Towards a new market model for the Dutch district heating sector

Drawing lessons from international experience with alternative market models for the district heating sector

Alexander Hong Gie Oei

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Cover photo: Laying a heat transmission pipeline – Nuon, Amsterdam
"With a spectacular drilling underneath the North Sea canal the connection of Amsterdam-North to the regional district heating grid of Nuon is becoming ever closer. Six cranes held an 800 meter long pipeline in the air just next to the Second Coen tunnel. Subsequently, the pipeline was pulled through a drilling hole underneath the busy shipping route of the North Sea canal at a depth of 40 meters during an eight hour long operation. The drilling did not cause any obstructions for traffic through the tunnel or over the canal" (Nuon & Lousberg, 2016).
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Preface

In 1972 the Club of Rome published their 'Limits to Growth' which set the stage for wide public debate about the sustainability of the "world population, industrialization, pollution, food production and (energy) resource depletion" (Meadows, Meadows, Randers, & Behrens, 1972, p.23). Meadows et al. (1972) spoke about the need for a transition from growth to global equilibrium to prevent reaching the limits to growth on this planet. She deemed it to be possible to build a more sustainable world if the world would act quickly and decisively.

Today, more than forty years later, we have started building that sustainable world Meadows envisioned. We have celebrated successes such as the establishment of the United Nations Framework Convention on Climate Change (1994) and the Kyoto protocol which followed shortly afterwards (1997). In the past decades our increasing awareness of sustainability issues has sprung many other environmental conservation initiatives on an international level, as well as on a national and local level.

Despite the success we have accomplished in the field of climate mitigation and environmental conservation we have also learned how difficult it is to achieve the sustainable world Meadows envisioned. Economic interest are so often at odds with environmental interest making it difficult to combine progress in welfare with progress in sustainability issues. As a result, we have learned that is difficult to incorporate the externalities of our economic activities in an appropriate manner in our decision making. Nevertheless, the tremendous speed at which renewable energy technologies are being developed and deployed around the world are promising. Yet, the question remains, whether our efforts towards sustainability will be in time and sufficiently substantial.

This thesis aims to support the efforts of building a more sustainable world by suggesting reforms of the economic organization of the heat provision system in the Netherlands. By changing the rules of the game, people and businesses can be incentivized to satisfy their heat demand in a more sustainable manner. District heating can play a key role in this. In doing so, the Netherlands can decrease its dependency on natural gas from the earthquake-sensitive Groningen region and instable import regions while at the same time lowering the carbon emissions from the heat provision system.

Depending on the background of the reader, it may be useful to zoom into those topics into which the reader is interested and skim over the parts the reader is already knowledgeable. Chapter 1, 2, and 3 set the stage of this research study and introduce the Dutch district heating sector and larger heat provision system. Subsequently, Chapter 4 dives into the topic of market design and explores the design space for a new market model for the Dutch district heating sector. Chapter 5 and 6 describe respectively the empirical work, being the international case studies, and the design work, being the proposed new market models for the Dutch district heating sector. Finally, Chapter 7 provides the conclusions and recommendations following this research study and Chapter 8 reflects upon the research.

I wish you a most interesting read of this thesis.

Alexander Oei
Delft, 10 November 2016

Acknowledgements

The thesis that lies before you represents the capstone research project of seven wonderful years of studying at the Faculty of Technology, Policy and Management. Working on the thesis project was a great pleasure and offered me the opportunity to meet many inspiring people working in the district heating sector. Finishing the thesis was however also a true challenge and I would not have been able to complete it without the support of a number of very special people. Therefore, hereunder I would like to express my gratitude to those who played an important role in helping me along the way with my research.

I would like to express my deepest gratitude towards Laurens de Vries. As my first supervisor Laurens has provided me with feedback on my many drafts and helped me to delineate my research through our discussions during the meetings. My greatest thanks goes however not to the substantive guidance Laurens provided me with, but to his continuous support and patience at times when my progress in the thesis was slower than I would have liked it to be.

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My thanks also goes to Paulien Herder who served as the chair of my thesis committee. Paulien's feedback and suggestions during the kick-off on my design process and topic delineation were very useful in determining the scope of the research project.

I am incredibly grateful to Mark Driessen who guided me at the Ministry of Economic Affairs. Through our discussions I learned a lot about the Dutch energy sector and the role the Ministry of Economic Affairs plays in governing it. His insights into how the administrative apparatus of the Dutch government works illuminated my understanding of how the policy process works in practice. Finally his patience and support throughout this thesis were incredibly valuable.

In addition, there were a great number of people during this thesis who were willing to free their time to explain how the district heating sector works and give me their views on specific design choices for the market design of the Dutch district heating sector. People who deserve special mention include Jinny Moe Soe Let from Eneco, Lex Bosselaar from RVO and my colleagues from the 'heat team' at the Ministry of Economic Affairs. Special thanks also goes to the people in the Swedish and Danish district heating sectors who I was able to interview for this thesis.

Finally, I would like to express my utmost gratitude towards my family and friends who were incredibly supportive during the writing of this thesis. Especially my brother Maxim Oei was very helpful in helping me structure my planning for the last stretch of this thesis. Also, my friends who provided me with encouragement, but also the at times much needed distraction from the thesis receive my deepest thanks.

Alexander Oei
Delft, 10 November 2016

Summary

The heat provision system is an important sector for the Netherlands for both the welfare of people and the Dutch economy. In 2012 the demand for heat in the Netherlands constituted roughly 36% of the primary energy demand, which translates into roughly 55% of the Dutch final energy consumption (CE Delft, 2014). Most of the heat demand is currently satisfied by the combustion of fossil fuels such as natural gas, coal and oil in a range of appliances (CBS, 2012; Ministry of Economic Affairs, 2015a). Consequently, in accordance with the magnitude of the heat demand and the fuels used to service it, the heat sector's greenhouse gas emissions are substantial[1]. Driven by climate policies, a decreasing availability of domestic natural gas resources and the risks of energy import dependency from politically-unstable regions, the Dutch government is now investigating pathways towards a more sustainable provision of heat (Ministry of Economic Affairs, 2015a).

In the pursuit of finding an appropriate pathway towards a more sustainable provision of heat it is useful to divide the heat sector in two functions in accordance with the heat demand: a low temperature heat function (<100ºCelsius) and a high temperature heat function (> 100-120ºCelsius) (RLI, 2015). The low temperature heat function covers the heat demand of the built environment, the horticulture sector and the low-temperature heat part of industry. The high temperature heat function concerns the industry sector (e.g. steel industry and (petro) chemical industry). This thesis focuses on the low temperature heat function because (1) there is much room for improvement and (2) the improvements can be done with existing technologies, whereas for the high temperature heat function still more time is needed to develop affordable alternatives for sustainable heat provision.

Within the low temperature heat function there currently exist multiple incentives to provide heat in a more sustainable manner. Alternatives to the currently dominant natural-gas fired heating appliances include district heating, electric heat pumps, wood-fired heating, solar heating and heat savings measures. Of these alternatives especially the district heating sector offers tremendous potential for decreasing greenhouse gas emissions and the dependency on natural gas. The potential of the district heating sector mainly lies in: (1) the possibility of using a variety of energy sources for heat production and (2) the large available potential of these energy sources (e.g. residual heat from industry and power plants).

The current regulatory framework already stimulates district heating networks, and other alternative forms of heating, by means of subsidies, grants, and other favorable regulatory arrangements. It is however not enough because there are physical and institutional-economic barriers that are impeding the growth of the district heating sector and a larger transition towards more sustainable practices in the heat provision sector. There is therefore a need to rethink how the market model for the heat provision sector, and more specifically the district heating sector, should be organized. Such a new market model should foster the way towards a more sustainable and more secure heat provision sector while remaining affordable and safe.

Research objective and research approach

Although the overarching goal is attaining a more sustainable heat provision sector as a whole the focus of this thesis lies on the opportunities that the *district heating sector* provide, given its large potential for decreasing overall greenhouse gas emissions and fossil fuel dependency. Consequently, the research

[1] In 2012 the Dutch heat sector was responsible for an estimated 88 Mton of CO_2 emissions (Warringa & Rooijers, 2015). To put that figure in perspective, this is 53% of total CO2 emissions of the Dutch energy sector or 46% of total CO2 emissions of the Netherlands (RIVM, 2014).

objective is formulated as: *"To develop a new market model for the district heating sector of the Netherlands that is aimed at facilitating a transition towards a more sustainable heat provision system."*

It follows that the end-result of this thesis consists of a proposal for a new market model for the Dutch district heating sector. To guide the research process the research study was framed as a *design exercise*. While performing a design exercise it is useful to use a design framework. For this study the engineering design framework called the 'meta-model for design' proved to be very useful. The 'meta-model for design' structures the design process in five research activities being: (1) developing goals, objectives and constraints, (2) developing the design space for a new market model for the district heating sector, (3) assessing the design space, (4) designing alternative market models and (5) selecting the most promising market model. By following the five research activities a new market model was designed. The research activities itself were supported by a range of research methods of which two deserve special mention: (1) the economic analyses, which were used to develop the design space, and (2) the international case studies, which enabled the assessment of the theoretical insights provided by the economic analysis in practice.

Design space and case studies

The design of a new market model for the Dutch district heating sector involves making many design choices on a range of topics. The topics over which the design choices have to be made are called the 'design variables'. The options between a policy-maker can choose per design choice, or design variable, are called the 'policy instruments'. Together, the collection of design variables and their possible design options, or policy instruments, make up the *design space*. Nine design variables were identified for the design of a new market model all with a range of different policy instruments. Of these nine design variables the first seven pertain to the regulation of the district heating sector and the last two pertain to steering the relative attractiveness of district heating versus other forms of heating. Table 1 presents the design variables.

Table 1: Design variables for the design of a new market model for the Dutch district heating sector.

Design variables
Regulating the district heating sector
1. Public versus private ownership
2. Network access conditions (for producers, retail companies and consumers)
3. Network unbundling
4. Integrated versus decentralized market
5. Tariff regulation
6. Congestion management method
7. Integration with neighboring networks
Steering the relative attractiveness of district heating versus other forms of heating
8. Incentives for consumers of heat
9. Incentives for producers of heat

Each of the policy instruments have pros and cons which can be analyzed by reviewing scientific literature. The theoretical insights drawn from scientific literature provided a good foundation for the further design process, but to make an informed decision for policy instruments for each of the nine design variables this thesis went beyond theoretical insights by collecting empirical insights from international case studies regarding alternative market models for the district heating sector. The case studies not only enriched the understanding of the pros and cons found for each of the policy instruments, but also provided inspiration on which policy instruments to combine together into new market model designs. Moreover, the case studies provided empirical evidence for what works in practice, and what is unlikely to work in practice.

The countries for the case studies were selected based on four criteria: (1) the *institutional context* of the countries had to be similar, (2) the *institutional organization* of the market model had to be distinctive, (3) *the current level of district heating* as compared to the Netherlands had to be higher and (4) the *availability of information and data* had to be adequate. Based on these four criteria two countries were selected for further review: Sweden and Denmark.

New market model designs

Designing new market models for the Dutch district heating sector involves choosing appropriate policy instruments for each of the nine design variables. Combined, the coherent 'package' of policy instruments forms the market model for the Dutch district heating sector. The selection process for choosing the appropriate policy instruments per design variable was guided by two tools: (1) a morphological chart and (2) the FULDA-method.

A morphological chart is a graphic representation of the design space for the market model design effort. On the vertical axis of the chart the nine design variables are listed and on the horizontal axis the most relevant means, or policy instruments, are listed. Depicting the design space graphically through a morphological chart was not only useful from a design perspective, because it fosters a good overview of the design space and facilitates creativity, but it also proved to be useful for the presentation of the market models in the report.

'FULDA' is an abbreviation for the 'function-based legal design & analysis method', developed by Knops (2008). The method was originally developed in order to facilitate the design of the legal organization of *technical functions* of energy infrastructure systems. In this thesis, the method is used to design the legal organization of the *institutional-economic functions* (represented by the design variables) of an energy infrastructure system, specifically the district heating system. The FULDA-method is comprised of three main steps of which the third step represents the 'core' of the method. During the third step of the method the appropriate policy instruments per design variable are selected. The justification for selection follows after answering four questions: A. Should someone be made explicitly responsible for this function? B. Who should be made responsible? Or: who should be allowed to perform this function? C. How should the function be further organized? D. What control possibilities for governments should be implemented? The four questions were therewith answered for all of the nine design variables.

While designing the new market models two topics were taken into account 'implicitly', meaning they did not form hard constraints, but were considered while choosing the appropriate policy instruments per design variable. These two topics were: (1) the principles of good market governance and (2) the future robustness of the market model designs. In order to ensure that the market models that were designed will result in 'good functioning regulatory frameworks' the designs adhered to the principles of good market governance (e.g. transparency, proportionality, accountability, etc.). In order to ensure that the market model designs will also perform well in the medium future, the expected impact of key exogenous factors on the district heating sector's market model performance were explored through a scenario-analysis.

The design effort resulted into two new, distinct, market models for the Dutch district heating sector which are directed at (1) facilitating the growth of the district heating sector including the use of more renewable heat production, and (2) providing an appropriate regulatory framework for the district heating sector taking into account the interests of key stakeholders. The reason for designing two distinct market models instead of one optimized market model is because depending on the assumptions one makes regarding the arguments for and against specific policy instruments, one may come to different conclusions. Two sets of assumptions, or perspectives, were taken as input for the designs: the 'Danish+ perspective' and the 'Swedish+ perspective'. An overview of the two market models that resulted from adopting these perspectives is given in Table 2.

Conclusions and recommendations

In this thesis two new, distinct, market models are proposed for the district heating sector which can facilitate meeting the Dutch energy and climate goals for the heat provision sector while taking into account the goals of heat remaining affordable, reliable and safe. These two market models are titled respectively the 'Danish+ perspective' and the 'Swedish+ perspective'.

Expected market model performance. In both market models the district heating sector is expected to grow with the share of renewable heat production increasing as well. At the same time, the market models also facilitate a transition towards more sustainable practices in the larger heat provision system as well. In the 'Danish+ perspective' market model the average price is expected to rise and a moderate amount of tariff differentiation will be introduced. In the 'Swedish+ perspective' market model the average price of heat remains relatively stable, but a larger amount of tariff differentiation is expected. The expectations about the future performance of the Dutch district heating sector presented in this thesis are however insufficiently substantiated and precise to be able to compare which perspective will perform better. Furthermore, the performance of the market models is largely dependent on political choices and trade-offs between variables which could not be incorporated in the design and thus also not in the market models' expected performance. Therefore this thesis does not choose a 'winner' out of the two proposed market models, but instead shows two feasible market models which both are able to attain the Dutch energy and climate goals if there is sufficient *political commitment*.

The two proposed market models do however leave room for *differentiation* within the chosen policy instruments regarding choices such as the height of subsidies and taxes or the manner in which the chosen tariff regulation system is further defined. Therefore, the market models should not be interpreted as blue-prints for the new market model for the Dutch district heating sector, but instead, as regulatory frameworks with clear lines which may be colored in further. Policy makers should define the further regulation in a *transparent* manner by making use of *stakeholder consultations* and clearly presented arguments.

If a policy maker does want to choose one market model to work with and define further I recommend to assess which assumptions underlying the two market models the policy maker deems the most accurate representation of reality. Consequently, the policy maker can choose to work with either the 'Danish+ perspective' or the 'Swedish+ perspective'.

Further research could focus on performing more case-studies on alternative market models for the district heating sector to (1) gain more insights regarding the pros and cons of the policy instruments from the design space in practice, or (2) focus on specific design variables to learn more about the further regulation of the market model for the design variable in question. In addition, further research could also focus on improving the assessment of the expected performance of the proposed market models by going beyond theoretical insights and empirical evidence given in this thesis by means of using modelling and simulation.

Table 2: Overview of the proposed market models and the Dutch market model. The blue-shaded cells represent choices for the design variables that differ from the Dutch market model. The orange-shaded cells represent choices for the design variables that differ from the Dutch market model, but are the same in Market model 1 and Market model 2.

Design variable	Dutch market model	Market model 1 'Danish+ perspective'	Market model 2 'Swedish+ perspective'
Regulating the district heating sector			
1. Public versus private ownership	Not prescribed. Public and private ownership are both allowed.	Any interested party (both public and private) has the right to initiate a heat project. The municipality authority is responsible for *approval* of the projects.	Not prescribed. Public and private ownership are both allowed.
2. Network access conditions (for producers, retail companies and consumers)	Producers: no regulation. Retail companies: not defined. Consumers: obligation to connect to electricity and natural gas. Bound-heat-consumers *must* pay the fixed part of the connection costs.	For producers: regulated access. Access request/ project proposal must be approved by the local municipality. For retail companies: Not regulated. For consumers: Zoning.	For producers: regulated access based on lowest cost principle. For retail companies: not regulated. For consumers: no *obligation* to connect consumers, but consumers may *request* access against non-discriminatory terms.
3. Network unbundling	Not regulated. Unbundling is however allowed.	Not regulated. Unbundling is however allowed.	Not regulated. Unbundling is however allowed.
4. Integrated versus decentralized market	Decentralized market: bilateral contracts.	Decentralized market: bilateral contracts.	Decentralized market: bilateral contracts.
5. Tariff regulation	End-user price regulation following the 'not-more-than-otherwise' principle.	Price-cap regulation (external benchmarking: NMDA-principle) transitioning into price-cap regulation based on the costs of district heating (benchmarking). Allow for tariff differentiation in medium future.	Hybrid-system. Price-cap based on external benchmark which is set such that district heating suppliers can recuperate their costs. In addition, tariff differentiation is allowed and competition *between* networks serves as a means to form competitive prices and products in the district heating sector. The competition between networks serves to protect consumers to being overcharged by their monopolistic heat suppliers.
6. Congestion management method	Not regulated.	Not regulated.	Not regulated.
7. Integration with neighboring networks	Not regulated, but certainly stimulated. Example: the heat roundabout South-Holland.	Not regulated, but certainly stimulated.	Not regulated, but certainly stimulated.
Steering the relative attractiveness of the district heating sector			
8. Incentives for consumers of heat	Investment subsidy for renewable energy (consumers and 'small and medium enterprises'); energy taxes.	Adjust the energy taxes as such to provide incentives for consumers to make the 'sustainable choice'. Evaluate the performance of the Investment Subsidies for Renewable Energy for consumers (ISDE).	
9. Incentives for producers of heat	Among others: SDE+, geothermal energy subsidies, EIA (see also Table 1-1)	Adjust the energy and coal taxes as such to provide incentives for producers to make the 'sustainable choice'. Strengthen the subsidies for renewable heat in the SDE+ for biomass-based CHP and add geothermal heat and solar heating. Also include an *obligation* to use residual heat from industry and power plants usefully if economically feasible.	

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1 Introduction

1.1 Change of an era: the need for a sustainable heat provision system

The heat provision system in the Netherlands is an important sector for both the welfare of people and the Dutch economy. In 2012 the demand for heat in the Netherlands constituted roughly 36% of the primary energy demand, which translates into roughly 55% of the Dutch final energy consumption (CE Delft, 2014). This 1200 petajoule (PJ) energy demand is consumed in three sectors for space heating and warm tap water in the *built environment*, for heating the greenhouses in the *horticulture sector* and for process heat in *industry* (Ministry of Economic Affairs, 2015a).

Most of the heat demand is currently satisfied by the combustion of fossil fuels such as natural gas, coal and oil in a range of appliances (CBS, 2012; Ministry of Economic Affairs, 2015a). In accordance with the magnitude of the heat demand and the fuels used to service it, the heat sector's greenhouse gas emissions are substantial. In 2012 the Dutch heat sector was responsible for an estimated 88 Mton of CO_2 emissions (Warringa & Rooijers, 2015). To put that figure in perspective, this is 53% of total CO2 emissions of the Dutch energy sector or 46% of total CO2 emissions of the Netherlands (RIVM, 2014).

Driven by climate policies, a decreasing availability of domestic natural gas resources and the risks of energy import dependency from politically-unstable regions, the Dutch government is now investigating pathways towards a more sustainable provision of heat (Ministry of Economic Affairs, 2015a).

By 2020 the Netherlands must decrease its greenhouse gas emissions by 16% compared to 1990 levels in accordance with climate goals set by the European Union (Council of the European Union, 2009). Moreover, forced by the recent climate case from Urgenda, the Dutch government might even be required to decrease its greenhouse gas emissions in 2020 by at least 25% compared to 1990 levels (Civil Court The Hague, 2015). If the greenhouse gas emission reduction targets are to be achieved an important contribution will have to come from the heat sector, given the large share and the dominantly carbon-based nature of heat provision in the primary energy demand.

From an energy security perspective it is also increasingly urgent to shift to a more sustainable heat provision system. Due to the depletion of domestic natural gas reservoirs it is expected that the Netherlands will become a net-importer of natural gas around 2030 (ECN, 2015). Moreover, in the last couple of years natural-gas production induced earthquakes in Groningen have become both stronger and more frequent. In order to mitigate these hazards the gas production levels have been decreased (Ministry of Economic Affairs, 2015b). Depending on these developments the domestically available natural gas production capacity, and flexibility, might become insufficient more quickly. At the same time import alternatives of natural gas are becoming less abundant and less secure. Stable suppliers such as Denmark, Norway and the UK also face stagnating or decreasing natural gas production levels. Other sources of natural gas such as from Middle-Eastern countries and Russia are becoming increasingly undesirable because of security of supply and geopolitical reasons (A. Correljé, 2011; RLI, 2015).

Hence, there is a need for a heat provision system which has a lower *climate and environmental impact* than the current heat provision system and which contributes to the *energy security* of the Netherlands. At the same time this system must also be *affordable* for both people (households) as economic undertakings (horticulture, businesses and industry).

1.2 Moving towards a sustainable heat provision sector: trends, regulatory efforts and barriers

The *heat vision* of the Dutch government, published the 2nd of April 2015 in a letter to parliament, builds strongly on a well-known and influential policy document for the Dutch energy sector: the 'Energy Agreement for Sustainable Growth'. The Energy Agreement was formed between more than forty organizations including the public, private and non-profit sector to achieve three goals: (1) decrease the final energy consumption of the Netherlands, (2) increase the share of renewable energy production and (3) create more jobs for the Dutch economy while working towards the first two goals (SER, 2013).

Soon after the agreement was closed, it was however noted that the energy agreement renounced to give the necessary perspective on the heat sector to achieve the goals it set for renewable energy (PBL, 2014), being 14% in 2020 (European Parliament & Council of the European Union, 2009) and 16% in 2023 (SER, 2013). Hence, enter the need and purpose of the heat vision.

The heat vision aims to give direction to the debate in how a more sustainable heat provision system may be achieved. Summarizing, the heat vision discusses three subjects: (1) plausible trends that are observed for the future of the heat sector, (2) the current regulatory framework (with special attention given to efforts towards heat savings and improved use of residual and renewable heat), and finally (3) the need to rethink the 'market model' of the Dutch heat provision system.

1.2.1 Plausible trends observed for the future of the heat sector

The heat vision observes that given the needs for a more sustainable heat provision system discussed in Section 1.1, multiple transition pathways exist for the heat sector. The variety of possibilities to achieve a more sustainable heat sector can be structured by dividing the heat sector in two functions according to the need for heat: a low temperature heat function (<100°Celsius) and a high temperature heat function (> 100-120°Celsius) (RLI, 2015).

Low temperature function

In the low temperature function heat is used for space heating and warm tap water in the built environment, for heating the greenhouses in the horticulture sector, and for low-temperature process heat in industry (RVO, 2013). Currently, the low temperature function is largely satisfied using natural gas. With 93% of the households connected to the nation-wide natural gas grid and most greenhouses using combined heat and power units or heat-only boilers fueled by natural gas the use of natural gas is wide spread (ECN, 2015).

However, driven by environmental considerations increasingly other alternatives are being pursued. Examples are heating using electric heat pumps in so called 'all-electric areas', district heating using centrally produced heat from oftentimes large installations, solar thermal heating, or hybrid forms of heating. Hybrid forms of heating include combinations of a conventional high efficiency individual central heating boiler with electric heat pumps, solar thermal installations or biomass fired stoves. Another increasingly employed concept is 'zero on the meter', which is a designation used for highly energy-efficient buildings that consume close to zero energy due to far going insulation and/or autonomous energy production (Ministry of Economic Affairs, 2015a).

High temperature function

In the high temperature function heat is used in the industry sector for producing chemical, steel, food, construction and paper products. Currently, the high temperature function is largely satisfied by natural gas, oil and coal (ECN, 2015).

The key to lowering the high temperature heat demand is by innovating production processes so that they may rely on lower temperatures. Examples of fundamental innovations in production technologies, processes and methods include biochemical technologies (e.g. producing chemicals with yeast and fermentation processes), membrane separation and advanced extraction (instead of relying on energy-intensive distillation techniques for product separation) (RLI, 2015).

Equally important is servicing the residual heat demand using more renewable and less-carbon intensive means. Avenues currently pursued are better use of residual heat by applying improved process-integration and clustering of energy-intensive companies. Also, fuel switching to less carbon-intensive fuels such as electricity and biomass, possibly via other energy carriers such as methane or hydrogen, are promising (RLI, 2015).

1.2.2 Relevant, existing, regulatory efforts that aim to steer the heat provision system

For both the low and high temperature heat demand the predicament is to lower the heat demand, and service the residual heat demand in a low-carbon, preferably renewable manner. Although dividing the heat demand into a low and high temperature function is useful for the purpose of analysis, in practice heat is a *cross-sectoral* and *cross-infrastructural* commodity. Per sector and per infrastructure specific institutional contexts exist which have to be taken into account when analysing options to steer the heat provision system towards a more sustainable pathway.

For the three sectors where heat is used (the built environment, the horticulture sector and industry) sector-specific goals and supporting policy instruments exist to steer the use of energy towards more sustainable practices. Table 1-1 summarizes the most important *sectorial* policy instruments currently of influence on the Dutch heat provision system. On a European level four directives are of importance: the Renewable Energy Directive (RED), the Energy Efficiency Directive (EED), the EU Emissions Trading System Directive (EU ETS) and the Energy Performance of Buildings Directive (EPBD). These four directives together form the institutional framework in which national (sectorial) legislation regarding heat is formed. In chapter three these directives and the resulting national legislation that is influenced by them are discussed.

