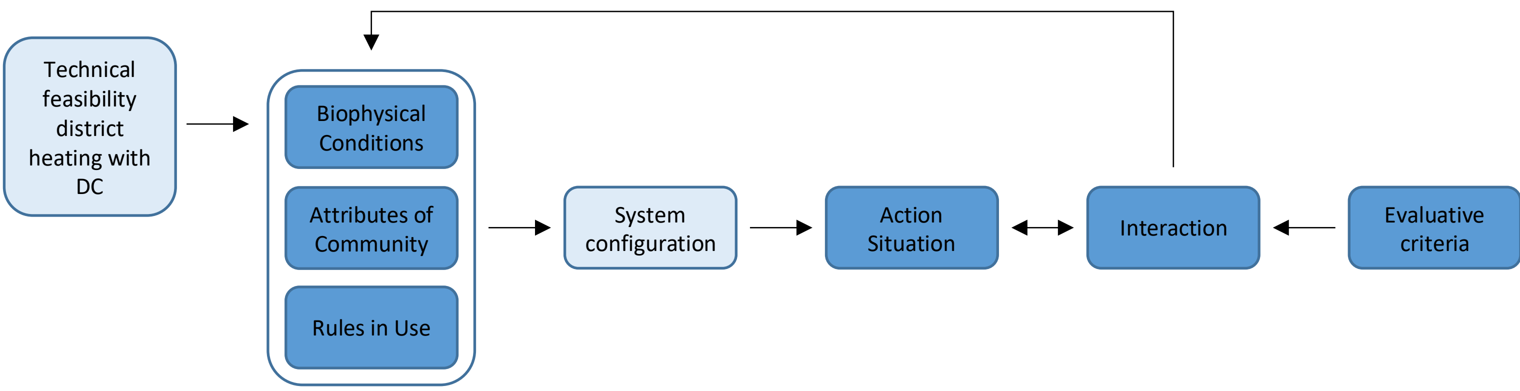

Figure 3: Conceptual model to map technical and social perspective of DH with DC

Based on the conceptual model a research design is developed and explained below in four steps. A visual representation of the research design is shown in figure 4 on page 14.

2.6.1 Methodology step I

The extent of the heat waste supply from DC for district heating for neighbourhoods in Amsterdam is assessed based on two estimations. First, the heat demand per neighbourhood of Amsterdam is estimated and validated by data of the CBS. Secondly, the heat supply from the DC that are located in Amsterdam is estimated. The estimations are made based on available datasets, literature review and interviews. This step aims to give answer on the following sub research question:

What is the extent of residual heat supply of DC for district heating for residential neighbourhoods in Amsterdam?

Estimation of heat demand per neighbourhood of Amsterdam

The heat demand per neighbourhood of Amsterdam is estimated using the building construction years per household address in Amsterdam from the BAG originating from 2016 (nlextract, 2016). The BAG dataset did not include the neighbourhood name where the address of the household is located, therefore the neighbourhood names were added by matching the postal codes of the BAG dataset with the corresponding neighbourhoods names for that postal code of a dataset of CBS (CBS, 2017b). The matching was successful for 446.526 addresses, but 14.243 addresses could not be matched and were matched based on their postal code without house number. As a result, 4.346 addresses were excluded from the total of 465.115 addresses from the BAG dataset since they could not be matched with a neighbourhood in Amsterdam. Since this number represents less than 1% of the total 469461 addresses this had little to no effect on the estimation of the heat demand.

The year of building construction per address of the BAG was selected for the estimation of the heat demand per neighbourhood by using the average gas use per household per building construction year from the data from Milieucentraal shown in table 1.

Table 1: Average gas use per household and its year of construction (Milieucentraal, n.d.)

Range of years of construction of household	Average gas use per household (m3)
2015 – 2020	1000
2000 – 2014	1160
1992 – 1999	1300
1975 – 1991	1380
1965 – 1974	1500
1946 – 1964	1560
Until 1945	1760

Per neighbourhood in Amsterdam the total amount of gas consumption of the addresses within each of the seven ranges is calculated per neighbourhood. The amount of addresses per range of step 1 were multiplied with the average gas use from table 1. The calculation of gas use is further defined in detail per household gas consumption purpose, cooking, SH & DHW. The gas use for cooking is subtracted from the total gas use since district heating only provides heat for SH and DHW. The gas use per consumption purpose of SH or DHW were calculated by multiplying the percentages from Milieucentraal (2019b) with the number of addresses. The total heat demand per neighbourhood is calculated by using the conversion factor of the Dutch gas operator Gasunie for gas in m^3 to GJ (Gasunie, n.d.). This resulted in the overview of the heat demand per neighbourhood of Amsterdam and a total heat demand for Amsterdam.

To validate the results of the calculation of the heat demand in the previous section, a dataset from CBS is used that shows the average gas use of privately-owned households per neighbourhood of 2016 (CBS, 2016). The average is estimated by CBS based on yearly average gas use of private households from the grid connection registers of the grid operators. In the calculation of the average gas use per household, households with a low gas use and connected to neighbourhood heating are included. Therefore, in some neighbourhoods the average gas use is low. The validation with the data per neighbourhood of CBS shows a deviation factor in this research of the estimation of the gas use and thus heat demand per neighbourhood for district heating.

Estimation of heat supply from datacenters

The heat supply from DC in Amsterdam is estimated using the dataset of the Warmteatlas that includes 34 DC in Amsterdam (RVO, 2018b). In addition, the data from the Dutch Data Center Map included two DC that were not included in the dataset of the Warmteatlas and included more detailed information on the maximum power for six DC (DDA, 2018). This additional data from DDA was added to the dataset of the Warmteatlas. As a result, 36 DC are present in Amsterdam of which 6 included the exact maximum power capacity, 22 DC included a range of maximum power capacity and 8 DC could not be included because of unavailable data on their maximum power capacity. The maximum power capacity of the 22 DC is estimated by using the average of the maximum power capacity range. The conversation with H. Schelvis showed that DC make only use of 70% of their maximum power capacity (Appendix B, Equinix). The conversation with E. Barentsen showed that 90% of all electricity used by a datacenter can be used as heat for district heating supply since this is the amount of electricity used by the servers and the remaining electricity is used by cooling equipment and lighting (Appendix B, DDA). Therefore, the maximum heat supply per datacenter is estimated in GJ as 70% of the total maximum power capacity and where an additional 10% is subtracted from.

Extent of heat supply from datacenters for neighbourhoods of Amsterdam

The extent is calculated in percentages based on the estimations from the previous two sections. The extent is therefore shown in a percentage of heat supply from DC for the heat demand of all neighbourhoods based on their construction years. Additionally, a percentage is calculated using the deviation factor from CBS when the heat demand based on grid operator registers would be taken into account.

2.6.2 Methodology step II: Spatial and social variables

The three IADF variables biophysical conditions, attributes of community and rules in use are analysed by a literature review and 11 interviews with actors from the market, technical and social sector. Each variable is operationalised to execute the literature review and to formulate questions to retrieve input from actors that are considered as experts for the IADF variables. This step aims to give answer on the following sub research question:

What are the spatial and social variables that influence the district heating system?

Biophysical conditions

The IADF variable biophysical conditions is defined by Polski & Ostrom (1999, p. 19) as the "*Physical and human resources and capabilities related to providing and producing goods and services. These conditions include production inputs like capital, labour, and technology, as well as sources of finance, storage, and distribution channels*.". The focus in this IADF variable on the production and provision of the good within the institutional system. In this research the good that is considered is the residual heat of DC and the institutional system is the district heating system. Therefore, the literature review and interviews are executed on the elements of production of residual heat by DC and the provision of the residual heat by a district heating system. According to Polski & Ostrom (1999) an analysis of the biophysical conditions should give answer on how the good is produced, provided, required technologies and processes, storage requirements and the scale and scope of the provision and production activity. This includes for energy systems the "*assets or artefacts that make up the supply chain of an energy system, i.e., the tangible objects involved in the operation of an energy system such as* *pipelines, wires, pressure stations, generation plants, control systems. Part of complex larger wholes of interacting, inter-connected components which support and sustain them.*" (Scholten & Künneke, 2016).

The production and scale and scope of the production of residual heat is answered by step I and supplemented with literature. The remaining elements are analysed through the literature review to give answer on the technical design and components of district heating. Interviews with actors from the market and technical sector were used to supplement the literature review.

Community of attributes
The IADF variable community of attributes is defined by Polski & Ostrom (1999, p. 22) as "*the demographic features of the community, generally accepted norms about policy activities, the degree of common understanding potential participants share about activities in the policy area, and the extent to which potential participants' values, beliefs, and preferences about policy-oriented strategies and outcomes are homogeneous."*. The focus of this IADF variable is on the actors of the district heating community and the extent of homogeneity based on their values, beliefs and preferences regarding their and others' policy-oriented strategies. According to Polski & Ostrom (1999) an analysis of the community of attributes should include the values and preferences of the actor to achieve their outcome, beliefs about their own and other actors in their policy strategy preferences and their relationship. All elements are analysed through the conduct of interviews with actors from the market, technical and social sector. The interview questions that were formulated for this IADF variable aimed to retrieve input on the values that were used per actor to achieve their vision as their desired outcome, the external effects of the policies or rules in use on the actor in terms of support or limitation and the experience of cooperation with other actors to determine the relationship with other actors. The interview questions were tested in a first interview and improved to obtain the most useful input from the actors. The interview questions for this IADF variable can be found in Appendix A.

Rules in use
The IADF variable rules in use is defined by Polski & Ostrom (1999, p. 22) as "*the minimal but necessary set of rules that are needed to explain policy-related actions, interactions, and outcomes."*. They *"can be thought of as the set of instructions for creating an action situation in a particular environment."* (Crawford & Ostrom, 2005, p. 17). Three types of rules are defined according to Crawford & Ostrom (2005, p. 58) and are analysed in this research by the literature review and the interviews. The three types of rules are constitutional-choice, collective-choice and operational rules and affect each other from constitutional towards operational rules. The constitutional-choice rules affect the collective-choice rules by determining who is eligible to be a participant in the district heating system. The constitutional-choice rules that determine the eligibility is analysed in this research on the national jurisdiction level and regional regulation. Additionally, financial allowances are set up to provide selected actors a financial compensation when taking part in a district heating system and is therefore included as well. The collective-choice rules are thus influenced by the national jurisdiction and regional regulation and determine what actors can take part in the district heating system. The actors that take part in the district heating system are then bound by contracts and the conditions of these contracts are determined by the constitutional-choice rules. Finally, the contracts then affect the operational rules that determine the day-to-day decisions of the actors. The interview questions for this IADF variable can be found in Appendix A.

2.6.3 Methodology step III: System configurations

The third step aims to develop system configurations of the three spatial and social variables that influence the actions and decisions. The sub research question that guides this step is as followed:

What district heating system configurations where DC are integrated as heat source of spatial and social variables influences decisions and actions of the actors?

The three variables of IADF from step I and II are used as three layers in the system configurations. Therefore, each IADF variable in step I and II is concluded with a visualisation of the IADF variable as layer with corresponding elements. The three layers are combined into a model to be used for the development of system configurations. First, the model is created as a general model consisting of the general elements of a district heating system configuration and is then in a detailed model enriched with options per element per layer. The interviews with the actors are used in the development of the system configurations since one question was specifically devoted to give input from their actor perspective on a district heating system where DC are integrated as heat source. This is supplemented by the input on the remaining questions since they were devoted to the three IADF variables. The interviews are analysed, and system configurations are developed when actors' perspectives on a district heating system with DC as heat source by the use of similar key words or terms that overlap or complement to each other as one system configuration.

2.6.4 Methodology step IV: Institutional feasibility

The fourth step aims to test the system configurations in an action situation to consider an alternative district heating system. The action situation is defined by Polski & Ostrom (1999, p. 27) as the "*conceptual space in which actors inform themselves, consider alternative courses of action, make decisions, take action, and experience the consequences of these actions. Who is present in this situation, the roles they play, the actions they take, and so on, are all affected by factors in the physical and material world, the community, and rules-in-use."*. The system configurations were analysed by a reflection per system configuration and are compared to each other. This is validated by an expert panel consisting of the graduation committee of this thesis.

Courses of action per option of characteristic components of the system configurations are proposed for the actors that were considered in this research. The courses of action include on the one hand the action that the actor is suggested to take on how to *affect* the choice of component option by its role and responsibilities to lead to one of the three system configurations. On the other hand, the courses of action include the action that the actor is suggested to take when the chosen option of the component of the system configuration has *effect* on the actor's role and responsibilities. The proposed courses of action are based on the findings on the role and actions that the actor can take based on the described system configurations and gained knowledge and interpretation from the interviews per actor. The courses of action are suggested for six actor groups that were formed based on the type of actor and the role they play in district heating and are shown in table 2. The alternative courses of action that can be considered per actor group from table 2 are visualised and described according to figure 4. Characteristic components were selected from the three system configurations that makes them distinctive from each other. Since the component applies to the three system configurations, at least two options are considered per component for the actor group that the actors can *affect* or has *effect* on the actors.

The alternative courses of action aim to answer the final sub research question that has guided this step:

What is the feasibility of the district heating system when influenced by the system configurations where datacenters are taken into account as heat supplying source in Amsterdam?

Table 2: Groups per type of actor and role in district heating

Group number	Type of actors	Sector	Actors that were considered in this research
1	Datacentres	Market	DDA, Equinix
2	Retailers, utility companies	Market	NUON, AEB, Engie
3	Consultancy, manufacturers	Technical	Greenvis, Thermaflex
4	Municipalities	Social	Municipality of Amsterdam
5	Grid operators	Social	Firan

6	Law and policy makers	Social	Ministry of Economic Affairs and Climate Policy, PBL

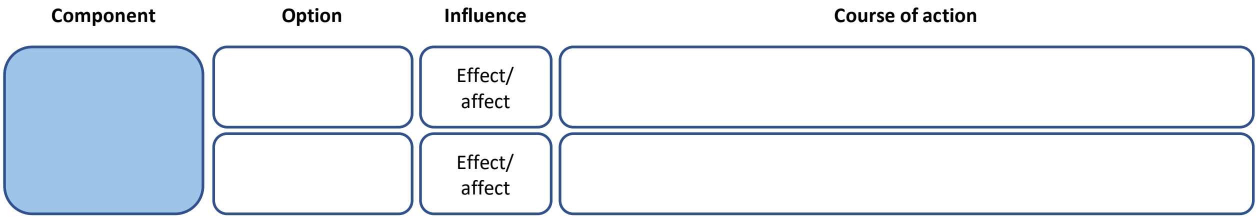

Figure 4: Visual lay out of courses of action per component that the actor group can affect or has effect on the actors.

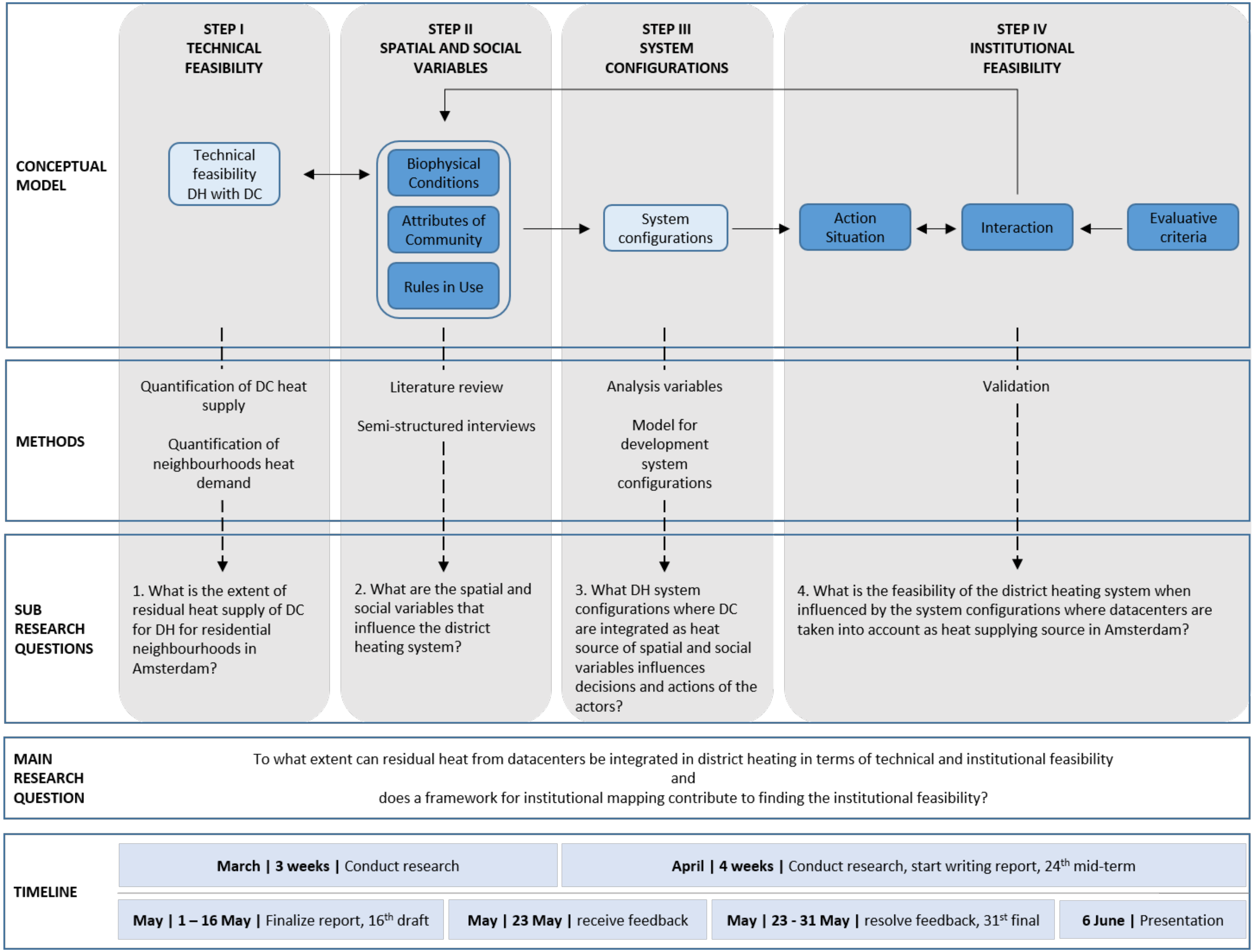

Figure 5: Research Design

3 Results step I & II: Technical feasibility & spatial and social variables

3.1 Biophysical Conditions

The biophysical conditions of district heating include the technical design and components of the district heating system. The following section describes the subsystems of district heating and its essential and allocable components. Furthermore, the extent of heat supply of DC for demand of neighbourhoods in Amsterdam is included. Lastly, the Biophysical Conditions layer for the use of the model for the development of system configurations is derived from the sub elements of this section. These sub elements of the biophysical conditions represent the spatial variables in the IADF model.

3.1.1 Technical design

The biophysical elements of the district heating system can be divided into two interrelated entities. On the one hand, the technical design that forms the overarching process starting with the production of heat for the district heating system to supplying the heat to the households that consume the supplied heat for the two end usages: space heating and domestic hot water. The process ends and starts over when the cooled water after the household consumer usage returns to the production of heat. On the other hand, to enable the process of supplying the heat to the households and return the cooled water several supporting technological components are required. The components correspond to the subdivision between high- (HT), mid- (MT) and low-temperature (LT) that is related to the temperature of the produced heat and the required temperature for the consumer end usage (City-zen, 2018). The technical design and components form together the input for the variable biophysical conditions in the conceptual model and will be used for the development of a model to analyse differentiating system configurations of district heating with DC.

The technical design and overarching process of the district heating system consists of three main subsystems (Rezaie & Rosen, 2012; Schmidt, 2018). The subsystems include the production of heat, distribution of heat and return to the production after it is used by the last subsystem the households as end consumers.

Production

Heat for district heating is produced in the form of steam or hot water at a temperature that is available from the heat energy in the production plant, which is a local energy source in vicinity of the area that the heat needs to be supplied to. The local energy sources can be one of the five suitable strategic local energy resources as mentioned earlier according to Werner (2013) with DC as potential heat sources from industrial processes. Three temperature ranges exist within district heating due to the available temperature of heat from the various production plants. High temperature sources are above 65-degree Celsius, mid-temperature between 40 and 65 degree Celsius and low-temperature sources between 25 and 40 degree Celsius (City-zen, 2018). One or more production plants from different types of local energy sources can be included in a district heating system (Bordin, Gordini, & Vigo, 2016). The required volume that the heat source should supply is determined by heat losses and customer demand (Rezaie & Rosen, 2012). In case of households the total customer demand is determined by the two household consumer purposes: SH and DHW.

Transportation & distribution

The produced heat is supplied to the consumers through two piping networks: transportation & distribution. Most district heating customers in Europe are connected to distribution networks that supplies heat with the same supply temperature to all district heating customers (Werner, 2017). The conversation with M. Buijk and H. Rödel of NUON showed that the transportation network that transfers the heat to the distribution network can be referred to as primary infrastructure of a district heating system and the distribution network that distributes the heat within the district heating customer area can be referred to as secondary infrastructure (Appendix B, NUON). The transportation & distribution network in district heating also transfer the cold water after household consumer use back to the production plant(s) in order to be reheated and transported and distributed to the households as customers (Bordin et al., 2016).

Consumption

After transportation & distribution of the heat the households can finally consume the supplied heat for their consumer usage SH or DHW. In order to use the heat in households for the two consumer end usages based on the subdivision in produced heat;

- HT can be used directly for SH and DHW independent from the household building insulation or energy label;
- MT can be used directly for SH for insulated household buildings with energy label D and better and needs additional heating to 60 degree Celsius for DHW;
- and LT can be used directly for SH for well-insulated household buildings with energy label B and better and needs additional needs additional heating to 60 degree Celsius for DHW (City-zen, 2018).

  Therefore, the household buildings should be fitted in terms of their energy label to allow the use of supplied temperature of the district heating system or additional heating via heat pumps is required in the district heating system or within the household building.

3.1.2 Essential technical components of district heating

The three subsystems require several technical components to operate according to the temperature level of the district heating system. The technical components of this category are *essential* for the subsystem to operate.