Heat is also cross-infrastructural because it can be produced by means of the conversion of energy from other energy carriers such as natural gas, electricity or biomass (e.g. logs or pellets), or transported directly through district heating networks. Alternatively, the heat demand can also be reduced by means discussed in Section 1.2.1. The institutional context of the infrastructures used to transport heat, or the energy carriers used to produce heat, is also discussed in chapter three.

Table 1-1: Overview of currently used policy instruments (ECN, 2015; Ministry of Economic Affairs, 2015a; Ministry of Interior Affairs and Kingdom Relations, 2015)

Sectors	European Legislation	National legislation
General framework		
Directives and national legislation	Renewable Energy Directive Energy Efficiency Directive EU Emissions Trading System Directive	SDE+, energy investment deduction (EIA), energy tax
Sector specific regulation		
Industry		
ETS sector		MEE
Non-ETS sector		MJA3
Built environment	Energy Performance of Buildings Directive	Building decision
Existing building stock		Energy label; Energy index (EI) – STEP, FEH, NEF, Energy performance and rent points system; Energy conservation programs (e.g. Zero on the meter)
New building stock		Connection obligation; Energy Performance Coefficient (EPC); Energy performance measures on a regional level (EMG)
Horticulture sector		MJA, Sectorial national emissions trading system
Technology specific regulation		
Geothermal energy		Exploration guarantees
Small heat options		Small heat options subsidies (in design)

The heat vision observes that although there are many (sector-specific) policy instruments directed at sustainability in the heat provision system, the transition towards sustainability is not moving at the desired pace. There is therefore a need to rethink the 'market model' of the Dutch heat provision system.

1.2.3 The need to rethink the 'market model' of the Dutch heat provision system

The goals for a new market model for the Dutch heat provision system are clear: more sustainable, more secure (lower dependency on domestic natural gas and natural gas imports), remain affordable, and be safe (Ministry of Economic Affairs, 2015a). At least roughly, there also exist alternatives on how to organize the physical system such, that these goals will be met: a combination of district heating in the low-temperature heat function, all electric areas and areas where natural gas is used (possibly green gas) (CE Delft, 2014). Yet, the transition towards a more sustainable heat sector will not occur automatically because there are physical/technological, institutional and economic barriers that inhibit households, businesses, glass horticulturists and industry to make more sustainable choices in satisfying their heat demand. Table 1-2 summarizes a handful of barriers recurring in literature for the uptake of district heating grids by briefly explaining and characterizing them.

The heat vision notes that in the low-temperature heat function, district heating grids could play an important role in delivering heat in a less carbon-intensive manner (Ministry of Economic Affairs, 2015a). However, as illustrated in a number of the barriers in Table 1-2, the cards in the current regulatory framework are not stacked in favor of district heating. It is therefore necessary to rethink how the market model for the heat sector, and especially the district heating sector, should be organized.

It should be noted that district heating is not the only means of servicing heat in a more sustainable way than the status quo. When considering how the district heating regulation could be reorganized to foster more district heating grids, the market model should also take into account that there are alternatives to district heating such as electric heat pumps, heat- cold storage, green gas, insulation and other applications.

The design space for a new market model of the Dutch heat provision system is a function of the market conditions, which can be influenced by taxes and subsidies, and the market design, which is determined by regulation regarding network access rules, tariffs, connection obligations, etcetera (de Vries, Correljé, & Knops, 2014). Summarizing, this thesis will look at the market conditions for heat delivery in a broad context and at the market design for the district heating sector. The market model under consideration includes an institutional and economic reality while at the same time being bound to the physical reality of the heat domain (see also Table 1-2).

Table 1-2: Overview of barriers to the growth of district heating networks

Barriers	Explanation	Characteristics
Transportation costs	District heating grids are characterized by *relatively high transportation costs* compared to the transportation costs of other energy carriers (e.g. natural gas and electricity). Heat has therewith an inherent local to regional character which makes a nation-wide district heating grid, similar to for instance the natural gas and electricity grids, not economically feasible. As a result, the number of heat producers and consumers per heat network are limited to locations where heat sources are in close proximity to demand centers of high enough heat density (Ministry of Economic Affairs, 2015a; PwC, 2015). This means that certain landscape types are economically more attractive than other landscape types (city versus rural areas).	Physical, economic
Security of supply	Delivering heat is bound to stringent *security of supply* regulations in the Netherlands, laid down in the Heat Act, because heat is considered a *merit good*. Heat is considered to be a *merit good* because of its vital importance for daily life of citizens, businesses and industry (Gent, Bergeijk, & Heuten, 2004). Although from a societal perspective it can be considered a good thing that the government aims to secure	Physical, institutional

	the availability, affordability and acceptability of heat provision, from a business perspective stringent *security of supply* obligations may be a barrier for heat delivery. In practice the obligation to always having to maintain heat delivery when needed constrains operational flexibility, which is possible for some heat sources (e.g. waste incineration plants), but more problematic for other heat sources (e.g. industries with flexible production capacities such as the steel industry).	
Freedom of choice	Since the liberalization of the Dutch energy sector consumers have gotten used to have freedom of choice regarding their energy supplier. District heating grids are oftentimes owned and operated by vertically integrated companies which leads consumers to be bound to one heat supplier.	Institutional
Price reference to natural gas	In the Netherlands 93% of households (ECN, 2015) are connected to the natural gas grid which makes natural gas the reference for the price of heat. To protect captive consumers from the monopoly position of district heating companies in the Netherlands the price of heat is capped according to the Not-More-Than-Otherwise principle (in Dutch abbreviated by NMDA). Because the costs of heat delivery are in practice oftentimes higher than the costs of heat production by means of natural gas, in many cases it is difficult to make district heating grids profitable since the asking price is capped.	Institutional, economic
Payback period of investments	Households, housing corporations and businesses oftentimes expect relatively short payback periods of investments, shorter than could be considered reasonable from a societal perspective (RLI, 2015). Because of the short payback periods expected, or high discount rates used, it is difficult to make closing business cases for new energy infrastructures which require high upfront capital investments.	Institutional, economic
Tax structure (energy tax)	The energy tax for small consumers in €/GJ on electricity is currently five times higher than it is on natural gas (Ministry of Economic Affairs, 2015a). As a result, electric heat pumps are at an economic disadvantage to natural gas fired central heating boilers. Another argument can also be made: if the energy tax on natural gas would be increased towards the level of that of electricity, the price of heat would also rise (NMDA) which leads to more district heating projects becoming profitable.	Institutional, economic
Negative externalities	Producing electricity from fossil-fuel fired thermal power plants goes hand in hand with the emissions of greenhouse gases, which constitutes a negative externality. In the European Union this negative externality is internalized in the price of electricity through an emissions trading system to incentivize the use of non-carbon fuels for the production	Institutional, economic

	of electricity. Currently, the emissions associated with natural gas fired heating or district heating is not internalized in the price. Since the district heating has relatively low carbon emissions per GJ compared to individual natural gas fired heating boilers incorporating the negative externalities of the greenhouse gas emissions associated with heat provision would be advantageous for district heating.	
Monumental buildings, historical city centers and the Dutch canals	District heating grids require thick pipelines that transport warm water to be laid out through the doorstep of a building. Laying down these infrastructures is limited in some occasions by rules (monumental buildings) and space (historical city centers and canals).	Institutional, physical and economic

1.3 Learning from international experience with alternative market designs for the heat provision sector

There exists a wide variety of alternative market models for heat provision systems in other countries. The experience with these alternative market models may serve as a resource in order to come to a well-informed policy intervention in the current market model.

Especially in a European context there exists an extensive body of literature on the regulation of the heat sector and the district heating sector specifically. To illustrate the variety of market models in the European district heating sector four paradigms are briefly described: the natural gas dominant paradigm, the Nordic paradigm, and the Eastern European paradigm.

The *natural gas dominant paradigm* is present in the UK and the Netherlands, where most households were connected to a natural gas grid after large natural gas fields were found in respectively the North Sea and Groningen. These countries are characterized by liberalized heating sectors where district heating only plays a small role (Lowes, 2015).

The *Nordic paradigm* including Finland, Sweden and Denmark, where District Heating holds high market shares following active stimulation policies in the second half of the twentieth century driven by primarily energy independence and climate motivations. Between these countries different market models exist ranging from the highly liberalized markets of Finland and Sweden to the more regulated district heating market of Denmark (Euroheat & Power, 2015).

The *Eastern European paradigm* where heat was historically viewed as a public good, a tradition dating back to the communist era. In line with this view high shares of collective and district heating applications exist in countries such as the Baltic states, Belarus and Poland (Euroheat & Power, 2015). The market models in these countries are also quite homogenous: vertically integrated utility companies own and operate the district heating networks. The heating companies are oftentimes either state-owned or operate under regulated conditions.

Finally there is a fragmented paradigm of countries including France, Germany, Austria and many other countries which have low shares of district heating overall, but do have a number of large district heating networks (Euroheat & Power, 2015).

Learning from the experience with subsidy schemes, fiscal policies, regulations on access, tariff regulation and other market model elements is useful in order to assess ex-ante what such choices for such market model elements would mean for the Dutch heat sector. Given the large physical system and institutional variety encountered, it can be concluded that there is much to learn from the international experience with alternative market models.

1.4 The Dutch policy window for a sustainable heat sector

Summarizing the preceding sections it may be concluded that there is currently a huge momentum for change in the Dutch heat sector. The existence of this momentum can be explained using Kingdon's Multiple Streams Approach (1984). Governments have to make decisions under ambiguity and uncertainty. According to the Multiple Streams Approach the likelihood of decisions being made is highest when the three streams – the problem stream, the policy stream, and the political stream – come together. In this moment a policy window is formed which is the opportunity for change. I argue that such a policy window currently exists for the heat sector in general and the district heating sector in particular. Figure 1-1 illustrates the application of the Multiple Streams Approach to the current developments in the heat sector.

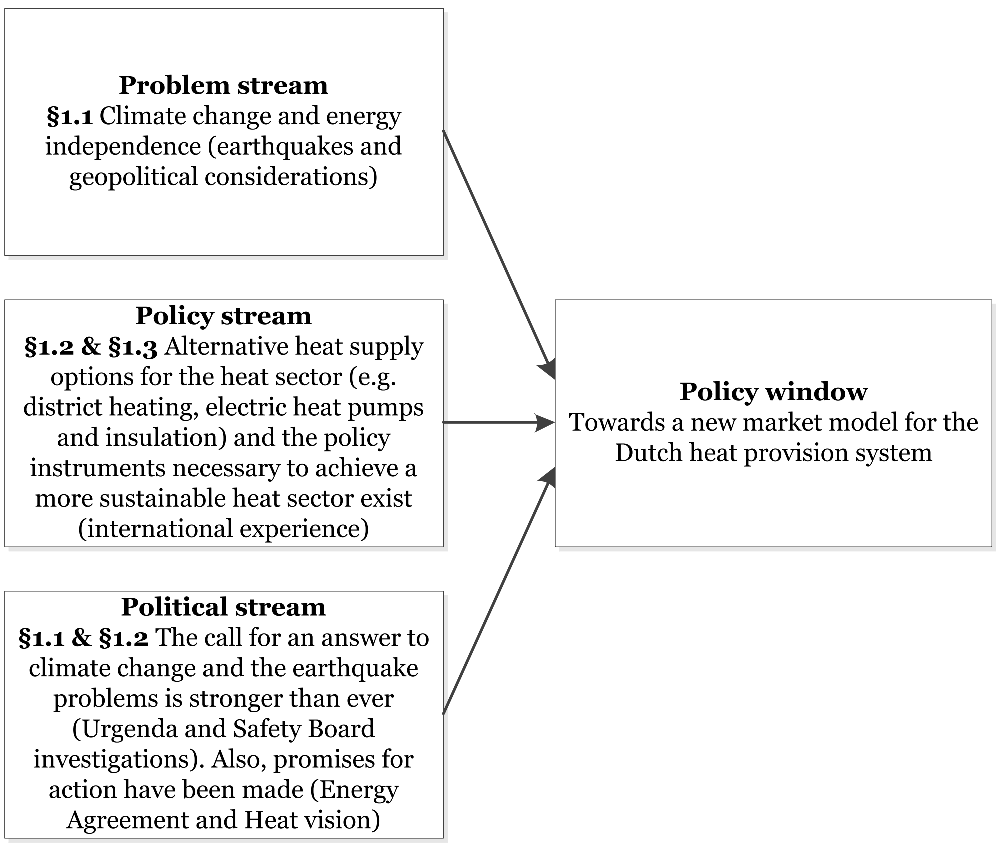

Figure 1-1: The policy window:
Illustrating the momentum towards a new market model for the Dutch heat provision system

Following this introductory chapter the research problem of this thesis is further scoped, and defined. Also, the research methods used in this thesis are discussed (chapter 2). Section 2.9 includes a reader into which the structure of this thesis is illustrated.

2 Research definition

In this chapter the research study is further defined in terms of scope, methods and structure. First a number of concepts are further defined (Section 2.1). Then, the knowledge gaps that are to be filled are discussed (Section 2.2). Subsequently, the resulting problem statement (Section 2.3), research objective (Section 2.4) and research questions (Section 2.5) are presented. How the research questions will be answered is discussed in the design process structure and research methods sections (Section 2.6 & 2.7). Given the research overview, the societal and academic relevance of the research is reflected on (Section 2.8). Chapter 2 closes with a brief depiction of how all the research activities and their results are presented in this document (Section 2.9).

2.1 Definitions

Chapter one concluded with the statement that this thesis works towards conceiving a new market model for the Dutch heat provision system, with a focus on the market design of the district heating sector. The research into a new, alternative, market model for the Dutch heat provision system starts with a definition of what actually is meant with the term 'market model'.

The Ministry of Economic Affairs defines a market model as *"a description of a defined market[2] in which one or multiple customer groups are being serviced"* (Ministry of Economic Affairs, 2015c). In this description the roles, relations and responsibilities of the participants in the market must be laid down. Very briefly this entails *who* is allowed to perform *what* activity under *which* conditions. Figure 2-1 graphically depicts what is included in a market model description.

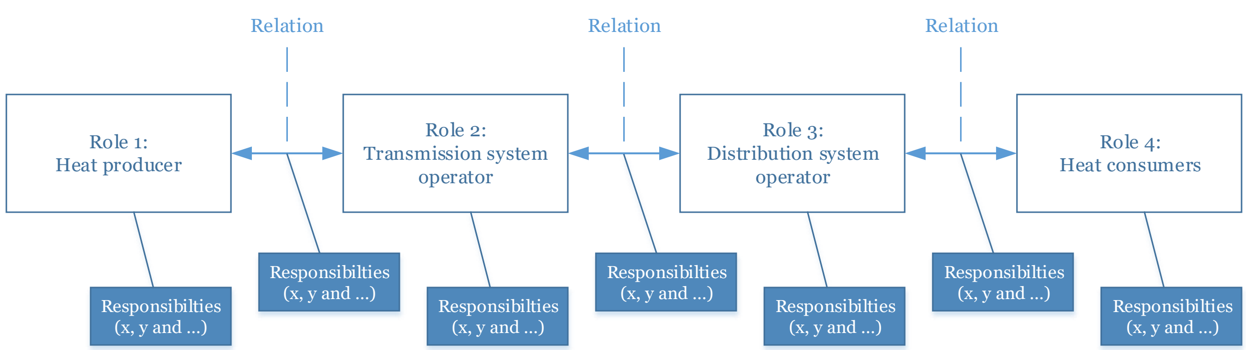

Figure 2-1: Illustration of the elements included in a market model description – roles, relations and responsibilities

The four *roles* identified in Figure 2-1 are denotations for organizations that fulfill a range of activities to enable the delivery of heat in the district heating sector. A role may be fulfilled by one individual or multiple individuals or organizations. At the same time, if one organization can fulfill multiple roles, that is also possible unless stated otherwise in the market model (Ministry of Economic Affairs, 2015c).

[2] Providing a precise definition of the defined market of the heat provision system is not trivial because heat may be provided via three physical infrastructures (natural gas, electricity and district heating) and various non-infrastructure bound means (e.g. insulation and solar thermal). A full description of the 'heat market' will follow in chapter 3.

Relations define how two roles in the market model interact. This can for instance be contract standards to which heat supplier's contracts with customers must comply. The way relations are defined determine how different parties that are fulfilling a role in the market interact with each other (Ministry of Economic Affairs, 2015c).

To both roles and relations, the market model description may attach *responsibilities*. An example is a legal obligation of a heat supplier to always uphold its service towards its consumers in light of security of supply considerations. For instance, in the Dutch heat act it is laid down that if a heat supplier cannot uphold its service he is responsible to compensate the damages for service interruption towards his consumers (Ministry of Economic Affairs, 2015c).

Shaping the roles, relations and responsibilities within the (district) heating sector occurs through laying down laws and regulations. Institutional economists call these laws and regulations *institutions*. Institutions are "the rules of the game" (North, 1990) that enable and constrain market parties' behavior and consequently market outcomes (Scholten, 2015). North defines institutions as "the humanly devised constraints that structure political, economic, and social interaction. They consist of both informal constraints (sanctions, taboos, customs, traditions, and codes of conduct) and formal rules (constitutions, laws, property rights)" (1991, p. 97). Government can influence and shape part of the institutional framework by changing the formal rules that apply to the (district) heating sector. In doing so, government may influence the incentive structure of the (district) heating sector and therewith market parties' behavior.

Williamson structured the breadth of the institutional environment by organizing it in a framework consisting of four layers of economic institutions (1998). The layers are defined based on two main criteria: the type of institutions and the frequency of change of institutions. Moving from top to bottom through the diagram the frequency of change of institutions increases. In other words, the higher the layer is positioned in the diagram, the more robust the institutions are to change. In Figure 2-2 Williamson's institutional framework is applied to the district heating sector.

The four layers of economic institutions respectively concern informal institutions, formal institutions, modes of organization and resource allocation and employment. The solid arrows indicate a constraining relation, institutions positioned in a higher layer constrain the space of possibilities of institutions in a lower layer. At the same time, dashed arrows moving upwards provide feedback to higher positioned layers. The orange rectangles highlight which of the layers of economic institutions are of primary interest when exploring alternative market models for the (district) heating sector.

Layer 1. To a large extent *informal institutions* govern our daily lives, and, therewith also economic transactions. They are robust 'rules' that typically change very slowly in the order of centuries to millennia. Because these institutions are so embedded in society they influence the make-up of a society's formal institutions. For example, the norms and traditions that led to the communist economic system led to a very different valuation of 'heat' than in a capitalist economic system. Whereas in the first system heat would be considered as a pure public good which must be provided by the state, in the second system heat would be considered as a merit good, which availability must be ensured by the state – which are two similar, but very different vantage points.

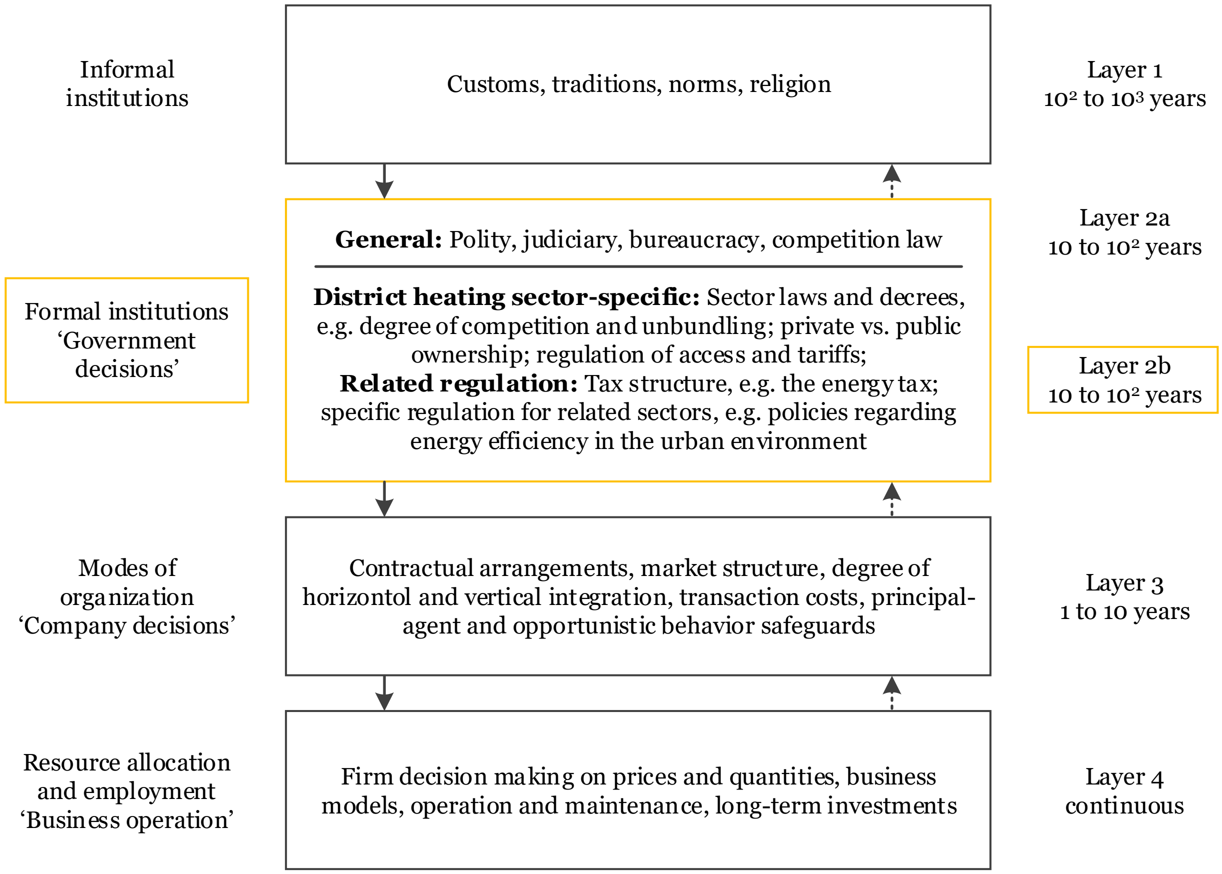

Figure 2-2: The four layers of economic institutions of the district heating sector (Adapted from: Scholten, 2015; Williamson, 1998)

Layer 2a & 2b. *Formal institutions* are tangible 'rules of the game'. Following the example of Scholten (2015) here this layer is subdivided in two sub layers: a *general* sublayer and a *specific* sublayer. The institutions in this level typically change at a faster pace in the order of a decade to a century (or their plurals). It has been nicknamed 'government decisions' because the institutions in this layer are conceived and may be altered by the government of a country, state or municipality.

The general sublayer concerns the institutional structure of a country. Are there stable institutions present that separate and define the legislative, executive and judiciary functions of a state? Can the rule of law be considered 'fair'? Is there a tendency towards securing a level playing field to foster competition through competition law, or, is there a large degree of public participation in economic undertakings?

The specific sublayer regards the laws and decrees that directly impact how the district heating sector is organized. Who may perform which of the roles in Figure 2-1? How are those roles related to each other? And what responsibilities are attached to these roles and relations? Examples include tariff regulation of the sale of heat, but also related regulation including the tax structure. For instance, in the Netherlands different energy tax rates exist for natural gas, electricity and heat, which strongly influences the relative attractiveness of these commodities to be used for the provision of heat (CE Delft, 2014).

In other words, this layer determines the space of possibilities for the market model. The general sublayer may be considered as considerably more robust to change than the specific sublayer. Given this fact, and the fact that currently legislation and regulation that is positioned in sublayer 2b is under review

(The Heat Act and related regulation), the focus of this thesis lies on sublayer 2b, while also acknowledging the influence of the other layers.

Layer 3. Economic transactions are governed by the *modes of organization* in a sector. Is there competition in the market for heat delivery, or are there (regional) monopolies? Are the different roles in the value chain organized in separate companies or organizations, or are they vertically integrated in one large company? This layer has been nicknamed 'company decisions' because it is companies that determine how they will organize their economic undertakings. However the space of possibilities in the modes of organization is constrained by the higher positioned institutional layers, most importantly, layer 2a & 2b. The typical frequency of change of these institutions lies in the order between a year to a decade (or their plurals).

Summarizing the preceding. Hereafter with the term 'market model' of the (district) heating sector is meant (1) the controllable part of the institutional organization of the district heating sector, which regards the institutions that define the roles, relations and responsibilities within the district heating sector (layer 2b and to some extent layer 2a in Figure 2-2), and (2) the design of the related regulation which influences the relative attractiveness of different heat supply options (layer 2b in Figure 2-2).

Layer 4. The economic activities that enable the economic transactions in the district heating sector are governed by the institutions labelled as 'resource allocation and employment'. These institutions concern the decisions, business models, protocols and so forth that govern the business operations. These institutions are decisions of firms and happen in a continuous fashion.

The institutions discussed, determine the make-up of the market model. Government wishes to influence this make-up through altering the institutions in sublayer 2b in order to shift the attractiveness of different heat supply options in favor of sustainability. However, the attractiveness of different heat supply options is only in part determined by the controllable part of the institutional framework (sublayer 2b) – the relative attractiveness is also determined by *exogenous factors* that are outside the control of government.

Exogenous factors to the government include physical factors, such as the natural endowment with energy sources, economic factors, such as the variety and dynamics of technology costs, and institutional factors, such as commonly held ideologies with respect to market organization (A. C. Correljé & de Vries, 2008). These exogenous factors will be taken into account when reviewing the market model of the district heating sector.

Level playing field

The heat vision also states that a new market model design must facilitate that all heat provision options may compete with each other on a *level playing field* (Ministry of Economic Affairs, 2015a). In economics, it is generally acknowledged that a market model should ensure that all market participants have *equal opportunity* for success, in other words, there should be a *level playing field* (Arneson, 2015).

The financial times Lexicon defines level playing field as "an expression for a market or industry in which all participants compete under the same conditions from regulatory and fiscal points of views" (Financial

Times, 2015). Equality of opportunity theorists posit that a level playing field is secured when two premises are met: (1) there should be equal initial conditions and (2) there should be a fair framework for interaction (Arneson, 2015). When looking over Table 2 one may argue that in the Dutch heat sector a level playing field for different heat options is lacking.

First of all, the *initial conditions* for different options to service the heat demand are not equal. For instance, there already exist nation-wide natural gas and electricity grids which have been largely paid off already. This makes it economically less attractive to lay down new infrastructure, for instance district heating grids.

Also, the *framework for interaction* is not fair to different options that service the heat demand. For instance, energy taxes for small consumers on electricity are charged five times higher than they are on gas, which is a strong competitive disadvantage towards electric heat pumps.

When discussing the design of the institutional organization of the district heating sector or the design of the related regulation that shapes the relative attractiveness of different heat supply options attention will be given to how changes to the current institutional framework will affect the level playing field in the heat provision sector. From a fairness perspective towards incumbent energy companies, households and businesses who have invested resources into their currently used heat supply options, vested interests will herewith be taken into account.

2.2 Scoping and knowledge gaps

There is currently a gap between the desired developments in the heat provision system, and the district heating sector in particular, and the actual developments. This gap is reflected in the pace and magnitude of the current pathway towards sustainability in the heat field. The heat vision identifies four areas of exploration in an implementation agenda which should close that gap being: (1) new market models and financing means of heat, (2) facilitating regional (residual) heat projects, (3) additional support for renewable heat and (4) innovation (Ministry of Economic Affairs, 2015a). This thesis will adopt these same areas of exploration while discussing new market models for the heat provision sector.

Although the areas of exploration are clear, a clearly structured *decision space* is still lacking. In the introduction a number of physical/technological, institutional and economic barriers were introduced that currently impede a transition towards a more sustainable heat provision system. An overview of the means to overcome these barriers is what is sought. How can, and should the market conditions be reshaped? How should the market design be restructured?

Moreover, when answering the questions posed above one must also consider the *coverage* of the regulation. What should be considered the 'heat market' for which a new market model must be designed? Is that only the low temperature function, as is currently the case, or should the high temperature function also be included, and in what way? Furthermore, what is considered district heating? Is that 'large' heat networks with a magnitude of more than 5000 connections[3], or, also smaller heat networks with a magnitude of dozens of connections such as 'block heating'?

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[3] The number of connections mentioned is an arbitrary number used in literature to indicate the order of magnitude of district heating networks (CE Delft, 2009).

The decision space should reflect the effects of the design choices on key performance indicators for the market model being the resulting affordability, availability and acceptability of the heat provision system. Questions related to that are what is considered affordable by heat consumers and what level of availability is required? Also, what should be part of the definition of acceptability, are values such as freedom of choice, renewability of energy resources and carbon emissions equally important, or are there preferences among these values?

It is observed in literature that different authors have different ideas about how to regulate the heat sector. They give specific suggestions on the adoption of policy measures, however do not show a comprehensive decision space. This thesis will fill that gap by providing a more comprehensive overview of the decision space in designing an alternative market model for the district heating sector. Furthermore this thesis will add value by drawing insights from the experience with regulatory instruments for the district heating sector in other countries through a systematic international comparison. In this way the theoretical insights used can be placed into the socially and technologically complex practice of the district heating sector which will help determine the suitability of regulatory instruments for the Dutch district heating sector.

2.3 Problem statement

Given the desire to overcome the institutional-economic barriers, given the physical/technological constraints, in achieving a more sustainable heat provision system a new market model for the provision of heat is sought. What such a new market model for the delivery of heat should look like is however currently unclear. This leads to the following problem statement:

> **It is unclear what a new market model for the delivery of heat should look like so that it may facilitate a transition towards a more sustainable heat sector in a socially cost-efficient manner at the desired pace given climate and energy goals of the Dutch government.**

2.4 Research objective

Although the overarching goal is attaining a more sustainable heat sector as whole, as mentioned, the focus of this thesis will lie on the opportunities that the district heating sector provide in attaining higher levels of sustainability. Following the problem statement while also adding more focus to this research study the research objective becomes:

> **To develop a new market model for the district heating sector of the Netherlands that is aimed at facilitating a transition towards a more sustainable heat provision system.**

The end-product of the research project will therewith be an analysis of the Dutch market model for the provision of heat and the analysis of a number of alternative market models for the district heating sector. An important source of knowledge and experience will come from the experience with alternative market models for the heat sector in other countries.

2.5 Research questions

Following the problem statement and research objective of Section 2.3 and Section 2.4 the central research question of this research study may be formulated as follows:

Central research question:

> **What should a new market model for the district heating sector of the Netherlands look like so that it will facilitate a transition towards more sustainable practices?**

Finding the answer to the central research question will be guided by the following research questions:

Research questions:

1. What are the *goals*, *objectives* and *constraints* for which a market model for the Dutch district heating sector has to be designed?
2. What is the design space for reshaping the market conditions for heat provision as a whole and restructuring the market design of the district heating sector?
3. What insights can be gained from international experience with alternative market models for heat provision and the district heating sector specifically?
4. What market model designs for the Dutch district heating sector are expected to contribute best to the climate and energy goals of the Dutch government?

2.6 Structuring the design process

The research study formulated in the previous sections is a design exercise. To structure the process of designing it is useful to make use of a design framework. The choice for a design framework was based on the needs for this research which can be summarized as 'to conceive an institutional artefact (a new market model design) for a complex socio-technical system'.

The market model to be designed is an institutional artefact, it's a description of the set of rules which should be used to govern the workings of the market. The (district) heating sector, to which the rules must apply, could be viewed as a system which consists of a social layer and a physical layer which are intricately connected to each other (Herder, Bouwmans, Dijkema, Stikkelman, & Weijnen, 2008). The social layer is represented by the actors that perform the roles of Figure 2-1. The physical layer is represented by the production installations, pipelines, heat exchangers and so forth, which together form the district heating network. In order to conceive an institutional artefact that is fit for purpose it is necessary to understand how both the social and physical layer work and interact. Given that viewpoint the design exercise is structured according to the systematic approach used in engineering design.

The engineering design framework used is an adapted version of the 'meta-model' initially developed by Westerberg et al. (1997). The meta-model is chosen because of its relative simplicity, its broad applicability[4] and because it could easily be adapted to the needs for this research study. Moreover, it has been proven useful in designing an institutional artefact for a complex socio-technical system in a research study similar to the one formulated in this thesis – the design of a functional legal design for the electricity sector (Knops, 2008). A more elaborate description of the meta-model's origins, workings and applications may be found

[4] "The broad applicability of the meta-model has been proven, among others, in a M.Sc. course taught collaboratively at Carnegie Mellon University and Delft University of Technology for more than 3 years" (Herder & Stikkelman, 2004).

in the journal article 'Designing Infrastructures Using a Complex Systems Perspective' (Herder & Stikkelman, 2004). Figure 2-3 graphically depicts how the design exercise of this thesis is structured along the lines of the engineering design meta-model.

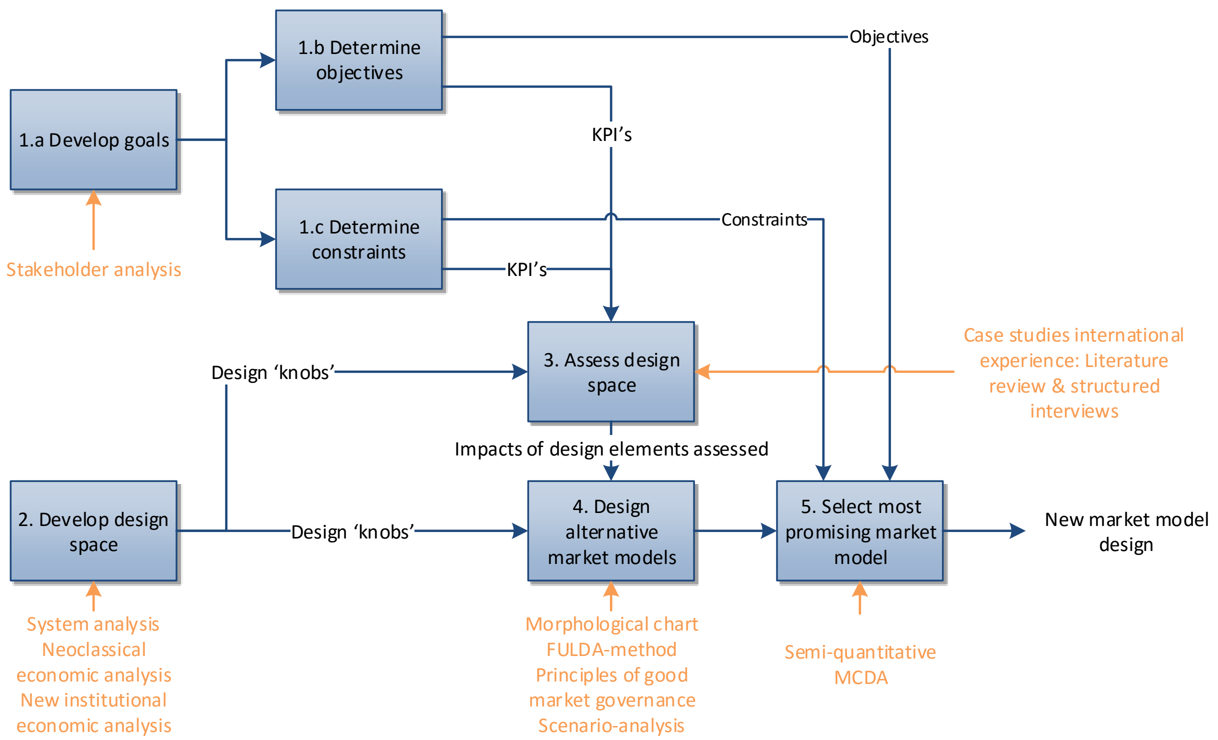

Figure 2-3: Application of the 'meta model' for the design process of conceiving a new market model design for the Dutch heat provision sector (Adapted from: Herder & Stikkelman, 2004)

The blue boxes represent five research activities that guide this research study along the lines of the research questions presented in section 2.5. The blue arrows represent information flows which are required inputs for the consecutive research activities in order to eventually arrive at new market model design. The orange arrows and text represent the research methods used during the research activities.

First the *goals, objectives and constraints* of the new market model must be identified. These three components are informed by a stakeholder analysis and result in the key performance indicators (KPI's) against which the new market model designs will be tested.

Second, the workings of the district heating sector are explored by means of a system analysis. The system analysis provides a deep understanding of how the socio-technically complex system of the district heating sector works. This understanding serves as the foundation for the development of the *design space*. Informed by theoretical insights drawn from a neoclassic economic analysis and a new institutional economic analysis the most important design variables and their various options for the new market model are identified.

The design variables are then *assessed* on their impacts on the key performance indicators by performing case studies on their workings in other countries. Because it is unlikely to be able to cover all design variables and their options with alternative market models found in other countries the case studies are supplemented by a literature review.

Subsequently, *alternative market models are designed* for the Dutch district heating sector using an engineering design tool called a 'morphological chart' and the FULDA-method. Elaborate attention will be given to the contextual differences between the application of the tested design variable options in the case studies and the potential application of the design variable options for the Dutch district heating sector's market model. In addition, the design effort will take note of the 'principles of good market governance' and a scenario-analysis in order to conceive *robust* market model designs.

Finally, if possible, the most promising market model is selected by evaluating the different market model designs using a semi-quantitative multi-criteria decision analysis (MCDA).

In the following section the research methods mentioned are discussed in more detail. A final note about Figure 2-3: although Figure 2-3 illustrates a chronological, sequential process, the actual research process is in practice also very much of an iterative nature in order to make optimal use of a progressively better insight.

2.7 Research methods

Table 2-1 shows how the research questions, research activities and research methods relate to each other. In this section the choice and use of the research methods is explained.

Table 2-1: The relation between the research questions, research activities and research methods

Research questions	Research activities	Research methods
RQ1: What are the goals, objectives and constraints for which a market model for the Dutch heat provision has to be designed?	**1.** Develop goals, objectives and constraints	- Stakeholder analysis
RQ2: What is the design space for reshaping the market conditions of the heat sector and restructuring the market design of the district heating sector?	**2.** Develop design space	- System analysis - Neoclassical economic analysis - New institutional economic analysis
RQ3: What insights can be gained from experience with alternative market models for heat provision in other countries?	**3.** Assess design space	- Case studies international experience
RQ4: What market model designs for the Dutch heat provision are expected to contribute best to the climate and energy goals of the Dutch government?	**4.** Design alternative market models	- Morphological chart - FULDA-method - Principles of good market governance - Scenario-analysis
Central research question: What should a new market model for heat provision in the Netherlands look like so that it will facilitate a transition towards more sustainable practices?	**5.** Select most promising market model	- Semi-quantitative Multi-Criteria Decision Analysis

Stakeholder analysis

The district heating sector, and the heat provision sector as a whole, is composed of a great many number of actors who together, through their actions, determine the performance of the heat provision system. If government wants to meet her objectives for the heat provision system, it will have to understand how she can move the heat actors towards making choices that contribute to heat availability, acceptability and affordability.

Freeman defined a stakeholder as “any group or individual who can affect or is affected by the achievement of the organization’s objectives” (Freeman, 1984). In the heat provision sector that broad definition applies to a great many of groups and individuals. To systematically *identify the relevant stakeholders*, their *interests* and *means* the analysis is structured.

There are a great many of stakeholder analysis techniques developed for a variety of purposes (see for example: Bryson, 2004; Grimble & Wellard, 1997; Hermans & Thissen, 2009). In this thesis the ‘basic stakeholder analysis technique’, as described in Bryson (2011), is deemed most useful because of its simplicity and wide applicability. The analysis is complemented by organizing the relevant stakeholders in a ‘power versus interest’ grid in order to identify which stakeholder interests are most important for the success of the new market model (Eden & Ackermann, 1998).

The stakeholder analysis informs what goals should be reached with the new market model laid down in normative objectives and hard constraints. The goals, objectives and constraints form the basis for the evaluation framework of the new market models to be designed.

System analysis

The (district) heating sector may be characterized as a socio-technically complex sector. In order to cope with that complexity both the physical and social layer of the system are analyzed in depth. In addition, the manner in which the physical and social layer are interconnected is explored. The analysis is structured according to the System Analysis approach. “System analysis may be used to develop and test ‘theories’, in other words, causal assumptions about how the world works” (Enserink et al., 2010, p. 51).

Neoclassical economic analysis

Heat is considered to be a *merit good* because of its vital importance for daily life of citizens, businesses and industry (Gent et al., 2004). Because of the fact that heat is considered a merit good, the government has a responsibility to ensure that heat is delivered to consumers in the right quantities, qualities and for acceptable prices. But what kind of role should the government assume in ensuring the adequate delivery of merit goods?

Next to being a merit good, the delivery of heat via district heating networks is also an infrastructure bound undertaking. Due to the high capital costs of the infrastructure it is economically inefficient to duplicate infrastructures; heat delivery is therewith characterized as a *natural monopoly*.

In a (natural) monopoly there is the risk that the monopolists does not supply goods in the desired prices, quantities or qualities. This is called a market failure. Neoclassic economic theoretical insights prescribe what role a government could assume in overcoming market failures.

In the year 2000 the Ministry of Economic Affairs, informed by neoclassic economic theoretical insights, published its evaluation framework on how to ensure public interests in infrastructure bound sectors (Ministry of Economic Affairs, 2000). This evaluation framework consisted of five steps: (1) inventory public interests of the sector, (2) translate the public interests into objectives and constraints for the sector, (3) design the regulatory arrangements that will ensure (economic) undertakings will act according to the public interest, (4) introduce competition if this can help ensuring the public interests in a more effective and efficient manner, and finally (5) determine the ownership rights in the value chain of the infrastructure sector .

The evaluative framework used while moving through the five steps will be used to show how other countries chose to regulate their infrastructure sectors and why. By reviewing what public interests, led to what objectives and constraints and the resulting regulatory arrangements, competition modality and ownership rights in other countries a new perspective may be gained on how the Dutch district heating sector could be organized. The same steps may also prove useful when considering how the market conditions for the heat provision sector in a broader sense should be shaped.

Starting point of the evaluative framework of the Ministry is that heat is a merit good and there is the risk of market failures in the infrastructure bound sector because it concerns a natural monopoly. While using the evaluative framework this thesis will therefore also build on earlier work in the field of market failure analyses on the district heating sector (PwC, 2015). When appropriate, a parallel between the district heating sector's regulation and other infrastructure sectors (e.g. the electricity and natural gas sectors) will be made. Experience with regulatory choices in other infrastructure sectors may substantiate arguments for regulatory choices in the district heating sector.

New institutional economic analysis

New institutional economics is a field in economics that deals with the analysis of institutions. "Its primary goal is not to give new answers to the traditional questions of economics, such as questions regarding resource allocation and the degree of utilization. Rather, it aims to answer new questions, such as *why economic institutions have emerged the way they did and not otherwise?*"(Arrow, 1987, p.734). Answering that question instills a deeper understanding of the evolutionary development of institutions which in turn will enable sharper micro-economic analyses.

In this thesis the theories of new institutional economic analysis will be used in the sense described above. Figure 2-2 maps the institutions of influence to district heating stakeholders by organizing them in Williamson's four layers model. Primarily the second layer, the 'rules of the game', and secondarily the third layer, the 'play of the game', are of interest for analysis purposes. Williamson's framework will be revisited when describing the institutional context of the countries' district heating sectors that are reviewed in the international case studies.

Case studies international experience

An international comparison of alternative market models that govern the (district) heating sector is executed in order to gain more understanding of the pros and cons of different regulatory instruments used in the (district) heating sector. The case studies use the objectives, constraints and design space as inputs to scope the research effort. First, a 'quick-scan' of countries with alternative market models for the district heating sector is performed. Then, in order to foster depth of analysis, two countries are selected for further review. The market models of these countries' district heating sectors are reviewed in-depth by means of literature reviews and semi-structured interviews.

Morphological chart

In order to structure the design of a new market model in a systematic manner the design challenge is framed as an 'engineering design' challenge. A useful tool drawn from engineering design to structure the design process is a *morphological chart*. In a morphological chart all the *functions* the system to be designed must fulfill are listed vertically and all the *means* that can fulfill the corresponding functions are listed horizontally. For example, a function to be designed is the tariff system, will tariffs for heat delivery be unregulated and left to the market (one mean), or will the tariffs for heat delivery be regulated using for example a cost-plus based system? By structuring the functions and means of the institutional artefact to be designed in one chart an overview of the design space is generated from which feasible market designs may be selected (Dym, Little, & Orwin, 2009).

FULDA-method

Designing new market models involves choosing appropriate means for all the identified functions by using the morphological chart. This selection process is guided by the FULDA Method. 'FULDA' is an abbreviation for the 'function-based legal design & analysis method', developed by Knops (2008). The method was originally developed in order to facilitate the design of the legal organization of *technical functions* of energy infrastructure systems. In this thesis, the method is used to design the legal organization of the *institutional-economic functions* (represented by the design variables) of an energy infrastructure system, specifically the district heating system. How the FULDA-method works is discussed extensively in Section 6.1.

Principles of good market governance

An efficiently working market requires *regulatory stability*, which is a prerequisite for investment security. Both the process of conceiving a new market model and the end-result should cause as little regulatory uncertainty as possible. In order to support the development of a good-functioning regulatory framework the designs will adhere to the 'principles of good market governance'. The 'principles of good market governance' are "a set of best practices for laws, regulations, processes and regulatory arrangements" (Knops, 2008, p.103) that together support the design of a good-functioning regulatory framework. Meeting these principles is especially important for the district heating sector where regulatory stability is necessary for businesses to be able to engage in the long-term investments that characterize the district heating sector[5] (Hancher, Larouche, & Lavrijssen, 2003). Furthermore, "the interests of end-users (consumers) are likely to be better served with appropriate supply and a dynamic market when the regulatory framework functions well and secures stability (see (Berg, 2001))" (Hancher et al., 2003, p. 341). Of course, good governance is only one determinant for market model performance, albeit a determinant of great importance.

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[5] The economic lifetimes of district heating projects are oftentimes over 30 years with technical lifetimes being even longer, oftentimes over 40 years.

Scenario-analysis

The business case for district heating is for a large part determined by the market model for the district heating sector. There are however also a great number of *exogenous factors* that affect the relative attractiveness of district heating versus other forms of heating. These exogenous factors can be of a physical, economic, social, or political nature (A. C. Correljé & de Vries, 2008). Taking these exogenous factors into account during the design process is crucial for the robustness of the market models to be designed. Because the number of exogenous factors is large and their future development is in many cases uncertain the future market model for the district heating sector will be exposed to a large space of uncertainty. To cope with this uncertainty a scenario-analysis is conducted. The scenario-analysis serves as an input for the design process so that the market models to be designed can take into account the conditions of likely scenarios in which the scenario must perform in the future.

Semi-quantitative Multi-Criteria Decision Analysis

As mentioned, the government is responsible to ensure the availability, acceptability and the affordability of the heat provision system. The derived goals from these three principles are oftentimes conflicting with each other, and in other occasions deemed more or less important. Also, the different goals have different metrics which makes it hard to compare the performance of different designs with each other.

In order to cope with the plurality of *goals*, *metrics* and attached *level of importance* a multi-criteria decision analysis (MCDA) tool may be used. If possible, the impact of design choices will be quantified along the metrics of the goals defined for the heat provision system. The relative *level of importance* of the different goals can be dealt with by assigning weights to the goals.

2.8 Scientific and societal relevance

The **scientific usefulness** of this thesis is twofold.

First of all, previous research has shown that the meta-model design approach as presented in Section 2.6 may be useful in structuring the design process and providing a systematic method to attain an institutional design for a complex (infrastructural) socio-technical system (See for example Apotheker, 2007; Koppenjan & Groenewegen, 2005; Kromhout, 2010). This thesis wants to reaffirm the usefulness of using the meta-model in a similar sector, the district heating sector, which is also a complex infrastructural socio-technical system.

Secondly, as (briefly) mentioned in Section 2.7 this thesis makes use of the FULDA-method, a method designed for the systematic design of the legal organization of a complex infrastructural system. The FULDA-method is used to aid in the process of finding the 'right' institutional design for the district heating sector. This is considered interesting because the FULDA-method has not been applied in this manner before and has also never been applied to the district heating sector. This thesis wants to confirm the practicability and usefulness of the FULDA-method in designing an institutional design for another sector than the electricity sector where it has been used before (Knops, 2008).

The **societal relevance** of this thesis lies in the importance of the well-functioning and sustainability of the Dutch (district) heating sector for people's welfare and horticulturists' and industry's economic interests. This thesis will aid policy makers in choosing an appropriate design for a new market model for the Dutch district heating sector. The advice will contribute to the development of a sound policy intervention that will (1) reduce carbon emissions from the heat provision sector and (2) decrease the sectors' dependency on natural gas and therewith increase energy independence. All the while, the policy intervention will do justice to the public goals of availability, affordability and acceptability and the goals that may be derived from these goals.

2.9 Research plan

Figure 2-4 illustrates the structure of this thesis. The orange text refers to the research methods introduced in this chapter and used in this thesis.

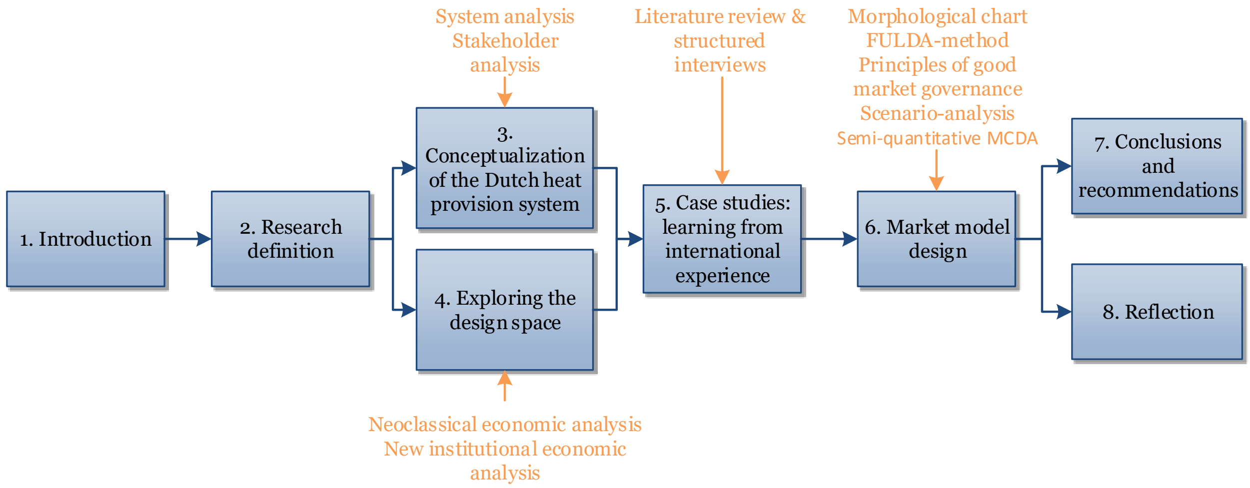

Figure 2-4: Structure of the thesis

3 Conceptualization of the Dutch heat provision system

In order to answer the first research question – *'What are the goals, objectives and constraints for which a market model for the Dutch heat provision has to be designed?'* – first a better understanding of the district heating system must be built. The district heating system may be viewed as a socio-technical system, consisting of a social layer (the institutional-economic layer), and a physical layer (the technological layer). This chapter provides an overview of both of these layers and how they are linked with each other. Understanding the workings of both layers and their linkages is necessary to understand how the heating system's performance is measured, and, what the government's goals are for the heating system's performance.

Figure 3-1 illustrates how the mentioned concepts relate to each other and when they are discussed in this chapter. Although the focus of this chapter, and this thesis, is on the district heating system, this chapter will also touch upon the natural gas heating system and the electric heating system as they are a part of the larger heat provision system.