Production

According to Ebrahimi et al. (2014) three types of cooling systems exist for DC to recover the residual heat for district heating. The conversation with H. Schelvis of Equinix showed that the cooling system they make use of in their DC are air-cooled (Appendix B, Equinix).

- Air-cooled datacenters

  In most DC the server racks are installed in aisles in the server rooms where one side of the server rack is being cooled as cold aisle and on the other side of the rack, the hot aisles, the warm air produced by the server racks is captured. The CRAC unit produces chilled air around 25 degree Celsius to cool the server racks on the cold aisles and is driven through the floor and perforated tiles or through diffusers in the ceiling. The warm air in hot aisles is captured and returned to the intake of the CRAC. The temperature of the captures heat is as low as 35 degree Celsius and can be extracted for district heating with a heat exchanger at the return to the CRAC unit.

- Water-cooled datacenters

  In the server racks, each server is cooled with cold plate loop heat exchangers and are cooled by the water entering the servers. The heat is extracted by the loop heat exchanger and can be in the range of 60 – 70 degree Celsius in case of new DC who produce heat at higher temperature levels.

- Two-phase cooled datacenter

The servers are submerged in heat transfer liquids and the heated liquid condenses on a water cooled spiral located above the servers. The heat extracted from the spiral can be as high as 70 – 80 degree Celsius.

Transportation & distribution

- Primary and secondary pipeline infrastructure
  The transportation & distribution of heat to and from the households and the heat production plants requires a network of pipes. The network of pipes includes supply pipes that supply heat from the production plant to the consumers and return pipes that return the cooled water after customer usage back to the heat production plant. The supply and return pipes determine the district heating system functioning by the product of flow and temperature difference. The supply and return pipelines are divided into primary and secondary pipes, of which the primary infrastructure consists of pipelines with a big diameter to transport the heat volume to the households. The secondary pipes consist of pipelines with a smaller diameter to distribute the heat from the primary infrastructure to the households.

- Substation
  Substations transform the supplied heat to either upgrade or lower the temperature or pressure to supply heat with the same supply temperature and pressure to all customers (Frederiksen & Werner, 2013; Werner, 2017). Substations can be placed in-between the primary and secondary infrastructure of district heating, called an area substation, or within the customer household building, called house substation or apartment substation. The ownership of the substations may be by the building owner, utility company or shared (Frederiksen & Werner, 2013).

Consumption

- Heat exchanger
  The heat exchanger substitutes the classic domestic boiler and warms water by transferring the heat from the supplied heat from district heating without mixing the two (Bordin et al., 2016). The heat exchanger enables therefore the consumer usage for SH and DHW.

3.1.3 Allocable technical components

The three subsystems require several technical components to operate according to the temperature level of the district heating system. The second category includes components that can be *allocated* in-between the subsystems for the operation of the district heating system.

- Heat pump
  The goal of the installation of a heat pump in district heating is to upgrade extracted heat to a higher temperature level (Frederiksen & Werner, 2013). Large heat pumps can be installed in the transportation & distribution subsystem or near the production of the heat to directly upgrade the heat to the preferred supply temperature. Smaller heat pumps that can be installed in individual buildings to upgrade the heat to the demanded supply temperature and to secure the temperature to 60 degrees Celsius to prevent legionella.

- Peak and back-up heating system
  The supply of heat when peak demand occurs or when back-up is required due to lower base load supply from the production plant can be covered by a fuel heat-only boiler. The fuel heat-only boiler can provide peak power in the cold season and usually the total amount of installed capacity will be large enough to provide backup capacity. Heat-only boilers running on oil or natural gas are capable of going into operation with a few minutes (Frederiksen & Werner, 2013). The fuel-heat-only boiler can be installed in the transportation & distribution subsystem.

- Storage

The installation of heat storage units is a solution when there is a mismatch between the production and supply of heat with the demand of heat from the households. Storage tanks can be installed in district heating to store heat nightly or hourly and supplied when the demand is high (Arteconi, Hewitt, & Polonara, 2012). Thermal energy storage can be placed central or decentral in district heating and can be supplemented with a buffer to store excess thermal energy (Arteconi et al., 2012; Nuytten, Claessens, Paredis, Van Bael, & Six, 2013).

- Pressure management
  Pressure drop is required in the transportation & distribution network in order to supply the heat from the heat production plant to the consumption. To achieve a larger water flow in the transportation & distribution network, the higher the required provided pressure drop (Frederiksen & Werner, 2013).

3.1.4 Production, capture and extraction of datacenter residual heat for district heating

Production of residual heat of datacenters
The data centre industry consists of DC facilities including computer servers to meet the increasing global demand for data processing, data storage systems and digital telecommunications due to the advances and increasing use of computer and electronic technology. As a result, an increasing amount computer servers and data centre facilities are required, resulting in a tremendous growth rate in number of servers with as consequence an increase in power density, electricity usage, size and floor area of DC facilities (Koomey, 2008; Wahlroos et al., 2017). The worlds electricity usage of DC doubled from 2000 to 2005, but the growth slowed down from 2005 to 2010 due to the DC industry's efforts to improve energy efficiency of the computer servers since 2005 (Koomey, 2011). Although DC require a high amount of electricity to secure their maximum operation capacity, the majority of servers in a DC operate at or below 20% of their maximum capacity most of the time, but 60–100% of the maximum power is still drawn from the grid (Ebrahimi et al., 2014). Another study shows that the power consumption of the sample DC was at least 60% - 80% of the maximum power consumption (Wahlroos et al., 2017). According to the conversation with H. Schelvis of Equinix DC grows gradually in its capacity due to the equipment and services that their clients install and use. Approximately 70-75% of the maximum power capacity of a datacenter is in use after 7 - 8 years of operation (Appendix B, Equinix). The operating servers of DC convert almost completely all supplied electrical power into heat, requiring large scale cooling systems to keep server rack temperatures within a safe operational range. However, several cooling technologies exist for DC but do not utilize the residual heat produced in DC (Ebrahimi et al., 2014; Wahlroos et al., 2017).

Capture and extraction of residual heat for district heating
Cooling systems enable a safe operating temperature for the server racks that are installed within DC. Since this is a major requirement for the DC to operate, a unique unit called the Computer Room Air Conditioning unit (CRAC) is responsible for controlling the temperature, humidity and dust of the server racks within a safe and efficient operational range (Ebrahimi et al., 2014; Kant, 2009; Rambo & Joshi, 2007). Three types of cooling systems exist for DC and for the CRAC to manage and recover the residual heat for district heating: air-cooled system, water-cooled system & two-phase cooled system (Ebrahimi et al., 2014).

3.1.5 Technical feasibility of residual heat supply from datacenters for heat demand of neighbourhoods Amsterdam

Heat demand of neighbourhoods
In Amsterdam 374 neighbourhoods are present with different construction years that require differentiating heat demands. The total heat demand of all 374 neighbourhoods in Amsterdam is estimated to be 27,04 PJ (Appendix C).

The CBS validation with the average gas use per neighbourhood has shown a deviation factor of 0.58 with the estimated heat demand per neighbourhood for district heating (Appendix D). It is therefore important to note that the extent of heat supply from DC for neighbourhoods Amsterdam can deviate when taken the deviation factor into account.

Heat supply from datacenters

In the Netherlands a total of 200 commercial DC is present with most DC located in and around Amsterdam. According to the DDA and Warmteatlas a total of 36 DC are present in Amsterdam and are owned by the companies shown in table 2. The total heat supply of the 26 DC that were taken into account is 1,42 PJ (Appendix F).

Table 3: Companies owning the datacenters located in Amsterdam (Dutch Data Center Association, n.d.; RVO, 2018b)

Amsterdam	Datacenter.com	Global Switch	Amsterdam	Switch Datacenters
Colt	Digital Realty Trust	Globalone	Maincubes	The Datacenter Group
Datacenter Alliance (DCA)	EdgeConnex	Gyrocenter	Nikhef	Verizon
Databarn Amsterdam B.V.	Equinix	Interxion	RDC	XS4ALL

Extent of heat supply from datacenters for neighbourhoods of Amsterdam

The DC in Amsterdam is estimated to supply heat for 5.3% of the total heat demand of neighbourhoods in Amsterdam (Appendix F). When the CBS validation would be taken into consideration, the percentage of heat supply from DC for heat demand of neighbourhoods in Amsterdam is expected to be 9.1% (Appendix F). Therefore, the extent of residual heat supply from DC in Amsterdam for its neighbourhoods is estimated to be between 5.3% and 9.1% (Appendix F).

3.1.6 Layer for system configuration

The biophysical conditions layer is based on the previous sections and shown in figure 6. The layer is constructed from the subsystems from the technical design of a district heating system and the corresponding technical components consisting of essential and allocable components. The subsystem production can include one or more production plants from varying local energy sources. The subsystem transport and distribution is divided into two subsystems since it requires two infrastructures where the allocable components can be placed in either of the two. The subsystem consumption depends on the supplied temperature from the heat production plant and the required temperature for the household building.

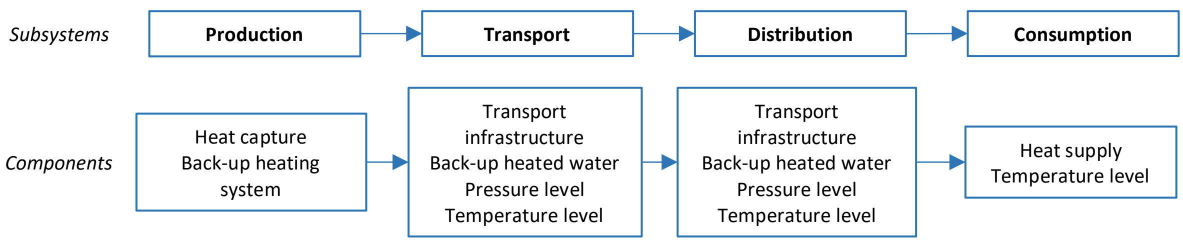

Figure 6: System configuration layer for biophysical conditions

3.2 Community of Attributes

The community of attributes of district heating includes the actors that are active in one or more subsystems from the biophysical conditions. The following section describes the actors of the community of district heating for the case of Amsterdam in terms of their vision and values regarding district heating, external effect from policies, laws and regulations in force and their relationship with other actors within the institutional setting of the subsystems, policies, laws and regulations. Lastly, the Community of Attributes layer for the use of the model for the development of system configurations is derived from the sub elements in this section. These sub elements of the community of attributes represent the social variables in the IADF model.

3.2.1 Actors of community

The actors of the district heating community for the case of Amsterdam can be derived from the subsystems that are introduced in the biophysical conditions, consisting of production, transportation & distribution and consumption. The subsystems lead to five categories of actors: producers, transporters, distributors, retailers and consumers. The actors are designated or enabled to be active in one or more categories when the policies, laws and regulations in force. The policies, laws and regulations are developed and maintained by actors from the social sector and are the Municipality of Amsterdam and the Dutch Ministry of Economic Affairs and Climate. Two actors perform an advising or consulting role for the abovementioned actors and from table 3. PBL is the Dutch Environmental Assessment Agency (PBL) and explores and analyses the policy possibilities that are considered by the Dutch government and Ministry of Economic Affairs and Climate Policy. Greenvis advises actors from the subsystems production and transportation & distribution on the development of district heating systems and increasingly work together with and for municipalities, provinces and national government in studies of district heating.

Table 4: DH actors active in one or more actor categories within the three subsystems of district heating

Subsystem	**Production**	**Transportation & distribution**			**Consumption**
Actor category	*Producers*	*Transporters*	*Distributors*	*Retailers*	*Consumers*
Actors	Datacenters NUON AEB	WPW Engie Firan Thermaflex	WPW Engie Firan Thermaflex	WPW Engie	Households of neighbourhoods

3.2.2 Homogeneity

Homogeneity is an important element of the community of attributes since it demonstrates the extent of similarities or differences between the actors of district heating. This includes actors' values, beliefs and preferences regarding their and others' policy-oriented strategies. This section describes the similar or different values that were used of the interviewed actors to achieve their vision in district heating as their desired outcome, the external effects of the policies or rules in use on the actor in terms of support or limitation and the experience of cooperation with other actors.

Vision and values

The interviewed actors share vision and values in the current and future development of district heating systems in Amsterdam together with actors from the social sector. Four shared vision and values are defined based on the interviews that were held that the district heating system should include from their perspective (Appendix B).

- Sustainable
  The value that was shared most by the actors in their vision for district heating is that the district heating system and sources should be sustainable. This is shared by WPW (NUON & AEB), datacenter Equinix, Firan and entails mainly the sustainability of production sources of heat. The conversation with M. Buijk and H. Rödel of NUON showed their vision is "*To be fossil-free in one generation*" in terms of their heat supplying sources. The conversation with H. Schelvis of Equinix showed that their vision is "*to make our business more sustainable by utilizing our residual heat for other purposes*". The conversation with K. Antonissen of Firan showed that Firan their vision is "*to establish a futureproof energy system that is sustainable in the production and consumption of energy*". Their vision corresponds to the vision of the municipality of Amsterdam that the conversation with B. Mantel showed: "*to develop a district heating system for Amsterdam that is sustainable in its production sources of heat*".

- Affordable
  A value that is important for the municipality of Amsterdam in the development of a district heating system for its city is the affordability for its citizens. AEB as heat producer and co-owner of WPW is the only actor from the district heating system that corresponds to the affordability by working together with housing associations to look into the affordability of a business case for the use of district heating for housing.
- Reliable and security of supply
  The Dutch Ministry of Economic Affairs and Climate states as values for safeguarding the public interests is the reliability and security of supply of heat. AEB and Equinix both share this value in their vision for district heating but from two perspectives. The conversation with R. van Ommen of AEB showed that AEB describes reliability and security from the heat supply perspective by that the "*district heating should be operating to accommodate the heat demand of the people in a household, office or other district heating customers*". The conversation with H. Schelvis of Equinix showed that their view is that they request safe and secure extraction of their residual heat with minimum impact on the day to day operation of the datacenter. Residual heat is available whole year round. Preferred is that as much residual heat as possible will be used, during the whole year.

- Open district heating
  The grid operator Firan and municipality both prefer that the current district heating system of Amsterdam is transformed into an open district heating system for the integration of sustainable heat sources that can supplement and compensate each other, with an established role for grid operator as sole manager of the district heating infrastructure and where the district heating system is non-discriminatory for heat producers and district heating customers.

External effects from rules-in-use

The interviewed actors shared the effect of the rules in use on their role and responsibilities in district heating. Two distinctions are made below, if the rules are either supportive or limiting for the actors.

- Supportive
  The Dutch Heat Act (1.0) enables energy suppliers to take the role and responsibilities for the subsystems of production and transportation & distribution. Next to this, energy suppliers are naturally allowed to be the retailer of the heat for households as customers. Retailer NUON states according to the conversation with M. Buijk and H. Rödel to be "*pleased with the Heat Act in force since it enables a monopoly situation for heat production, infrastructure management and retail. However, this demands transparency, supervision or both. Therefore, the Dutch Authority for Consumers and Markets (ACM) reviews retailers' maximum tariff, maximum return and the security of heat supply in district heating*" (Appendix B). The monopoly situation also enables the exploration of possibilities for energy suppliers

in taking part in one of the district heating subsystems. As a result, Engie can explore in projects to find out what district heating subsystem works best for their company to act in.

The obligation to have established a heat plan in 2021 per neighbourhood per municipalities is favoured by the Municipality of Amsterdam, since the municipality can direct the preferred heat supply per neighbourhood in terms of its sustainability. This will result in the obligation to connect the current and future households to the designated heat supply for the neighbourhood.

- Limiting
  The Dutch Heat Act (1.0) prevents differentiation of heat tariffs in the supplied district heating temperature. According to Firan, this has a negative effect on the affordability of district heating when LT district heating is supplied since additional costs on top of the tariff should be paid. This additional fee is needed because the heat within a LT network should be increased in the district heating network or within the buildings of households to a safe temperature for DHW. Furthermore, the Dutch Heat Act (1.0) prevents district heating customers to switch between retailers due to the lease contract for a heat pump that is leased from the retailer. Finally, the Dutch Heat Act (1.0) and municipal regulation disregards a clear role for a district heating operator that exploits, manages and operates the primary and secondary infrastructure considering social interests. This is enhanced by an unclear designation of areas by the municipality to supply heat with district heating and which actor is responsible of the exploitation, management and operation of district heating infrastructure.

Relationship with other actors
The relations between the actors in an operating district heating system is bounded by contracts between the actors from the subsystems. The contracts result from the cooperation between the actors in the initiation of a district heating project and require transparent cooperation between the actors to settle the terms within the contracts. According to the Heat Act (1.0) any heat producing actor can offer its heat to an energy supplier for integration into an existing district heating system or for the development of a new district heating system. This results in that a heat producing actor can start the initiation phase by signing one or more letters of intent with the interested energy supplier and or district heating grid operator. The DDA stimulates the inclusion of DC as heat producing actors in district heating by bringing actors together with the aim to lead via a letter of intent or initiation phase to the establishment of an operational district heating system with DC as heat supplying actor according to the conversation with E. Barentsen (Appendix B). DC can therefore select actors who can invest and exploit a district heating system with the residual heat from the operation of the DC. The conversation with H. Schelvis showed that Equinix participates in several investigations for the use of residual heat. Multiple Letters of Intent, with multiple actors, for the use of residual heat for district heating are signed or are in preparation. However, Equinix experiences differentiation in interests within actors that signed the letter of intent or between letters of intent (Appendix B). Therefore, transparency is key in aligning interests and contract terms in the exploration of a district heating system where one or more DC are included as heat supplying sources. Moreover, Equinix admits that they need to establish selection criteria to choose between the proposals that will follow after investigation to continue the cooperation towards the development or realization of a district heating system in which their residual heat is utilized as heat production unit.

3.2.3 Layer for system configuration
The layer of community of attributes is based on previous sections and shown in figure 7. The layer summarizes the homogeneity elements that correspond to the entire configuration of the district heating system and the actors that are required or can take part in one or more subsystems.

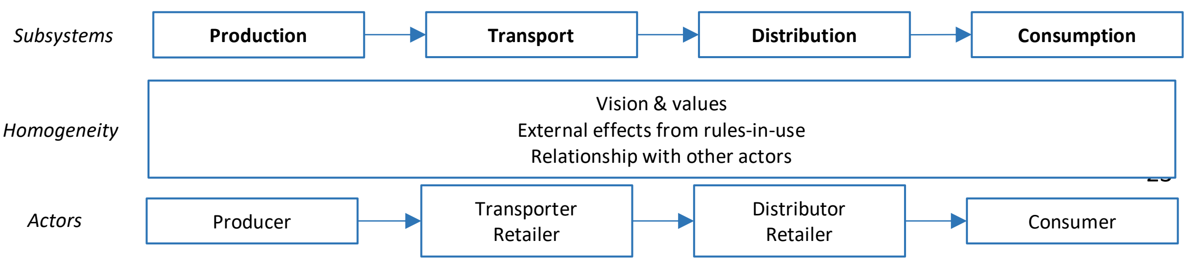

Figure 7: System configuration layer for Community of Attributes

3.3 Rules-in-Use

Three types of Rules-in-Use consist according to Crawford & Ostrom (2005) and are analysed accordingly for district heating. The following section describes the constitutional rules consisting of national jurisdiction, regional regulation and financial compensation regulations. Followed by the description of the collective-choice rules consisting of the contracts, based on the influence of the constitutional-choice rules, that bound actors in and between subsystems of district heating. The constitutional-choice rules and collective-choice rules lead to the designation of roles and responsibilities per actor for the district heating system. The operational rules entail this and are also described. Finally, the Rules-in-Use layer for the use of the model for the development of system configurations is derived from the sub elements in this section. These sub elements of the rules-in-use represent the social variables in the IADF model.

3.3.1 Constitutional rules

National jurisdiction

- Heat Act 1.0

  The Dutch Heat Act 1.0 has been in force since 2014 and has set the terms for the supply of heat to customers of district heating. A distinction is made between the producer of heat and the supplier of heat and the obligations towards each other. Furthermore, obligations apply for the retailer towards the customers of district heating in terms of the tariff and compensation in case of a supply interruption. The execution of the Heat Act 1.0 and its obligations are controlled by the ACM on behalf of the Ministry of Economic Affairs and Climate Policy and can demand data and information from the producer, retailer and heat customer. All 14 rules derived from the Heat Act 1.0 in table 4 and 5 when violated results in a penalty payment or fine imposed by the ACM.

Table 5: Rules from Heat Act 1.0 for producers

#	Rule
1.	Producers are obliged to negotiate reasonable prices and conditions on the request of the retailer.
2.	Producers must inform the Minister of the Ministry of Economic Affairs and Climate Policy when the producer no longer will be able to meet its legal obligations and the production of heat will be terminated.
3.	Producers allow measurements in pipes and installations by the ACM when the Ministry of Economic Affairs and Climate demands data and information for the control of the execution of the Heat Act.
4.	Producers must provide information on the sustainability of the heat source for the guarantee of origin of the heat for district heating.
5.	Producers can be obliged to make useful utilization of residual heat when residual heat is present or else a tariff or prohibition on the discharge of residual heat can apply.

Table 6: Rules from Heat Act 1.0 for retailers

#	Rule
6.	Retailers is obliged to negotiate with heat producers on reasonable prices and conditions for the supply of heat from the producer to the retailer.
7.	Retailers must take care of reliable heat supply for district heating customers on reasonable terms.
8.	Retailers are permitted to charge the heat supply for customers at most based on the maximum tariff where the tariff is based on the same costs that the customer would pay for an equal use of natural gas.

9.	Retailers must inform customers of any changes in the tariff for the heat supply.
10.	Retailers must inform customers of any changes in the terms for the heat supply.
11.	Retailers should refrain themselves of any form of unjustified discrimination towards its customers.
12.	Retailers must inform the Minister of the Ministry of Economic Affairs and Climate Policy when the producer no longer will be able to meet its legal obligations and the supply of heat will be terminated.
13.	Retailers allow measurements in pipes and installations by the ACM when the Ministry of Economic Affairs and Climate demands data and information for the control of the execution of the Heat Act.
14.	Retailers must provide information on the sustainability of integrated heat sources in the district heating system for the guarantee of origin of the heat for district heating.