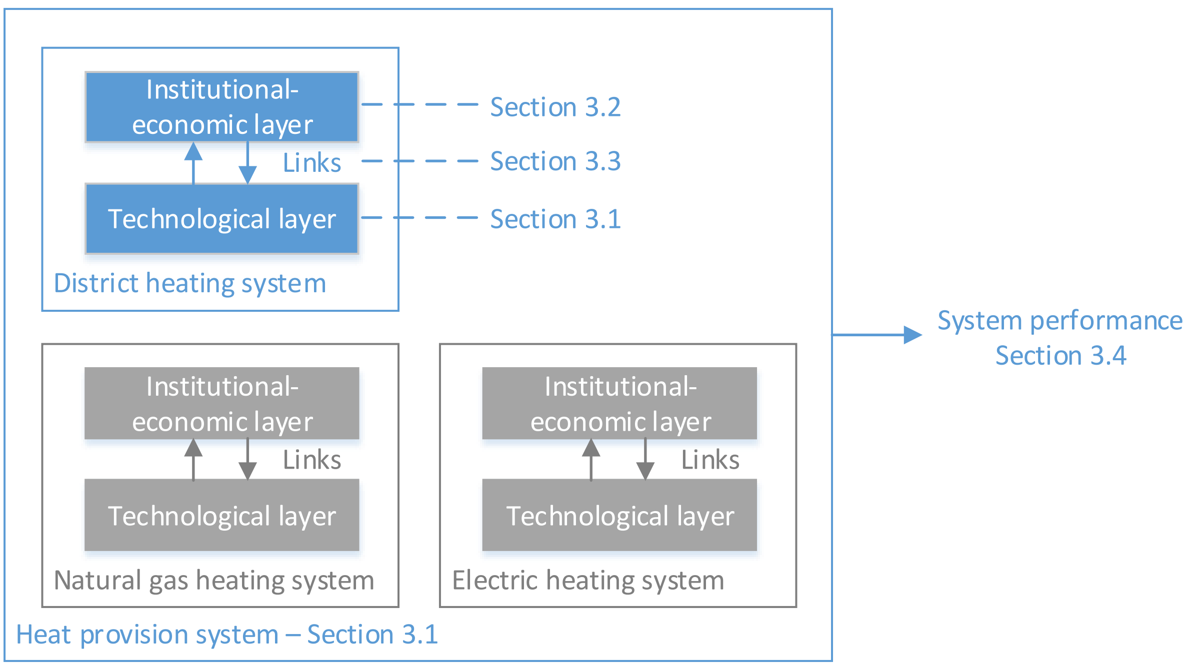

Figure 3-1: Structure of the heat provision system and organization of this chapter (Adapted from: Knops, 2008)

3.1 The technological layer of the heat provision system and the role of district heating

The technological layer of the heat provision system is comprised of multiple networks of physical components that are interconnected and interacting with each other. The three main energy carriers that are used to provide heat in the Netherlands are natural gas, heat (transported in the form of hot water or steam), and electricity. Figure 3-2 depicts the value chains of these three commodities that provide heat in the Netherlands. The district heating value chain is highlighted in blue.

Although the characteristics and attributes of the components of the three value chains differ, their structure is similar. In all three value chains, or infrastructures, the commodity is first *produced*. Consequently, the commodity is *transported* (or transmitted), from the production location to a demand center using large capacity connections. Then, close to the demand center the transmission network delivers its commodity to *distribution* networks which bring the commodity to the end-user using smaller capacity connections. At the end-user the *delivery or production of heat* takes place where it is *consumed*.

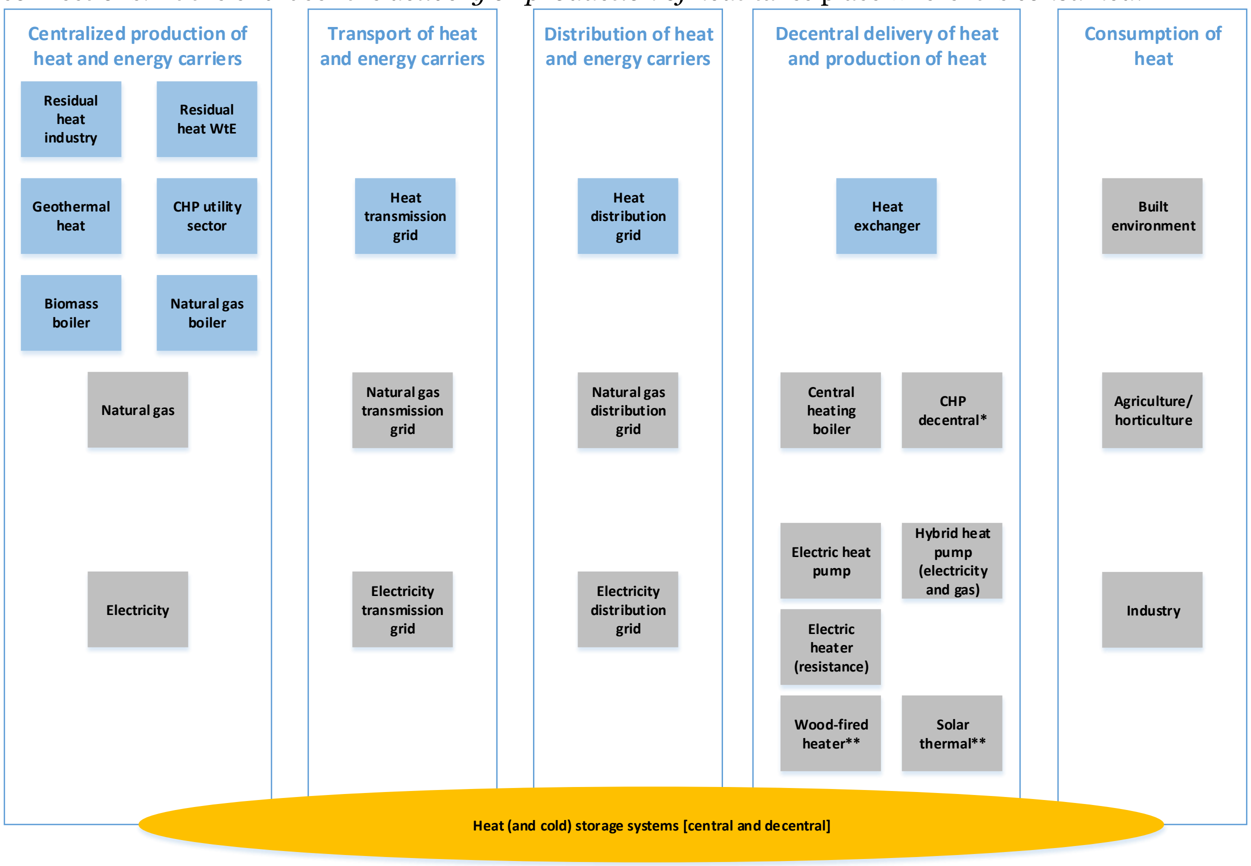

Figure 3-2: Illustration of the three value chains (heat, natural gas and electricity) that together form the heat provision system.

Figure 3-2 shows that there are a great many pathways to provide heat. Figure 3-2 however doesn't show the fact that not all pathways are feasible. Heat provision is *temperature dependent*, which means that the temperature of the heat source and the heat demand must match.

Temperature considerations. Figure 3-3 illustrates the heat demand of the Netherlands for the year 2012 per consumption sector by temperature segments – households and utility buildings together constitute the built environment in Figure 3-2. The largest part of the heat demand (62%) concerns low quality heat (<100 ^{o}Celsius) and is almost entirely attributed to the built environment and the agriculture/horticulture sector. The rest of the heat demand concerns heat of a higher quality (>100 ^{o}Celsius) and is largely attributed to the industry sector.

Whereas the combustion of natural gas yields high enough temperatures to service the entire spectrum of the heat demand. District heating and electric heating on the other hand, are typically used to service the low temperature heat demand because their heat sources are of a lower temperature than needed in many industrial processes[6].

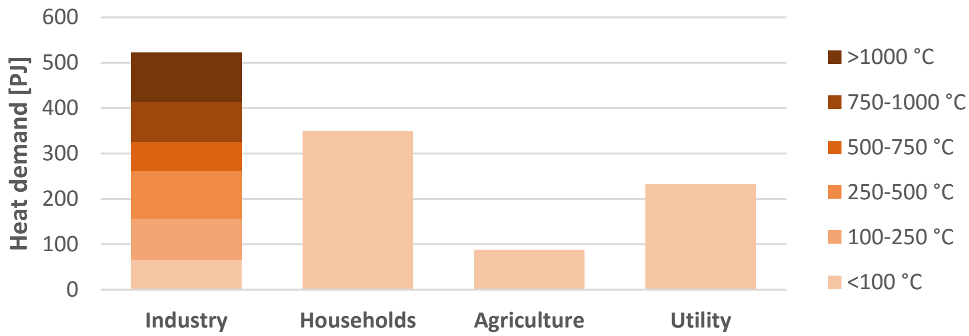

Figure 3-3: Heat demand of the Netherlands in 2012 per consumption sector by temperature segment (CE Delt, 2014)

District heating networks for the low temperature heat function exist in different types. Based on the flow temperatures within the network roughly three types of district heating networks are distinguished: high temperature systems, medium temperature systems and low temperature systems. Table 3-1 shows which heat production technologies are eligible to feed-in heat for what type of district heating system and what type of users may be connected to these heating systems.

A district heating network is a closed system. Heat is fed-in to the network and drawn-out of the network by means of heat exchangers. The system operator, oftentimes the owner of the transport network, must balance the heat load with the required heat generation while continually monitoring the temperature and pressure of both the supply flow and the return flow. Depending on the lay-out of the network there may or may not be a need for a transmission network[7].

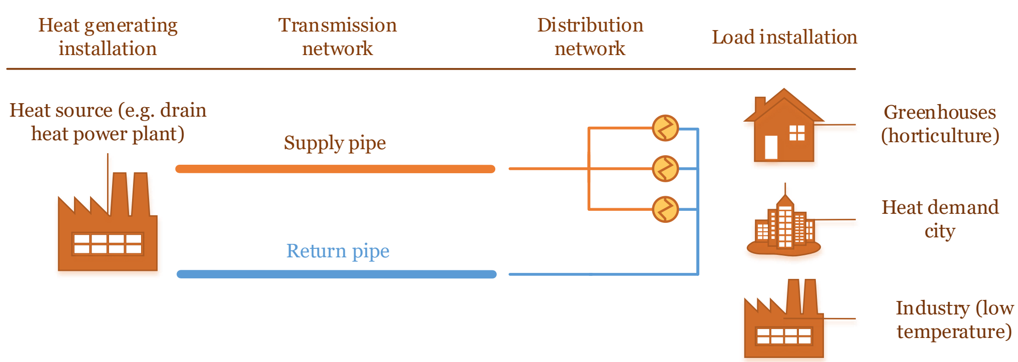

Figure 3-4: Schematic overview of a district heating system

[6] There are examples where high temperature residual heat is used in industrial heat networks such as in the Rotterdam harbour and the Chemelot project in Limburg, but the number of such networks is limited because residual heat and for example geothermal heat or oftentimes of a lower temperature than the temperatures required for industrial processes. Therefore, in this thesis the focus lies on the applications of district heating networks in the low temperature function.

[7] In some cases the heat source is close enough to the heat demand that solely a distribution network suffices.

Table 3-1: Types of district heating systems and its eligible heat sources and heat consumers distinguished by the flow temperature in the district heating network (Eneco, 2015)

Type of system	High temperature systems	Medium temperature systems	Low temperature systems
Flow temperature	100- 140 °Celsius	70 - 100 °Celsius	45 - 70 °Celsius
Eligible heat sources	- Residual heat industry - Residual heat waste incinerators - Drain heat power plant - Ultra-deep geothermal heat (>3.5 km deep) - Biomass boiler - Natural gas boiler	- Residual heat industry - Residual haet waste incinerators - Drain heat power plant - Geothermal heat (>2-3.5 km deep) - Biomass boiler - Natural gas boiler - Industrial electric heat pumps	- Residual heat industry - Residual heat waste incinerators - Drain heat power plant - Geothermal heat (>1-2km deep) - Biomass boiler - Natural gas boiler - Industrial electric heat pumps
Eligible heat consumers	- Existing houses and utility buildings - Industry - Horticulture sector	- New houses and utility buildings - Renovated houses and utility buildings - Horticulture sector	- New houses and utility buildings - Renovated houses and utility buildings

Next to the temperature and pressure of the system water, the system operator must also monitor various other quality parameters. These system water quality parameters include: (1) the particle size of contaminants – to prevent wear and tear of pipes and pumps, (2) the acidity – to prevent corrosion, (3) the oxygen concentration – to prevent cavitation damage, (4) the calcium concentration – to prevent calcification, (5) the chloride concentration – to prevent biomass growth and associated disturbances, (6 & 7) the concentration of iron and copper – both to prevent wear and tear of pipes and pumps (Eneco, 2015).

3.2 The institutional-economic layer of the heat provision system

The institutional-economic layer of the heat provision system concerns the trading of goods and services related to heat. It concerns the contractual relations between all market parties that together enable the provision of heat. Depending on the institutional organization of the *roles* in the system there can be a great many number of market parties operating in the system and engaging in contractual relations with each other, or, there may very well only be a few. In this section first a number of examples of possible market models for the district heating sector is given as well as a brief discussion of observed trends in institutional organization (Section 3.2.1). Then, we dive deeper into the economics of the network industry that district heating is (Section 3.2.2).

3.2.1 Modes of organization: examples of market models for the district heating sector

In Figure 2-1 the different roles that can be distinguished in the market model for the district heating sector were graphically depicted being the: (1) heat producer, (2) transmissions system operator, (3) distribution system operator and (4) heat consumer. These roles represent separate functions within the district heating sector, being, heat generation, heat transport, heat distribution and heat consumption. However, although distinct roles, these functions do not necessarily have to be executed by separate organizations. One organization may fulfill multiple of these functions all together, or separate organizations may fulfill one or multiple of the responsibilities attached the different roles in the district heating sector. Table 3-2 illustrates three exemplary market models for the provision of heat in the district heating sector, all having different institutional organizations of the ‘roles.

Next to the three exemplary market models shown in Table 3-2, there are also other market configurations possible. The number of possible configurations is in practice determined by the institutional framework.

For example, the European electricity sector, also an energy infrastructural sector, had prior to the liberalization of its market model one prevailing market model: that of vertical integration where the entire value chain was serviced by one energy company. After the liberalization of the European electricity sector, in order to allow for competition, the potential commercial activities of the value chain (electricity generation and retail sale) where separated from those that represent a natural monopoly (the network related activities). In the newly established institutional framework who was allowed to perform which role within the electricity sector was determined by law, which constrains the number of possible market models (Künneke, 2008).

In the district heating sector, despite many market model configurations being possible, there appears to be a trend towards a market model of vertical integration (see Figure 3-5). Whereas in 2009 only four of the thirteen large scale district heating networks (networks with more than 5000 connections) were fully vertically integrated, today, nine out of the thirteen large scale district heating networks are fully vertically integrated (CE Delft, 2009; JIN Bioteam, 2015a).

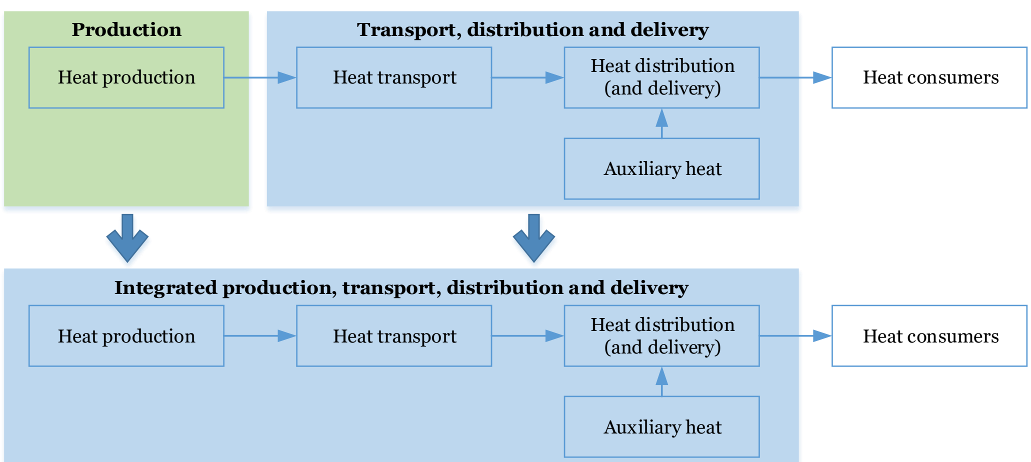

Figure 3-5: Trend towards vertical integration in the district heating sector (Adapted from:(JIN Bioteam, 2015b)

Table 3-2: Three exemplary market models for the district heating sector

<table>
<tr><th>Roles</th><th>Market model 1 ‘Vertically integrated’</th><th>Market model 2 ‘Joint venture’</th><th>Market model 3 ‘Single buyer model’</th></tr>
<tr><td>Heat producer
Physical responsibilities
• Controlling plant dispatch
• Maintenance
Institutional-economic responsibilities
• Tariffs and terms of use
• Contract negotiations
• Investment in heat generation capacity
• Billing clients</td><td rowspan="3">Full-service heat company
The heat company produces, transports and distributes and delivers heat to its consumers.

Example: the Utrecht district heating network which is owned and operated by ‘Eneco’ (Nuon, 2014).</td><td>One or multiple heat producers</td><td>One or multiple heat producers</td></tr>
<tr><td>Transport system operator
Physical responsibilities
• Building networks and connections
• Operation and maintenance
Institutional-economic responsibilities
• Tariffs and terms of use
• Contract negotiations
• Data collection heat transmission
• Data processing & transfer
• Billing clients</td><td rowspan="2">Joint-venture service heat company
Heat company that is owned jointly by the heat producer and heat retail company.

Example: The Amsterdam Westpoort district heating network which is operated by ‘Westpoort Warmte’. Westpoort warmte is partly owned by the ‘Afval Energie Bedrijf Amsterdam’ (heat producer) and ‘Nuon Warmte’ (heat retail company) (CE Delft, 2009).</td><td rowspan="2">One service heat company
One heat company transports, distributes and delivers heat to its consumers. Heat is bought from one or multiple producers – of which one may also be the heat company itself.

Example: Both of the large-scale district heating networks in Rotterdam. The Southern network is owned and operated by the ‘Warmtebedrijf Rotterdam’ and the Northern network by ‘Eneco’ (AVR, 2016).</td></tr>
<tr><td>Distribution system operator
Physical responsibilities
• Building networks and connections
• Operation and maintenance
Institutional-economic responsibilities
• Tariffs and terms of use
• Contract negotiations
• Securing heat
• Data collection heat distribution
• Data processing and transfer
• Billing consumers</td></tr>
<tr><td>Heat consumer
Physical responsibilities
• Consuming heat
• Adequately organizing load installation
Institutional-economic responsibilities
• Contract negotiations
• Paying bills
• If needed: providing data on heat consumption</td><td>Heat consumer</td><td>Heat consumer</td><td>Heat consumer</td></tr>
</table>

The trend towards vertical integration can be explained as an attempt by the heat companies to increase the economic efficiency and ensure the sustainability of their operations (JIN Bioteam, 2015b). According to the heat companies themselves integrating the value chain will yield (1) lower transaction costs, (2) higher operational efficiencies and (3) improved design of the lay-out of the district heating systems (Herman Exalto, director Eneco heat & cold, 2015).

Transaction costs. When production is separated from the rest of the value chain, the heat supplier must secure heat generating capacity by means of a contract with the heat producer(s). The costs associated with securing these contracts and also the *risk premiums* that are usually incorporated in the price are now no longer a part of the costs of district heating delivery.

Operational efficiency. Integrating the value chain enables the possibility of improved dispatch of generating installations since the system operator has real-time information about the demand developments and flow capacities within the system. This may yield a more efficient use of generating installations and lower use of the more expensive auxiliary heating units which are oftentimes incorporated in district heating systems.

Improved lay-out of district heating systems. A vertically integrated heat company has complete information about the entire value chain. This makes it possible to optimize and coordinate investments in generating and network installation such that costs may be minimized.

Although vertical integration may lead to lower costs and improved operational efficiency, it also leads to a loss of competition at the heat generation side. “Textbook microeconomic theory suggests that competition and the profit motive result in internal (production) and external (market) efficiency and that those benefits are passed on to customers in the form of lower prices and costs” (Jamasb & Pollitt, 2005, p. 1). Whether the benefits of vertical integration outweigh the benefits of competition is however difficult to quantify. Also, one may question whether it is necessary to vertically integrate the value chain to attain higher operational efficiencies and improved design of the lay-out of district heating systems. It could very well be possible that those two described benefits may be attained through improved information exchange and better coordination between different functions within the value chain.

The discussion on who may be responsible for which function within the value chain of the district heating sector is only one of the design variables in the market model. Other institutional design variables include rules about the content of contracts between heat suppliers and heat consumers, or the presence of tariff regulation in the occurrence of a (natural) monopoly situation. Chapter 0 includes a comprehensive discussion on the relevant design variables for the design of the institutional artefact: a new market model for the Dutch district heating sector.

3.2.2 The economics of district heating: what sets district heating apart?

District heating may be characterized as a network industry similar to other energy infrastructure sectors such as the electricity sector and the natural gas sector. When viewed as a network industry, theory informs us on the following relevant economic characteristics of the district heating sector: (1) high *sunk costs* of the infrastructures, (2) network externalities, (3) scale and synergy advantages, and (4) limited availability of resources (Ministry of Economic Affairs, 2000).

The high *sunk costs* are especially represented in the large investment costs that are associated with building the transport and distribution network of the district heating grid. These long, thick pipes that transport the hot water over oftentimes long distances are expensive, and may only be used for the purpose of transporting and distributing hot water, hence, the costs are sunk.

Network externalities are present in the form that generally the more producers and consumers are connected to the network, the higher the economic value of the network becomes. Since in a large scale network the costs of transportation and distribution may be shared over a larger number of consumers the average cost of heating may decrease, while at the same time offering a larger distribution market for the heat producers.

Scale and synergy advantages are represented in the previously mentioned argument above, as well as in advantages such as the fact that typically larger heat producers are characterized by having relatively high upfront investment costs combined with relatively low operational costs which together give lower average costs than smaller heat producers, hence a scale advantage. Examples of synergy advantages are higher operational efficiencies and improved design of the lay-out of district heating systems in vertically integrated systems.

Limited availability of resources is represented in the fact that because transporting district heat is expensive, the heat production facilities must be in close geographical proximity to the heat consumer centers. In addition, the heat sources must be of adequate capacity and temperature. Because of these necessities there are in practice usually only a limited number of eligible heat producers that can feed-in to a district heating grid.

The four economic characteristics together determine for an important part why the value chain of the district heating sector has a tendency towards vertical integration, which is to the benefit of the heat supplier owning the transport and distribution network. In addition, it explains why the transport and distribution parts of the value chain of district heating may be characterized as a *natural monopoly*. Indeed it would be economically inefficient to duplicate the network activities in the district heating sector because of the high sunk costs, network externalities and scale and synergy advantages associated with these network activities.

Although the characteristics mentioned typically hold for all district heating systems their relative importance differs for different types of district heating systems. District heating systems can be divided in two categories: non-industrial heat networks (which are the focus of this thesis) and industrial heat networks. Then, the non-industrial heat networks can be characterized as either area bound heat delivery or building bound heat delivery. Figure 3-6 gives an overview of the different types of district heating systems that may be distinguished.

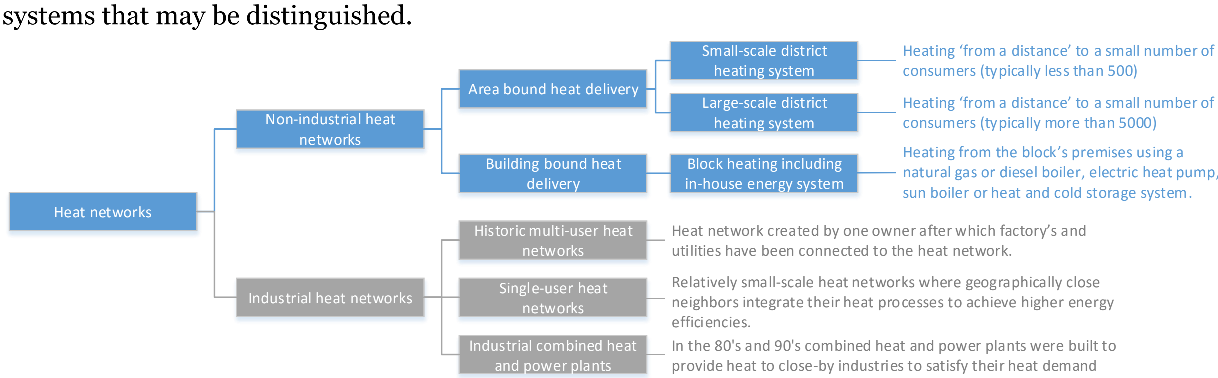

Figure 3-6: Classification of different types of district heating systems (Ecorys, 2016)

When discussing the economics of district heating one must be aware of the variety of different types of district heating systems. For example, in small-scale district heating systems the capital expenditures associated with the costs of heat transportation are comparatively lower than in large-scale district heating systems because the distance from heat producer to heat consumer is typically shorter. On the other hand, the operational expenditures of small-scale district heating systems are oftentimes higher than those of large-scale district heating systems because in the larger district heating systems economies-of-scale reduce the costs of heat production (e.g. heat from a small natural gas boiler versus heat from a waste incinerator).

In addition to the variety of types of district heating systems, there is also a large variety in the way those systems are set-up. Examples of system-dependent characteristics are the types of heat producers (e.g. residual heat from industry, drain heat from a CHP facility, etc.), types of heat consumers (small or large; low, medium or high temperature), level of heat density (GJ/km^2) and the topology of the network (star network, bus-network, ring structure, etc.). This wide variety and the sparseness of availability of data on the costs of district heating makes it difficult to acquire a complete overview of the costs of district heating. Therefore instead, Table 3-3 gives an overview of the share of different cost categories in the total costs of district heating for small-scale and large-scale district heating systems and the average of those combined – providing insight in the cost structure and magnitude of different district heating systems.

In Table 3-3 a number of figures stand out. First, the share of capital expenditures (CAPEX) in the total costs of heat delivery was indeed found to be larger in large-scale heat networks than in small-scale heat networks. However, the figures shown are likely derived from district heating networks that for a large part have already been paid off, which may lead to an underappreciation of the share of the CAPEX in the total costs of district heating. For example, interviews taken with representatives from the heat companies Nuon and Ennatuurlijk informed that the CAPEX in new district heating networks constituted approximately two-thirds of the total costs and correspondingly the OPEX one-third of the total costs (Nuon & Ennatuurlijk, 2015), which is very different from the figures in Table 3-3 (CAPEX: 9-30%; OPEX: 70-91%).

Second, the range for the average price of district heating is much higher for small-scale district heating systems than it is for large-scale district heating systems. Possible explanations may lie in economies-of-scale effects and network externalities.

Third, the ranges given are fairly wide on almost all the cost categories. This emphasizes that the variety of types of district heating systems and differences in system set-up cause large differences in the cost structures and magnitudes of total costs of district heating systems.

Another cost category in Table 3-3 is the *opportunity costs of capital*. These costs may be expressed as a percentage of the total CAPEX and are primarily dependent on: (1) the magnitude of and ratio between the invested outside capital and equity capital, and (2) the interest obligations on the outside capital and the compensation for the providers of equity capital, which is dependent on the *risk profile* of the district heating network (CE Delft, 2009).

Table 3-3: Share of different cost categories heat delivery in total costs (CE Delft, 2009)

Cost categories	Large scale heat networks	Small scale heat networks	Average of heat networks
Capital expenditures (CAPEX)			
Depreciation	9-30%	7-12%	9-28%
Opportunity costs of capital	-	-	-
Operational expenditures (OPEX)	70-91%	88-93%	72-91%
Purchasing costs heat	42-63%	48-80%	44-64%
Purchasing costs of heat as percentage of OPEX	52-77%	52-88%	53-77%
Costs of auxiliary heating and or buffering	-	-	-
Operation and maintenance costs	9-14%	3-18%	9-14%
Administrative costs	2-6%	1-3%	2-5%
Overhead and miscellenaous costs	4-20%	8-20%	4-20%
Delivery (in)dependent costs			
Delivery independent fraction	37-58%	20-52%	36-56%
Delivery dependent fraction	42-63%	48-80%	44-64%
Delivery independent fraction in € per connected consumer	323.2-798.4	218.7-1,438.9	323.2-841.8
Delivery dependent fraction in € per GJ	4.4-11.4	14.3-17.7	5.2-17.3
Average price of heat in € per GJ	10.9-27.4	18.7-46.5	11.7-34.1[8]

The researchers mentioned that they did not have enough data to distinguish the share of the opportunity costs of capital in the total cost figures, but they did find through a survey that the total opportunity costs of capital ranged from 5.5% to 12% before interest and taxes (CE Delft, 2009). These figures are in line with the opportunity costs of capital that ACM estimated in her profitability monitor, being 5.6 – 7.4 % (ACM & Ecorys, 2015).

The *risk profile* of a district heating network is primarily dependent on external drivers. From interviews it was learned internal drivers only play a small role in the risk profile of district heating networks. That is because process risks and control risks are all very manageable (Moe Soe Let et al., 2015). External drivers such as supply risks and demand risks are however another case. On the supply side district heating suppliers must be sure that their heat producers are capable of delivering heat according to the demand profile of the district heating network, and, remain doing so for a long period of time. On the demand side district heating suppliers must project the future heat demand and make sure that the heat demand of their district heating networks remains large enough for it to be economically viable. Trends such as a warming

[8] Table 3.3 is adopted from a CE Delft study directed at gaining insight into the cost structures of district heating (CE Delft, 2009). The cost ranges shown are indicative, based on information provided by seven different heat suppliers. The data on large-scale heat networks stems from six heat suppliers covering 17 different 'objects'. The data on small-scale heat networks stems from 4 heat suppliers covering 33 different 'objects'. Given the limited number of different objects in the data sample the figures cannot be interpreted as averages for the Dutch district heating sector. Instead, the figures show the ranges of cost fractions for different cost categories and the ranges of the costs of district heating for small-scale versus large-scale heat networks.s

climate and more energy-efficient housing reduce the heat demand which directly impacts the business case of a district heating network.

A final note on the business case of a district heating network is represented through Figure 3-7. District heating networks are characterized by large upfront investment costs which require a long time to be recovered. The cost categories in Table 3-3 and the discussion about e.g. the risk profile sketches, very briefly, how a district heating supplier must balance its business case. When looking at Figure 3-7 one may derive that other important factors in the business case of a district heating network are the technical life time of the assets that together form the district heating network and the depreciation period. Typical technical life times and depreciation periods for district heating networks range from 30 to 50 years.

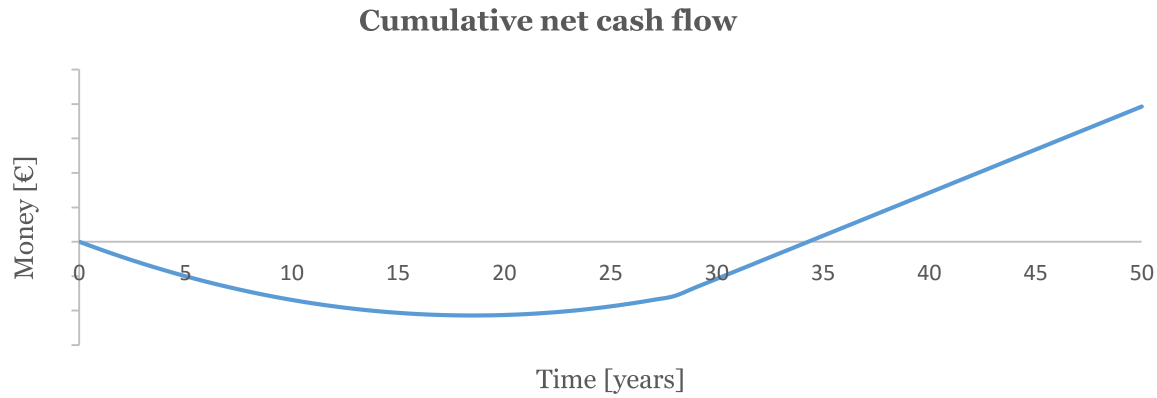

Figure 3-7: Cumulative net cash flow of a fictive district heating system (based on CE Delft, 2009).*

**In a non-fictive cumulative net cash flow diagram of a district heating system the line would be less smooth. That is because of factors such as the year to year variability in heat demand (dependent primarily on the temperature throughout the year) and costs of heat production (dependent on energy prices). These factors are not incorporated in* Figure 3-7. *Also, the replacement costs of (parts of) the system's network installations have not been incorporated in the figure.*

3.3 Aligning the engineering perspective and the institutional-economic perspective

So far the technological and institutional-economic layers of the socio-technical system that is the district heating system have been discussed *separately*, while, in fact they are very much interconnected. In this section first the keynotes of these two different, but intertwined, paradigms are summarized after which an overview is given how the two system layers are linked to one another.

In the **technological paradigm** engineers pursue design goals such as *system robustness* and *operational reliability*. "The engineers pay attention to infrastructure assets, network topology, and control system design to handle the flows of heat and possible disturbances" (Scholten, 2015, p. 8). All the while following design principles such as the n-1 principle[9], to secure network robustness, or control mechanisms

[9] The n-1 principle is a term from the network robustness literature, refering to a network that remains fully functional even in the event that one node (e.g. a heat producer or heat transfer station), or one link (a heat transmission or distribution pipe) might fail. An example of a network topology that meets this criterion is the *ring structure,* as opposed to for instance a *star network* which does not remain fully interconnected in the event of a node or link failure.

such as operating with back-up auxiliary heat generators or heat buffers. Their primary concern is that the technical system works as it should: providing heat from producers to consumers in the necessary quantities and qualities.

In the **institutional-economic paradigm** economists, policy makers, and legal experts pursue design goals such as *market efficiency*[10] and achieving *socially desirable outcomes* (in light of the goals of availability, affordability and acceptability). "The economists and their counterparts focus on designing market models that address potential market failures and imperfections, opportunistic behavior and social objectives[11]" (Scholten, 2015; Stoft, 2002). They follow design principles such as the expediency and efficacy of the policy instruments used to structure and steer the market, while minimizing the occurrence of unintended consequences of their interventions (Ministry of Economic Affairs, 2015c). Their primary concern is that the market model in place effectively allocates the goods (heat) and services according to societal needs.

When designing a new market model for the district heating system one must be aware of the differences between the design goals, design principles, and overall system make-up of the two different paradigms. The design goals, design principles and system considerations of the technological layer belong to a different paradigm than those of the institutional-economic layer. Sometimes, the design goals are complementary, but they may also be at odds with each other. By definition that means that policies for the district heating system must perform a balancing act between the goals for the technological paradigm and the goals for the institutional-economic paradigm. This should however not come as a surprise since the goals underlying the goals for both paradigms are also at odds with each other – being the energy infrastructure goals of availability, affordability and acceptability.

Given that policies for the district heating system are oftentimes inherently trade-offs between multiple goals in oftentimes different paradigms it is even more important to prevent the occurrence of unintended consequences. For that, it is necessary to have a good understanding of how the two paradigms are connected to each other and behave as one socio-technical system. Figure 3-8 illustrates the linkages between the technological layer and the institutional-economic layer of the district heating system.

The solid arrows represent linkages from the institutional-economic subsystem to the technical subsystem, whereas the dotted lines represent linkages from the technical system to the institutional-economic subsystem. The dashed lines indicate the operating relations between the operators of the district heating system and the district heating system's physical components. Finally, the thick arrows between

[10] Market efficiency is a broad term which can be further detailed by distinguishing two types of market efficiencies: (1) *static efficiency* and (2) *dynamic efficiency*. Static market efficiency regards the allocative efficiency of the market, i.e. how well the market provides its goods and services in the right quantities and qualities, and the technical market efficiency, which refers to the waste of resources within enterprises. Dynamic market efficiency regards the ability of the market's enterprises to innovate (Gent, Bergeijk, & Heuten, 2004).

[11] Social objectives for the district heating system may for instance be *freedom of choice* (Can consumers choose their own heat supplier or not?), *universal access* (Can all consumers connect to a district heating network, or another heat production means at an acceptable cost?), or *fairness* (Are all consumers treated equally? Is there no form of discrimination in connection or delivery tariffs?).

the physical installations in the technical subsystem show the flow of heat towards the heat users and the cooled flows, back to the heat generating installations.

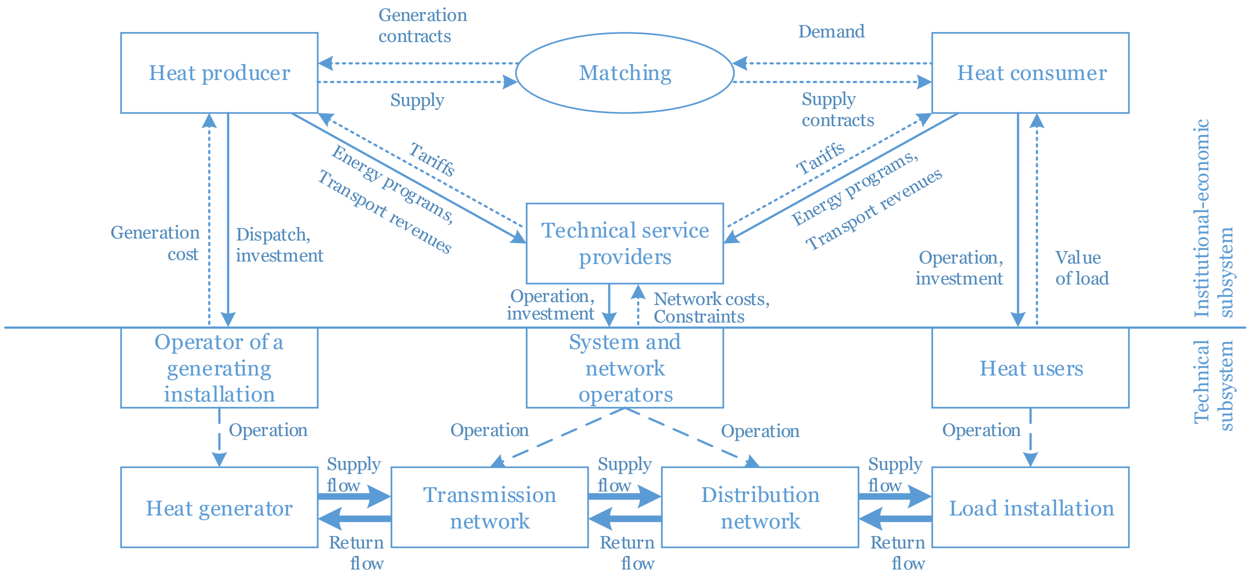

Figure 3-8: Links between the technical and the institutional-economic layers of the District heating system (Adapted from: De Vries, 2004; Knops, 2008).

3.4 Performance criteria for a new market model

In section 3.1 to 3.3 a further conceptualization of the (district) heating sector is given. Building on that insight, this section will answer the first research question of this thesis: "What are the *goals*, *objectives* and *constraints* for which a market model for the Dutch district heating sector has to be designed?"

In Figure 2-3 the design approach of this thesis was illustrated. The *goals* for the Dutch district heating sector, which may be translated in *objectives* and *constraints* serve to formulate *performance indicators* from which the system's performance may be derived. In other words: whether the district heating sector performs as it should. In this thesis the point of view of the Ministry of Economic Affairs is taken since this government Ministry is responsible for the well-functioning of the (district) heating sector.

Figure 2-3 also showed that the goals, and resulting objectives and constraints are informed by a *stakeholder analysis*. The stakeholder analysis includes a more thorough investigation into (1) the goals and means of the Ministry of Economic Affairs, specifically the 'Directorate General Energy, Telecom and Competition' (hereafter DG-ETC), (2) an identification of the main stakeholders in the district heating sector and (3) the stakeholders' respective level of interest in and power to influence the (district) heating regulation. Appendix A includes the three step stakeholder analysis in more depth, here, the highlights are given.

Operationalizing the public goals of reliability, affordability and acceptability

Heat may be considered as a *merit good* because of its importance for people's welfare and the production processes in vital economic sectors such as the horticulture sector and process industry. Being as such, it is the Ministry's task to secure the (district) heating sector's well-functioning. In practice this may be translated into the main goal of 'securing sustainable heat provision' which means a *reliable*[12]*, affordable* and *acceptable* heat provision. Table 3-4 operationalizes the goals of reliability, affordability and acceptability in measurable performance indicators which may be used to evaluate the system's performance. When reviewing Table 3-4 three observations must be made. First of all, by **operationalizing** the goals of reliability, affordability and acceptability it becomes clear what these goals in practice entail. With that realization the tension between the sometimes conflicting goals also becomes apparent: lower average duration and frequency of service interruptions might be acquired by investing in a more robust infrastructure lay-out, however the costs associated with a more robust infrastructure lay-out and therewith more reliable heat provision may increase the costs of heating.

Second, the operational goals, or performance indicators, hold measurable units and in some cases **specific targets**. Although the intentions and goals of the Ministry are clear as stated in various policy documents such as the Energy Report 2011 and 2015 and the Heat vision, there appears to be a lack of specific targets for the goals for the district heating sector. In many cases sector wide targets exist such as for renewable energy production, energy efficiency and carbon dioxide emissions but for other performance indicators specific targets are missing. Therefore the goals for the district heating sector will all be interpreted as objectives and none as constraints. Objectives with in some cases clear target values, but no binding requirements.

Third, inherent in the goals for the district heating sector one must also be aware of the difference and tension between **the short-term versus the long-term**. That is, reliability for instance may be subdivided in a short-term component and a long-term component. On the short-term, reliability entails a well-functioning heat provision system which means as few as possible interruptions, and when interruptions occur they are of the shortest duration possible. On the long-term reliability entails securing the long-term security of supply which includes lowering the dependency on natural. Tension arises when for instance savings on maintenance will lead to lower costs and thus more affordable heating in the short-term, but possibly higher total costs in the long-term because the lower level of maintenance may lead to breakdown or shorter lifetimes of infrastructure equipment.

[12] Reliability and availability are oftentimes used interchangeably. In this thesis the goal of reliability is chosen to lay more emphasis on the physical component of availability than the social distributive component (universal access to heat – see Table 3-4).

Table 3-4: Operationalization of the evaluative framework for the goals for the district heating sector. Main goal of the Ministry: 'Securing sustainable heat provision' – see Appendix A-1 for more background.

Goals	Performance indicator	Target
More reliable district heating		
Lower average duration of service interruptions	Average duration of service interruptions in minutes	Unspecified; direction <
Lower frequency of service interruptions	Number of service interruptions per year over 1000 connections	Unspecified; direction <
Lower dependency on natural gas	Percentage of heat provision based on natural gas	Unspecified; direction <
Securing universal access to heat	Coverage level of potential heat consumers	All must be connected to a reliable, affordable and acceptable heat source. Next to that the government is aiming to connect at least 1 million households to district heating by 2020[13].
More affordable district heating		
Lower costs of heating	€ per GJ	Unspecified; direction <
More acceptable district heating		
More renewable heat production	Percentage of renewable heat production	Unspecified; energy sector-wide at least 14% by 2020.
Higher energy efficiency	Fraction of energy used usefully in heating systems	Unspecified; energy sector-wide at least 1.5% savings per year.
Lower emissions of polluting gases[14]	Example given: Emissions of CO_2 in ton per year	Installation dependent constraints. Target for CO_2 is decreasing emissions by 16% in 2020 compared to 1990 levels.
Less safety incidents	Number of safety incidents per year over 1000 connections	Unspecified; direction <

[13] Motion Jan Vos and Leegte concerning the potential of residual heat for heating the built environment using district heating grids (Vos & Leegte, 2014).

[14] Polluting gases include NOx, COx (particularly CO2), PMx (particulate matter) and other gases such as SOx. The allowed emissions for these gases are defined by the Ministry of Infrastructure and Environment. The Directorate General must take into account the aim to lower emissions of polluting gases when designing policies for the heat sector.

Identifying the main stakeholders and their importance to the Ministry of Economic Affairs
Next to the goals of the Ministry of Economic Affairs there are also other stakeholders in the district heating regulation dossier with their own interests and goals. Identifying these stakeholders is important to better understand the values at stake when proposing alterations to the market model of the district heating sector.

The stakeholder analysis led to the identification of *eighteen* different actors and groups of actors. Of these stakeholders eight are *public actors*, one group of actors may be considered *semi-public actors* and another nine are *private actors*. Appendix A-2 lists the eighteen actors and groups of actors and their interests, goals and means (See Table A-1).

The multitude of actors may be explained by the fact that heat is a vital commodity for people, horticulturists and industry. Because the cost of heating constitutes an important part of people's monthly expenses, the horticulturists' and industry's production costs heat is also considered a 'top of the agenda' issue for many actors.

The power of different actors to influence the policy process of the formation of new legislation for the district heating sector however differs. The Ministry aims to incorporate the goals and interests of all stakeholders, it is however clear that some actors have a louder voice than others. Figure 3-9 illustrates this fact by posing how the interests and power of the different stakeholders is distributed in a power/interest matrix. This matrix may be used to better understand which stakeholder's interests *must* be taken into account at all times, and which stakeholders could be influential in steering the regulation in the desired direction.

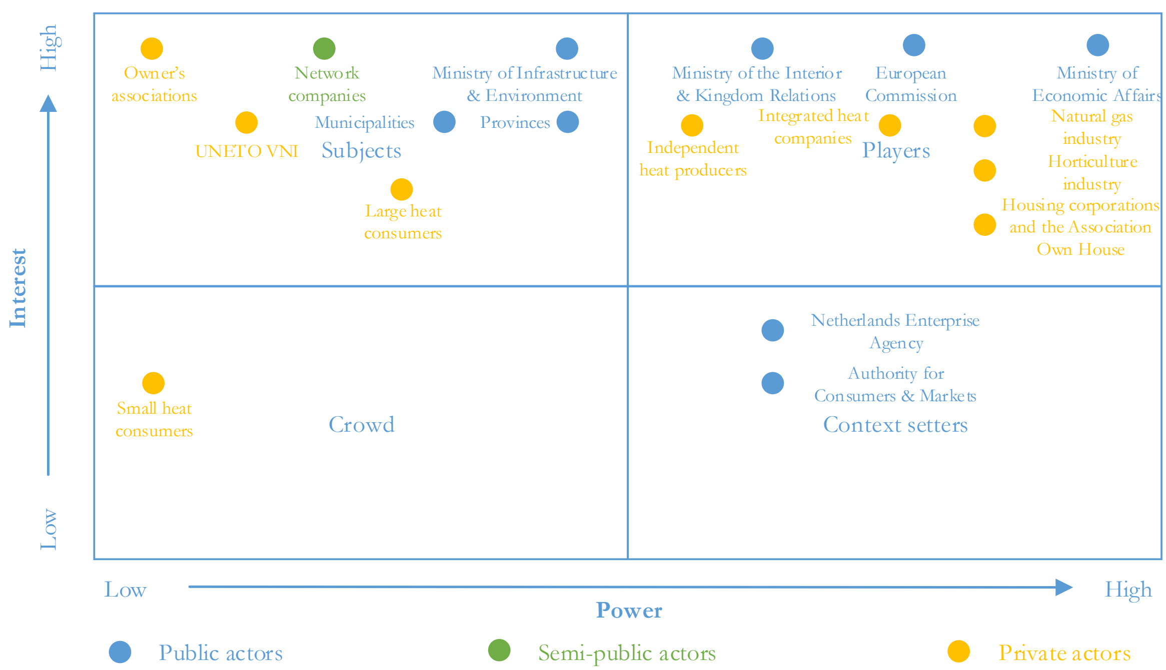

Figure 3-9: The eighteen groups of actors organized by their interest in and power to influence the district heating regulation. The power/interest matrix holds four quadrants, namely the 'subjects', 'players', 'crowd' and 'context setters'. For more background see Appendix A-3.

4 Exploring the design space

In this chapter the design space for a new market model for the district heating sector is explored. In the previous chapters most of the dilemma's surrounding the functioning of the district heating system have already been discussed. Section 4.1 gives an overview of these dilemma's using their economic terms: the *market imperfections* and *market failures* in the district heating sector. Subsequently, the possible avenues for remediating the identified market imperfections and market failures are explored. This involves three steps: (1) identifying the design variables, (2) assessing the pros and cons of the policy instruments per design variable and (3) analyzing the interdependency between the identified policy instruments – Section 4.2 to 4.4. Finally, in Section 4.5 the chapter closes by giving an overview of how the design space fits in the structure of the design process that is followed in this thesis.

4.1 Market imperfections and market failures in the district heating sector

Textbook economics gives us that there are two categories of flaws that may occur in the functioning of a market: market imperfections and market failures. Table 4-1 gives a schematic overview of the key concepts used in this section.

In order to understand how market imperfections and market failures arise in the district heating sector one must understand 7 key characteristics that are inherent to the district heating sector. Below, these characteristics and their impact on the functioning of the market are explained with reference to the district heating systems' value chain – heat generation, heat transport, heat distribution and heat delivery (see Figure 3-4 to revisit the technical system lay-out). Table 4-2 summarizes the market imperfections and market failures encountered in the district heating sector.

Table 4-1: Two categories of flaws in the functioning of markets (Gent et al., 2004)

Market imperfections	Market failures
"Imperfections in the results of competition, caused by the structure of or the behavior of (an) enterprise(s) on the market in question"	*"The inadequacy of a market to translate some demand and supply signals into appropriate prices, quantities and qualities."*
1. Static inefficiency: - **Allocative inefficiency.** The available supply of goods and services is inappropriately tuned to the needs of consumers in terms of prices, quantities and qualities. - **Productive inefficiency.** The occurrence of waste within enterprises. **2. Dynamic inefficiency:** - Enterprise insufficiently ensure continuing innovation within the market	**1.** The lack of or insufficient production of **quasi-collective goods.** **2.** Market parties do not or insufficiently account for **positive and negative externalities** in their activities. **3. Difficult goods.** The insufficient production or consumption of goods of which the government is of the opinion she has a special responsibility for. In addition, this also concerns goods of which the government is of the opinion that consumers inappropriately value the worth of these goods.

Key characteristic 1: District heating systems are of a local to regional character

A combination of two attributes of district heating systems cause them to have a local to regional character: (1) the geographic distribution of eligible heat sources, and (2) the heat transport costs are relatively high.

First of all, for a heat source to be eligible as a heat producer its heat must be of a high enough temperature. In addition, the capacity of the heat source must be large enough to justify the investment costs of decoupling or producing heat (economies of scale). Given these requirements there are only a limited number of suitable heat production locations in a given geographic area.

Secondly, the transportation costs of heat are relatively high because of the costs of the infrastructure in general and the relatively high losses of heat over large distances. Because of that reason the heat demand center must be in close proximity to heat production locations.

Considerations for the production side of the district heating system

The local to regional character of district heating systems cause that most district heating systems, even the larger ones, are typically dependent on only one or two large heat producers for their production. The large market shares of the heat producers yield the risk of the heat producer having **market power**. Having market power entails that the heat producer would be able to influence either prices, quantities or qualities of the heat he is providing in his benefit because he has a large market share in the district heating system and his consumers have no suitable alternative. The occurrence of market power may cause **allocative inefficiencies** to arise which is undesirable.

Moreover, it should be noted that the situation of market power is solidified by the fact that to some extent there is also a **natural monopoly** when it comes to heat production. Since there are only a limited number of heat production locations eligible for heat production and even if there are multiple locations eligible in close proximity, the costs of having two heat production installations is in many cases less cost effective due to the economies of scale effects that are present in heat production.

Considerations for the transport and distribution side of the district heating system

The local to regional character of district heating systems is partly caused by the relatively high transportation costs. Because of the high transportation costs transport and distribution of heat is a **natural monopoly** which gives the holder of the infrastructure **market power**.

Considerations for the delivery of heat in a district heating system

The local to regional character of a district heating system causes district heating systems to not only have a small number of producers, compared to similar systems such as the electricity and natural gas infrastructure systems, but also have a relatively small number of consumers. This means that competition for retail services in many district heating systems might increase transaction costs more than it might lower prices or increase quality of service due to the benefits that competition may yield **(natural monopoly)**.

Key characteristic 2: District heating systems are closed systems with relatively many quality parameters (compared to similar energy commodity infrastructure systems – see also Section 3.1)
The heat provided by heat producers is carried by the system water which flows from the heat producer through the transport and distribution systems to the heat consumers and then *returns* back to the heat producer. Because this is a closed system the amount of heat fed-in to the system by different heat producers and drawn from the system by different heat consumers affects all members of the system. Since the operational efficiency of the system is highly temperature dependent coordinating the feeding in of heat and extraction of heat is crucial.

Considerations for the system operation of district heating systems
The need for coordination causes synergies in the form of value chain optimization in operation (dispatch of heat generating installations and consumption patterns) and design (where and how to lay out the district heating transport and distribution grids) when the value chain is operated by a single entity, in other words, when the value chain is vertically integrated. This doesn't mean that the value chain *must* be vertically integrated, an unbundled value chain may function just as well, but might require more coordination which increases transaction costs and therewith the total costs of heat delivery.

Neither the producers nor the consumers in the district heating system themselves are directly affected by their choices regarding their production and consumption levels, but indirectly they are through the effects of their choices on the systems efficiency in operation and design. Their actions affect the larger district heating system and therewith can be seen as a **negative externality** of their activities.