- Heat Act 2.0
  It is expected that district heating will play a larger role in the Dutch heat supply as alternative for the use of natural gas for heating. Therefore, Minister E. Wiebes of Ministry of Economic Affairs and Climate Policy is working on a succeeding law: Dutch Heat Act 2.0 where the roles and responsibilities of actors will be clearly determined and while safeguarding the public interests' reliability, affordability and sustainability. The Dutch Heat Act 2.0 is under development in a legal process and may enter into force in January 2022.
  It will include three main themes: market organization, tariff regulation and sustainability of heat sources (Wiebes, 2019). The conversation with B. Mantel of the municipality of Amsterdam showed that municipalities, especially the G4 of the Netherlands (Amsterdam, The Hague, Rotterdam, Utrecht) are stimulated and requested from the national government to give input on the succeeding Heat Act and give examples on their district heating systems (Appendix B). In table 6 expectations to anticipate on from the Heat Act 2.0 are stated.

Table 7: Expectations from Heat Act 2.0

#	Expectation
I.	Market organization must be consistent with the technical and economical characteristics of the district heating market and contribute to efficient market outcomes.
II.	Market organization must offer space for local customization for diversity of potential heat sources and district heating systems.
III.	Market organization must enable control options for municipalities and national government to safeguard public interests.
IV.	For the market organization a distinction will be made in the applied rules between large regional transport networks, medium-sized local distribution networks and small-scale heating systems.
V.	Tariffs must be determined by an alternative calculation than the maximum tariff based on natural gas price from Heat Act 1.0.
VI.	The sustainability of district heating should be achieved according to the high degree of heterogeneity and safeguarding the public interests' affordability and reliability.
VII.	No split in actor roles for production and retail from district heating infrastructure.

Regional and local regulations

- Regional energy strategy

The Dutch government has stated in her coalition agreement to set up a regional approach to achieve an optimal mix of energy saving, sustainable heat usage and sustainable generation of energy. The main goal of the regional energy strategies is to find out the current energy or heat demand within the region and how this will develop (CE Delft et al., 2017). The insight of the heat demand together with the estimation of the future heat demand in the region can be used by municipalities for the development of a heat plan per neighbourhood that sets the alternative heat system for natural gas.

- Heat plan
  Municipalities are obliged to have set up a heat plan in 2021 for the neighbourhoods of their city that includes a planning for the transformation of the heating system on natural gas into a heating system based on an alternative energy heat source (Ollongren et al., 2018). The heat plan per neighbourhood will include the preferred alternative heating system for the neighbourhood. The heat plans for the neighbourhoods of a city will direct which neighbourhoods of a city will be transformed into a district heating system. However, no legal instrument for municipalities exists yet to enable municipalities to prescribe an alternative heating system for a neighbourhood (CE Delft et al., 2017).

- Concession
  Municipalities can make use of a concession contract to achieve a directing role in prescribing a district heating system for its city, neighbourhoods or neighbourhoods. Four advantages exist of a concession contract with actors of the district heating system for a municipality and are listed below (AKD, 2018).
    - The construction and operation for a defined duration can be legally enforced by the municipality as a direct control instrument for security of heat supply.
    - Requirements can be set on quality, sustainability, performance, numbers of customers and security of supply.
    - Certain non-profitable areas can be prescribed to connect to the heat network to prevent 'cherry-picking' by market actors.
    - To cover the full risk of the construction and operation of a district heating system by the concession, the municipality may accompany the concession with a fixed operating contribution.

  Currently, the municipality of Amsterdam has two concession contracts for the district heating system that is in place. One concession contract with retailer NUON, which is almost expired, and one concession contract with WPW. The conversation with B. Mantel of the municipality of Amsterdam showed that the municipality is able to make use of these concession contracts to execute the preferred alternative heating system for the neighbourhood (Appendix B).

Financial allowances

- Subsidy
    - SDE+ & SDE++
      Companies and organizations that are or will produce renewable energy, such as heat or residual heat can apply for the subsidy SDE+ or the future SDE++ to close the financial gap in the investment or exploitation of the renewable energy. The SDE++ takes residual heat from DC into account to close financial gaps and will be in force in 1 January 2020 (Wiebes, 2018).

    - ISDE subsidy
      Customers of district heating that need to invest in a heat pump for their household building can apply for the ISDE subsidy. The amount of the subsidy per heat pump is on average between 1000 and 2500 euros (RVO, 2019).

- Energy saving loan

Prospective customers of a district heating system need to pay their grid operator (or via the energy supplier) in the connection of their household building to the district heating distribution infrastructure. The national energy saving loan can be used by prospective district heating customers to afford the connection fee (Nationaal Energiebespaarfonds, n.d.).

- Investment from municipality
    - Operating contribution in concession
      The municipality can when in concession with a market actor for a district heating system accompany the contract with a fixed operating contribution to close a financial gap (AKD, 2018).

    - Establishment of municipal heat company
      The municipality can establish their own heat company to either take on all tasks of heat production, distribution, operation of district heating infrastructure and supply or only as the operator of the district heating infrastructure. The municipality can via its own heat company set requirements for the district heating system but above all construct district heating networks for neighbourhoods where this would be unprofitable by compensating with neighbourhoods that are profitable (Energeia, 2019).

3.3.2 Collective-choice rules

Eligible actors
Heat Act 1.0 supports energy suppliers in their eligibility for experimentation and obtain a role with responsibilities and corresponding activities in the subsystems production and transportation & distribution, since no restrictions are included for the energy supplier per subsystem. Through this, the energy suppliers are eligible for operating both subsystems, which is common in district heating currently and results in a monopoly position.

Heat Act 1.0 is unsupportive for a grid operator since no clear role is defined for them in the transportation & distribution subsystem. Although the grid operator can manage and operate an energy infrastructure network due to its experience in managing and operating the grid for the electricity and gas sector. Through the Heat Act 1.0, the grid operator is not the only eligible actor to take part in the subsystem transportation & distribution despite its experience in grid management and operation.

The regional and local regulations, regional energy strategy, heat plan and concession, can designate the actors that are eligible by policy or contract to take part in a subsystem of district heating. This requires from policy makers such as the municipality or province to take on a directing role in deciding which actors are eligible to take part within the subsystem of district heating.

Contracts
In the four subsystems one or more, due to the eligibility, actors are responsible for the operation of the subsystem. The subsystems are sequentially connected to each other and according to Persson & Werner (2012, p. 129) this "sequential collaboration should be based on trust and it is important to clarify the terms of collaboration in contracts and to agree mutually on long term strategies for this collaboration". (Persson & Werner, 2012, p. 129). The terms of the collaboration contracts are obliged from national jurisdiction and supplemented with additional terms that is agreed upon by the involved actors. The terms and conditions of these contracts define the operational rules per actor in the subsystems of district heating.

3.3.3 Operational rules

Contract heat producer with retailer

Retailers enter into a contract with a heat producer to fulfil the heat demand from its customers. The contract consists according to the conversation with M. Buijk and H. Rödel of NUON of four elements: reason of cooperation, technical details, economical agreements and legal (Appendix B, NUON). The technical details include the supply temperature, power and pressure of the heat from the heat producer and how to contact in case of malfunctioning of heat supply or maintenance planning. The economical agreements include the agreements on the financial benefits for the heat producer and financial costs for the retailer and the billing of the financial flows. The legal section includes the laws that are applicable, inevitably the Heat Act 1.0 and from 2022 the Heat Act 2.0, handling in case of a dispute and the duration of the contract.

Supply agreement retailer with customer

Customers of a district heating system enter into a supply agreement with the retailer for a reliable heat supply. The Dutch Heat Act 1.0 has prescribed the elements of the supply agreement that must be included:

- Personal details and address of retailer.
- Description of levels of heat quality covering the minimum- and maximum supplied temperature, tariff and conditions of the supplied heat.
- Conditions for suspension or termination of supply agreement.
- Description of financial compensation in case of failure on supplied heat or malfunctioning of levels of heat quality.

Connection agreement grid operator with heat producer and district heating customers

In case of a distinctive role for the operation of the district heating infrastructure the heat producer and district heating customers must record their connection to the district heating infrastructure in a connection agreement. In the connection agreement is stated the connection fee that the heat producer or district heating customer must pay and the duration according to the conversation with K. Antonissen of Firan (Appendix B).

3.3.4 Layer for system configuration

The layer of rules-in-use is based on previous sections and shown in figure 8. The layer summarizes per subsystem the constitutional, collective-choice and operational rules.

3.4 Model for system configurations

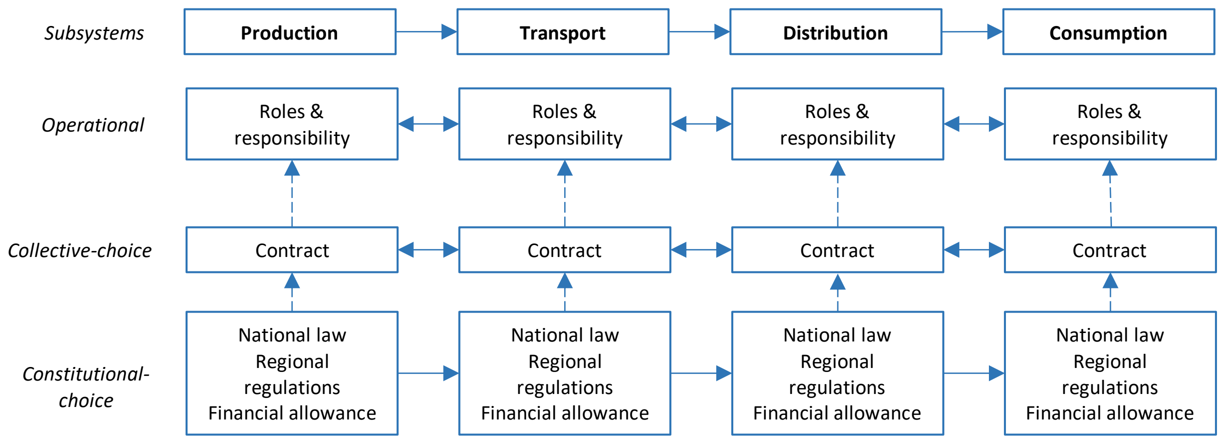

Figure 8: System configuration layer for Rules-in-Use

The three variables of the IADF model have led to the social and spatial variables of a district heating system. A model has been developed to create district heating system configurations where DC are integrated as heat supplying source. In general, the model consists of four columns that represent the four subsystems from the biophysical layer and apply to the two remaining layers. Furthermore, the model consists of three main rows that represent the three variables of IADF as layers and consist of the sub elements of the layer. This has led to the model in figure 9 that summarizes the general spatial and social variables of a district heating system. The model is elaborated in figure 10, showing the detailed spatial and social variables as various options per layer and column for system configurations that are developed.

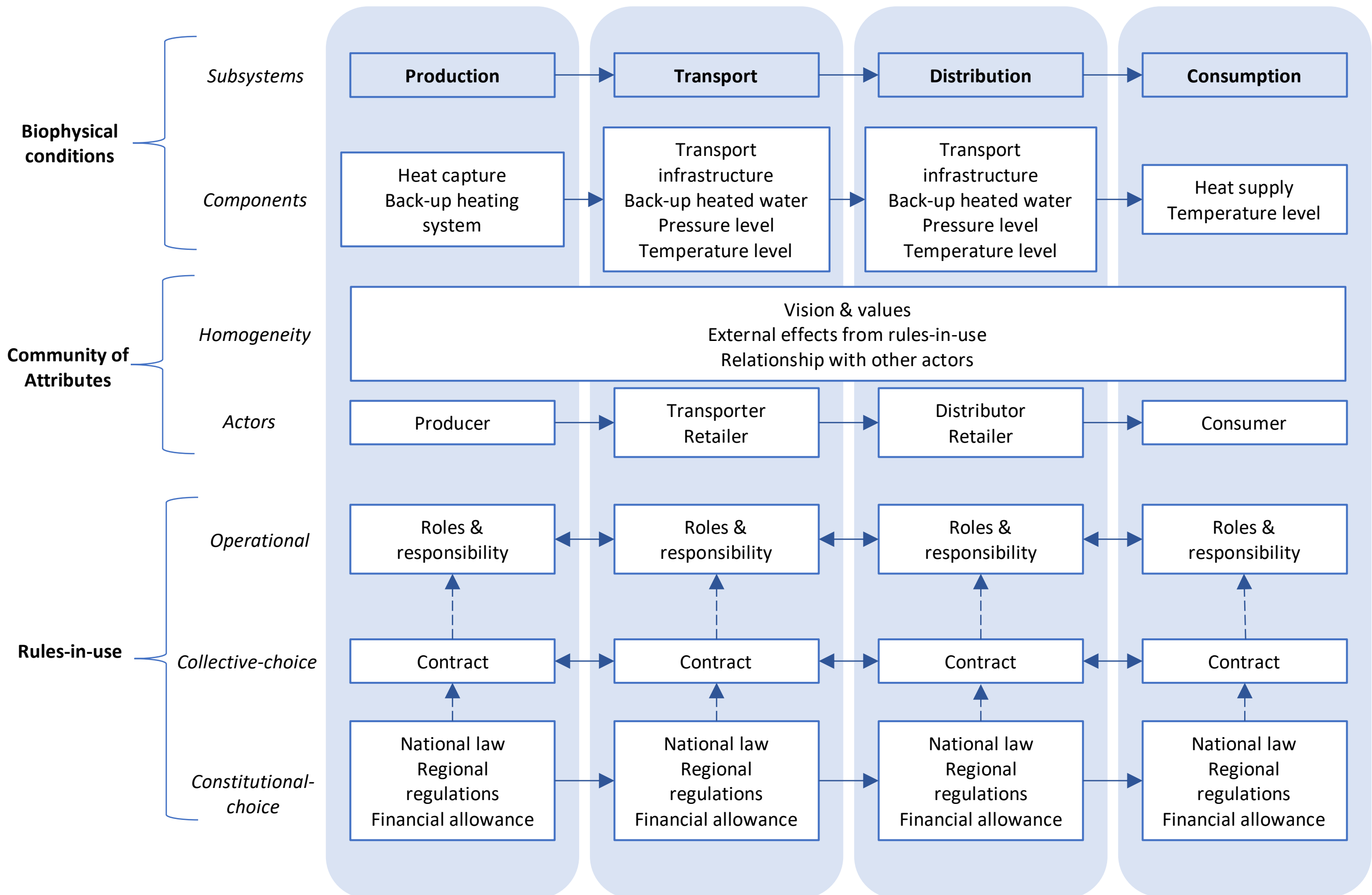

Figure 9: General model for development of system configurations

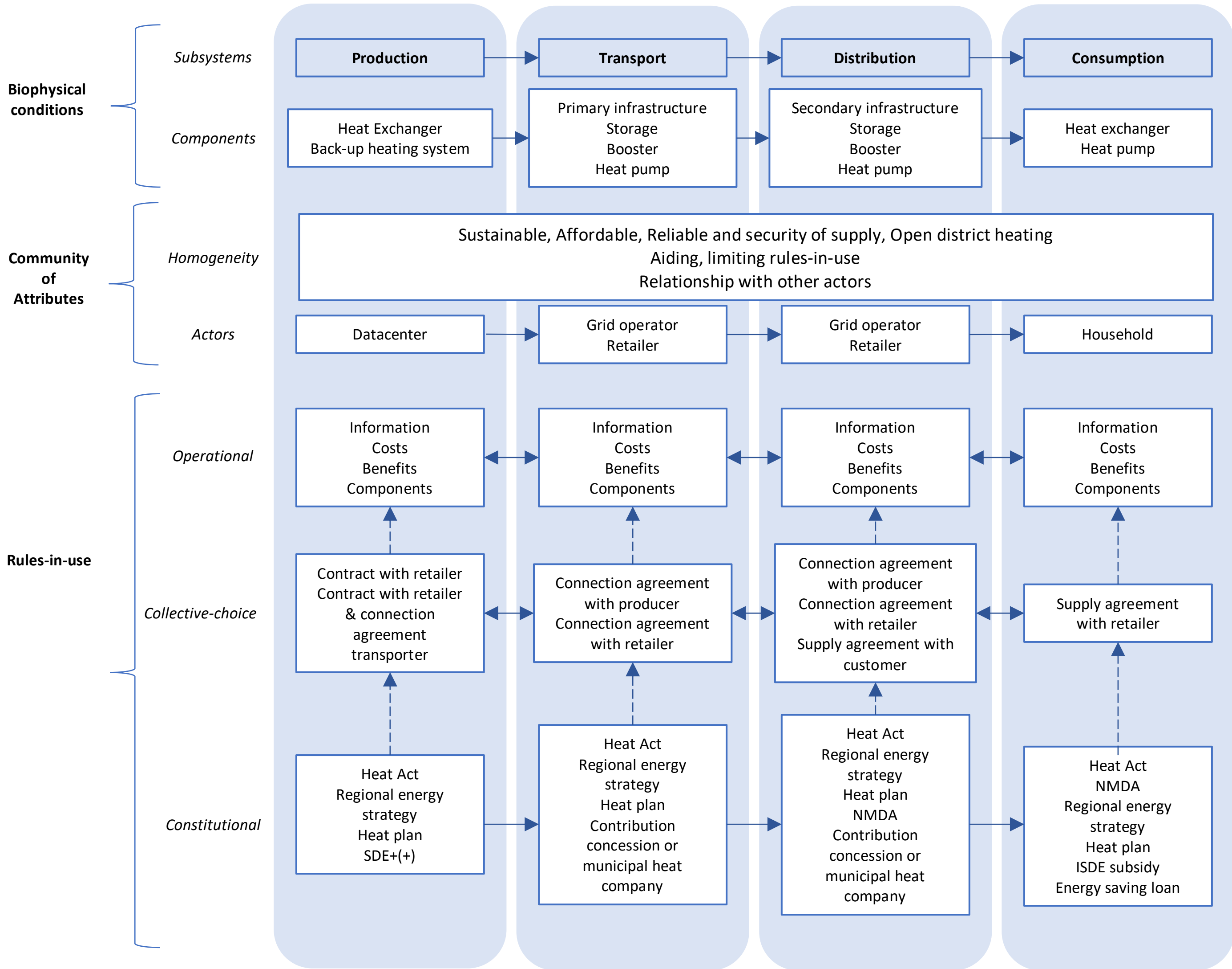

Figure 10: Detailed model for development of system configurations

4 RESULTS STEP III: SYSTEM CONFIGURATIONS

Three system configurations are developed where the district heating system with DC as heat supplying source and actor of heat production. The descriptions of the system configurations include only major characteristic elements per system configuration is elaborated upon in this chapter and the institutional feasibility of the three system configurations will be reflected upon in step IV.

All three system configurations show similar characteristics in the three layers that the system configuration is built on. This includes that datacenters in Amsterdam can supply heat for 5.3% of the total heat demand of neighbourhoods in Amsterdam (Appendix E). Additionally, the datacenters do not demand benefits for their supply of residual heat to the district heating system since the residual heat is offered to the district heating industry without demanding benefits in 2017 and confirmed in the conversation with E. Barentsen of the DDA (Dutch Data Center Association, 2018, Appendix B, DDA). Furthermore, the conditions in the contracts agreed by the sequential actors include supply temperature, pressure, duration, ownership of technical components of the district heating system. Lastly, for consumers financial allowance options apply and affordability is safeguarded by the succeeding Heat Act from 2022.

4.1 SYSTEM CONFIGURATION A: CONTEMPORARY SITUATION

System configuration A (figure 11) represents the situation of a district heating system where DC together with other heat sources are the heat producers of a district heating supply temperature of 65 degrees Celsius. The supply temperature is dependent on the volume of heat supply of DC. When small DC are considered and located in vicinity to the residential heat demand, the temperature is upgraded to 70 – 75 degrees Celsius with a heat pump to avoid at all times legionella. When large DC are considered the temperature is upgraded to 90 – 120 degrees Celsius with a heat pump. The heat retailer exploits and manages the district heating infrastructure for transportation and distribution and purchases or owns the heat from various heat producers and sells the heat to the customers. In addition, the heat retailer owns the allocable technical components of storage, back-up systems and substations and can own the heat exchanger at the heat production. According to the conversation with R. van Ommen of AEB the ownership of the heat exchanger will depend on the assurance from the heat retailer or heat producer in terms of their financial capability, expertise and guarantee of quality (Appendix B). However, the conversation with H. Schelvis from the datacenter Equinix has shown that they are only willing to own the pipeline infrastructure to transport the heat to the heat exchanger and not willing to invest, own and be responsible for the maintenance of the heat exchanger (Appendix B).

The vision and aim of the heat retailer for the district heating system is to make use of sustainable heat sources where DC are classified as sustainable heat sources due to utilization of residual heat. The Heat Act is supportive in the heat retailer's preference in managing the district heating infrastructure and selling the heat to customers while ensuring affordability for customers of the district heating system. The succeeding Heat Act that will be in force from 2022 will therefore maintain the preceding Heat Act to continue this role and responsibilities for retailers while ensuring the public interest of affordability. As result, the implementation of the heat plans per neighbourhood by the municipality is focused on the selection of a heat retailer for the exploitation, management and operation of the district heating infrastructure and to sell the heat to the consumers. This selection can be based on a connection to an existing or new district heating system and corresponding heat retailer.