Key characteristic 3: District heating systems cause external effects
Next to the negative externality caused by the fact that district heating systems are closed systems, district heating systems themselves also have external effects. Through the use of natural resources for the production of heat and the associated emissions of greenhouse gases and other pollutants the district heating sector affects the natural environment. These negative effects on the environment are only in part incorporated in the price of heat delivery and can therefore be considered **negative externalities.**

Key characteristic 4: District heating systems offer the possibility of storage
In network infrastructures a common problem is found in **congestion externalities**. If one road, pipeline, or transmission cable is congested due to a utilization rate that surpasses its capacity, this may lead to congestion in that particular link, possibly also affecting other links that are connected to it. In district heating networks this externality may also occur if due to sudden demand pattern fluctuations[15] the transport pipelines cannot deliver the required capacity.

Heat buffers offer the possibility to alleviate congestion by strategic dispatch and placement of the buffers. Greenhouse operators use heat buffers to produce heat (or draw it from a district heating grid) when commodity prices are low (filling their heat buffers) and when prices are high depend on their buffers.

[15] An example of a sudden demand pattern fluctuation is for instance weather variability: sunny clear skies may suddenly turn into heavy rainfall or vice versa leading to steep changes in the heat demand.

Similarly, large combined heat and power plants that deliver heat to a district heating network use heat buffers to optimize their dispatch, allowing them to produce at high capacity when electricity prices are high, and tune down when electricity prices are low. Finally, district heating network operators may strategically place heat buffers in their network to be able to cope with sudden demand pattern fluctuations without having to lay down very large capacity pipelines.

On the contrary to for instance the electricity infrastructure, heat storage is economically an attractive option. Moreover, the use of heat buffers cause a **positive externality**: when reacting to the price signals of the electricity sector the heat buffer is effectively absorbing the intermittency in the electricity generation (e.g. renewables) and consumption patterns.

Table 4-2 Inventory of market imperfections and failures

Production	Transport and distribution	Delivery	Consumption	Storage
Market power, solidified by the presence of a natural monopoly	Natural monopoly	Natural monopoly (in small to medium scale networks)	Negative externality in consumption patterns.	Reduces market power from producers and lowers the risk on congestion.
Negative externality in dispatch patterns				Positive externality in balancing effect on intermittent renewables.
Negative externality in emissions of greenhouse gases and other pollutants				

Regulating market imperfections and failures

The four key characteristics of the district heating sector described above inhibit competition on the production side, the transport and distribution side and the delivery side. Although, storage may alleviate some of the problems caused by the characteristics of the district heating sector storage alone will not solve the market imperfections and failures being **market power, natural monopolies and negative and positive externalities.**

Many of the problems encountered in the district heating sector are not unique to the district heating sector. In other (infrastructure) sectors the identified market imperfections and failures also occur, which has led to the emergence of a large toolbox of instruments to alleviate or solve these market flaws. Before exploring the toolbox of *regulation* three more characteristics of the district heating system must be discussed which must be taken into account when exploring options to regulate the district heating sector.

Key characteristic 5: Information asymmetry

In the Netherlands the heat price for small consumers is capped by the Not More Than Otherwise-principle, which is a price reference to the price of natural gas. The price protects small (captivated) consumers from excessively high pricing from their monopolistic heat supplier. However, because the price is fixed and the costs of district heating vary strongly among different district heating networks, the profits district heating suppliers make also vary strongly. How large the profits exactly are is difficult to estimate.

In 2015 the Authority Consumer & Markets (ACM) published her first profitability monitor of the district heating sector to assess the magnitude of the profits made in the district heating sector. The assessment was based on the costs and revenues figures provided by heat suppliers. The reported returns (3.1% in 2014 and 7.8% in 2013) were within or below the bounds of what the ACM considers reasonable (between 5.5 – 7.5% in 2014 and between 6.0 – 8.0% in 2013).

But since these figures are only providing information on two reference years it is difficult to draw hard conclusions from them.

First of all, the returns on district heating operations are highly dependent on the temperature. A cold winter may strongly increase revenues, whereas a warm winter will strongly decrease revenues.

Secondly, there is the issue of assets that are used for both electricity production and heat production. There is no insight given into how heat suppliers that operate CHP facilities attribute the costs of that production over their respective products, heat and electricity, nor are there any rules for that. Potentially, a CHP-heat supplier could attribute more of her fixed costs to her heat production than to her electricity production which would lower her 'accounting returns' on the heat operation side. Because the heat supplier has more knowledge about her actual costs *(information asymmetry)* the regulator is hindered in having proper insight into the actual profits made on the heat production *(principal-agent problem)*.

Moreover, if the regulator comes up with creative means to regulate CHP-heat suppliers such that cost attribution is split 'fairly' over the electricity and heat production this does not mean that the problem is solved right away. Actors are also *reflective*. This entails that actors interact, learn and display strategic behavior (Herder et al., 2008). Actors will try to maximize their own utility by finding new ways of playing the system's new rules in their benefit. In time, actors will learn to neutralize the interventions by others[16].

Key characteristic 6: The natural gas reference situation

In the Netherlands 93% of households (ECN, 2015) are connected to the natural gas grid which makes natural gas the reference for the price of heat. For the district heating sector this means that consumers desire (1) similar levels of service and (2) freedom of choice, just like there exists in the natural gas sector. This reference situation constrains the design space for the district heating sector because policy instruments that infringe on this deeply rooted desire of consumers will most likely not make it. Consumers and consumer organizations would oppose these policy instruments which would make it difficult to implement them.

[16] The process of interaction, learning and displaying strategic behavior is extensively described by De Bruijn & Ten Heuvelhof (2008).

Key characteristic 7: Bounded rationality

Designing a market model that incentivizes a more sustainable district heating sector requires insight into how actors make their decisions. However, actors are not rational entities, but have *bounded rationality* (Simon, 1982). For example, actors are all expected to maximize their own utility, but due to incomplete information, misinterpretation of information, or other reasons actors may choose to act in unexpected ways. While designing policy instruments for the district heating sector this must be taken into account.

4.2 Identifying the design variables

Section 4.1 described four key characteristics (1 to 4) of the district heating sector which together cause a number of *market imperfections* and *market failures* (see Table 1-1). Acknowledging three more key characteristics (5 to 7) of the district heating sector informs that there are limits to the capability of regulation to solve the market imperfections and market failures identified.

Earlier, in Section 2.1 the institutional environment of the district heating sector was depicted by using Williamson's four layer model (see Figure 2-2). Of the four layers that together constitute the institutional environment of the district heating sector the second layer is of interest for this section. The second layer covers the 'government decisions' which may be divided into a 'general' part (layer 2a) and a 'district heating sector-specific' part including the 'related regulation' (layer 2b). It is layer 2b that entails the *design variables* that are of interest for this study.

The design variables themselves can be split up into two categories: the variables that determine the regulation of the district heating sector (district heating sector-specific regulation) and the variables that determine the relative attractiveness of district heating versus other forms of heating (related regulation). Both categories of design variables are important parts of the design space for a new market model for the district heating sector (see Section 4.2.1 & 4.2.2 respectively).

4.2.1 Regulating the district heating sector

When in Section 3.2 the institutional organization of the Dutch district heating sector was discussed three exemplary modes of organization were presented that currently exist in the Dutch district heating sector (See Table 3-2) The room within companies may make choices on how to structure their modes of organization in their respective district heating systems is determined by the choices made over the design variables that regulate the district heating sector.

In their paper about the design of (hybrid) electricity markets Correljé and de Vries (2008) identified thirteen *design variables* that together structure the design space for the market design of the electricity sector. These design variables are respectively the: (1) degree of market opening, (2) pace of market opening, (3) integrated versus decentralized markets, (4) public versus private ownership, (5) competition policy and horizontal unbundling, (6) network unbundling, (7) network regulation of network tariffs and access conditions, (8) congestion management method, (9) arrangements with neighboring networks and interconnector congestion management, (10) balancing mechanism (in decentralized markets), (11) wholesale and end user price regulation, (12) capacity mechanism, (13) position of regulator.

As an energy infrastructure sector, the electricity infrastructure sector holds many commonalities with the district heating infrastructure sector, and as such most of the market design variables identified can also be applied to the district heating sector. While acknowledging the importance of all thirteen design variables, for the purpose of this study, some of the design variables are more important than others. In order to align the design variables better with the needs for this study a number of the thirteen design variables are not used in further analysis and others are rearranged. The result is a list of nine design variables (see Table 4-3). Below, these nine design variables are discussed as well as the reason for omitting the design variables that are not used in further analysis.

Table 4-3: Design variables for the design of a new market model for the Dutch district heating sector.

Design variables
Regulating the district heating sector
1. Public versus private ownership
2. Network access conditions (for producers, retail companies and consumers)
3. Network unbundling
4. Integrated versus decentralized market
5. Tariff regulation
6. Congestion management method
7. Integration with neighboring networks
Steering the relative attractiveness of district heating versus other forms of heating
8. Incentives for consumers of heat
9. Incentives for producers of heat

(1) Public versus private ownership. The first design variable concerns the choice regarding which parts of the value chain should be owned and/or operated by public bodies, and which parts should be owned and/or operated by private organizations. In market economies it is generally considered unnecessary or even undesirable for government to participate in activities that could also be executed by market parties (to favor competition) (A. C. Correljé & de Vries, 2008). However, if the good in question (heat) is considered a *merit good* because of the importance of the function it fulfills public ownership may be a means for the government to secure public goals such as the reliability, affordability and acceptability of the provision of heat. Government intervention is considered justified if market flaws such as market imperfections or market failures occur (see Section 4.1).

Public ownership is one of the means for government to exert control over the activities related to district heating. Public ownership may be desirable if the public interests are difficult to capture in the form of contracts. This situation occurs when it is difficult to fully specify the desired level of performance of the industry in question, or when it is difficult to measure the performance because of *information asymmetries* (Blokland, 2008).

As mentioned, many district heating systems have historically been developed by public bodies such as municipalities or publicly-owned energy companies which means the starting conditions often include public ownership of at least parts of the value chain. Main variables to consider when privatizing a public energy sector include (1) the degree of privatization (ranging from a government monopoly to full privatization), (2) which segments in the value chain should be privatized (see Figure 3-4), and (3) the character of the new private owner's[17] (A. C. Correljé & de Vries, 2008).

[17] The means for the government to attract private capital to a (formerly) public sector are through a system of concessions (which happens often in public transport systems), through the flotation of packets of shares in the industry, or through the merger with a private (foreign) energy company.

Ideally, the choice between public versus private ownership along the main variables discussed should be made based on social cost benefit analyses (Ministry of Economic Affairs, 2006). In a social cost benefit analysis the potential benefits of privatization (among others competition and the attraction of private capital and revenues for the government from the sale of public assets) can be weighed against the costs of privatization (the possible emergence of market flaws and the costs of regulating the newly entered private firms). Costs of regulation that could be included in such an analysis are the execution and enforcement costs of the regulation, the administrative burden imposed on companies and possible market distortions caused by the government intervention.

Depending on the choices made regarding the main variables in choosing for public or private ownership the resulting horizontal and vertical structure of the district heating sector changes. This has consequences for the relation between the energy companies active in the sector and the Ministry of Economic Affairs and the regulator (the ACM). As the relationship between the players in the sector change, also the policy process changes because the energy companies in the sector will change their attempts of influencing the formulation of energy policies at the Ministry and the regulator.

(2) Network access conditions. The second design variable concerns the rules on how third parties may gain access to the district heating network – oftentimes also called third party access conditions. Rules for the network access conditions must be formulated for three parts in the district heating value chain: (1) on the wholesale side for heat producers, (2) on the retail side for heat suppliers and finally (3) also on the retail side for heat consumers.

Third party heat producers are heat producers that wish to feed-in heat into an existing heat network that is not their own. The network owner has a natural monopoly to transport and distribute the heat to its consumers which is why regulation might be necessary for third parties to be able to connect to their networks under 'fair terms'. Two options are possible: negotiated third party access and regulated third party access. The details and pros and cons of these options are discussed in Section 4.3.

Third party heat suppliers are heat retail companies that wish to provide heat delivery services to heat consumers (small and/or large of nature) on a network that is not theirs. Again the network owner has a natural monopoly to transport and distribute the heat to its consumers. Competition between heat retail companies on one network has been proven to be possible in the electricity and natural gas infrastructure sectors, but require the unbundling of network activities from potentially commercial activities being the activities associated with wholesale production and heat delivery. The pros and cons of network unbundling are discussed under design variable three.

Depending on the available infrastructures in the proximity, heat consumers can satisfy their heat demand in various ways such as the combustion of natural gas in heat boilers, electric heat appliances or using district heating. In the Netherlands there is an obligation to connect consumers to both the natural gas grid and the electricity grid if a consumer asks to be connected. The regional distribution network operators (e.g. Stedin or Alliander) is then obliged to realize a connection to the asking consumer. The current regulatory framework provides a barrier for the uptake of district heating. If in an area a district heating network is rolled-out and consumers would switch from district heating to another form of heating (e.g. electricity or natural gas) it could be difficult for district heating networks to attain the necessary level of participation in an area for its infrastructure to become economically profitable. Moreover, having multiple infrastructures servicing the heat demand in the same area might not be the most economically efficient solution since the duplication of infrastructures is costly. An alternative that is suggested in politics is ‘the right to be connected to heat’ instead of ‘the right to be connected to natural gas and electricity’[18]. The right to be connected to heat could be designed to be technology neutral so that district heating can equally compete with the electricity and natural gas infrastructures. Local energy distribution operators or the municipality could potentially then decide where which energy infrastructure will service which consumers.

(3) Network unbundling. The third design variable regards the choice whether to separate the network activities from the potentially competitive wholesale (production) and retail activities (delivery). Unbundling serves the purpose of preventing that the network manager attains or allocates unfair competitive advantages on commercial activities (wholesale and retail). Therewith, unbundling may contribute to securing non-discriminatory access, which is also a goal of formulating the network access conditions. Moreover, unbundling separates commercial interests from network interest which is important because these interests oftentimes compete (e.g. short-term profit versus long-term network reliability and well-functioning).

Five different levels of unbundling can be distinguished: “(1) no unbundling, (2) separate accounting by the network manager, (3) administrative separation (the network manager forms a separate business unit), (4) juridical separation (the network manager forms a separate legal person – but may be part of a larger firm), and finally (5) ownership unbundling (network manager is juridical separate and is the owner of the network)” (de Vries et al., 2014, p.61). From 1 to 5 the different levels of unbundling are progressively stricter from no unbundling at all to the situation where the network manager is juridical separate, owns the network and is not allowed to be active in commercial functions.

When choosing the level of unbundling one must assess the benefits and costs of both the reorganization from the status quo to the chosen level of unbundling and the potential costs and benefits of unbundling. Pollitt (2008) executed such an assessment of the benefits and costs of ownership unbundling for the transmission grids of the electricity and natural gas systems. The assessment includes ten factors[19] for which the potential benefits and costs of ownership unbundling are identified and assessed using case-studies. The study concludes that ownership unbundling “appears to be closely associated with competitive wholesale and retail markets and effective regulation of monopoly networks” (Pollitt, 2008, p. 712). Moreover, Pollitt continues with the suggestion that ownership unbundling “is likely to be successful in facilitating more competition” (Pollitt, 2008, p. 712).

(4) Integrated versus decentralized markets. Matching heat production and demand can be organized either through integrated or decentralized markets.

In an integrated market “the system operator operates a mandatory pool, in which physical and economics aspects of [heat] trade are strongly connected” (A. C. Correljé & de Vries, 2008, p.7). The most

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[18] See for instance the Parliamentary motion of Van Veldhoven on the proposal to explore the alternatives for changing ‘the right to be connected to natural gas’ into ‘the right to be connected to heat’ (Van Veldhoven, 2015).

[19] These factors are: effect on competition, ease and effectiveness of regulation, facilitation of privatisation, security of supply, transaction costs of unbundling, costs of capital/investment, synergy/ focus effects, double marginalisation, likelihood of foreign takeovers and the risk of arbitrary government intervention.

well-known example is the 'nodal pool' which is the market model used for the electricity system of the United States of America. In a nodal pool the dispatch of production facilities is determined by an optimization that takes into account the offered supply, the asked demand and the costs and capacity of transport. It is called a nodal pool because the prices that arise are calculated by calculating the costs of transporting heat between nodes. Following this system it is possible to prevent congestion because the location of supply and demand and the limitations and costs of the available transport capacity are incorporated in the optimization (CE Delft, 2015). This system does however "combine both economic and physical control over the system in the hands of a single party, potentially facilitating governance" (A. C. Correljé & de Vries, 2008, p.10).

In a decentralized market "the system operator only has a technical function and supply and demand meet elsewhere, either bilaterally or in voluntary [heat] exchanges" (A. C. Correljé & de Vries, 2008, p.7). Different matching mechanisms exist of which the most well-known in Europe is the market coupling model. The market coupling model is a market that exists of multiple regions wherein the market aims to optimize both the region's prices as the daily collective transports between the different regions. Trade between heat producers and suppliers may occur on a bilateral market or an independent (spot) market exchanges (CE Delft, 2015). The benefit of a decentralized market is that it is a proven model that is well-understood by the market parties currently active in the energy sector in Europe. The drawback is that the physical aspects and economic aspects of energy trade are no longer directly connected which requires additional regulation to manage congestion and secure generation adequacy.

(5) Tariff regulation. The end-use price of heat can be broken-down into the wholesale price, the network tariffs, the tariffs for retail services and possible taxes. In the Netherlands the end user price for small consumers of heat is currently regulated through the Heat Act and Heat Regulation. Wholesale and end user price regulation serve as a means to control the affordability of heat which is a balancing act between satisfying the interests of consumer groups and defining a 'reasonable' profit for heat producers and suppliers. Network tariff regulation is a resultant of the previous design choices: a public network owner and manager's tariffs are oftentimes regulated to provide incentives for economic efficiency whereas a private network owner and manger's tariffs may also be regulated but then to ensure a level playing field for all parties using the network (producers, consumers and retail companies). The degrees of freedom in which heat prices may be regulated is large. Two main variants may be distinguished: (1) a price-cap system, which constitutes a maximum tariff based on a benchmark that is not connected to the actual costs of the heat company and (2) a cost-plus system, which translates into maximum tariffs that are based on the actual costs of a heat company plus a 'reasonable' return (Ecorys, 2016).

(6) Congestion management. If transport capacity is inadequate to fulfill the required or desired heat flows in a heat network congestion arises. There are different means to prevent or manage congestion such as integrating transport costs and capacities into the matching process of demand and supply (integrated markets), using dynamic tariffs to provide incentives to not use congested pipelines or explicit (capacity) auctions that allocate the limited transport capacity over the heat companies that would like to make use of the network (de Vries et al., 2014).

In the district heating sector congestion is of a lesser concern than it is in the electricity sector because of three reasons: (1) heat flows are more easily predicted than electricity flows which makes it easier to design the networks as such so that congestion will not occur, (2) the district heating networks are oftentimes built with large slack capacities to prevent congestion because laying out the infrastructure is an expensive operation and (3) part of the variability in heat demand or heat production may be overcome by the use of buffering, which is easier implemented in district heating systems than in electricity systems. Nevertheless, it may be necessary to incorporate a congestion management strategy in the market model to prevent congestion from occurring.

(7) Integration of neighboring networks. As the district heating sector grows it is likely that a similar development as in the electricity sector has occurred will unfold: small to medium autonomous networks will grow and progressively neighboring networks may interconnect with each other to improve economies of scale and attain synergy advantages. Since connecting two neighboring networks may have a significant impact upon the competitiveness of the networks and market parties involved, it may well be undesirable for some parties to cooperate in linking their respective networks – despite the potential economic benefits for the system as a whole and the consumer. Therefore, designing rules on network integration and how to deal with interconnector congestion management is an important part of the design space.

Omission of design variables

The seven design variables described above will be taken into account in further analysis for both the case studies and the design process of a new market model for the Dutch district heating sector. The other six design variables described by Correljé and de Vries (2008) are also important variables in the description of a market model, however, they are not considered as instrumental as the other seven for reaching the goals that the Ministry holds for the district heating sector (see Table 3-4). Below the meaning of the other six design variables are discussed as well as why they will be omitted from further analysis.

Degree of market opening. The degree of market opening describes to what extent the market model allows for competition within the district heating system. Figure 4-1 positions five design options on the continuum that the degree of market opening is. Among these five design options a variety of different ways of implementation are possible. The reason the degree of market opening is not explicitly being investigated further in this study is because it is considered a resultant of the choices on the seven design variables that have been described above. Depending on the choices made on these design variables the configuration of the degree of market opening will arise.

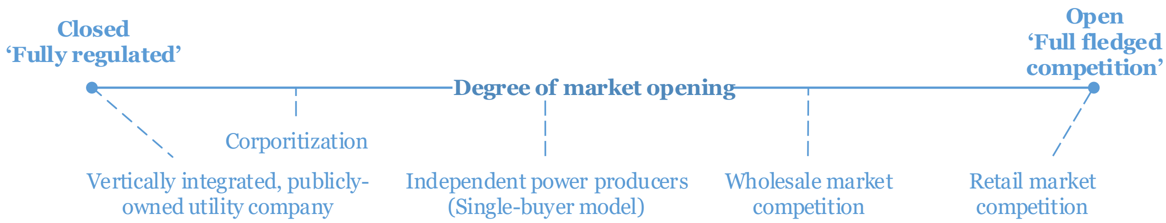

Figure 4-1: Different degrees of market opening set-out on a scale from being fully regulated (closed market) to a state where there is full-fledged competition (open market) – See Appendix B for a full description of the different degrees of market opening.

Pace of market opening. Changing the current degree of market opening, or any changes to the current market model for that matter, can be done gradually, or at once. The pace of change is of importance because, for example, increasing the competitive forces in the market too swiftly may cause investment security to drop and cause slower growth of district heating networks in the Netherlands. This would impede the government's goals to increase the share of district heating in the heat provision sector. Alternatively, not opening the market further, or not swift enough, may cause incumbent energy companies to gain socially unacceptable profit levels, or, not give these companies enough incentives to innovate their products and production processes (lack of allocative and dynamic market efficiency). Next to the impacts of the pace of change on market performance and efficiency the pace of change is also important because the goals the government holds for the energy sector incorporate constraints and objectives that are time-dependent (renewable energy and climate goals). In this study however the focus does not lie on how the process of change should be organized, rather the focus lies on what the new market model of the district heating sector eventually should look like. Therefore, where relevant attention will be given on the pace of change to the market model, but it will not be the focus of this study.

Competition policy and horizontal unbundling. Competition policy influences the fierceness of the level of competition that companies may expect in a given sector. A strong regulator that will monitor the abuse of market power and acts when horizontal integration might cause competitive pressures to subside is very different from a regulator that allows horizontal integration to occur as long as the companies in question do not make 'socially unacceptable profits'. The discussion about the competition policy and horizontal unbundling is however one that transcends the district heating sector and is part of a larger discussion on the overall business climate in the energy sector and the Netherlands as a whole. This is not the focus of this study.

Although not the focus of this study, the issues of competition policy and horizontal unbundling are however embedded in the decisions of the seven design variables that are taken into account. This becomes clear when touching upon two connected topics: freedom of choice and the introduction of competition. Currently, there is no *freedom of choice* for consumers on the retail side in the Dutch district heating sector which represents a problem for unsatisfied district heating consumers who are unable to choose another supplier. At the same time, households or businesses who generate their heat by means of natural-gas fired heating boilers *do* have the possibility of choosing their preferred supplier. Similarly, on the wholesale side there is the possibility of competition between heat generators, but it is not mandatory for owners' of district heating systems to allow third parties to provide heat to their networks.

When considering introducing competition on the wholesale side or/and the retail side of the district heating value chain the decision should be made vis-à-vis the decisions made regarding the *ownership* of (segments of) the district heating value chain (public versus private).

On the wholesale side, for competition to be effective it is possible that horizontal unbundling on a local level is necessary because otherwise incumbent (publicly-owned) energy companies would have market power, making it difficult for new entrants to compete. Correljé and de Vries (2008, p.8) note that "fringe competition may provide some benefits, but due to economies of scale and the long life cycle of key assets such as [large suppliers of residual heat], it is not likely to lead to a level playing field for competition very quickly".

On the retail side, for competition to be effective, some form of vertical separation is necessary. Without vertically separating the value chain new entrants on the retail market would have an unfair disadvantage in competing with incumbent energy companies who would own the entire value chain. However, studies into the effects of vertical separation (or unbundling) and the introduction of retail competition on the performance of the electricity sector show that vertical integration might very well be a necessary instrument in an energy infrastructure system for *risk hedging* (Boroumand, 2015). Others find that neither of the extremes, full vertical integration versus full unbundling, is the optimal solution for dealing with the risks associated in energy infrastructures and argue that a mixture form should be adopted (Chao, Oren, & Wilson, 2008).

Balancing mechanism. Heat demand and production must be equal to each other in order to maintain network temperature and efficiency, and, to satisfy the needed heat flows for consumers. However, because on a real-time basis the heat demand may fluctuate strongly along the patterns of weather variability there is a need for a balancing mechanism when there are multiple heat producers connected to the network. That said, there is more leeway in balancing district heating networks than there is in electricity networks because of the possibility of buffering. The pipelines themselves plus decentralized and centralized storage vessels may well be enough to provide the real-time demand fluctuations that are associated with weather variability. Given this, and the fact that there is currently no indication that a balancing mechanism is being used or required in any of the district heating networks I encountered during my desk study this design variable will not be the focus of this study hereafter.

Capacity mechanism. Capacity mechanisms are a means to stimulate the investment in energy commodity generation adequacy when there is the concern of underinvestment by market parties. Theoretically, there is a need for some form of a capacity mechanism when there are price restrictions, because foregone revenues may cause generating companies to underinvest in sufficient capacity (Hogan, 2005; Stoft, 2002). So far, however, there has not been any indication of a lack of investment in heat generating capacity in the Netherlands which is why the need for a capacity mechanism is not discussed any further here.

Position of the regulator. Finally, the position of the regulator influences the interplay between the Ministry of Economic Affairs, the regulated industry and the regulator himself, and, the "degree of detail, specificity and generality in which regulatory problems can be solved"(A. C. Correljé & de Vries, 2008, p.9). For the purpose of this study the position of the regulator is largely considered as an unalterable design variable because it is part of a wider discussion on how the energy sector as a whole should be regulated and therewith not the focus of this thesis. When relevant, attention will however be given to on what level the regulatory power should be located. This is for instance relevant when discussing network tariffs and access conditions (third party access), or the arrangements between neighboring networks.