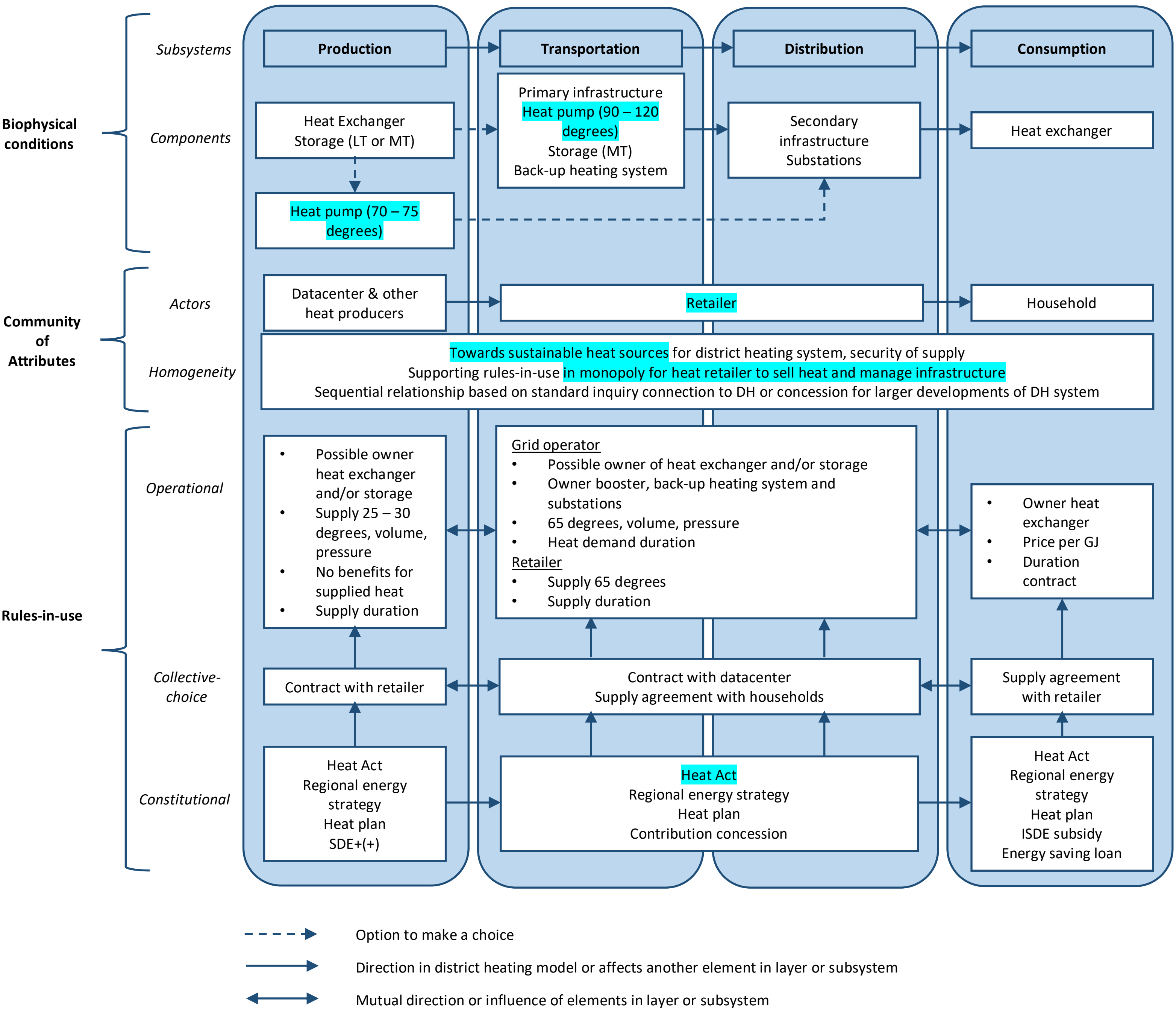

Figure 11: System configuration A: Contemporary situation

4.2 SYSTEM CONFIGURATION B: OPEN DISTRICT HEATING AND INDEPENDENT MANAGEMENT OF INFRASTRUCTURE

System configuration B (figure 12) represents the situation of a district heating system where DC together with other heat sources are the heat producers of a district heating supply temperature of either MT or LT. The choice for either MT or LT will affect the dimension and insulation of the pipeline infrastructure for transportation and distribution of the MT or LT heat. The supply of MTs requires the upgrade of available residual heat from DC with a heat pump located on or near the location of the DC. The LT district heating system supplies consumers who inhabit household buildings that are fitted in terms of their energy label for LT district heating supply and require heat pumps for additional heating within the household building for DHW usage.

The vision guiding this system configuration is that the district heating system is an open district heating system with several retailers and the use of several renewable heat sources that complement or replace each other and provide security of supply. This aligns with the current vision of the municipality of Amsterdam to develop a district heating system that is open, sustainable and affordable according to the conversation with B. Mantel (Appendix B). The infrastructure in this system configuration is managed by one heat network operator, either a grid operator or municipal heat company, who is designated as the only allowed actor to manage and operate the district heating infrastructure by the Heat Act from 2022. Since datacenters are not willing to own and be responsible for the maintenance of the heat exchanger, the heat network operator owns the allocable technical components of storage, back-up systems and substations and owns the heat exchanger at the heat production. The implementation of the heat plans per neighbourhood by the municipality is focused on the local grid operator or the establishment of a municipal heat company to safeguard the exploitation, management and operation of the district heating infrastructure and to sell the heat to the consumers.

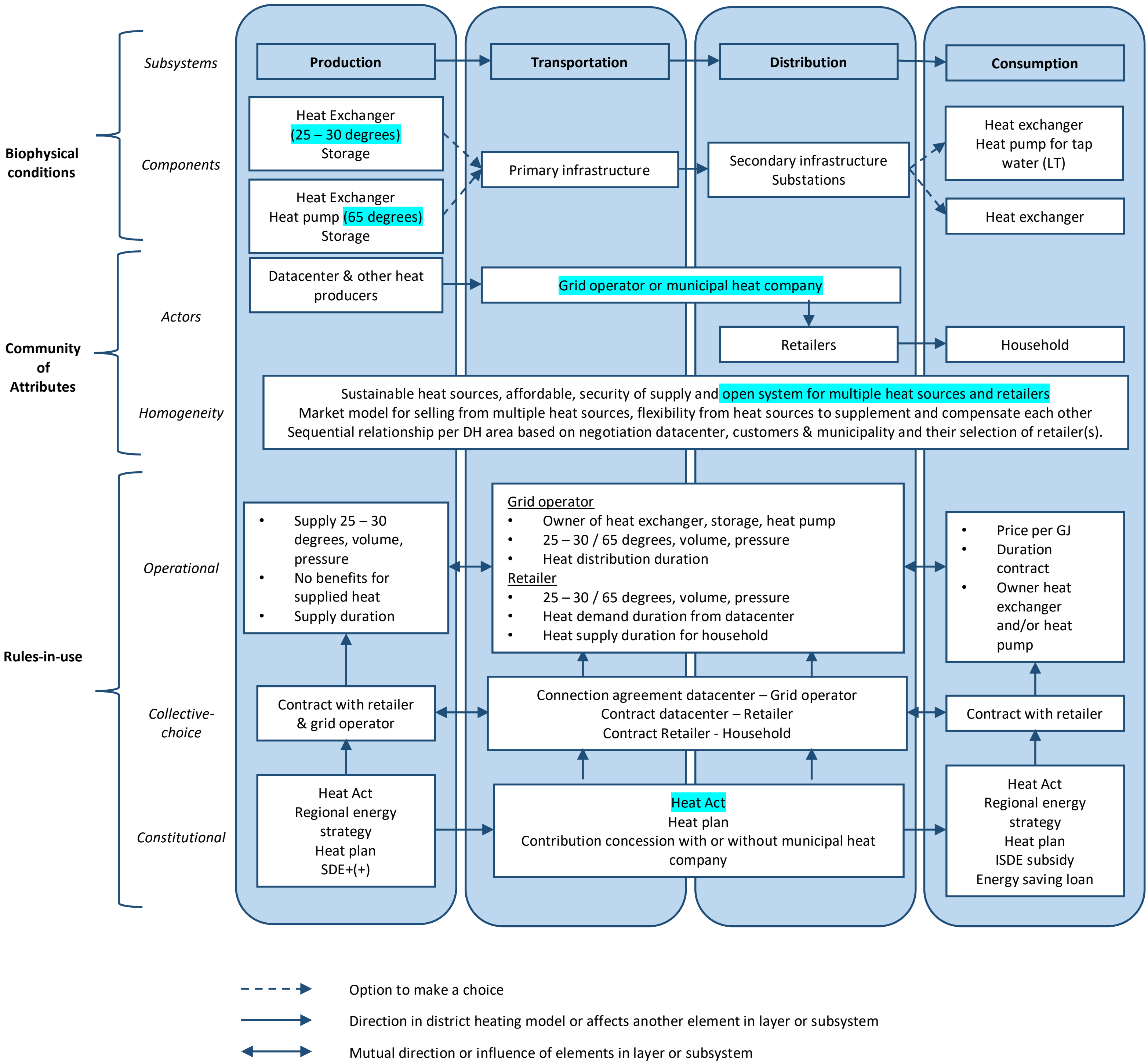

Figure 12: System configuration B: Open district heating and independent management of infrastructure

4.3 System configuration C: Experimentation of various district heating systems

System configuration C (figure 13) represents the situation of a district heating system that enables the development of new district heating systems and maintains contemporary district heating systems in different ranges of temperatures and actors that are allowed to take part in one or more subsystems. The choice for either MT or LT will affect the dimension and insulation of the pipeline infrastructure for transportation and distribution of the MT or LT heat. When MT supply is chosen for the district heating system, this requires the upgrade of available residual heat from DC with a heat pump located on or near the location of the DC. When LT supply is chosen for the district heating system, the household buildings of the consumers that are fitted in terms of their energy label for LT supply require heat pumps for additional heating within the household building for DHW usage. The actor that is selected or has taken the role to be responsible for the subsystems transportation and distribution will own the essential and allocable technical components of storage, back-up systems and substations and owns the heat exchanger at the heat production, since datacenters are not willing to own and be responsible for the maintenance of the heat exchanger.

The vision of this system configuration is based on the three values of public interests: sustainability, affordability, security of supply. In light of this vision, the succeeding Heat Act will be highly supportive for the various district heating systems and the selected or preferred actors per subsystem. The implementation of the heat plans per neighbourhood by the municipality is focused on either a local grid operator, the establishment of a municipal heat company or selection of a heat retailer to safeguard the exploitation, management and operation of the district heating infrastructure and to sell the heat to the consumers.

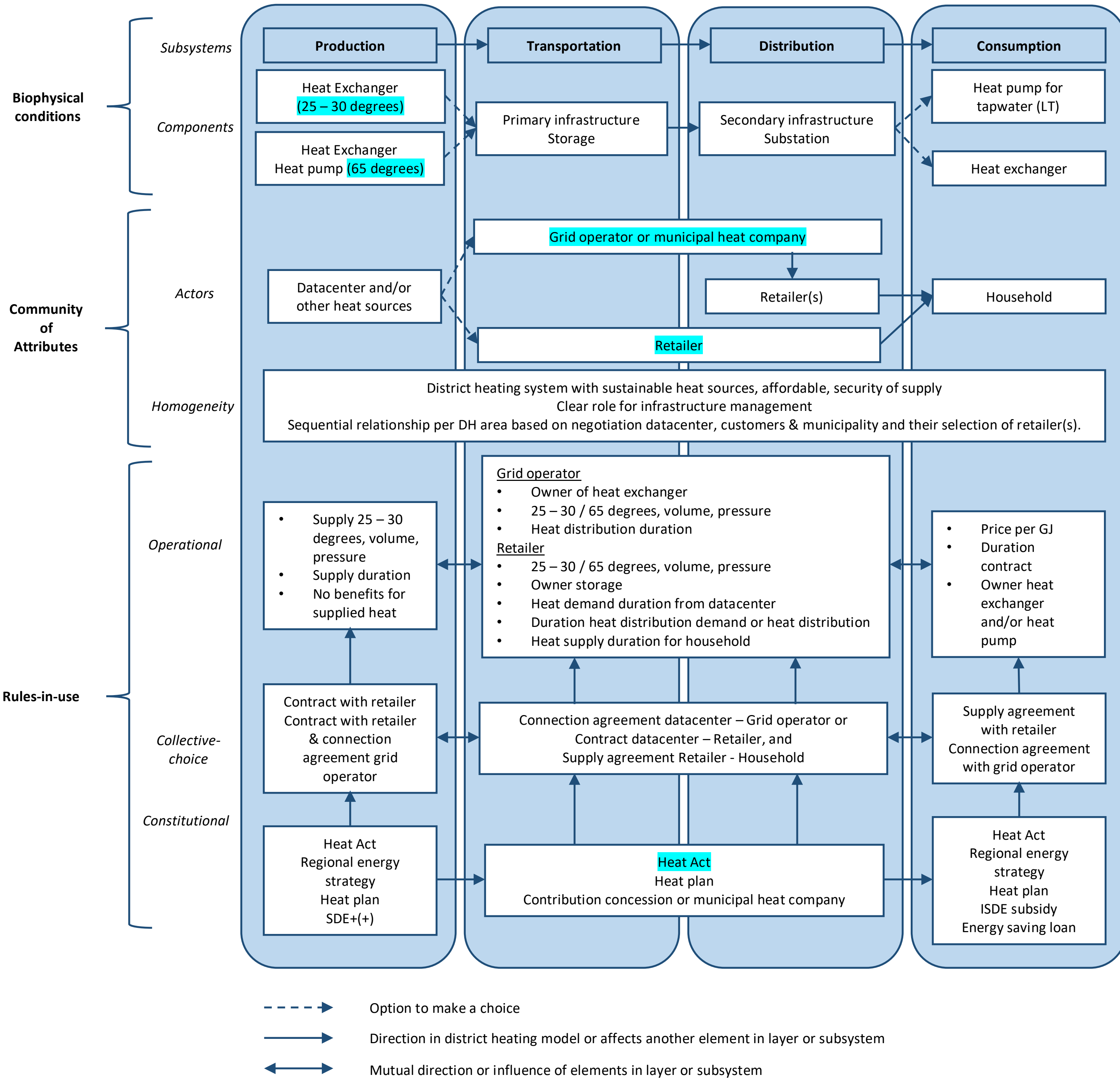

Figure 13: System configuration C: Experimentation of various district heating systems

5 RESULTS STEP IV: INSTITUTIONAL FEASIBILITY

The institutional feasibility of the three system configurations is reflected upon per and by comparing the three system configurations. This section aims to show how and in what way the system configurations diverge from the contemporary district heating system in Amsterdam and what alternative courses of action are required to be decided upon.

5.1 SYSTEM CONFIGURATION A: CONTEMPORARY SITUATION

This system configuration corresponds to the current district heating system in Amsterdam and requires little adaptation of the contemporary institutional system, in particular the Heat Act. The succeeding Heat Act will be in force from 2022 and this system configuration shows that the Heat Act would maintain to enable the allowed roles and responsibilities for a retailer in the subsystems of transportation and distribution and in selling the heat to the customers. This corresponds to expectation VII of table 6 (page 35) of the succeeding Heat Act that in the near future actor roles will not be split for production and retail from district heating infrastructure. The affordability for customers of district heating should therefore be secured via supervision on the tariff that are set by the retailer. Moreover, supervision is required on safeguarding the transition towards sustainable heat sources since other (less sustainable) are or might be integrated. The succeeding Heat Act in this system configuration would require of municipalities to select a heat retailer per or combination of heat plans of neighbourhoods for the responsibility of the subsystems transportation and distribution including the sale of the heat to consumers. The grid operators of electricity and gas would still be disregarded in a role in the district heating system. Since no designated role for grid operators exist by law, they will have to participate in various prospective projects for district heating systems, via letters of intent, to create and enable a role in district heating.

5.2 SYSTEM CONFIGURATION B: OPEN DISTRICT HEATING AND INDEPENDENT MANAGEMENT OF INFRASTRUCTURE

This system configuration demonstrates the impact that the succeeding Heat Act could have from 2022 onwards in terms of the designated role for the management and operation of the district heating infrastructure by a grid operator or municipal heat company in cooperation with or without a grid operator. This would have a large effect and adaptation of the contemporary institutional system and require a directing role of the municipality in developing a vision and strategy to achieve an open district heating system. This could be done via heat plans per neighbourhood where the municipality decides per or combination of neighbourhoods to make a grid operator or municipal heat company responsible for the exploitation, management and operation of the district heating infrastructure and sale of heat to consumers. Among other organizations, municipalities of the G4 of the Netherlands will give input on the development of the succeeding Heat Act and give examples on their district heating systems. This requires the directing role of municipalities to establish a district heating system similar to this system configuration to influence the development of the succeeding Heat Act to support and align this with their vision for district heating system(s) for the city. Since one concession of the municipality of Amsterdam expires soon, the establishment of this system configuration by the municipality of Amsterdam could influence the development of the succeeding Heat Act and as result influence the development of any other district heating systems in the Netherlands.

An open district heating system also requires a market model for multiple retailers on one district heating infrastructure and multiple heat sources. In addition to this, flexibility should be ensured by the grid operator of municipal heat company and the integrated heat sources when the supply of heat to the district heating system varies due to supplementation or compensation. Contracts will play an important role to secure these operational rules on flexible heat supply of the heat producer, such as DC, to the retailer and grid operator or municipal heat company. The number of contracts can be expected to be the high due to the number of retailers and heat producers and can result in complexity between the various contracts and corresponding actors. Therefore, platform management should be considered to maintain the overview of applied contracts, addition of contracts and adaptation or termination of contracts.

5.3 System configuration C: Experimentation of various district heating systems

This system configuration demonstrates a high uncertainty in actions and responsibilities per actor and disregards the designation of actors per subsystem due to the many available options that are supported by the succeeding Heat Act from 2022. This system configuration therefore has little effect on the current district heating system and continues the experimentation of configurations of supply temperatures, technical components, actors per subsystem next to continuing the current district heating system. This could have as affect that actors that can or want to take part in a subsystem are uncertain of their designated role. Furthermore, market actors could decide how each district heating system is configurated or municipalities that have sufficient capacity can take a directing role in the preferred district heating system(s) by developing heat plans per neighbourhood in terms of their technical components per subsystem, actors per subsystem and supply temperatures.

5.4 Comparison of system configurations

The three system configurations described illustrate three types of district heating systems where DC are integrated as heat source. The main characteristic similarity between the three system configurations is to safeguard one or more public interests: affordability, sustainability and security of supply to comply with the succeeding Heat Act according to the letter of Minister E. Wiebes (Wiebes, 2019). The largest difference between the three system configurations is the variation in the substantive context of the constitutional rules that are similarly present in each system configuration, in particular the succeeding Heat Act that will be in force from 2022. Due to these variations, system configuration C demonstrates a situation where still a lot of experimentation in district heating systems is supported by the succeeding Heat Act. System configuration B demonstrates the largest difference with system configuration A, since the succeeding Heat Act permits only a grid operator or municipal heat company to bear the responsibility of managing and operating the district heating infrastructure of transportation and distribution. However, due to a high number of heat sources and retailers in the district heating system complexity in applicable contracts could be a result and would require platform management.

The development of the succeeding Heat Act will take the experiences into account of municipalities who take on a directing role in setting examples of new district heating systems, such as system configuration B and C, that are distinctive from the contemporary district heating system that is represented by system configuration A. This offers a chance for municipalities to take on this directing role in participating in the development of the Regional Energy Strategies and the development of the heat plans per neighbourhood. Especially the heat plans can on the one hand be very useful to demonstrate the possible district heating system configurations for the development of the succeeding Heat Act, since municipalities can experiment and demonstrate their vision for district heating system(s) for its city. On the other hand, a legal instrument for municipalities currently lacks to prescribe an alternative heating system to support the heat plans of the municipality, which can lead to uncertainty from the municipality towards the prospective and current actors in the district heating systems and their subsystems. The certainty for municipalities should in one way or another be created and designed for municipalities since the heat plans per neighbourhood should be established in 2021. The heat plans will therefore be established before the succeeding Heat Act will enter into force from 2022, so a preview of the substantive context would be rather useful for municipalities to take on a directive role and designate roles for other actors within one or more subsystems of a district heating system.

A transition towards system configuration B or C, when a divergence is desired from system configuration A, has to be stimulated by municipalities by taking a directive role in the development of future district heating systems for its city and neighbourhoods. This is especially required since the heat plans per neighbourhood will be established in 2021 before the succeeding Heat Act will enter into force in 2022. System configuration C could be favoured by municipalities when they want to continue experimentation with various district heating systems, although this enlarges the uncertainty for actors in a designated role and responsibilities for one or more subsystems. System configuration B could be favoured by municipalities when their vision for a district heating system aligns with an open district heating system. However, system configurations B and C are largely diverging from the current district heating system as represented by system configuration A. A challenge can be foreseen for municipalities to decide between one of the three system configurations to prefer as district heating system for the city and neighbourhoods and to either let the types of district heating system coexist or replace each other.

5.5 SYSTEM CONFIGURATIONS AND THE AFFECT OF OR EFFECT ON ACTORS

The three system configurations demonstrate three district heating systems for the actors of the three sectors that were considered in this research. The three system configurations are described by the vision and characterized by the components of the three layers of the IADF. Five key components and the options that define distinctively the system configurations are selected and can be found in Appendix G. The following section describes the proposed courses of action per option of the five selected key components for each actor group.

5.5.1 Actor group 1: Datacenters

The proposed courses of action that correspond to the options of the key components for the DC are shown in figure 14. Overall, the proposed courses of action are focused on the effects from the five components and demands thoughtful selection of and cooperation with eligible actors and establishment of terms and conditions in contracts. In the cooperation with the district heating operator the investment and ownership of the heat exchanger and/or heat pump should be discussed. The heat plan per neighbourhood will direct the options and corresponding courses of action that the DC should take. This will lead the proposed courses of action for the DC.

Component	Option	Influence	Course of action
Supply temperature	High-temperature	Effect	• Discuss investment and ownership of heat pump and heat exchanger with district heating operator.
	Mid- and low temperature		
Number of heat sources in district heating system	DC and other heat sources	Effect	• Demand of heat should be secured through contracts to avoid surplus of residual heat.
	One DC		
District heating operator	Retailer	Effect	• Establish cooperation with the retailer for grid connection contract and supply of residual heat.
	Municipal heat company	Effect	• Establish cooperation with municipal heat company for grid connection contract and supply of residual heat.
	Grid operator	Effect	• Establish cooperation with grid operator for grid connection contract • Establish cooperation with retailer for supply of residual heat.
Sale of heat	One retailer	Effect	• Establish contract with retailer for supply of residual heat.
	Multiple retailers	Effect	• Select retailer from eligible retailers to establish contract for supply of residual heat.
Succeeding Heat Act	Monopoly situation for	Effect	• Cooperation with only one market actor for connection to infrastructure of district heating and sale of residual heat.
	Social actors in charge of	Effect	• Number of contracts are dependent on type of district heating operator (either municipal heat company or grid operator).
	Heat plans are supported	Effect	• Heat plans direct the options of the other components and datacenters will need to take action according to the preferred option.

Figure 14: Courses of action for datacenters.

5.5.2 Actor group 2: Retailers and utility companies

The proposed courses of action that correspond to the options of the key components for the retailers and utility companies are shown in figure 15. Retailers and utility companies will mainly experience effects from the options of the five key components. Several options result in that they could continue their current activities in district heating when they match with the current district heating system that they are active in. When the option of a key component differentiates from the contemporary district heating systems this has as consequence that the actor should transform the strategy of their business according to the effect of the option. The actors can only have influence on the supply temperature level when they consider household buildings for a district heating system that can be supplied with HT, MT or LT.

Component	Option	Influence	Course of action
Supply temperature	High-temperature	Effect and/or affect	• Continue activities in high-temperature district heating. • Investments in heat pumps when DCs are considered to upgrade the temperature of the residual heat to HT.
	Mid- and low temperature	Effect and/or affect	• Phase out HT heat sources • Lower supply temperature in current district heating system • Add LT heat sources such as DCs
Number of heat sources in district heating system	DC and other heat sources	Affect	• Expand district heating system and consumers by adding multiple heat sources of required supply temperature or upgrade produced temperature
	One DC	Affect	• Only a DC with large amounts of residual heat in vicinity of a neighbourhood should be considered to be the single heat producer in order to achieve a profitable business case.
District heating operator	Retailer	Effect	• Continue activities in management and operation of district heating infrastructure next to sale of heat to consumers.
	Municipal heat company or grid operator	Effect	• Transform district heating business to only sale of heat.
	Grid operator	Effect	• Transform business operations in district heating when no longer eligible as district heating operator.
Sale of heat	One retailer	Effect	• Continue activities in sale of heat to consumers. • Continue activities in partnerships and contracts with heat producers.
	Multiple retailers	Effect	• Compete among other retailers of heat for consumers and lowest tariff. • Establish new partnerships with heat producers.
Succeeding Heat Act	Monopoly situation for market actors	Effect	• Continue activities in sale of heat and management and operation of district heating infrastructure.
	Social actors in charge of infrastructure	Effect	• Transform district heating business to only sale of heat.
	Heat plans are supported	Effect	• Heat plans direct the options of the other components and retailers and utility companies will need to take action according to the preferred option.

Figure 15: Courses of action for retailers and utility companies.

5.5.3 Actor group 3: Technical consultancy or manufacturers

The proposed courses of action that correspond to the options of the key components for the technical consultancy and manufacturer companies for district heating are shown in figure 16. Companies that have expertise in the development of business cases or are involved to provide the infrastructure and technical components will mainly experience effects from the options of the five key components. The options will affect the development of the business cases where the supply temperature and number of heat sources should be taken into account. The remaining options of the district heating operator will affect the type of clients that they will work with and for.

Component	Option	Influence	Course of action
Supply temperature	High-temperature	Effect	• Focus development of business cases and projects for the exploitation of the district heating infrastructure to preferred supply temperature.
	Mid- and low temperature		
Number of heat sources in district heating system	DC and other heat sources	Effect	• Take multiple sources of heat and amount of supply of heat into account in development of business cases.
	One DC	Effect	• Take one source of heat and amount of supply of heat into account in development of business cases.
District heating operator	Retailer	Effect	• Client to develop business cases and projects for the exploitation of the district heating infrastructure.
	Municipal heat company		
	Grid operator		
Sale of heat	One retailer	Effect	• Take one retailer into account that has influence on the heat load on the transportation and distribution infrastructure.
	Multiple retailers	Effect	• Take multiple retailers into account that have influence on the heat load on the transportation and distribution infrastructure.
Succeeding Heat Act	Monopoly situation for market actors	Effect	• Client to develop business cases and projects for the exploitation of the district heating infrastructure.
	Social actors in charge of infrastructure		
	Heat plans are supported	Effect	• Heat plans direct the options of the other components and consultancy and manufacturer companies will need to take action according to the preferred option.

Figure 16: Courses of action for technical consultancy and manufacturers in district heating systems.

5.5.4 Actor group 4: Municipalities

The proposed courses of action that correspond to the options of the key components for municipalities are shown in figure 17. Municipalities have the ability to influence and set the preferred options of district heating operator, number and type of heat sources, supply temperature per neighbourhood via the heat plan per neighbourhood. This affects the other actor groups and therefore demands a directive role from the municipalities. This has two results, when the preferred option corresponds to the contemporary district heating system the municipality can continue her current activities and partnerships in district heating. However, when the preferred option differs from the contemporary district heating system, new activities, partnerships or even the establishment of a municipal heat company is recommended.

Component	Option	Influence	Course of action
Supply temperature	High-temperature	Affect	• Set preferred supply temperature in heat plan per neighbourhood according to household buildings characteristics of demand and energy label.
	High- and mid temperature		
Number of heat sources in district heating system	DC and other heat sources	Effect	• Set preferred amount of heat sources in heat plan per neighbourhood. • Number of neighbourhoods to connect to district heating system is related to amount of heat supply from the heat source(s).
	One DC		
District heating operator	Retailer	Effect	• Continue partnership with retailer that is currently the district heating operator of the district heating system of the city.
	Municipal heat company	Effect	• Establish municipal heat company with responsibility for management and operation of district heating infrastructure and sale of heat.
	Grid operator	Effect	• Establish new partnership for management and operation of district heating infrastructure with grid operator.
Sale of heat	One retailer	Effect	• Take one or multiple retailers into account that want to make use of local heat sources in the city for the sale of heat to the consumers of residential neighbourhoods.
	Multiple retailers	Effect	
Succeeding Heat Act	Monopoly situation for market actors	Effect	• Continue partnership with retailer that is currently the district heating operator of the district heating system of the city.
	Social actors in charge of infrastructure	Effect	• Establish municipal heat company. • Establish partnership with grid operator.
	Heat plans are supported	Affect	• Set preferred district heating operator, number and type of heat sources, supply temperature per neighbourhood. Use this to demonstrate and give advice to the development of the succeeding Heat Act

Figure 17: Courses of action for municipalities.

5.5.5 Actor group 5: Grid operators

The proposed courses of action that correspond to the options of the key components for the grid operators are shown in figure 18. The effects of the options of the key components are mainly focused on the designated or undesignated role for grid operators in the management and operation of district heating infrastructure. As effect, grid operators can or cannot take an active role in the management and operation of district heating.

Component	Option	Influence	Course of action
Supply temperature	High-temperature	Effect	• Integrate contemporary situation as actor for both or either management and operation of transport or distribution of heat.
	Mid- and low temperature	Effect	• Relatively new district heating system where no actors yet dominate, opportunity to become leading district heating operator and focus activities on.
Number of heat sources in district heating system	DC and other heat sources	Effect	• Large scale infrastructure for transportation and distribution due to amount of heat sources and consumers.
	One DC	Effect	• Small scale infrastructure for transportation and distribution due to single heat source and consumers.
District heating operator	Retailer	Effect	• No designated role and business case in transportation or distribution.
	Municipal heat company	Effect	• Only role and business case in transportation and distribution when included as partner in municipal heat company.
	Grid operator	Effect	• Take active role in the management and operation of the transportation and distribution infrastructure to transport and distribute heat from heat producers to consumers.
Sale of heat	One retailer	Effect	• Take one retailer into account that has influence on the heat load on the transportation and distribution infrastructure when the grid operator is the district heating operator or is partner in municipal heat company.
	Multiple retailers	Effect	• Take multiple retailers into account that have influence on the heat load on the transportation and distribution infrastructure when the grid operator is the district heating operator or is partner in municipal heat company.
Succeeding Heat Act	Monopoly situation for market actors	Effect	• No designated role in transportation or distribution of district heating infrastructure.
	Social actors in charge of infrastructure	Effect	• Take active role in the management and operation of the transportation and distribution infrastructure.
	Heat plans are supported	Effect	• Heat plans direct the options of the other components and grid operators will need to take action according to the preferred option.

Figure 18: Courses of action for grid operators.

5.5.6 Actor group 6: Law and policy makers

The proposed courses of action that correspond to the options of the key components for law and policy makers are shown in figure 19. Law and policy makers can have the most influence on the options of key components in comparison to the other actor groups. Their influence is mainly focused on setting the eligibility of market and/or social actors and legal support for heat plans in the succeeding Heat Act. Furthermore, one or more of the three public interest should be secured per option of the key components.

Component	Option	Influence	Course of action
Supply temperature	High-temperature	Affect	• Establish legal or policy guidelines per temperature option for district heating operators, partnerships, investment and ownership of heat exchangers, heat pumps. • Consider differentiating tariff for LT heat since this requires additional investments for heat pumps at consumers. • Secure public interest security of supply.
	Mid- and low temperature		
Number of heat sources in district heating system	DC and other heat sources	Affect	• Secure public interest of sustainable heat sources and DCs next to affordability and security of supply.
	One DC	Affect	• Secure public interest of affordability and security of supply next to sustainability of the residual heat of the DC.
District heating operator	Retailer	Affect	• Set eligible and ineligible actors for management and operation of district heating infrastructure in succeeding Heat Act. • Secure public interests of affordability, security of supply and sustainability.
	Municipal heat company		
	Grid operator		
Sale of heat	One retailer	Affect	• Continue legal eligibility of a single retailer for sale of heat from current Heat Act in succeeding Heat Act. • Secure public interest affordability.
	Multiple retailers	Affect	• Set in succeeding Heat Act terms to transform district heating market into an open market that allows competition between retailers. • Secure public interest affordability.
Succeeding Heat Act	Monopoly situation for market actors	Affect	• Continue legal eligibility of a single market actor for sale of heat next to management and operation of district heating infrastructure. • Secure public interests of affordability, security of supply and sustainability.
	Social actors in charge of infrastructure	Affect	• Set eligible social actors for management and operation of district heating infrastructure. • Secure public interests of affordability, security of supply and sustainability.
	Heat plans are supported	Affect	• Establish legal support for execution of heat plan per neighbourhood by municipalities.

Figure 19: Courses of action for law and policy makers.

6 DISCUSSION

This chapter discusses the evaluation of the three system configurations on the implications for the actors of district heating. Furthermore, the methods applied for finding the technical and institutional feasibility is evaluated and recommendations are made to enhance current research.

6.1 DISTRICT HEATING AND RESIDUAL HEAT FROM DATACENTERS AS URBAN PROCESS

In Urban Symbiosis the use of by-products from operations in cities or urban areas is seen as an opportunity for alternative systems. The fundamentals of Urban Symbiosis support the usage of heat from these sources but the extent of sustainability of the source should be taken into account. The use of the residual heat from the urban and industrial process of DC should be included in district heating systems, since DC are considered as sustainable heat sources when they make use of electricity of renewable energy sources. The three system configurations show the institutional opportunity of residual heat of DC for district heating to contribute as sustainable heat source. The system configurations show that district heating systems can be configured in multiple variations due to the institutional system that supports or limits options of the components and actors of a district heating system. The assessment of the extent of residual heat supply quantifies this opportunity. The assessment has shown that DC produce a significant amount of residual heat to use as input for district heating and three institutional systems of district heating are developed to support this. Apart from DC, other sustainable heat sources can be considered that were excluded from this research such as heat from thermal power stations, heat obtained from waste incineration, heat from industrial processes, geothermal heat sources and biomass.

6.2 IMPLICATIONS FOR ACTORS OF DISTRICT HEATING

The system configurations that were developed in this research outline three distinct types of district heating systems where DC are integrated as heat source. The system configurations for each actor group are evaluated on the implications for the six actor groups.

The DC are at the starting point of integrating as heat producers of residual heat in district heating systems. The three system configurations show the possible type of district heating systems to take part in and cooperate with the actor that leads the development and operation of the district heating system. Since DC can enter into various letters of intent with the different actors that currently are permitted to take this role, could also direct the type of district heating system to be developed. This implies the capability of DC to select and cooperate with actors that align with their vision and are eligible as district heating operator.

The retailers and utility companies are active in system configuration A: contemporary situation where they are permitted to be active in subsystems production, transportation, distribution and sale of heat. This has resulted in a strong monopoly position for them in current district heating systems that have taken time and investments to realize. When the institutional system of configuration A is maintained this implies for retailers and utility companies that they can continue their current activities in district heating. However, municipalities, law or policy makers could prefer either system configuration B or C and direct the development of new district heating systems or transformations of contemporary district heating systems to these types of district heat systems. This would imply adaptation of their developed district heating systems and transformation of their business operations in district heating.

The technical consultancy or manufacturer companies work for and with actors from district heating systems and the three system configurations determine the clients that they shall work for and with. When district heating systems are being developed as according to the institutional system of system configuration A, this implies that the clients that they will work for and with will be mainly retailers and utility companies from the market sector since they are eligible as district heating operator. When district heating systems are being developed according to the institutional system of system configuration B or C, this implies that the clients that they shall work for are from a diverse group of clients depending on the configured district heating system that are either retailers, utility companies, municipal heat companies or grid operators.

Municipalities can take a directive role in the development of future district heating systems to continue with the contemporary district heating systems of system configuration A and cooperation with the retailer as district heating operator. On the other hand, municipalities can direct the development of new or transformation of current district heating systems to either system configuration B or C when the preferred district heating operator, number and type of heat sources, supply temperature is included in the heat plans for the neighbourhoods. The heat plan per neighbourhoods directs future developments of district heating and designates the role and responsibilities of the other actors. This implies that municipalities take a directive role to provide certainty for the actors that can have a designated role in one of the three system configurations. However, the succeeding Heat Act will be in force from 2022 and could be in contrary to the established heat plans. Although the development of the succeeding Heat Act will be done in cooperation with municipalities and this implies for municipalities to give input on their experience with the three system configurations. Additionally, the establishment of a municipal heat company gives municipalities the possibility to be in charge of the district heating infrastructure and sale of heat to affect the development of all district heating systems in its city.

Grid operators are dependent on the role that they get designated via the municipality in the heat plans of the neighbourhoods of a city or when grid operators are included in the succeeding Heat Act as eligible district heating operator. The institutional system of system configurations A does not provide this designated role and prevents an active role for grid operators in district heating systems due to the exclusion of grid operators as eligible district heating operator in the succeeding Heat Act.

Law and policy makers are in charge of the development of the succeeding Heat Act that is expected to give direction to one of the three system configurations. System configuration A would imply that the succeeding Heat Act is a continuation of the contemporary district heating systems and corresponding eligible actors per subsystem. System configuration B and C would imply that the succeeding Heat Act is the opposite of the current Heat Act. The institutional system of system configuration B would imply the inclusion of social actors, such as a municipal heat company or grid operator, as eligible and in charge of the district heating infrastructure in the succeeding Heat Act. The institutional system of system configuration C would imply the inclusion of social and market actors, such as retailers and utility companies, to be eligible in charge of the district heating infrastructure.

6.3 METHOD TECHNICAL FEASIBILITY

The results of the estimation of the heat supply from DC that are located in Amsterdam is based on the maximum power capacity where three assumptions were made and can influence the estimated heat supply when variations occur. First, only 6 DC included the exact maximum power capacity and 22 DC included a range of their maximum power capacity. The average of the range of maximum power capacity is used in the estimation of the heat supply. It is expected that the 22 DC vary in their maximum power capacity within this range. As a result, the total heat supply could be higher or lower than the estimation used in this study. Secondly, it is assumed by the statement of H. Schelvis of Equinix that 70% of DC maximum power capacity will be used by DC. The estimation of the utilized power per DC is based on this percentage. It is expected that not all DC in Amsterdam fully utilize their capacity but will reach the 70% within a few years. The conversation with H. Schelvis shown that DC reach the 70% utilization of its maximum power capacity between 7 and 8 years (Appendix B). Lastly, a subtraction of 10% of the utilization of the maximum power is made due to the assumption based on the conversation with E. Barentsen of DDA that this included the electricity usage for cooling equipment and lighting and should be excluded in the estimation of heat supply. The 10% can vary per DC and can have a minor influence on the estimation of the heat supply from DC. The losses of heat in the transportation and distribution of heat to residential neighbourhoods is not taken into account since no distances were used in the assessment of the heat supply with the residential heat demand. The results of the extent therefore present the residual heat supply of the considered DC at the production and thus location of the DC.

The results of the estimation of the heat demand per neighbourhood of Amsterdam is based on the number of households in one of the seven ranges of household building construction year and the corresponding average gas use for the household consumption purposes. The reason for the usage of this method is the availability of data. Two other methods were considered as well because of a more accurate estimation of the heat demand but could unfortunately not be applied due to unavailability of data. Therefore, the methods are included in the recommendations (section 6.3) for improvement of the estimation of the heat demand per neighbourhood. The estimation of the total gas use per neighbourhood is validated by the average gas use per neighbourhood of CBS. The data of CBS is based on the grid operator registers. Therefore, the calculation of heat supply from DC using the CBS validation is more accurate. The heat demand for households is subject to change when the energy label of the household building is improved, or the heat consumption pattern is changed, because this decreases the heat demand. This is not taken into account in the estimation of the heat demand of the residential neighbourhoods of Amsterdam but is recommended for further research since households are or can become stimulated to improve their energy label.

6.4 METHOD INSTITUTIONAL FEASIBILITY

The three system configurations are based on the literature review and interviews where the technical design and components, eligible actors and shared vision and values lead the development of the system configurations. In general, the technical design and components are not very distinctive but in combination with the eligible actors per subsystem and the vision and values overarching the district heating system, they have impact on the constitutional-choice rules that enables the system configuration. Therefore, the model for the development of the system configurations was very helpful to visualise all three IADF variable layers of the system configurations. However, the context of the constitutional rules differentiates between the system configurations and is validated by discussing the system configurations with an expert panel. The model for the development of the system configurations is used to analyse the interviews with the actors from the three sectors. As a result, the system configurations are a representation of the preferred district heating system with DC as heat source by a combination of actors. The interviews reflect the current perspective of the actor on district heating and is thus influenced by their current vision and values in district heating. The system configurations reflect therefore current perspectives on district heating systems and could be adjusted in the future when the actor's vision and values change. Therefore, it should be taken into account that the developed system configurations are subject to changes in vision and values due to political preferences or company strategies. Proposed courses of action are developed based on the options per characteristic component of the three system configurations. The proposed courses of action were developed according to the findings on the role and actions based on the described system configurations and gained knowledge and interpretation from the interviews per actor. However, the actors that were considered in this research are can decide what actions to take and this could be research in further research by using the action situation of the IADF.

6.5 RECOMMENDATIONS FOR ENHANCEMENT OF THIS RESEARCH

The research of this thesis could be further enhanced by including a couple recommendations for the technical and the institutional feasibility.

Technical feasibility:

For a more accurate estimation of the residual heat supply from DC in Amsterdam, the exact maximum power capacity and current operational power capacity of the considered DC should be used.

The extent of residual heat supply from DC for residential neighbourhoods can be further researched when distances are taken into account between the location of supply and demand. This will lead to a more accurate estimation of the extent of residual heat supply from DC with the heat demand.

The estimation of the heat demand from the neighbourhoods in Amsterdam could be compared by applying two other methods that unfortunately could not be applied in this thesis due to publicly unavailable data:

- For the calculation of heat demand by building type and years of construction, the dataset from RVO contained the average gas use per building type and year of construction (RVO, 2018a). However, the BAG dataset did not include building type per address.
- For the calculation of heat demand by square meters of household, the BAG dataset did contain square meters per address. The building type per address in combination with the square meters would be required to get the best possible estimation of the gas demand per address.

The grid operator registers can be used to validate and assess to the two abovementioned methods to find out which method could be used for the most accurate estimation of heat demand per neighbourhood.

Predictions on the change of heat demand from the residential neighbourhoods can be assessed by taking into account improvements of the energy label of the household buildings. This will lead to future scenarios of heat demand and improvement of the extent of heat supply with the heat demand.

Institutional feasibility
The system configurations represent the current perspectives of the actors considered in this thesis. No alternative subsystem options were considered that are based on technological innovations or examples system configurations from abroad. This could lead to new insights to the actors that are active in the district heating sector in Amsterdam and The Netherlands.

The actors considered in this research were selected from the three sectors: market, technical and social. In the interviews and literature research the ACM was often mentioned as actor that bears the responsibility to control the execution of rules by the actors if they act within the designated role, responsibilities and activities. Since the ACM plays a significant role in controlling each actors' role, responsibilities and activities they should be included in the configuration of district heating systems.

The future constitutional-choice rules, such as the Heat Act and Regional Energy Strategies, are taken into consideration in the research of this thesis. However, the actor's future vision or strategies were not part of this research. These visions and strategies could help to predict decisions and actions taken in action situation of the IADF framework.

7 CONCLUSION

The extent of heat supply from DC was essential to be researched when considered as heat source for a district heating system to secure heat to residential neighbourhoods in light of the fundamentals or Urban Symbiosis. Furthermore, the realization of an institutional system of district heating where DC as supplying heat source are integrated was required to be researched as this will cause substantial changes and requirements in the roles and responsibilities from DC operators and the actors operating in the district heating system of Amsterdam. The following main research question is answered through this research:

To what extent can residual heat from datacenters be integrated in district heating in terms of technical and institutional feasibility and does a framework for institutional mapping contribute to finding the institutional feasibility?

This chapter summarizes the results of the four research steps on the technical and institutional feasibility by taking into account the previous discussion chapter and gives insight on the use of the IADF for institutional mapping. Lastly, recommendations are made to use the results of this research for further research on district heating systems.

7.1 RESIDUAL HEAT FROM DATACENTERS FOR DISTRICT HEATING

A high amount of DC are present in the Netherlands and are mainly located in and around Amsterdam where 36 DC of the total of 200 commercial DC in the Netherlands. This research investigated the use of DC for district heating since they are recommended as suitable sustainable heat sources for district heating. The research objective is comprised by the fundamentals of Urban Symbiosis where the use of by-products from operations in cities or urban areas is seen as an opportunity to serve as an alternative raw material for potential users in geographic proximity and contributes to environmental benefits. Two main conclusions can be made. First, the number of DC in Amsterdam and the extent of residual heat supply for district heating has shown that DC should be considered as heat supplying source that is sustainable and in proximity of the heat demand from residential neighbourhoods. Secondly, district heating systems can be configured in multiple variations due to the institutional system that supports or limits options of the components and actors.