4.2.2 Steering the relative attractiveness of district heating versus other forms of heating

In order to attain the goals the Ministry holds for the district heating sector the district heating sector needs to grow. The growth of the district heating sector is however dependent not only the regulatory framework for the district heating sector itself, but also on its relative attractiveness to other forms of heating. These other forms of heating include, but are not limited by, electric forms of heating, heating with natural gas fired-boilers or heat savings measures. Two additional design variables that have to be taken into account are identified with respect to the relative attractiveness of district heating: (8) the incentives for consumers of heat and (9) the incentives for producers of heat.

(8) Incentives for consumers of heat. The eighth design variable of concern is the incentives that are in place to encourage consumers to make the 'sustainable choice'. Consumer surveys inform that 98% of consumers base their decisions primarily based on the price of their contract (Van Ofwegen - Director Nuon Heat, 2015). Facets such as sustainability and freedom of choice are only concerns of a second-order. In part, the price of heat is determined by exogenous factors such as technology developments and energy prices, but in part it is also determined by alterable variables such as the *energy tax* on electricity and natural gas or *investment subsidies* in heat savings measures or more environmentally friendly means of heating. Influencing the incentives for consumers of heat is crucial to increase the level of renewable heat consumption and decrease the emissions of polluting gases associated with heat consumption.

(9) Incentives for producers of heat. The ninth design variable concerns the incentives for producers of heat. Energy companies determine their heat production portfolio for a large part based on exogenous factors such as technology developments, energy prices, and expected regulatory measures that are of impact on their businesses such as the price of European emission allowances in the emissions trading scheme. In part, these exogenous factors are outside the (direct) control of the Ministry, but some are also part of the design space. For example, choices regarding subsidizing renewable forms of heating such as geothermal energy or biomass-fired heat producers, or taxing less environmentally friendly alternatives are ways to influence the relative attractiveness of district heating to other forms of heating.

4.3 Assessing the pros and cons of the policy instruments

In the previous section *nine design variables* for a new market model for the Dutch district heating sector have been identified being seven *district heating specific* design variables and two design variables that are directed at *steering the relative attractiveness of district heating versus other forms of heating* (related regulation). In this section a selection of existing *policy instruments* per design variable are discussed along with a brief analysis on their pros and cons (see Table 4-4). Together, the policy instruments described represent the 'toolbox' for designing a new market model.

A new market model for the Dutch district heating sector may be defined by choosing policy instruments from Table 4-4 for each of the nine design variables. This 'package' of policy instruments then represents the description of the market model and form the rules of the game to which all market parties must abide. Since there are nine design variables all with multiple options the design space offers room for a great number of possible designs. However, the design is not fully unconstrained: choosing a policy instrument in one design variable has consequences for the remaining choices the policy maker can make in other design variables. This *interdependency* between policy instruments is described in Section 4.3.

Table 4-4: The design space for a new market model for the Dutch district heating sector

Policy instruments per design variable	Explanation	Pro's	Con's
Regulating the district heating sector			
1. Public versus private ownership			
Public versus private ownership of the production activities	Public versus private ownership.	Public ownership: Through direct control it is easier to secure generation adequacy and make the trade-off between the affordability and the acceptability of heat production. Private ownership: Competition may provide lower energy prices and innovation through the pressure of the invisible hand.	Public ownership: A governmental body may be less efficient than a private actor which is driven by a profit motive and possibly has to compete with other parties for the graces of its clients. Private ownership: A private heat producer, when possessing over market power, might be earning undesirably high profits at the cost of the consumer. Also issues regarding security of supply should likely be more precisely be defined.
Public versus private ownership of the network activities	Public versus private ownership.	Public ownership: Through direct control the network reliability and well-functioning may be secured. Also, public ownership supports non-discriminatory access. Private ownership: Possibly, a private actor may achieve the same level of performance as a public party, but at lower costs.	Public ownership: A governmental body may be less efficient than a private actor which is driven by a profit motive. Private ownership: A private actor could potentially be less concerned about the reliability and well-functioning of the network if the requirements for these goals are not properly defined.
Public versus private ownership of the delivery activities	Public versus private ownership.	Public ownership: Through direct control universal access to heat without discrimination in connection costs is more likely to be achieved. Private ownership: Delivery activities may be provided by multiple retail companies operating on the same network. Having multiple companies competing for the graces of the consumer could lower prices and spur innovation.	Public ownership: A governmental body may be less efficient than a private actor which is driven by a profit motive and possibly has to compete with other parties for the graces of its clients. Private ownership: A private party will have to be regulated to prevent adverse selection of consumers (retail companies only willing to serve clients which have low connection costs).

2. Network access conditions			
Access conditions for producers			
No regulation	Access occurs through bilateral or multilateral contracts.	Low regulatory costs.	Entry-barrier for producers. Network manager might abuse his monopolistic position to dictate unfavorable and/or discriminatory terms for connection.
Negotiated access	Rules stipulate the obligation of a network manager to negotiate terms when a producer requests access to the network. The regulator however does not have any power to force the network manager to connect a producer if these negotiations should fail.	Relatively low regulatory costs. Lightens the entry-barriers for prospective producers, but do not completely take them away because a network manager is not obligated to bring the negotiations to a mutually satisfactory closing.	Entry-barrier for producers. Network manager might abuse his monopolistic position to dictate unfavorable and/or discriminatory terms for connection.
Regulated access	Rules stipulate the obligation of a network manager to connect a producer that requests access if this producer meets a set of predefined criteria.	Medium regulatory costs. Entry-barrier for producers removed. Network manager must provide 'fair' non-discriminatory terms for connection to all prospective producers. The competitive pressure of (potentially) new producers may lower prices and spur innovation.	The pressure of new producers potentially entering the market may significantly lower investment security of incumbent energy companies causing those companies to delay investment or underinvest in their facilities.
Access conditions for retail companies			
No regulation	Idem with no regulation for producers.	Idem with no regulation for producers.	Idem with no regulation for producers.
Negotiated access	Idem with negotiated access for producers.	Idem with negotiated access for producers.	Idem with negotiated access for producers.
Regulated access	Rules stipulate the obligation of a network manager to provide access to a retail company that requests access if this retail company meets a set of predefined criteria.	Entry-barrier for retail companies removed. Network manager must provide 'fair' non-discriminatory terms of access for all prospective retail companies. The competitive pressure of (potentially) new retail companies may lower prices and spur innovation.	If the number of consumers is not large enough it might not be efficient to provide delivery services by multiple companies as opposed to having one retail company serving all consumers.
Access conditions for consumers			

No regulation	Access occurs through bilateral or multilateral contracts.	Only the most profitable district heating connections are realized, which supports the business case of district heating.	Adverse selection by retail companies is likely with no regulation.
Negotiated access	Rules stipulate the obligation of a network manager to negotiate terms when a consumer requests access to the network. The regulator however does not have any power to force the network manager to connect a consumer if these negotiations should fail.	Relatively low regulatory costs. Lightens the connection-barriers for prospective consumers, but does not completely take them away because a network manager is not obligated to bring the negotiations to a mutually satisfactory closing.	Connection-barrier for consumers. Network manager might abuse his monopolistic position to use adverse selection.
Regulated access: obligation to connect - Natural gas and electricity - District heating, natural gas and electricity - Zoning	An obligation to connect a consumer that requests access to an energy network can force network managers and retail companies to provide access to their networks in a non-discriminatory manner. Costs may be socialized over all consumers. Different variants exist. Currently in the Netherlands there is the obligation to connect consumers to the natural gas and electricity grid. With zoning the network company or regulator predefines the areas where which energy network (e versus g versus h) will service which consumers.	Universal access to heat against non-discriminatory terms. Competition between infrastructures which is possibly beneficial for consumers. Zoning does not offer competition or freedom of choice, but does prevent duplication of infrastructures and the connection of economically unviable consumers.	An obligation to connect might lead to network companies having to connect economically unviable consumers which is not efficient. An obligation to connect might also lead to the duplication of infrastructures which might also be economically inefficient.
3. Network unbundling			
No unbundling	Ownership of the district heating network is not defined by the regulator, that is, the networks are allowed to be in the hands of a vertically integrated utility company, but may also very well be owned by a dedicated network company.	Not prescribing the mode of organization provides room from a variety of organizational models which could support the growth and business cases of district heating networks.	No regulation might cause further vertical integration in the district heating sector creating companies with market power and diminishing the opportunities for new entrants to enter the market. Entrants who might be able to produce or deliver heat more environmentally friendly or cheaper than the current energy incumbents.
Separate accounting by the network manager	Vertical integration is allowed, but network managers must keep their financial accounting of network related activities separate from commercial activities.	Separate accounting leads to more transparency making it more likely that network managers will not abuse their monopolistic position versus competitors	It is difficult to monitor whether the network manager is truly not using its control over network assets to favor his own commercial activities over

		and parties seeking access to the network. Separate accounting is a light form of unbundling without the need to split-up companies which can be a challenging, lengthy task for the regulator, possibly also costing jobs for the companies involved.	competing parties because of an information asymmetry with the regulator.
Administrative separation	Vertical integration is allowed, but the network manager forms a separate business unit to separate network related activities from commercial activities.	The same benefits as those for separate accounting, but with administrative separation the separation is possibly more clear.	Easier to monitor than separate accounting but the information asymmetry persists.
Juridical separation	The network manager forms a separate legal person, but this legal person may still be part of a larger firm so vertical integration is still allowed.	Most strict form of unbundling before ownership unbundling. Same benefits as separate accounting, but it is harder for the network manager to exploit his or her monopolistic position because of increased transparency.	Easier to monitor than administrative separation but the information asymmetry persists.
Ownership unbundling	Network manager is juridical separate and is the owner of the network	Most strict form of unbundling. Ownership unbundling supports non-discrimination for network access, supports competition on the wholesale side and enables competition on the retail side. In addition, ownership unbundling separates commercial interests from network interest which supports network reliability and well-functioning.	Easier to monitor than juridical separation and information asymmetry can do less harm, but this comes at the cost at an increase of transaction costs.
4. Integrated versus decentralized market			
Nodal pool market	In a nodal pool market the dispatch of production facilities is determined by an optimization that takes into account the offered supply, the asked demand and the costs and capacity of transport. The prices that arise are calculated by calculating the costs of transporting heat between nodes.	Prevents congestion because the locations of both supply and demand and the limitations and costs of the available transport capacity are incorporated in the optimization.	The system "combines both economic and physical control over the system in the hands of a single party, potentially facilitating governance" (A. C. Correljé & de Vries, 2008, p.10).

Independent exchange plus bilateral market	An independent exchange provides a platform where heat producers and large heat consumers and heat suppliers can meet to trade under predefined conditions. An exchange may exist next to a bilateral market.	An independent exchange lowers the transaction costs of contracting and supports a competitive market which is to the benefit of the consumer. The existence of a bilateral market next to an independent exchange may facilitate long-term contracts for predictable load to support the investment security of heat producers.	Physical aspects and economic aspects of energy trade are not directly connected which requires additional regulation to manage congestion and secure generation adequacy.
Bilateral market	Heat trade occurs on a bilateral market between heat producers and large heat consumers and heat suppliers.	Supports investment security of heat producers due to likely higher heat prices because of lower transparency and therewith a less competitive market situation.	Relatively high transaction costs because of heavy contract negotiations between heat producers and large heat consumers and suppliers. Also similar costs as with the independent exchange due to the lack of a connection between the physical aspects and economic aspects of energy trade.
5. Tariff regulation			
Wholesale price / network tariffs / tariffs for retail services			
Price cap – external benchmark	The regulator determines a maximum price based on an external benchmark that is not directly related to the costs of the heat activity. In the Netherlands this system is currently used to determine the end-use price of heat for small consumers using the 'Not-more-than-otherwise' principle (NMDA in Dutch). The external benchmark for the NMDA is the price consumers would have to pay if they would be connected to the most used alternative to district heating: natural gas. Another possible external benchmark includes an all-electric tariff.	Relatively easy to estimate because the prices of external benchmarks are known. Is favorable for bound-consumers who do not have any alternative to district heating. These bound-consumers are therewith secure that they at least do not pay more for their heat than similar consumers would.	In practice the acceptance of an external benchmark for heat delivery is oftentimes difficult because one-size might not fit all and consumers not always trust their heat suppliers. Many consumers believe that either the heat price estimated by the regulator is too high, or that their heat supplier charges them a too large heat consumption. Another drawback from an external benchmark is the disparity between the benchmark and the actual costs made by the heat supplier. If the actual costs are higher than the benchmark the heat supplier will have difficulty to close his

			business case leaving him little room for maneuvering.
Price cap – based on costs of heat delivery (also benchmarking)	The regulator determines a maximum price based on an estimation of the actual costs of a representative heat supplier or group of heat suppliers. Examples include yardstick regulation, a model calculation or an 'open book' method.	Favorable for heat suppliers because the benchmark is directly related to their actual costs. Gives an incentive to be the 'best-of-the-class' among heat suppliers so that profit is maximized. This incentive mimics actual competition between heat suppliers even though they might not compete over the same consumers.	Relatively difficult to estimate the right price and incorporate strong enough incentives for improvements in cost efficiency and service. Partly, this is due to information asymmetry between the regulator and the heat supplier, and partly this is because estimating the costs of many different heat suppliers is a resource-intensive process.
Cost-plus	The heat supplier may charge the consumer with the actual costs of heat delivery plus a predefined 'reasonable return'. This form of tariff regulation is oftentimes called efficiency regulation.	Favorable for heat suppliers: their costs are covered no matter what and they can expect to receive a return on their investment. Efficiency incentives may be incorporated in the tariff definition using for instance bonus/malus structures.	Difficult to assess whether heat suppliers are operating efficiently. Setting the tariff too high results in socially undesirable returns for heat suppliers, but setting the tariff too low results in budget problems for heat suppliers which may result in decreased network reliability or heat delivery service.
Standardized cost-plus	In this system predefined standard costs are determined per cost item. These standard costs may then be used to calculate the prices the heat supplier may charge its consumers.	Similar benefits as with the cost-plus system, but likely a closer fit to the actual costs of heat suppliers because it is possible to define different standard costs for different cost items which enables the regulator to account for differences between heat suppliers. E.g. different standard costs may be defined for different heat sources.	Similar costs as with the cost-plus system. Because the standardized cost-plus system is more detailed than the cost-plus system it is however even harder to estimate the right tariffs and the process is more costly because for every possible cost item a price must be defined.
Taxes			
Energy tax on electricity	In the Netherlands consumers pay a tax on electricity. This tax is regressive, that is a higher tax per energy unit is paid by small consumers than by large consumers to prevent a too large tax burden on the energy-intensive industry.	Taxing energy use is an incentive for energy savings and energy-efficiency.	A regressive tax spares the energy-intensive industry which supports economic growth, but directly undermines energy savings and energy efficiency goals. Also, small consumers are oftentimes the least financially

			strong which makes bearing a high energy tax a burden for them.
Energy tax on natural gas	The use of natural gas is also taxed. Similar to electricity this tax is regressive.	Idem.	Idem.
Energy tax on heat delivery	There is currently no tax on heat delivery, which could be seen as an implicit subsidy since similar energy users who use electricity or natural gas to satisfy their heat demand do have to pay taxes.	Idem.	Idem.
6. Congestion management method			
Integrated markets	In integrated markets the physical and economic aspects of energy trade are directly coupled. This makes it possible to incorporate transport costs and capacities into the matching process of demand and supply thereby preventing congestion from occurring.	Congestion does not arise.	Requires independent operation of the network activities and dispatch of production facilities by a systems operator which is a large change from the status-quo.
Dynamic transport tariffs	Incorporates the costs of transport and the available capacities into the network tariffs which provides an incentive not to use highly utilized pipelines and to match demand and supply in close geographical proximity.	Easy to implement. Approaches the use of the actual costs of transport which is economically efficient.	Congestion may still arise and is not completely avoided with this system.
Explicit (capacity) auctions	The limited transport capacity is allocated to heat suppliers through capacity auctions. The two most used auction clearing methods include the 'pay-as-bid' and 'marginal bid' methods.	Auctions may provide proper incentives for market parties to bid as such that the congested pipeline will be used optimally by the cheapest generators, increasing welfare by lowering the average heat generation costs over the two markets together.	Bidding in an auction may be risky for market participants when the 'pay-as-bid' method is used because if they bid too high they might not make a profit on their heat sales, but if they bid too low they might not win any capacity for the pipeline and not sell any heat over the pipeline at all.
Market splitting	If between two separate markets (A and B) an interconnector is present and this interconnector is congested the market operator will buy heat from the heat market with the lower price (e.g. A) and sell it in the market with the higher price (e.g. B). As a	"Market splitting leads to an efficient dispatch of generation because the cheapest generators are being used for generation"(de Vries et al., 2014, p.74). Furthermore, because generators only need to bid in their own markets and they do not know whether there bids will	Closing the actual physical bilateral contracts between two different markets is sometimes difficult when the two markets are located in different countries. For district heating this will however at first not be an issue in the Netherlands since district heating is a

	result the prices in in market A and B will move closer together.	be used for their own market or the connected market the risks related to bidding in an action are avoided.	regional affair, and it is unlikely that in the near future cross-border heat pipelines will be laid-out.
Redispatching	With redispatching the market is cleared as if there is an unlimited amount of transport capacity. When congestion occurs the transmission system operator or network manager decreases the heat production output from the 'exporting market' (upstream of the congested pipeline) and increases the heat production output from the 'importing market' (downstream of the congested pipeline). The heat producers that are forced to decrease their heat production still receive the worth of their capacity bids but have to reimburse the transmission system operator with the avoided costs from decreased production. The additionally acquired heat in the 'downstream market' is paid for by the transmission system operator. In part the reimbursement from the upstream heat producers covers these costs.	The costs the transmission system operator has to make to balance the system and alleviate congestion represent the value of congestion. This value can be taken as a proxy for transmission capacity expansion in order to efficiently dimension the network.	"A disadvantage of redispatching is that the market does not receive any signals regarding congestion, and will therefore not adjust its trade patterns accordingly" (de Vries et al., 2014, p. 77). A second disadvantage is that redispatching is susceptible for strategic behavior of heat producers because oftentimes "the solution to congestion may depend on only a small number or even upon unique generators" (de Vries et al., 2014, p. 77). This predictability may cause generators to try and game the system by overcharging the TSO for offering additional capacity or undervaluing their avoided costs effectively lowering the reimbursement for the TSO.
7. Integration with neighboring networks			
No intervention	The regulator will not enforce the integration of neighboring networks even when this is likely to increase market efficiency in the networks concerned. Despite there being no regulatory intervention neighboring networks could also choose to integrate themselves.	Market integration will occur when it is considered beneficial for all parties considered due to possible synergy effects or economies of scale.	Market integration will not occur if the stakeholders that will lose money due to the market integration have blocking power or decision power. These stakeholders could be heat producers in the 'importing network' or heat consumers in the 'exporting network' – In the exporting network the prices will rise after market integration.
Regulating the interconnection of district heating networks	The regulator will enforce the integration of neighboring networks when he/she deems this is likely to increase market efficiency in the networks concerned.	Market integration may enhance the competitiveness in the district heating networks concerned.	Prices in the 'exporting network' may rise due to the integration of the networks.

Policy instruments per design variable	Explanation	Pro's	Con's
Steering the relative attractiveness of district heating versus other forms of heating			
8. Incentives for consumers of heat			
Subsidies, tax and obligations	In order to steer consumers to choose the most environmentally friendly option for heating against affordable costs a combination of subsidies, tax and obligations can be used. Examples include the 'small heat options' subsidy for electric heat pumps and heat savings measures, a shift in energy taxes from electricity to natural gas, so that electricity may become cheaper and natural gas more expensive. As a result heating with electric heat pumps and district heating will become relatively more attractive. An example of an obligation includes the regulations in the built environment for energy efficiency of new buildings (using energy performance coefficients)	Steering consumers with subsidies, tax and obligations directly influences the business cases of all the different options of heating making it possible to support the business cases of district heating and other renewable forms of heating to attain the acceptability goals for heat (more renewables, higher energy efficiency, less emissions and more safe).	Government intervention represents a market distortion and can decrease the investment security of market parties while increasing the business cases of others. Concerns regarding protecting the level playing field and welfare transfers will unavoidably arise.
9. Incentives for producers of heat			
Subsidies, tax and obligations	Similar to subsidies, taxes and obligations directed at consumers these policy instruments can also be used to steer the heat production portfolios of heat producers. Examples include a subsidy for renewable heat production (SDE+), technology specific support (geothermal energy subsidies), taxing the use of fossil fuels and carbon emissions (coal tax and EU ETS) and possibly obligating that residual heat from industry and power plants is used in a useful manner (when deemed economically feasible).	Similar to benefits for consumers.	Similar to costs for producers.

4.4 Assessing the interdependency between policy instruments

In the year 2000 the Ministry of Economic Affairs drafted a memorandum that described the considerations regarding the safeguarding of public goals in network sectors (Ministry of Economic Affairs, 2000). The memorandum aims to guide policy makers in the process of market design and therewith also touches upon the coherence of and interdependency between policy instruments. Although the memorandum does not cover the full breadth of the design space for a new market model for the district heating sector it does include an insightful visualization of part of the interdependency between policy instruments. Figure 4-2 illustrates whether, where in the value chain, and how competition should be introduced in a network industry. It illustrates not only that there is a certain *order of preference* in selecting the appropriate regulatory framework, but also that choices in one design variable have consequences for the choices in other design variables. The reason for that is that the packages of policy instruments must be internally consistent with each other to form a feasible market model design. For example, competition on the infrastructures on the retail side requires the separation of the network activities from the commercial activities (unbundling) *and/or* the definition of third party access regulation.

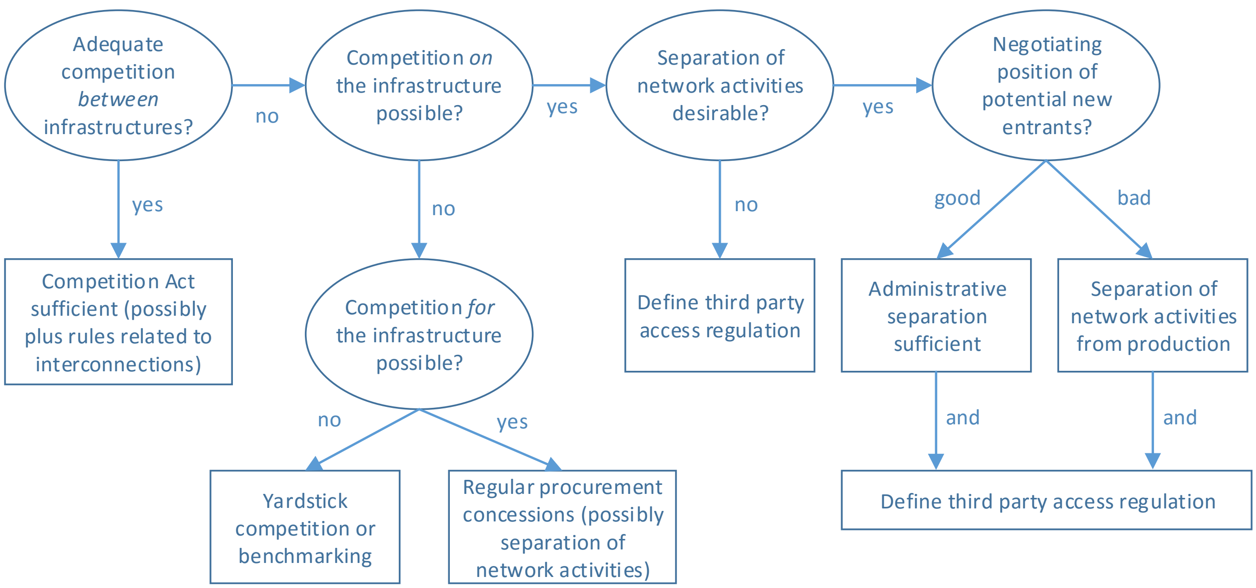

Figure 4-2: Selection chart for market design of network industries (Ministry of Economic Affairs, 2000, p. 19)

In order to guide the market model design process Table 4-5 illustrates how the coherence of and interdependency between policy instruments affects the feasible policy instrument combinations. Checkmark signs stand for positive relationships, meaning that choices can be made 'relatively' irrespective of each other. Exclamation marks signs stand for 'attention required', signalling that choices in one design variable directly affect the choices for the other design variable and possibly incompatible combinations of policy instruments are present. Two important observations from Table 4-5 can be made: (1) for design variables 1 to 6 many of the choices for policy instruments are interdependent with each other, and (2) for design variables 7 to 9 choices for policy instruments can be made 'relatively' irrespective of the choices made in the other design variables. These two observations will serve useful when designing new market models for the Dutch district heating sector.

Table 4-5: Interdependency between policy instruments. Checkmarks indicate that choices for these design variables can be made 'relatively' irrespective of each other. Exclamation marks indicate that choices for the design variables involved require attention: possibly there are interaction effects or incompatible combinations present.

	D1.	D2.	D3.	D4.	D5.	D6.	D7.	D8.	D9.
D1.									
D2.	!								
D3.	!	!							
D4.	✓	✓	✓						
D5.	!	✓	!	✓					
D6.	✓	✓	✓	!	!				
D7.	✓	✓	✓	✓	✓	✓			
D8.	✓	✓	✓	✓	✓	✓	✓		
D9.	✓	✓	✓	✓	✓	✓	✓	✓	

4.5 Synthesis

The second research question of this research study inquires: "What is the design space for reshaping the market conditions for heat provision as a whole and restructuring the market design of the district heating sector?" Informed by the goals for the district heating sector (see Table 3-4) and an understanding of both the physical and institutional-economic parts of the district heating system (Section 3.1 & 3.2) in this chapter that *design space* for a new market model for the district heating system was explored.