This research has found the extent of supply of residual heat from DC to the demand for district heating of all neighbourhoods for the case of Amsterdam. A total of 28 DC is used for the assessment of the technical feasibility to use DC as heat source for district heating for all neighbourhoods in Amsterdam. The extent of residual heat supply from the 26 considered datacenters in Amsterdam is estimated to be 1,42 PJ. The residential heat demand from the neighbourhoods in Amsterdam is estimated to be 27,04 PJ. The technical feasibility of residual heat supply from DC for the neighbourhoods of Amsterdam is estimated, in combination with a CBS validation, to supply between 5.3% and 9.1%. This shows that DC can contribute as heat source to the current or new district heating system(s) of Amsterdam. Since DC are considered as sustainable heat sources, this research has shown that the amount of available residual heat of DC should be considered by district heating operators and the municipality. To add to the total available heat supply and as addition to sustainable heat sources to integrate in district heating systems in the development of district heating in Amsterdam. It is therefore recommended for DC to prepare and enhance their capability to cooperate with actors from district heating to connect DC to new and/or existing district heating systems where the residual heat can be used.

In order to find the new roles and responsibilities of actors in a district heating system where DC are integrated as heat supplying source the social and spatial variables of the IADF were analysed. This resulted in the development of a model to develop district heating system configurations according to the three main variables of the IADF with corresponding components. First, the layer of biophysical conditions is set up with the subsystems and technical essential and allocable components of district heating. The number of residual heat supply from DC for district heating from the research on the technical feasibility should here be taken into account. Second, the layer of community of attributes is set up with the optional actors responsible for one or more subsystems and the homogeneity is described by the vision and sequential relationship that is shared by the actors present in the entire district heating system. Lastly, the layer of rules in use is set up where all applied legal rules for actors of district heating are included in the constitutional-choice rules. They influence the collective-choice rules that consist of the contracts between the actors between the subsystems of the biophysical conditions. The constitutional-choice and collective-choice rules influence the daily role, responsibilities and activities of the actor(s) per subsystem of the district heating system.

Three system configurations are developed according to the model with IADF layers that represent each a district heating system where DC are integrated as residual heat supplying source. The literature review on the three IADF variables and the interviews with actors from the three sectors: market, technical and social sector is used for the development of the three system configurations. In short, the first system configuration corresponds to the current district heating system of Amsterdam with a retailer that is the district heating operator and retailer of the heat where the current and succeeding Heat Act allows the retailer to be active in multiple subsystems of the district heating system. The second system configuration demonstrates an open district heating and independent management of the infrastructure of the district heating system where the succeeding Heat Act has most impact by allowing only a municipal heat company or grid operator as eligible district heating operator. Additionally, to the second system configuration, multiple retailers are present for the sale of heat to consumers where a market model will be required for. The third and last system configuration demonstrates various district heating systems that are allowed to experiment with in ranges of temperature, actors eligible per subsystem and technical components by the succeeding Heat Act. The last system configuration therefore represents a high uncertainty through the experimental characteristic of this system configuration.

The three system configurations are compared to each other and the affect of or effect on district heating actors is described per characteristic component of the three system configurations to assess the institutional feasibility. The comparison between the system configurations showed that they are distinctive in the constitutional-choice rules, in particular the succeeding Heat Act, that enables which actors are eligible to be responsible per subsystem or the option for one or more actors per subsystem. The heat plans could be used by the municipality to experiment with the system configurations and demonstrate their vision. Through this experimentation and demonstration of district heating systems they could give advice to the development of the succeeding Heat Act. The participation of social actors, such as municipalities and provinces, to give input in the development of the succeeding Heat Act confirms the argument of Crawford & Ostrom (2005, p. 18) that "*rules are often self-consciously crafted by individuals to change the structure of repetitive situations that they themselves face in an attempt to improve the outcomes that they achieve*.". System configuration C enlarges the uncertainty that the succeeding Heat Act could give for all interested actors in a district heating system with DC as heat supplying source. In contrary, system configuration B minimizes uncertainty and gives certainty by including eligible actors per subsystem in the succeeding Heat Act.

The actors that have most influence in affecting the components and their options in the development of new district heating systems or transformation of existing district heating systems are the social actors: law and policy makers and municipalities.

- Law and policy makers are in charge of the development of the succeeding Heat Act and can use the input and experience in various district heating systems from municipalities. Above all, the three public interests affordability, security of supply and sustainability should be secured by the succeeding Heat Act in either of the three system configurations.
- Municipalities can demonstrate district heating systems via the heat plan that needs to be established per neighbourhood to see what system configuration works and which not to give input in the development of the succeeding heat act. However, a conflict between the succeeding Heat Act and municipalities could emerge when the heat plans divert from the succeeding Heat Act. Additionally,

municipalities can become active in district heating system as actor through the establishment of a municipal heat company to be in charge of future developments of district heating in the infrastructure, temperature level and sale of heat.

Actors that will be most influenced by the effect of the components and their options in the development of new district heating systems or transformation of existing district heating systems are the market and technical actors: DC, grid operators, retailers and utility companies and technical consultancy and manufacturer companies of district heating.

- The cooperation of DC with a district heating operator is dependent on the preferred system configuration by the law and policy makers and municipality. However, in advance of heat plans and the succeeding Heat Act they are currently allowed to cooperate with multiple possible district heating operators from the three system configurations to develop a new or connect to an existing district heating system.
- Retailers and utility companies can continue their current activities in district heating at least until the establishment of heat plans per neighbourhood by municipalities in 2021 or the succeeding Heat Act that will be in force from 2022. They should take into consideration that they might have to transform their business operations into either only sale of heat when they are not eligible anymore as actor for the management and operation of district heating infrastructure. The possible multiple heat sources in a district heating system and the effect on the heat load in the transportation and distribution infrastructure should be taken into account when they are designated or eligible as district heating operator.
- Grid operators are dependent on the designated role for district heating operator in the heat plans established by the municipality or when their eligibility is secured through the succeeding Heat Act that will be in force from 2022. Additionally, the grid operators can try to enter into a partnership with a municipal heat company to safeguard a role in district heating. The possible multiple heat sources or retailers in a district heating system and the effect on the heat load in the transportation and distribution infrastructure should be taken into account when they are designated or eligible as district heating operator.
- The clients of technical consultancy and manufacturer companies are influenced by the choice for a system configuration since this determines the district heating operator. This could result in to have only retailers, municipal heat company with or without grid operator or a combination of the actors to work for and with as clients.

7.2 IADF FOR INSTITUTIONAL MAPPING

The conceptual model for the research design is the IADF for mapping of the institutional feasibility and demonstrates some advantages and disadvantages.

The advantages are as followed:

- The analysis of the biophysical conditions, community of attributes and rules-in-use by literature showed a thorough analysis of options per IADF variable to map the institutional system of district heating. The interviews conducted added to missing elements of the literature review and together could be easily translated in various options per IADF layer, which lead to the model for the development of the system configurations.
- The analysis of the IADF variables have proven to be configured into three system configurations of district heating where DC are integrated as heat supplying source.
- The analysis and comparison of the three system configurations offered insight on possible alternate courses of action from the contemporary district heating system.
-

The disadvantages are as followed:

- The IADF did not include control mechanisms or actors that manage the overall functioning of the district heating system and its subsystems. The actions or decisions taken based on the choice of a system configuration would influence the designated roles, responsibilities and actions of actors. Therefore, control mechanisms or actors, such as the ACM, should be taken into account as well.
- The IADF did not include the economic variables in this research that could influence the system configurations and actions and decisions to be taken. This should be taken into account since affordability is a public interest to safeguard in the development of future district heating systems and will be included in the succeeding Heat Act.

7.3 RECOMMENDATIONS FOR FUTURE RESEARCH

The results of this thesis could be used for an extension of the current research on district heating systems where DC are integrated as heat source. The following recommendations can lead to extension or broadening of the research by using the results of this thesis for the technical and institutional feasibility.

In this research the local heat source that was considered are DC. However other local heat sources that produce residual heat could be valuable as heat supplying source for district heating for neighbourhoods of cities as well. The research could be broadened when more local heat sources are considered to identify the local heat sources that could supply a district heating system of residual heat that is affordable, secure of supply and sustainable.

The results of the technical feasibility of this research can be used in Geographical Information Systems (GIS) for geographic mapping and select households per neighbourhood to connect to district heating system with DC as heat source. By using GIS the geographical information of district heating can be mapped and used for modelling and simulation (Bernd Möller, 2010; Finney et al., 2012; Gils, Cofala, Wagner, & Schöpp, 2013; Nielsen & Möller, 2013). To map geographic information of local energy demand and supply a GIS tool, called PLANHEAT, has been developed recently and is therefore recommended to apply in further research (PLANHEAT, n.d.). PLANHEAT consists of three modules: mapping, planning and simulating the local energy demand and supply. As result, PLANHEAT shows possible future scenarios, helps to understand and compare the future scenarios.

The institutional feasibility can be further assessed to execute a thorough research on the action situation where actions and decisions will be decided upon by the actors of district heating. The research and results of this thesis can be used in research on the action situation. First, the technical feasibility can be used to guide and inform the actors in an action situation when alternative courses of action or district heating system are considered. Secondly, this research has given insight in the available alternating courses of action. Subsequently, the most likely actions to be taken by actors that can affect the institutional system can be assessed and concluded in future research and how this influences the institutional system or the actors and their eligibility. Lastly, this research has not taken into account any economic variables that influence the actions and decisions considered by actors within the system configurations.

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APPENDIX A INTERVIEW QUESTIONS PER IADF VARIABLE

BIOPHYSICAL CONDITIONS

1. Kunt u voor de keten omschrijven van warmtenetten vanaf productie tot consument?
2. Welke warmtebronnen wordt er gebruik van gemaakt voor het warmtenet?
3. Wat is voor jullie de maximale afstand voor het leveren van warmte?
4. Wat is de exacte warmteproductie van de datacenters in Amsterdam?

COMMUNITY OF ATTRIBUTES

5. Wat is de visie van de actor op warmtenetten?
6. Hoe is de relatie tussen de actoren in het warmtenet systeem?
    a. Hoe verloopt de samenwerking
    b. Met wie werken jullie het meest samen
7. Wat zijn (mogelijke) nieuwe actoren in een warmtenet systeem waarin DC zijn opgenomen als warmtebron?
8. Wat vindt de actor van de bestaande regelgeving voor warmtenetten?
9. Denk je dat dit warmtenet met datacenters realiseerbaar is zonder of met financiële tegemoetkoming?

RULES-IN-USE

10. Momenteel is er wet- en regelgeving van toepassing op warmtenetten, hoe heeft de huidige wet- en regelgeving invloed op jullie om deel te nemen aan warmtenetten?
    a. Warmtewet 1.0
    b. Warmtenet 2.0
11. Andere wet- en regelgeving van toepassing?
    a. Gemeentelijke regelgeving
    b. Provinciale regelgeving
12. Wat zijn sancties indien er niet wordt voldaan aan de wet- en regelgeving dat van toepassing is?
13. Zijn er momenteel veranderingen gaande/aangekondigd mbt op nationale wetgeving en regionale regelgeving die van toepassing zijn op het warmtenetsysteem die lage temperatuur leveren?
14. Wordt er gebruik gemaakt van een financiële tegemoetkoming vanuit de overheid of andere partijen voor de realisatie en operatie van een warmtenet?
15. Zijn de huidige contracten waarmee jullie werken geschikt voor het werken met meerdere warmteproducenten?
    a. Voor welke actoren geldt het contract?
    b. Welke elementen in het contract stelt de actor waar verantwoordelijk voor?
    c. Welke afspraken of regelgeving heeft hier invloed op?
16. Zijn er nog andere dingen vastgelegd die van toepassing zijn op de samenwerking tussen actoren van het warmtenetsysteem?
17. Op basis van het contract waar is de actor verantwoordelijk voor? Wie heeft er een voorrangsrol in het warmtenet systeem?

SYSTEEMSAMENSTELLING

18. Hoe ziet het warmtenet systeem eruit vanuit het perspectief van uw organisatie als datacenters worden opgenomen als warmtebron?
    a. Technisch: warmtenet netwerk, als 1 of meerdere warmtebronnen
    b. Collectief: samenwerking met andere partijen
    c. Wet- en regelgeving: van toepassing om dit te faciliteren

APPENDIX B TRANSCRIPTS OF INTERVIEWS

The transcripts of the interviews are not publicly available, contact the author for the possibility to view the transcripts of the interviewed actors in the overview below.

Social	Market	Technical
Municipality of Amsterdam Alliander Firan Planbureau voor Leefomgeving Ministry of Economic Affairs and Climate	Nuon AEB Engie Dutch Data Center Association Datacenter	Greenvis Thermaflex

APPENDIX C HEAT DEMAND FROM NEIGHBOURHOODS IN AMSTERDAM

Neighbourhoods	Total heat demand in GJ	Heat demand for pace heating in GJ	Heat demand for domestic hot water in GJ
Aalsmeerwegbuurt Oost	85333.56	70017.28	15316.28
Aalsmeerwegbuurt West	101106.72	82959.36	18147.36
Afrikahaven	101.4	83.2	18.2
Alexanderplein e.o.	16236.48	13322.24	2914.24
Alfa-driehoek	90.48	74.24	16.24
AMC	53.82	44.16	9.66
Amerikahaven	45.24	37.12	8.12
Amstel III deel A/B Noord	53.82	44.16	9.66
Amstel III deel A/B Zuid	41173.08	33783.04	7390.04
Amstel III deel C/D Noord	0	0	0
Amstel III deel C/D Zuid	107.64	88.32	19.32
Amstelglorie	60.84	49.92	10.92
Amstelkwartier Noord	67538.64	55416.32	12122.32
Amstelkwartier West	30559.62	25074.56	5485.06
Amstelkwartier Zuid	182.52	149.76	32.76
Amstelpark	373.62	306.56	67.06
Amstelveldbuurt	63970.92	52488.96	11481.96
Amsterdamse Bos	1536.6	1260.8	275.8
Amsterdamse Poort	43615.26	35786.88	7828.38
Andreasterrein	23718.24	19461.12	4257.12
Anjeliersbuurt Noord	86204.82	70732.16	15472.66
Anjeliersbuurt Zuid	122440.5	100464	21976.5
Architectenbuurt	58496.1	47996.8	10499.3
Baanakkerspark Noord	20650.5	16944	3706.5
Baanakkerspark Zuid	15151.5	12432	2719.5
Balboaplein e.o.	110550.18	90707.84	19842.34
Banne Noordoost	78953.94	64782.72	14171.22
Banne Noordwest	60332.22	49503.36	10828.86
Banne Zuidoost	99772.92	81864.96	17907.96
Banne Zuidwest	75720.84	62129.92	13590.92
Banpleinbuurt	24318.06	19953.28	4364.78
Beatrixpark	0	0	0
Bedrijvencentrum Osdorp	2030.34	1665.92	364.42
Bedrijvencentrum Westerkwartier	897.78	736.64	161.14
Bedrijvengebied Cruquiusweg	23006.88	18877.44	4129.44

Bedrijvengebied Veelaan	1209.78	992.64	217.14
Bedrijvengebied Zeeburgerkade	1605.24	1317.12	288.12
Bedrijvenpark Lutkemeer	1283.1	1052.8	230.3
Bedrijventerrein Hamerstraat	9094.02	7461.76	1632.26
Bedrijventerrein Landlust	20421.18	16755.84	3665.34
Bedrijventerrein Nieuwendammerdijk	304.2	249.6	54.6
Bedrijventerrein Schinkel	494.52	405.76	88.76
Bedrijventerrein Sloterdijk I	939.9	771.2	168.7
Beethovenbuurt	37330.02	30629.76	6700.26
Begijnhofbuurt	24176.88	19837.44	4339.44
Belgi+½plein e.o.	32194.5	26416	5778.5
Bellamybuurt Noord	92579.76	75962.88	16616.88
Bellamybuurt Zuid	156059.28	128048.64	28010.64
Bertelmanpleinbuurt	44547.36	36551.68	7995.68
Betondorp	134108.52	110037.76	24070.76
BG-terrein e.o.	27686.1	22716.8	4969.3
Bijlmermuseum Noord	63706.5	52272	11434.5
Bijlmermuseum Zuid	79677	65376	14301
Blauwe Zand	68581.5	56272	12309.5
Bloemenbuurt Noord	81960.84	67249.92	14710.92
Bloemenbuurt Zuid	80601.3	66134.4	14466.9
Bloemgrachtbuurt	129423.06	106193.28	23229.78
Borgerbuurt	97684.86	80151.68	17533.18
Borneo	53947.14	44264.32	9682.82
Bosleeuw	173716.14	142536.32	31179.82
Bretten Oost	0	0	0
Bretten West	0	0	0
Buiksloterbreek	6021.6	4940.8	1080.8
Buiksloterdijk Oost	3104.4	2547.2	557.2
Buiksloterdijk West	3615.3	2966.4	648.9
Buiksloterham	16235.7	13321.6	2914.1
Buikslotermeer Noord	72128.16	59182.08	12946.08
Buikslotermeerplein	29520.66	24222.08	5298.58
Buiteneiland	0	0	0
Buitenveldert Midden Zuid	123732.96	101524.48	22208.48
Buitenveldert Oost Midden	114793.38	94189.44	20603.94
Buitenveldert West Midden	27149.46	22276.48	4872.98
Buitenveldert Zuidoost	126955.14	104168.32	22786.82
Buitenveldert Zuidwest	148916.04	122187.52	26728.52
Burgemeester Tellegenbuurt Oost	108679.74	89173.12	19506.62

Burgemeester Tellegenbuurt West	90536.16	74286.08	16250.08
Burgwallen Oost	69304.56	56865.28	12439.28
Buurt 10	49314.72	40463.36	8851.36
Buurt 2	81377.4	66771.2	14606.2
Buurt 3	166102.56	136289.28	29813.28
Buurt 4 Oost	86381.88	70877.44	15504.44
Buurt 5 Noord	84795.36	69575.68	15219.68
Buurt 5 Zuid	97387.68	79907.84	17479.84
Buurt 6	76959.48	63146.24	13813.24
Buurt 7	50770.98	41658.24	9112.74
Buurt 8	94158.48	77258.24	16900.24
Buurt 9	118896.96	97556.48	21340.48
Buyskade e.o.	104239.2	85529.6	18709.6
Calandlaan/Lelylaan	35884.68	29443.84	6440.84
Centrumeiland	0	0	0
Circus/Kermisbuurt	34015.02	27909.76	6105.26
Coenhaven/Mercuriushaven	219.96	180.48	39.48
Columbusplein e.o.	133339.44	109406.72	23932.72
Concertgebouwbuurt	70012.8	57446.4	12566.4
Cornelis Douwesterrein	0	0	0
Cornelis Schuytbuurt	104969.28	86128.64	18840.64
Cornelis Troostbuurt	146041.74	119829.12	26212.62
Cremerbuurt Oost	92422.2	75833.6	16588.6
Cremerbuurt West	230597.64	189208.32	41389.32
Czaar Peterbuurt	90714.78	74432.64	16282.14
D-buurt	77940.72	63951.36	13989.36
Da Costabuurt Noord	179776.74	147509.12	32267.62
Da Costabuurt Zuid	97761.3	80214.4	17546.9
Dapperbuurt Noord	141635.52	116213.76	25421.76
Dapperbuurt Zuid	127121.28	104304.64	22816.64
De Aker Oost	100915.62	82802.56	18113.06
De Aker West	88509.72	72623.36	15886.36
De Bongerd	31473	25824	5649
De Eenhoorn	80301	65888	14413
De Heining	176.28	144.64	31.64
De Kleine Wereld	65921.7	54089.6	11832.1
De Klenckebuurt	21904.74	17973.12	3931.62
De Omval	20995.26	17226.88	3768.38
De Punt	153284.82	125772.16	27512.66
De Wester Quartier	56410.38	46285.44	10124.94
De Wetbuurt	57432.96	47124.48	10308.48
De Wittenbuurt Noord	53451.84	43857.92	9593.92

De Wittenbuurt Zuid	32468.28	26640.64	5827.64
Delflandpleinbuurt Oost	66439.62	54514.56	11925.06
Delflandpleinbuurt West	115843.26	95050.88	20792.38
Den Texbuurt	37944.66	31134.08	6810.58
Diamantbuurt	114872.94	94254.72	20618.22
Diepenbrockbuurt	22423.44	18398.72	4024.72
Don Bosco	65798.46	53988.48	11809.98
Dorp Driemond	37596.78	30848.64	6748.14
Dorp Sloten	15812.94	12974.72	2838.22
Drieburg	0	0	0
Driehoekbuurt	123133.92	101032.96	22100.96
Duivelseiland	59648.16	48942.08	10706.08
Durgerdam	10899.72	8943.36	1956.36
E-buurt	29608.8	24294.4	5314.4
Ecowijk	30700.8	25190.4	5510.4
Eendrachtspark	8013.72	6575.36	1438.36
Elandsgrachtbuurt	191376.12	157026.56	34349.56
Elzenhagen Noord	44683.08	36663.04	8020.04
Elzenhagen Zuid	35511.84	29137.92	6373.92
Emanuel van Meterenbuurt	55941.6	45900.8	10040.8
Entrepot-Noordwest	38315.94	31438.72	6877.22
Erasmusparkbuurt Oost	55834.74	45813.12	10021.62
Erasmusparkbuurt West	141724.44	116286.72	25437.72
F-buurt	89266.32	73244.16	16022.16
Fannius Scholtenbuurt	152136.66	124830.08	27306.58
Felix Meritisbuurt	100361.82	82348.16	18013.66
Filips van Almondekwartier	37299.6	30604.8	6694.8
Flevopark	318.24	261.12	57.12
Frankendael	706.68	579.84	126.84
Frans Halsbuurt	116415	95520	20895
Frederik Hendrikbuurt Noord	152208.42	124888.96	27319.46
Frederik Hendrikbuurt Zuidoost	135486.78	111168.64	24318.14
Frederik Hendrikbuurt Zuidwest	41971.8	34438.4	7533.4
Frederikspleinbuurt	36567.96	30004.48	6563.48
G-buurt Noord	55692	45696	9996
G-buurt Oost	94739.58	77735.04	17004.54
G-buurt West	73344.96	60180.48	13164.48
Gaasperdam Noord	51511.98	42266.24	9245.74
Gaasperdam Zuid	46110.48	37834.24	8276.24
Gaasperpark	373.62	306.56	67.06
Gaasperplas	1416.48	1162.24	254.24

Gein Noordoost	67914.6	55724.8	12189.8
Gein Noordwest	85531.68	70179.84	15351.84
Gein Zuidoost	84014.58	68935.04	15079.54
Gein Zuidwest	40563.12	33282.56	7280.56
Gelderlandpleinbuurt	154376.04	126667.52	27708.52
Gerard Doubuurt	85939.62	70514.56	15425.06
Geuzenhofbuurt	73681.92	60456.96	13224.96
Gibraltarbuurt	159768.96	131092.48	28676.48
Gooisekant	9165	7520	1645
Gouden Bocht	7112.04	5835.52	1276.52
Groenmarktkadebuurt	12892.62	10578.56	2314.06
Grunder/Koningshoef	28953.6	23756.8	5196.8
Haarlemmerbuurt Oost	67979.34	55777.92	12201.42
Haarlemmerbuurt West	95234.1	78140.8	17093.3
Hakfort/Huigenbos	62751.78	51488.64	11263.14
Harmoniehofbuurt	60609.12	49730.56	10878.56
Haveneiland Noord	36689.64	30104.32	6585.32
Haveneiland Noordoost	102077.04	83755.52	18321.52
Haveneiland Noordwest	61133.28	50160.64	10972.64
Haveneiland Oost	96587.4	79251.2	17336.2
Haveneiland Zuidwest/Rieteiland West	43754.88	35901.44	7853.44
Helmersbuurt Oost	95068.74	78005.12	17063.62
Hemelrijk	27436.5	22512	4924.5
Hemonybuurt	103413.18	84851.84	18561.34
Hercules Seghersbuurt	108023.76	88634.88	19388.88
Het Funen	25483.38	20909.44	4573.94
Hiltonbuurt	2227.68	1827.84	399.84
Hoge Dijk	663.78	544.64	119.14
Holendrecht Oost	57404.88	47101.44	10303.44
Holendrecht West	74433.06	61073.28	13359.78
Holysloot	6640.92	5448.96	1191.96
Hondecoeterbuurt	73776.3	60534.4	13241.9
Hoofdcentrum Zuidoost	0	0	0
Hoptille	47330.4	38835.2	8495.2
Houthavens Oost	20350.2	16697.6	3652.6
Houthavens West	67772.64	55608.32	12164.32
Huntum	4391.4	3603.2	788.2
IJplein e.o.	76815.96	63028.48	13787.48
IJsbaanpad e.o.	212.94	174.72	38.22
IJselbuurt Oost	101685.48	83434.24	18251.24
IJselbuurt West	100572.42	82520.96	18051.46
Jacob Geelbuurt	85949.76	70522.88	15426.88

Jacques Veldmanbuurt	111227.22	91263.36	19963.86
Jan Maijenbuurt	90081.42	73912.96	16168.46
Java-eiland	78928.2	64761.6	14166.6
Johan Jongkindbuurt	21780.72	17871.36	3909.36
Johannnes Vermeerbuurt	52079.04	42731.52	9347.52
John Franklinbuurt	77326.86	63447.68	13879.18
Julianapark	29984.76	24602.88	5381.88
K-buurt Midden	57019.56	46785.28	10234.28
K-buurt Zuidoost	19512.48	16010.24	3502.24
K-buurt Zuidwest	22755.72	18671.36	4084.36
Kadijken	101056.02	82917.76	18138.26
Kadoelen	51380.94	42158.72	9222.22
Kalverdriehoek	15314.52	12565.76	2748.76
Kantershof	60680.1	49788.8	10891.3
Kattenburg	43211.22	35455.36	7755.86
Kazernebuurt	31899.66	26174.08	5725.58
Kelbergen	22288.5	18288	4000.5
KNSM-eiland	68633.76	56314.88	12318.88
Kolenkitbuurt Noord	94835.52	77813.76	17021.76
Kolenkitbuurt Zuid	56579.64	46424.32	10155.32
Koningin Wilhelminaplein	80849.34	66337.92	14511.42
Kop Zeedijk	50827.92	41704.96	9122.96
Kop Zuidas	17041.44	13982.72	3058.72
Kortenaerkwartier	70710.9	58019.2	12691.7
Kortvoort	74458.8	61094.4	13364.4
Kromme Mijdrechtbuurt	100396.14	82376.32	18019.82
L-buurt	88955.88	72989.44	15966.44
Laan van Spartaan	64175.28	52656.64	11518.64
Landelijk gebied Driemond	2015.52	1653.76	361.76
Landlust Noord	83314.92	68360.96	14953.96
Landlust Zuid	156912.6	128748.8	28163.8
Langestraat e.o.	81456.18	66835.84	14620.34
Lastage	45863.22	37631.36	8231.86
Legmeerpleinbuurt	63755.64	52312.32	11443.32
Leidsebuurt Noordoost	48591.66	39870.08	8721.58
Leidsebuurt Noordwest	12199.2	10009.6	2189.6
Leidsebuurt Zuidoost	13167.18	10803.84	2363.34
Leidsebuurt Zuidwest	7227.48	5930.24	1297.24
Leidsegracht Noord	30881.76	25338.88	5542.88
Leidsegracht Zuid	30412.98	24954.24	5458.74
Leliegracht e.o.	83643.3	68630.4	15012.9
Linnaeusparkbuurt	87441.9	71747.2	15694.7
Lizzy Ansinghbuurt	91710.84	75249.92	16460.92

Loenermark	44029.44	36126.72	7902.72
Lootsbuurt	81684.72	67023.36	14661.36
Louis Crispijnbuurt	85501.26	70154.88	15346.38
Lucas/Andreasziekenhuis e.o.	10998	9024	1974
Marathonbuurt Oost	60128.64	49336.32	10792.32
Marathonbuurt West	104538.72	85775.36	18763.36
Marcanti	34121.1	27996.8	6124.3
Marine-Etablissement	205.92	168.96	36.96
Marjoleinterrein	7580.82	6220.16	1360.66
Markengouw Midden	72857.46	59780.48	13076.98
Markengouw Zuid	44824.26	36778.88	8045.38
Markthallen	0	0	0
Marnixbuurt Midden	7962.24	6533.12	1429.12
Marnixbuurt Noord	62361	51168	11193
Marnixbuurt Zuid	31380.96	25748.48	5632.48
Medisch Centrum Slotervaart	14001	11488	2513
Meer en Oever	77992.2	63993.6	13998.6
Mercatorpark	58.5	48	10.5
Middelveldsche Akerpolder	84612.06	69425.28	15186.78
Middeneiland Zuidoost	0	0	0
Middeneiland Zuidwest	0	0	0
Middenmeer Noord	82848.48	67978.24	14870.24
Middenmeer Zuid	149958.12	123042.56	26915.56
Minervabuurt Midden	75826.92	62216.96	13609.96
Minervabuurt Noord	42052.92	34504.96	7547.96
Minervabuurt Zuid	84879.6	69644.8	15234.8
Molenwijk	82141.02	67397.76	14743.26
Museumplein	343.2	281.6	61.6
NDSM terrein	103329.72	84783.36	18546.36
Nelson Mandelapark	0	0	0
Nes e.o.	18190.38	14925.44	3264.94
Nieuw Sloten Noordoost	70120.44	57534.72	12585.72
Nieuw Sloten Noordwest	61803.3	50710.4	11092.9
Nieuw Sloten Zuidoost	43637.88	35805.44	7832.44
Nieuw Sloten Zuidwest	42444.48	34826.24	7618.24
Nieuwe Diep/Diemerpark	820.56	673.28	147.28
Nieuwe Kerk e.o.	34759.14	28520.32	6238.82
Nieuwe Meer	301.86	247.68	54.18
Nieuwe Oosterbegraafplaats	205.92	168.96	36.96
Nieuwendammerdijk Oost	7785.18	6387.84	1397.34
Nieuwendammerdijk Zuid	0	0	0

Nieuwendammmerdijk West	24908.52	20437.76	4470.76
Nieuwendijk Noord	23453.82	19244.16	4209.66
Nieuwmarkt	69448.08	56983.04	12465.04
Nintemanterrein	2152.8	1766.4	386.4
Noorder IJplas	107.64	88.32	19.32
Noorderstrook Oost	58.5	48	10.5
Noorderstrook West	53.82	44.16	9.66
Noordoever Sloterplas	90051	73888	16163
Noordoostkwadrant Indische buurt	182743.86	149943.68	32800.18
Noordwestkwadrant Indische buurt Noord	148936.32	122204.16	26732.16
Noordwestkwadrant Indische buurt Zuid	154346.4	126643.2	27703.2
Olympisch Stadion e.o.	56819.88	46621.44	10198.44
Ookmeer	119.34	97.92	21.42
Oostelijke Handelskade	33975.24	27877.12	6098.12
Oostenburg	57618.6	47276.8	10341.8
Oosterdokseiland	13205.4	10835.2	2370.2
Oosterpark	6658.08	5463.04	1195.04
Oosterparkbuurt Noordwest	135219.24	110949.12	24270.12
Oosterparkbuurt Zuidoost	128174.28	105168.64	23005.64
Oosterparkbuurt Zuidwest	107242.2	87993.6	19248.6
Oostoever Sloterplas	54210.78	44480.64	9730.14
Oostpoort	47522.28	38992.64	8529.64
Oostzanerdijk	8131.5	6672	1459.5
Orteliusbuurt Midden	77133.42	63288.96	13844.46
Orteliusbuurt Noord	52678.08	43223.04	9455.04
Orteliusbuurt Zuid	73489.26	60298.88	13190.38
Osdorp Midden Noord	81535.74	66901.12	14634.62
Osdorp Midden Zuid	77131.08	63287.04	13844.04
Osdorp Zuidoost	111705.36	91655.68	20049.68
Osdorper Binnenpolder	626.34	513.92	112.42
Osdorper Bovenpolder	15513.42	12728.96	2784.46
Osdorpplein e.o.	103719.72	85103.36	18616.36
Oude Kerk e.o.	34737.3	28502.4	6234.9
Overamstel	518.7	425.6	93.1
Overbraker Binnenpolder	304.98	250.24	54.74
Overhoeks	65749.32	53948.16	11801.16
Overtoomse Veld Noord	122335.98	100378.24	21957.74
Overtoomse Veld Zuid	103992.72	85327.36	18665.36
P.C. Hooftbuurt	36382.32	29852.16	6530.16
Papaverweg e.o.	19347.9	15875.2	3472.7
Paramariboplein e.o.	135911.88	111517.44	24394.44

Park de Meer	31917.6	26188.8	5728.8
Park Haagseweg	22424.22	18399.36	4024.86
Parooldriehoek	7300.8	5990.4	1310.4
Passeerdersgrachtbuurt	39393.9	32323.2	7070.7
Petroleumhaven	431.34	353.92	77.42
Pieter van der Doesbuurt	68438.76	56154.88	12283.88
Plan van Gool	81900	67200	14700
Planciusbuurt Noord	16433.04	13483.52	2949.52
Planciusbuurt Zuid	9609.6	7884.8	1724.8
Plantage	93569.58	76775.04	16794.54
Postjeskade e.o.	115044.54	94395.52	20649.02
Prinses Irenebuurt	42748.68	35075.84	7672.84
RAI	0	0	0
Ransdorp	8069.88	6621.44	1448.44
Rapenburg	40378.26	33130.88	7247.38
Rechte H-buurt	74709.96	61300.48	13409.48
Reguliersbuurt	19546.02	16037.76	3508.26
Reigersbos Midden	61747.92	50664.96	11082.96
Reigersbos Noord	99095.88	81309.44	17786.44
Reigersbos Zuid	58749.6	48204.8	10544.8
Rembrandtpark Noord	19546.02	16037.76	3508.26
Rembrandtpark Zuid	26442	21696	4746
Rembrandtpleinbuurt	20219.16	16590.08	3629.08
RI Oost terrein	100072.44	82110.72	17961.72
Riekerhaven	20791.68	17059.84	3731.84
Riekerpolder	341.64	280.32	61.32
Rieteiland Oost	3722.16	3054.08	668.08
Rietlanden	56518.8	46374.4	10144.4
Rijnbuurt Midden	85893.6	70476.8	15416.8
Rijnbuurt Oost	103286.82	84748.16	18538.66
Rijnbuurt West	71593.08	58743.04	12850.04
Robert Scottbuurt Oost	63184.68	51843.84	11340.84
Robert Scottbuurt West	86633.82	71084.16	15549.66
Rode Kruisbuurt	5282.94	4334.72	948.22
Sarphatiparkbuurt	222528.54	182587.52	39941.02
Sarphatistrook	73861.32	60604.16	13257.16
Scheepvaarthuisbuurt	22317.36	18311.68	4005.68
Scheldebuurt Midden	106927.08	87735.04	19192.04
Scheldebuurt Oost	80926.56	66401.28	14525.28
Scheldebuurt West	155469.6	127564.8	27904.8
Schellingwoude Noord	122.46	100.48	21.98
Schellingwoude Oost	11706.24	9605.12	2101.12
Schellingwoude West	1683.24	1381.12	302.12

Schinkelbuurt Noord	96543.72	79215.36	17328.36
Schinkelbuurt Zuid	61836.06	50737.28	11098.78
Schipluidenbuurt	38298	31424	6874
Science Park Noord	82572.36	67751.68	14820.68
Science Park Zuid	9550.32	7836.16	1714.16
Sloterdijk II	517.14	424.32	92.82
Sloterdijk III Oost	0	0	0
Sloterdijk III West	1353.3	1110.4	242.9
Slotermeer Zuid	112817.64	92568.32	20249.32
Sloterpark	0	0	0
Sloterweg e.o.	5839.86	4791.68	1048.18
Spaarndammerbuurt Midden	51764.7	42473.6	9291.1
Spaarndammerbuurt Noordoost	100807.98	82714.24	18093.74
Spaarndammerbuurt Noordwest	75298.08	61783.04	13515.04
Spaarndammerbuurt Zuidoost	36584.34	30017.92	6566.42
Spaarndammerbuurt Zuidwest	61066.2	50105.6	10960.6
Spiegelbuurt	41088.06	33713.28	7374.78
Sporenburg	52387.14	42984.32	9402.82
Sportpark Middenmeer Noord	53.82	44.16	9.66
Sportpark Middenmeer Zuid	10281.96	8436.48	1845.48
Sportpark Voorland	0	0	0
Spuistraat Noord	38423.58	31527.04	6896.54
Spuistraat Zuid	38514.84	31601.92	6912.92
Staalmanbuurt	74883.9	61443.2	13440.7
Staatsliedenbuurt Noordoost	41129.4	33747.2	7382.2
Stationsplein e.o.	0	0	0
Steigereiland Noord	46541.04	38187.52	8353.52
Steigereiland Zuid	42681.6	35020.8	7660.8
Strandeiland	0	0	0
Surinamepleinbuurt	55064.1	45180.8	9883.3
Swammerdambuurt	72034.56	59105.28	12929.28
Teleport	26164.32	21468.16	4696.16
Terrasdorp	118021.8	96838.4	21183.4
Transvaalbuurt Oost	168222.6	138028.8	30193.8
Transvaalbuurt West	138127.86	113335.68	24792.18
Trompbuurt	109685.16	89998.08	19687.08
Tuindorp Amstelstation	29581.5	24272	5309.5
Tuindorp Frankendael	99614.58	81735.04	17879.54

Tuindorp Nieuwendam Oost	89083.8	73094.4	15989.4
Tuindorp Nieuwendam West	32056.44	26302.72	5753.72
Tuindorp Oostzaan Oost	138182.46	113380.48	24801.98
Tuindorp Oostzaan West	32396.52	26581.76	5814.76
Twiske Oost	23821.2	19545.6	4275.6
Twiske West	51645.36	42375.68	9269.68
Uilenburg	47523.06	38993.28	8529.78
Utrechtsebuurt Zuid	50909.82	41772.16	9137.66
Valeriusbuurt Oost	47707.92	39144.96	8562.96
Valeriusbuurt West	87104.16	71470.08	15634.08
Valkenburg	46200.96	37908.48	8292.48
Van Brakelkwartier	31873.92	26152.96	5720.96
Van der Helstpleinbuurt	161517.72	132527.36	28990.36
Van der Kunbuurt	16546.14	13576.32	2969.82
Van der Pekbuurt	164356.14	134856.32	29499.82
Van Loonbuurt	59300.28	48656.64	10643.64
Van Tuyllbuurt	159862.56	131169.28	28693.28
Veluwebuurt	56134.26	46058.88	10075.38
Venserpolder Oost	92562.6	75948.8	16613.8
Venserpolder West	149303.7	122505.6	26798.1
Vervoerscentrum	0	0	0
Vivaldi	34903.44	28638.72	6264.72
Vliegenbos	1685.58	1383.04	302.54
Vogelbuurt Noord	45508.32	37340.16	8168.16
Vogelbuurt Zuid	132599.22	108799.36	23799.86
Vogeltjeswei	12522.9	10275.2	2247.7
Vondelpark Oost	190.32	156.16	34.16
Vondelpark West	0	0	0
Vondelparkbuurt Midden	28833.48	23658.24	5175.24
Vondelparkbuurt Oost	35300.46	28964.48	6335.98
Vondelparkbuurt West	81144.96	66580.48	14564.48
VU-kwartier	2031.9	1667.2	364.7
Walvisbuurt	28955.16	23758.08	5197.08
Waterloopleinbuurt	37057.8	30406.4	6651.4
Weesperbuurt	115860.42	95064.96	20795.46
Weespertrekvaart	52153.92	42792.96	9360.96
Weesperzijde Midden/Zuid	113024.34	92737.92	20286.42
Werengouw Midden	133931.46	109892.48	24038.98
Werengouw Zuid	34189.74	28053.12	6136.62
Westelijke eilanden	102124.62	83794.56	18330.06
Westerdokseiland	44623.8	36614.4	8009.4
Westergasfabriek	135.72	111.36	24.36
Westerstaatsman	121283.76	99514.88	21768.88

Westhaven Noord	742.56	609.28	133.28
Westhaven Zuid	117	96	21
Westlandgrachtbuurt	139102.86	114135.68	24967.18
Weteringbuurt	100448.4	82419.2	18029.2
WG-terrein	100795.5	82704	18091.5
Wielingenbuurt	99473.4	81619.2	17854.2
Wildeman	147094.74	120693.12	26401.62
Willemsparkbuurt Noord	54846.48	45002.24	9844.24
Willibrordusbuurt	111312.24	91333.12	19979.12
Wittenburg	72047.04	59115.52	12931.52
Woon- en Groengebied Sloterdijk	27828.84	22833.92	4994.92
Zaagpoortbuurt	49472.28	40592.64	8879.64
Zamenhofstraat e.o.	53.82	44.16	9.66
Zeeburgerdijk Oost	9186.84	7537.92	1648.92
Zeeburgereiland Noordoost	0	0	0
Zeeburgereiland Noordwest	343.2	281.6	61.6
Zeeburgereiland Zuidoost	19787.04	16235.52	3551.52
Zeeburgereiland Zuidwest	3890.64	3192.32	698.32
Zeeheldenbuurt	65007.54	53339.52	11668.02
Zorgvlied	978.9	803.2	175.7
Zuidas Noord	6971.64	5720.32	1251.32
Zuidas Zuid	64560.6	52972.8	11587.8
Zuiderhof	182.52	149.76	32.76
Zuiderkerkbuurt	70466.76	57818.88	12647.88
Zuidoostkwadrant Indische buurt	108563.52	89077.76	19485.76
Zuidwestkwadrant Indische buurt	107610.36	88295.68	19314.68
Zuidwestkwadrant Osdorp Noord	64167.48	52650.24	11517.24
Zuidwestkwadrant Osdorp Zuid	119453.88	98013.44	21440.44
Zunderdorp	11438.7	9385.6	2053.1
Zwarte Gouw	861.9	707.2	154.7
Total	27046665.36	22192135.68	4854529.68

APPENDIX D CBS VALIDATION OF HEAT DEMAND

Neighbourhoods	Total gas use per neighbourhood (m3)	Percentage higher or lower than CBS statistics
Aalsmeerwegbuurt Oost	1282700	-41%
Aalsmeerwegbuurt West	1399350	-46%
Afrikahaven	0	-100%
Alexanderplein e.o.	272330	-35%
Alfa-driehoek	0	-100%
AMC	0	-100%
Amerikahaven	0	-100%
Amstel III deel A/B Noord	0	-100%
Amstel III deel A/B Zuid	0	-100%
Amstel III deel C/D Noord	0	#DIV/0!
Amstel III deel C/D Zuid	0	-100%
Amstelglorie	0	-100%
Amstelkwartier Noord	0	-100%
Amstelkwartier West	0	-100%
Amstelkwartier Zuid	0	-100%
Amstelpark	0	-100%
Amstelveldbuurt	1363470	-17%
Amsterdamse Bos	0	-100%
Amsterdamse Poort	665820	-40%
Andreasterrein	57090	-91%
Anjeliersbuurt Noord	1540140	-30%
Anjeliersbuurt Zuid	2031840	-35%
Architectenbuurt	853400	-43%
Baanakkerspark Noord	384770	-27%
Baanakkerspark Zuid	341880	-12%
Balboaplein e.o.	1437920	-49%
Banne Noordoost	1643040	-19%
Banne Noordwest	1098580	-29%
Banne Zuidoost	1353400	-47%
Banne Zuidwest	1050000	-46%
Banpleinbuurt	758960	22%
Beatrixpark	0	#DIV/0!
Bedrijvencentrum Osdorp	0	-100%
Bedrijvencentrum Westerkwartier	0	-100%
Bedrijvengebied Cruquiusweg	0	-100%
Bedrijvengebied Veelaan	32400	4%

Bedrijvengebied Zeeburgerkade	0	-100%
Bedrijvenpark Lutkemeer	36960	12%
Bedrijventerrein Hamerstraat	262260	12%
Bedrijventerrein Landlust	284400	-46%
Bedrijventerrein Nieuwendammerdijk	0	-100%
Bedrijventerrein Schinkel	0	-100%
Bedrijventerrein Sloterdijk I	0	-100%
Beethovenbuurt	1127610	18%
Begijnhofbuurt	334640	-46%
Belgi+½plein e.o.	577850	-30%
Bellamybuurt Noord	1340160	-44%
Bellamybuurt Zuid	2044260	-49%
Bertelmanpleinbuurt	636020	-44%
Betondorp	1938420	-44%
BG-terrein e.o.	487600	-31%
Bijlmermuseum Noord	87120	-95%
Bijlmermuseum Zuid	149820	-93%
Blauwe Zand	1182200	-33%
Bloemenbuurt Noord	1433250	-32%
Bloemenbuurt Zuid	1373100	-34%
Bloemgrachtbuurt	2231100	-33%
Borgerbuurt	1548000	-38%
Borneo	77700	-94%
Bosleeuw	2783000	-38%
Bretten Oost	0	#DIV/0!
Bretten West	0	#DIV/0!
Buiksloterbreek	153270	-1%
Buiksloterdijk Oost	117720	48%
Buiksloterdijk West	125240	35%
Buiksloterham	0	-100%
Buikslotermeer Noord	811200	-56%
Buikslotermeerplein	504900	-33%
Buiteneiland	0	#DIV/0!
Buitenveldert Midden Zuid	2409030	-24%
Buitenveldert Oost Midden	1686930	-43%
Buitenveldert West Midden	797160	15%
Buitenveldert Zuidoost	2523960	-22%
Buitenveldert Zuidwest	2477760	-35%
Burgemeester Tellegenbuurt Oost	1642260	-41%
Burgemeester Tellegenbuurt West	1319000	-43%
Burgwallen Oost	1139050	-36%
Buurt 10	1014200	-20%
Buurt 2	1351210	-35%

Buurt 3	3150960	-26%
Buurt 4 Oost	1567650	-29%
Buurt 5 Noord	1311300	-40%
Buurt 5 Zuid	1522600	-39%
Buurt 6	1417000	-28%
Buurt 7	898380	-31%
Buurt 8	837070	-65%
Buurt 9	1909950	-37%
Buyskade e.o.	1608300	-40%
Calandlaan/Lelylaan	614990	-33%
Centrumeiland	0	#DIV/0!
Circus/Kermisbuurt	552980	-37%
Coenhaven/Mercuriushaven	0	-100%
Columbusplein e.o.	1834880	-46%
Concertgebouwbuurt	1763010	-2%
Cornelis Douwesterrein	0	#DIV/0!
Cornelis Schuytbuurt	2669160	-1%
Cornelis Troostbuurt	1958320	-48%
Cremerbuurt Oost	1263870	-47%
Cremerbuurt West	3243300	-45%
Czaar Peterbuurt	1107410	-52%
D-buurt	1630570	-18%
Da Costabuurt Noord	2089010	-55%
Da Costabuurt Zuid	1288470	-49%
Dapperbuurt Noord	2104530	-42%
Dapperbuurt Zuid	21220	-99%
De Aker Oost	2208480	-15%
De Aker West	1387240	-39%
De Bongerd	448350	-44%
De Eenhoorn	1119000	-46%
De Heining	0	-100%
De Kleine Wereld	1139490	-33%
De Klenckebuurt	321530	-43%
De Omval	4160	-99%
De Punt	3210620	-18%
De Wester Quartier	602700	-58%
De Wetbuurt	842240	-43%
De Wittenbuurt Noord	985300	-28%
De Wittenbuurt Zuid	513360	-38%
Delflandpleinbuurt Oost	1045200	-39%
Delflandpleinbuurt West	1591100	-46%
Den Texbuurt	401800	-59%
Diamantbuurt	2253880	-23%

Diepenbrockbuurt	347550	-40%
Don Bosco	2644200	57%
Dorp Driemond	766800	-20%
Dorp Sloten	393300	-3%
Drieburg	0	#DIV/0!
Driehoekbuurt	0	-100%
Duivelseiland	834240	-45%
Durgerdam	171990	-38%
E-buurt	1392840	83%
Ecowijk	6020	-99%
Eendrachtspark	0	-100%
Elandsgrachtbuurt	2962080	-40%
Elzenhagen Noord	1005720	-12%
Elzenhagen Zuid	892000	-2%
Emanuel van Meterenbuurt	0	-100%
Entrepot-Noordwest	977820	0%
Erasmusparkbuurt Oost	620200	-57%
Erasmusparkbuurt West	2132480	-41%
F-buurt	1811380	-21%
Fannius Scholtenbuurt	1779920	-54%
Felix Meritisbuurt	357600	-86%
Filips van Almondekwartier	754650	-21%
Flevopark	4350	-47%
Frankendael	0	-100%
Frans Halsbuurt	0	-100%
Frederik Hendrikbuurt Noord	2066580	-47%
Frederik Hendrikbuurt Zuidoost	1945800	-44%
Frederik Hendrikbuurt Zuidwest	626940	-42%
Frederikspleinbuurt	546250	-42%
G-buurt Noord	1066240	-25%
G-buurt Oost	1918080	-21%
G-buurt West	1641690	-13%
Gaasperdam Noord	0	-100%
Gaasperdam Zuid	1628300	38%
Gaasperpark	360	-96%
Gaasperplas	26840	-26%
Gein Noordoost	0	-100%
Gein Noordwest	1828160	-17%
Gein Zuidoost	1604740	-26%
Gein Zuidwest	868840	-16%
Gelderlandpleinbuurt	2911700	-26%
Gerard Doubuurt	1377000	-38%
Geuzenhofbuurt	920550	-51%

Gibraltarbuurt	2226800	-46%
Gooisekant	213850	-9%
Gouden Bocht	0	-100%
Groenmarktkadebuurt	282150	-15%
Grunder/Koningshoef	608000	-18%
Haarlemmerbuurt Oost	1202320	-31%
Haarlemmerbuurt West	1827820	-25%
Hakfort/Huigenbos	1131000	-30%
Harmoniehofbuurt	1465780	-6%
Haveneiland Noord	1089270	16%
Haveneiland Noordoost	0	-100%
Haveneiland Noordwest	0	-100%
Haveneiland Oost	0	-100%
Haveneiland Zuidwest/Rieteiland West	0	-100%
Helmersbuurt Oost	0	-100%
Hemelrijk	494400	-30%
Hemonybuurt	1445900	-45%
Hercules Seghersbuurt	1731430	-37%
Het Funen	443980	-32%
Hiltonbuurt	28050	-51%
Hoge Dijk	34710	104%
Holendrecht Oost	0	-100%
Holendrecht West	1839390	-4%
Holysloot	164920	-3%
Hondecoeterbuurt	2328320	23%
Hoofdcentrum Zuidoost	0	#DIV/0!
Hoptille	0	-100%
Houthavens Oost	304500	-42%
Houthavens West	0	-100%
Huntum	0	-100%
IJplein e.o.	2682760	36%
IJsbaanpad e.o.	3160	-42%
IJselbuurt Oost	0	-100%
IJselbuurt West	1584670	-39%
Jacob Geelbuurt	1396800	-37%
Jacques Veldmanbuurt	2391200	-16%
Jan Maijenbuurt	1413470	-39%
Java-eiland	1322160	-35%
Johan Jongkindbuurt	7340	-99%
Johannnes Vermeerbuurt	722540	-46%
John Franklinbuurt	1764360	-11%
Julianapark	530700	-31%
K-buurt Midden	1044900	-29%

K-buurt Zuidoost	379680	-24%
K-buurt Zuidwest	829950	42%
Kadijken	1885970	-27%
Kadoelen	979560	-26%
Kalverdriehoek	257400	-34%
Kantershof	1004150	-35%
Kattenburg	408200	-63%
Kazernebuurt	0	-100%
Kelbergen	140970	-75%
KNSM-eiland	1602040	-9%
Kolenkitbuurt Noord	1494040	-39%
Kolenkitbuurt Zuid	965160	-33%
Koningin Wilhelminaplein	808500	-61%
Kop Zeedijk	390500	-70%
Kop Zuidas	470800	8%
Kortenaerkwartier	749700	-59%
Kortvoort	1408620	-26%
Kromme Mijdrechtbuurt	1396840	-46%
L-buurt	1603410	-30%
Laan van Spartaan	0	-100%
Landelijk gebied Driemond	0	-100%
Landlust Noord	1054360	-51%
Landlust Zuid	1901530	-53%
Langestraat e.o.	1761750	-16%
Lastage	823480	-30%
Legmeerpleinbuurt	1191960	-27%
Leidsebuurt Noordoost	782170	-37%
Leidsebuurt Noordwest	226600	-28%
Leidsebuurt Zuidoost	184230	-45%
Leidsebuurt Zuidwest	109140	-41%
Leidsegracht Noord	552000	-30%
Leidsegracht Zuid	700440	-10%
Leliegracht e.o.	1866360	-13%
Linnaeusparkbuurt	1836060	-18%
Lizzy Ansinghbuurt	1844480	-22%
Loenermark	760740	-33%
Lootsbuurt	1224020	-42%
Louis Crispijnbuurt	1205600	-45%
Lucas/Andreasziekenhuis e.o.	341220	21%
Marathonbuurt Oost	0	-100%
Marathonbuurt West	1401160	-48%
Marcanti	561590	-36%
Marine-Etablissement	2190	-59%

Marjoleinterrein	0	-100%
Markengouw Midden	868800	-53%
Markengouw Zuid	804870	-30%
Markthallen	0	#DIV/0!
Marnixbuurt Midden	0	-100%
Marnixbuurt Noord	955500	-40%
Marnixbuurt Zuid	432960	-46%
Medisch Centrum Slotervaart	334080	-7%
Meer en Oever	1433130	-28%
Mercatorpark	640	-57%
Middelveldsche Akerpolder	0	-100%
Middeneiland Zuidoost	0	#DIV/0!
Middeneiland Zuidwest	0	#DIV/0!
Middenmeer Noord	0	-100%
Middenmeer Zuid	3368350	-12%
Minervabuurt Midden	1357860	-30%
Minervabuurt Noord	1076250	0%
Minervabuurt Zuid	2580600	19%
Molenwijk	2295540	9%
Museumplein	5950	-32%
NDSM terrein	0	-100%
Nelson Mandelapark	0	#DIV/0!
Nes e.o.	0	-100%
Nieuw Sloten Noordoost	1716120	-5%
Nieuw Sloten Noordwest	1414040	-11%
Nieuw Sloten Zuidoost	947210	-15%
Nieuw Sloten Zuidwest	895590	-18%
Nieuwe Diep/Diemerpark	18880	-10%
Nieuwe Kerk e.o.	0	-100%
Nieuwe Meer	5050	-35%
Nieuwe Oosterbegraafplaats	0	-100%
Nieuwendammerdijk Oost	0	-100%
Nieuwendammerdijk Zuid	0	#DIV/0!
Nieuwendammmerdijk West	0	-100%
Nieuwendijk Noord	638580	6%
Nieuwmarkt	1113840	-37%
Nintemanterrein	41600	-25%
Noorder IJplas	2920	6%
Noorderstrook Oost	0	-100%
Noorderstrook West	0	-100%
Noordoever Sloterplas	0	-100%
Noordoostkwadrant Indische buurt	2159700	-54%
Noordwestkwadrant Indische buurt Noord	1793330	-53%

Noordwestkwadrant Indische buurt Zuid	2050440	-48%
Olympisch Stadion e.o.	1250080	-14%
Ookmeer	240	-92%
Oostelijke Handelskade	0	-100%
Oostenburg	1119300	-24%
Oosterdokseiland	268800	-21%
Oosterpark	71780	-58%
Oosterparkbuurt Noordwest	1668780	-52%
Oosterparkbuurt Zuidoost	1800030	-45%
Oosterparkbuurt Zuidwest	1764430	-36%
Oostoever Sloterplas	984400	-29%
Oostpoort	1097630	-10%
Oostzanerdijk	93160	-55%
Orteliusbuurt Midden	1697240	-14%
Orteliusbuurt Noord	680340	-50%
Orteliusbuurt Zuid	942210	-50%
Osdorp Midden Noord	1425690	-32%
Osdorp Midden Zuid	833080	-58%
Osdorp Zuidoost	1722600	-40%
Osdorper Binnenpolder	12430	-23%
Osdorper Bovenpolder	0	-100%
Osdorpplein e.o.	4882500	84%
Oude Kerk e.o.	449030	-50%
Overamstel	10170	-24%
Overbraker Binnenpolder	0	-100%
Overhoeks	0	-100%
Overtoomse Veld Noord	0	-100%
Overtoomse Veld Zuid	954170	-64%
P.C. Hooftbuurt	353760	-62%
Papaverweg e.o.	810250	63%
Paramariboplein e.o.	416850	-88%
Park de Meer	740250	-10%
Park Haagseweg	0	-100%
Parooldriehoek	140400	-25%
Passeerdersgrachtbuurt	639940	-37%
Petroleumhaven	7070	-36%
Pieter van der Doesbuurt	0	-100%
Plan van Gool	1358000	-35%
Planciusbuurt Noord	108900	-74%
Planciusbuurt Zuid	112000	-55%
Plantage	1330830	-45%
Postjeskade e.o.	1678000	-43%
Prinses Irenebuurt	1279670	17%

RAI	0	#DIV/0!
Ransdorp	261120	26%
Rapenburg	601350	-42%
Rechte H-buurt	345060	-82%
Reguliersbuurt	317520	-37%
Reigersbos Midden	1224080	-23%
Reigersbos Noord	2455180	-3%
Reigersbos Zuid	1309200	-13%
Rembrandtpark Noord	421080	-16%
Rembrandtpark Zuid	0	-100%
Rembrandtpleinbuurt	324480	-37%
RI Oost terrein	0	-100%
Riekerhaven	0	-100%
Riekerpolder	0	-100%
Rieteiland Oost	0	-100%
Rietlanden	342160	-76%
Rijnbuurt Midden	1390830	-37%
Rijnbuurt Oost	1594950	-40%
Rijnbuurt West	994170	-46%
Robert Scottbuurt Oost	885400	-45%
Robert Scottbuurt West	616640	-72%
Rode Kruisbuurt	160080	18%
Sarphatiparkbuurt	2884920	-49%
Sarphatistrook	1239680	-35%
Scheepvaarthuisbuurt	499500	-13%
Scheldebuurt Midden	2004480	-27%
Scheldebuurt Oost	1450170	-30%
Scheldebuurt West	2899200	-27%
Schellingwoude Noord	0	-100%
Schellingwoude Oost	351500	17%
Schellingwoude West	50840	18%
Schinkelbuurt Noord	1515130	-39%
Schinkelbuurt Zuid	992250	-37%
Schipluidenbuurt	0	-100%
Science Park Noord	1828530	-14%
Science Park Zuid	0	-100%
Sloterdijk II	4140	-69%
Sloterdijk III Oost	0	#DIV/0!
Sloterdijk III West	0	-100%
Slotermeer Zuid	1626030	-44%
Sloterpark	0	#DIV/0!
Sloterweg e.o.	279720	87%
Spaarndammerbuurt Midden	731700	-45%

Spaarndammerbuurt Noordoost	1419860	-45%
Spaarndammerbuurt Noordwest	1107970	-43%
Spaarndammerbuurt Zuidoost	550160	-41%
Spaarndammerbuurt Zuidwest	872100	-44%
Spiegelbuurt	830800	-21%
Sporenburg	0	-100%
Sportpark Middenmeer Noord	0	-100%
Sportpark Middenmeer Zuid	187110	-29%
Sportpark Voorland	0	#DIV/0!
Spuistraat Noord	751940	-24%
Spuistraat Zuid	715110	-28%
Staalmanbuurt	590850	-69%
Staatsliedenbuurt Noordoost	624120	-41%
Stationsplein e.o.	0	#DIV/0!
Steigereiland Noord	219600	-82%
Steigereiland Zuid	0	-100%
Strandeiland	0	#DIV/0!
Surinamepleinbuurt	1017600	-28%
Swammerdambuurt	1200540	-35%
Teleport	0	-100%
Terrasdorp	1923740	-36%
Transvaalbuurt Oost	2621960	-39%
Transvaalbuurt West	2025700	-43%
Trompbuurt	1738800	-38%
Tuindorp Amstelstation	554040	-27%
Tuindorp Frankendael	1855350	-27%
Tuindorp Nieuwendam Oost	1586310	-31%
Tuindorp Nieuwendam West	591800	-28%
Tuindorp Oostzaan Oost	2459520	-31%
Tuindorp Oostzaan West	534470	-36%
Twiske Oost	452880	-26%
Twiske West	1294650	-2%
Uilenburg	517120	-58%
Utrechtsebuurt Zuid	917700	-30%
Valeriusbuurt Oost	1217760	0%
Valeriusbuurt West	1878120	-16%
Valkenburg	354320	-70%
Van Brakelkwartier	468440	-43%
Van der Helstpleinbuurt	2187180	-47%
Van der Kunbuurt	250240	-41%
Van der Pekbuurt	2658480	-37%
Van Loonbuurt	1240400	-18%
Van Tuyllbuurt	2701640	-34%

Veluwebuurt	764610	-47%
Venserpolder Oost	1632780	-31%
Venserpolder West	2422620	-37%
Vervoerscentrum	0	#DIV/0!
Vivaldi	0	-100%
Vliegenbos	0	-100%
Vogelbuurt Noord	822120	-30%
Vogelbuurt Zuid	2314200	-32%
Vogeltjeswei	0	-100%
Vondelpark Oost	0	-100%
Vondelpark West	0	#DIV/0!
Vondelparkbuurt Midden	604340	-18%
Vondelparkbuurt Oost	760320	-16%
Vondelparkbuurt West	1452450	-30%
VU-kwartier	39520	-24%
Walvisbuurt	677040	-9%
Waterloopleinbuurt	551950	-42%
Weesperbuurt	1754880	-41%
Weespertrekvaart	0	-100%
Weesperzijde Midden/Zuid	1596320	-45%
Werengouw Midden	1823360	-47%
Werengouw Zuid	813780	-7%
Westelijke eilanden	1732000	-34%
Westerdokseiland	758450	-34%
Westergasfabriek	0	-100%
Westerstaatsman	1569920	-50%
Westhaven Noord	17640	-7%
Westhaven Zuid	0	-100%
Westlandgrachtbuurt	1964160	-45%
Weteringbuurt	1818180	-29%
WG-terrein	1653000	-36%
Wielingenbuurt	1993950	-22%
Wildeman	2255840	-40%
Willemsparkbuurt Noord	1431120	2%
Willibrordusbuurt	1649560	-42%
Wittenburg	1179000	-36%
Woon- en Groengebied Sloterdijk	611520	-14%
Zaagpoortbuurt	518300	-59%
Zamenhofstraat e.o.	0	-100%
Zeeburgerdijk Oost	165480	-30%
Zeeburgereiland Noordoost	0	#DIV/0!
Zeeburgereiland Noordwest	0	-100%
Zeeburgereiland Zuidoost	0	-100%

Zeeburgereiland Zuidwest	0	-100%
Zeeheldenbuurt	986880	-41%
Zorgvlied	74630	197%
Zuidas Noord	0	-100%
Zuidas Zuid	142290	-91%
Zuiderhof	0	-100%
Zuiderkerkbuurt	1219710	-32%
Zuidoostkwadrant Indische buurt	1772100	-36%
Zuidwestkwadrant Indische buurt	1791790	-35%
Zuidwestkwadrant Osdorp Noord	1234050	-25%
Zuidwestkwadrant Osdorp Zuid	1875000	-39%
Zunderdorp	436320	49%
Zwarte Gouw	0	-100%
Total	4.03E+08	-42%

APPENDIX E HEAT SUPPLY OF DATACENTERS IN AMSTERDAM

Datacenters	**Heat supply in GJ**
Century Link Amsterdam	0
Colt - Duivendrecht	0
Colt - Oud Zuid	10206
Databarn Amsterdam B.V.	10206
Datacenter.com	0
DCA	0
Digital Realty Trust	35271.936
Digital Realty Trust	29393.28
Digital Realty Trust	32659.2
Digital Realty Trust NL	69400.8
Digital Realty Trust NL	39690
EdgeConnex	39690
Equinix AM1	39690
Equinix AM2	39690
Equinix AM4	0
Equinix AM5	39690
Equinix AM6	39690
Equinix AM7	39690
Equinix AM8	39690
Global Switch	416404.8
Globalone	0
Gyrocenter	10206
Interxion AMS 5	122472
Interxion AMS-1 / AMS-4	10206
Interxion AMS-2	10206
Interxion AMS8	204120
Interxion AMS-9	10206
KPN Datacenter Amsterdam	12247.2
Maincubes	0
Nikhef Housing	10206
RDC Datacentrum	0
Switch Datacenters	39690
The Datacenter Group (TDCG) - Amsterdam	39690
Verizon - Kollenbergweg	10206
Verizon Joan Muyskenweg	10206
XS4ALL DC2	10206
Total	1420929.216

APPENDIX F EXTENT OF HEAT SUPPLY FROM DATACENTERS FOR NEIGHBOURHOODS OF AMSTERDAM

Total heat demand (GJ)	**Total heat supply of datacenters (GJ)**	**Extent of supply in percentage**
27046665.36	1420929.216	5.3%
15687065.91	1420929.216	9.1%

APPENDIX G KEY COMPONENTS AND OPTIONS OF SYSTEM CONFIGURATIONS

Layer of IADF	Key components	Option per system configurations		
		A: Contemporary situation	*B: Open district heating and independent management of infrastructure*	*C: Experimentation of various district heating systems*
Biophysical conditions	*Supplied temperature*	High temperature	Mid-temperature and Low-temperature	Mid-temperature and Low-temperature
	Number of sources in district heating system	DC and other heat sources	DC and other heat sources	One DC or multiple DC and other heat sources
Community of Attributes	*Management and operation of the transportation and distribution of heat*	Retailer	Municipal heat company or grid operator	Retailer or municipal heat company or grid operator
	Sale of heat	One retailer	Multiple retailers	One or multiple retailers
Rules in use	*Succeeding Heat Act*	Continuation of current Heat Act where monopoly situation for market actors is maintained	Legal eligibility of social actors for transportation and distribution Legal support for heat plans of municipality for the development of district heating systems	Legal flexibility for social and market actors that want to be in charge of transportation and distribution Legal support for heat plans of municipality next to support for market actors in the development of district heating systems