The new market model must support the attainment of the goals for the district heating sector while addressing the market flaws that have arisen because of the key characteristics of the district heating sector described in Section 4.1. Nine design variables have been identified which together represent the choices that have to be made in order to arrive at a new description of a market model (Section 4.2). The variety of options available for these nine choices are the policy instruments. Table 4-4 gives an overview of selected policy instruments along with a brief analysis of their positive and negative effects on market performance. Combinations of policy instruments along all nine design variables together form a new market model for the district heating sector. Finally in Section 4.4 the coherence of and interdependency between policy instruments was addressed. The consideration in this section have to be taken into account while navigating the design space because they constrain the feasible combinations of policy instruments to form new market models. In the next chapter case studies of alternative market models for the district heating sector are used to find the most promising policy instruments and combinations of policy instruments for a new market model for the district heating sector.

5 Case studies: International experience with alternative market models for the heat sector

In Chapter 4 the design space for a new market model for the Dutch district heating sector was presented. The insights given into the benefits and costs of the available policy instruments was however mainly inspired by theoretical insights and empirical insights from other sectors than the district heating sector. The case studies serve to gain more understanding about the benefits and costs of a selection of the different policy instruments. The improved understanding will support the selection of the most promising policy instruments to be used during the market design phase.

First, the selection of the countries for the case studies is explained (Section 5.1). Subsequently, for comparative purposes, a brief summary of the Dutch market model for the district heating sector is given (Section 5.2). Then, the two case-studies are described in-depth being the market models for the district heating sectors of Sweden (Section 5.3) and Denmark (Section 5.4). Finally, the market models of the case studies and their performance are compared with the Dutch market model and its performance (Section 5.5)

5.1 Selection of countries for the case studies

District heating is used in many countries across the globe as a means to satisfy the heat demand of households, businesses, horticulture and industry. Some of these countries have district heating sectors that have already matured over the course of decades and others have increased the use of district heating only in recent years. Next to the fact that the maturity of the district heating sectors vary, also the heat sources used, heat demand profiles, regulatory frameworks and institutional context vary. In order to select case-studies from the seemingly large amount of eligible countries four selection criteria were used:

1. Institutional context: comparability of the laws and regulations of the country with respect to heat and energy policies.
2. Institutional variety: the distinctiveness of the market model as compared to the Dutch market model for the district heating sector.
3. Current level of district heating as compared to the Netherlands: comparability of the heat demand and the heat sources used and or available in the country of interest.
4. Availability of information and data.

Designing a market model is context-dependent and if the insights gained from the case-studies are to be generalized to insights for the design of a new market model for the Dutch district heating sector the institutional context should be comparable. Since the design space of the market model to be designed will be influenced and constrained by EU law & regulations only countries within the European Economic Area have been considered for analysis.

Secondly, the market model for the district heating sector of the country of interest should be clearly distinct from the market model of the Dutch district heating sector. In order to maximize learning it is useful to look at market models that have used different combinations of policy instruments than were chosen in the Netherlands.

Third, in order for the district heating sectors' characteristics to be comparable countries with a similar latitude as the Netherlands were taken into account to ensure a similar heat demand profile. Also, attention was given to the heat sources used to prevent unique local conditions in specific countries to cause bias in the analysis of the regulatory frameworks impact on market performance[20]. Moreover, preferably the country of interest has a high share of renewables fed into their district heating systems since attaining renewability is an important goal for the Dutch district heating sector.

And finally fourth, in order for the analysis of the countries district heating sectors' regulatory framework to be useful the necessary information and data has to be available.

Based on these criteria four countries stood out: Sweden, Denmark, Finland and Poland. All four countries are members of the European Union, have distinct market models from the Dutch market model, and have a high level of district heating (including high shares of renewables in the heat production). However, because of time-constraints to this research study only two countries can be reviewed in-depth. From the four countries that stood out the availability of information and data for Sweden and Denmark was judged as best which is why these two countries have been selected for further investigation. The information and data used and the process followed for the selection of the case-studies is described in more detail in Appendix C.

5.2 Summary of the Dutch market model for the heat sector

The Netherlands is a western-European country with approximately 16.9 million inhabitants (CBS, 2015). With a GDP of 677 billion euros in 2015 (17th highest country in the world) and a primary energy usage per capita of 192 GJ in 2013 (27th highest country in the world) the Netherlands has a strong and energy-intensive economy (ECN, 2015; The World Bank, 2013, 2015a).

District heating has a long standing history in the Netherlands. Already in 1923 the first heat project was realized in the city of Utrecht. It was however only from the 1980s onwards that district heating played a noteworthy role in satisfying the heat demand. With support of the national government many district heating projects were realized by the regional energy companies in pursuit of energy savings policies. These district heating networks were large-scale networks, mainly fueled by drain heat from power plants (combined heat and power facilities) and are still in operation today. Figure 5-1 shows where the ten largest (by number of connected households) district heating networks in the Netherlands are located (CE Delft, 2009, p.11).

District heating still only plays a minor role however in the Dutch heat provision system. Of the 1224 Petajoule (PJ) Dutch heat demand 148 PJ is delivered by transported heat. Of that 148 PJ, 112 PJ is produced steam, mainly consumed by industry through industrial heat networks, and approximately 27 PJ is consumed by small consumers through district heating networks (Ecorys, 2016). The rest of the heat demand is satisfied by heat production on location using primarily natural gas, coal and oil as energy sources (ECN, 2015). The Dutch government however intends to stimulate the use of district heating because of its capability to make the district heating sector more energy-independent and more environmentally friendly.

The current regulatory framework for the district heating sector allows for a large variety of different market models (see also Section 3.2). Table 5-1 gives a brief overview of the choices the Dutch government made

[20] For example, Iceland was excluded for analysis because this country has vast geothermal and hydro-electric resources that the Netherlands does not possess over making the sector's difficult to compare.

on the nine design variables of interest for this study and the consequences these choices have for the performance of the district heating sector.

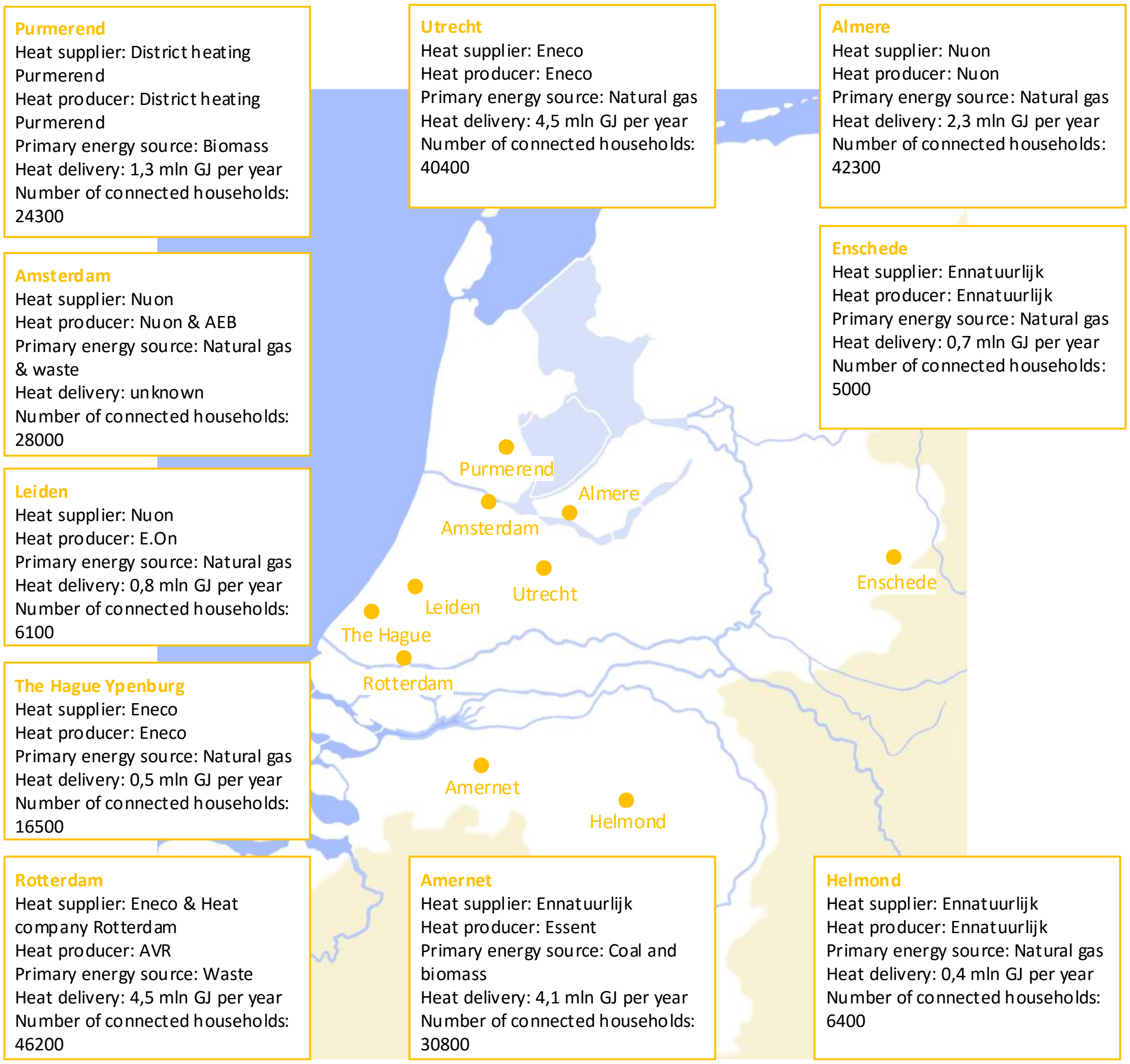

Figure 5-1: Overview of the ten largest district heating networks in the Netherlands by number of connected households (CE Delft, 2009; ECN, 2015; Ennatuurlijk, 2016; Nuon, 2016).

In the Netherlands there are approximately 7.5 million households. Approximately 330.000 of these households are connected to district heating networks, whereas the rest satisfies its heat demand with other means (almost all natural gas). Together the ten district heating networks displayed above serve 75% of the district heating connected households. The rest of the 330.000 households are served by 5 other 'large' district heating networks (networks with at least 5000 connected households) and a great number of small networks (estimated to be 6900 in number) (Ecorys, 2016).

Table 5-1: Regulatory framework or 'market model' of the Dutch district heating sector

Design variable	Chosen policy instrument(s)	Consequences
Regulating the district heating sector		
1. Public versus private ownership	Not prescribed. Both public and private actors may (and do) own and manage production, transport and distribution activities.	Various modes of organizations exist. Public versus private ownership of production assets, network assets and distribution/delivery activities.
2. Network access conditions (for producers, retail companies and consumers)	Producers: no regulation. Retail companies: not defined. Consumers: obligation to connect to electricity and natural gas. Bound-heat-consumers *must* pay the fixed part of the connection costs even if they do not want to consume heat, but satisfy their heat demand in another manner.	Third party heat producers may attain connection to the network through negotiating with network owners. There is however no obligation for network owners to negotiate with prospective third party heat producers. As a consequence, third parties are only connected if this is in the interest of the network owner. Retail competition over the network by multiple companies does not occur in the Netherlands. Consumer that would like to be connected to district heating can only do so if it can form an agreement with the heat supplier in question. For both electricity and natural gas consumers can demand to be connected against non-discriminatory terms. Because bound-heat-consumers must pay the fixed connection costs they do not have the freedom to switch to e.g. electric heating or wood-fired boilers.
3. Network unbundling	No unbundling.	Various modes of organizations exist. Vertical integration, single-buyer model and single-buyer model with the single-buyer being a joint venture firm of multiple companies (see Table 3-1).
4. Integrated versus decentralized market	Decentralized market: bilateral contracts.	Physical and economic aspects of heat trade are not directly connected.

5. Tariff regulation	End-user price regulation following the 'not-more-than-otherwise' principle.	Energy companies must make their business cases under the constraint of a sales price they cannot influence, which is not directly connected to their actual costs. On the flip-side: bound-consumers are protected from possible abuse of the monopolistic position of their heat suppliers.
6. Congestion management method	Not regulated.	The lack of incorporation of congestion management methods might lead to inefficient network lay-out or dimensioning causing congestion in the future. So far, there is however no indication for that being the case in any of the district heating networks.
7. Integration with neighboring networks	Not regulated.	Integration of neighboring networks might be hampered by strategic behavior.
Steering the relative attractiveness of district heating versus other forms of heating		
8. Incentives for consumers of heat	Investment subsidy for renewable energy (consumers and 'small and medium enterprises'); energy taxes.	Incentivizes consumers to switch from natural gas to either district heating, electric heating or other ways of satisfying their heat demand such as heat savings measures and solar boilers.
9. Incentives for producers of heat	Among others: SDE+, geothermal energy subsidies, EIA (see also Table 1-1)	Incentivizes industry and the power sector to utilize residual heat more usefully/optimally.

5.3 Sweden

In this section the Swedish district heating sector is discussed. First of all a brief overview of its historical development is given followed by a discussion of the current role of district heating in the Swedish energy sector and its future prospects. The information provided in this section is based on four structured-interviews and a desk-study of relevant literature. For more information about the structured-interviews see Appendix D.

Sweden is a Northern-European country with approximately 9.8 million inhabitants (The World Bank, 2015b). With a GDP of 443 billion euros in 2015 (22nd highest country in the world) and a primary energy usage per capita of 215 GJ in 2013 (20th highest country in the world) Sweden has a strong and energy-intensive economy (The World Bank, 2013, 2015a).

Historical development

In order to understand the development and current state of the Swedish district heating sector one must look at its history. Up until the 1940s almost the entire heat demand was satisfied by oil-fired boilers. In the 1950s this changed. Driven by concerns regarding the security of supply of *electricity* the Swedish *municipalities* started with the construction of *combined-heat-and-power* (CHP) plants. The municipalities saw the CHP-facilities as an appropriate means to secure the need for extra electricity generation capacity and at the same time satisfy the local heat demand of its inhabitants in an efficient way. Heat was therewith seen as a public good. Moreover, the outlay of the district heating grids by municipal heat companies and heat administrations (executive branch of the municipality) occurred at the same moment many new dwellings were built. This timing was fortunate for district heating and enabled it to grow steadily during the 1950s and 1960s. Another important 'enabler' for this was that Swedish municipalities have the authority to impose taxes independently from the regional or national governmental authorities.

A second driver of growth for the district heating sector were the occurrence of 2 events in the 1970s: the oil crises of 1973 and 1979. The oil crises caused Sweden to become increasingly aware of its energy-dependency on oil-imports from oftentimes geopolitically instable regions. The national government responded by drafting the first national energy policies to become less dependent on oil (first energy act was established in 1975 – before that energy policy was a part of general industrial politics). District heating was seen by the national government as an important means to lower the oil-dependency of the country. A carbon tax and energy tax on fossil fuels proved to be very instrumental in the further stimulation of CHP-facilities and district heating grids fuelled by biomass, heat from waste incinerators and residual heat from industry.

In 1996 the Swedish electricity and natural gas sector were liberalized. At the same time, district heating grids were also deregulated, but not unbundled as were the electricity and natural gas grids. The deregulation of the district heating sector allowed for new entrants to enter the district heating sector, which was previously wholly dominated by municipal parties. The new entrants were three large private energy companies: Vattenfall, E.on and Fortum Värme[21].

The entrance of the three private parties to the district heating sector had large consequences for the district heating consumers. The energy companies argued that the networks they acquired from the municipal district heating bodies were economically not profitable because the prices were too low. The municipal district heating companies used cost-plus pricing, but oftentimes subsidized the tariffs using funds drawn from municipal taxes. The new entrants did not have the same ability to tax, which is why, they argued, prices had to be increased. In some cases this resulted in steep price rises of up to 15%. Obviously, such a steep price increase did not go unnoticed and this did hurt the relationship between district heating consumers and the district heating suppliers during the end of the 1990s and the early 2000s. Figure 5-2 and Figure 5-3 illustrate respectively the growth and energy composition of the district heating sector throughout its history.

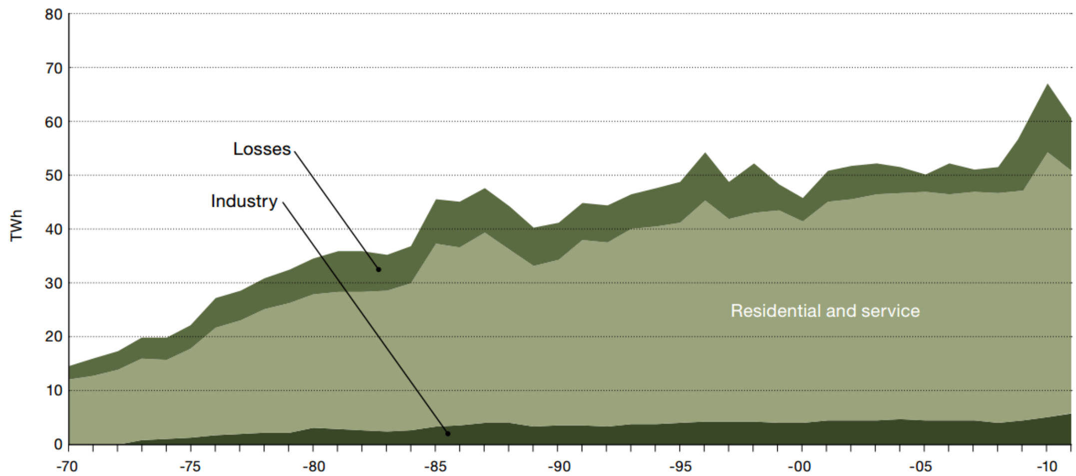

Figure 5-2: The use of district heating from 1970-2011. The substantial increase in 2009 and 2010 can largely be attributed to unusually cold winters (Swedish Energy Agency, 2012, p. 51).

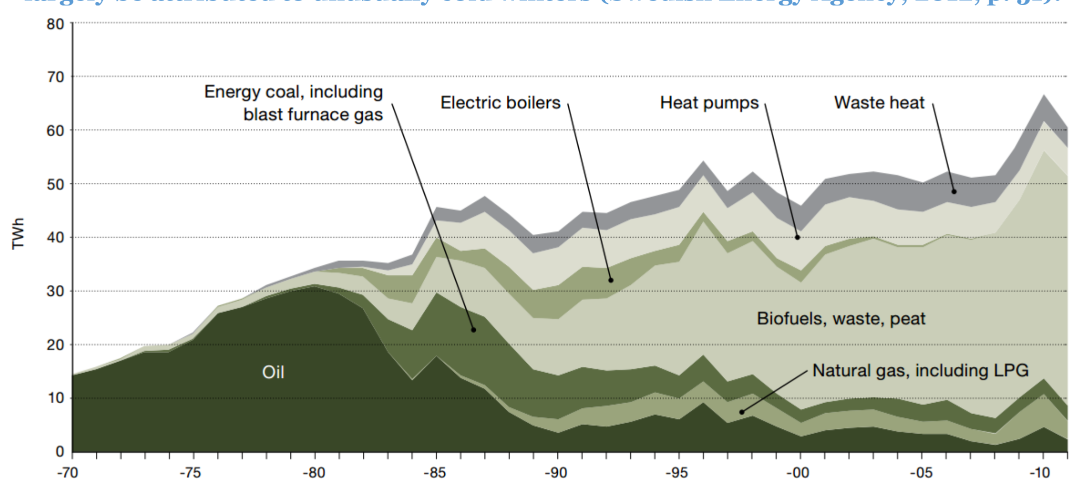

Figure 5-3: Energy sources for district heating 1970-2011 (Swedish Energy Agency, 2012, p.53)

[21] The three new entrants are private energy companies, but all have large shares of public participation: Vattenfall (Fully owned by the Swedish state), Fortum Värme (part of the energy company Fortum which is for 51% owned by the Finnish state), and E.on (partly owned by various German governmental bodies).

Current role of district heating in the Swedish energy system

In Sweden approximately half of the heat demand for the residential and services sector is satisfied by district heating grids. District heating is present in 270 out of 290 municipalities and holds market shares of 93% in apartment buildings and 83% in commercial and other buildings. In freestanding houses the share of district heating is lower, being 12%, but it is growing in recent years (Swedish Energy Agency, 2012). There are various reasons why district heating has been able to become so successful in Sweden which can be summarized by three factors: municipal push, a favourable regulatory framework and a positive public perception.

As described under the historical development the municipal push to develop CHP facilities and district heating grids alongside the building of new dwellings enabled a strong and steady growth of the district heating sector from the 1950s onwards.

Sweden has made a number of choices on the nine design variables that are all supportive of the business case for district heating in Sweden. First of all the energy and environmental taxation system favoured the development of district heating over other forms of heating. Throughout the years the system has been augmented in many ways and is currently fairly complex. "There are different taxes on electricity, fuels and emissions, and the tax levels vary between sectors" (Ericsson, Karin, 2009). A summary of the influence of the taxes is given in Table 5-2. Secondly, there is no tariff regulation which allows district heating companies the room for setting their prices as they see fit (including price differentiation between). The Swedes rely on competition *between* networks to ensure that district heating suppliers do not abuse their monopolistic position (there is no freedom of choice between heat suppliers). The Swedish Energy Agency and Energy Markets Inspectorate deem this an appropriate option because in Sweden because there are two alternatives present which present a competitive product versus district heating: electric heat pumps and the traditional pellet-fired Swedish stoves. In practice this means that district heating companies charge different prices in 440 price regions which are distributed over 500 district heating networks. These prices are in part based on the varying costs per network and in part based on the alternative to district heating, which suggests that the competition *between* networks is effective in capping the heating prices. Another positive factor for the business case of district heating is that there is no obligation to connect consumers for district heating suppliers. This means that district heating companies can choose only to connect the economically attractive heat consumers. The benefit of course is that district heating becomes more affordable, but the downside is that not all may attain access to the benefit of having district heating (adverse selection). Table 5-2 gives an overview of the regulatory framework and explains how the 'Swedish choices' on the nine design variables affect the position of district heating in Sweden.

Finally, the public perception of district heating grids is good, despite their being cause for discontent from consumers regarding the supply of district heating. There is no freedom of choice between district heating suppliers for small heat consumers, there are large price differences between different district heating networks (costs are socialized per price region and network, not over the entire country) and prices were strongly increased in the late 1990s and early 2000s. A possible explanation for the fact that people are generally satisfied with their district heating service may be found in the fact that people *can* switch to electric heat pumps or pellet-fired stoves for heating purposes. Also, consumers are 'used to the fact' that there are price differences between different price regions and many are proud of the fact that their district heating networks have good environmental and reliability performance. Furthermore, although price differences may be large, district heating is considered an affordable means of heating.

Finally, the district heating product that is delivered is fully carefree: all maintenance is carried out by the district heating company.

A note on the future prospects of district heating in the Swedish energy system

Growth in District heating has for many years been stable and since more than eight out of ten Swedes live in urban areas there are still good opportunities for continued expansion. There are already plans to both expand and densify existing network and to build entirely new networks in more than 100 locations (Svensk Fjärrvärme, 2016). That said, the competitive pressure from electric heat pumps is becoming increasingly strong for district heating suppliers. Due to falling electricity prices and innovation in electric heat pumps district heating prices in various networks have been lowered in 2015 in order to compete with the alternatives (Gunnarsson - Fortum Värme, 2016).

Table 5-2: Regulatory framework or 'market model' of the Swedish district heating sector

Design variable	Chosen policy instrument(s)	Consequences
Regulating the district heating sector		
1. Public versus private ownership	Not prescribed. In practice the district heating sector is dominated by vertically integrated heat companies. Two types of players dominate the district heating field: municipal heat companies and large energy companies (Vattenfall, E.on and Fortum Värme). Both types have public ownership, although the large energy companies also have private shareholder stakes (E.on and Fortum).	Public ownership in the district heating sector makes it easier to align public goals with the policies of the district heating companies.
2. Network access conditions (for producers, retail companies and consumers)	For producers: regulated access since 2014. Third-party producers must receive access from a network owner/heat supplier when they request access if they can produce heat against lower costs than the incumbent. For retail companies: not regulated. For consumers: no obligation to connect consumers.	Removes entry-barrier for heat producers and opens the door for wholesale competition along the lines of the single-buyer model. Possibly this will lead to lower prices for the consumer. However, the opposite may also be true, crowding out of existing, more expensive, heat production capacity may lead to higher social costs than if the cheaper heat producer would not have entered the market. In practice the regulated access has not been used yet because "deals that are economically attractive between third parties and incumbents have already been undertaken" (Holmström - Swedish District Heating Association, 2016). Heat suppliers are not obligated to connect consumers. In practice this means the most economically attractive consumers are connected whereas other are not. These consumers can then choose to use an alternative form of heating or negotiate terms of access with their local heat supplier.
3. Network unbundling	No unbundling.	Almost all district heating grids are fully vertically integrated. An exception is the network of Fortum Värme that has opened up her network for third-party producers on their own initiative to attract cheaper and more environmentally friendly heat sources than they are currently using. The 'open district heating' initiative follows the single-buyer model with Fortum Värme being the single-buyer.
4. Integrated versus decentralized market	Decentralized market: bilateral contracts.	Vertically integrated companies manage and operate their networks and therewith also their heat trade.

5. Tariff regulation	No tariff regulation. The Swedish Energy Agency and Regulator (Energimarknadsinspektion) rely on competition *between* networks to form competitive prices and products in the district heating sector. However, there is an extensive energy and carbon tax that does influence prices (see design variable 8 and 9).	Price differentiation is also allowed, but discrimination is not. Therewith the district heating companies charge different prices in their 440 price regions over 500 networks.
6. Congestion management method	Not defined.	Network are operated by vertically integrated companies. Full information allows them to optimize their network lay-out and heat production dispatch to prevent congestion.
7. Integration with neighboring networks	Not defined.	Network linking occurs where economically attractive.
Steering the relative attractiveness of district heating versus other forms of heating		
8. Incentives for consumers of heat	Investment subsidies: replacement of oil and direct electric heating in buildings. Energy and carbon tax system: The differentiated energy and carbon tax and value-added tax levels on oil, electricity, natural gas, district heating and wood pellets are providing consumers incentives towards the more environmentally friendly alternatives.	In the 1970s and 1980s mainly housing organizations were targeted with investment subsidies to replace oil and direct electric heating in buildings. More recently, attention has shifted to households. The replacement investment subsidies have attracted many applicants and have therewith speeded up the replacement of oil heating and direct electric heating. On the other hand, the subsidies have also been criticized because of poor cost efficiency (Boverket, 2008). Moreover, the administrative costs were high and "the replacement of oil heating would also have been profitable without the subsidy due to the old age of most installed oil boilers and the high oil prices, including the energy and carbon taxes" (Ericsson, Karin, 2009, p.37).
9. Incentives for producers of heat	Taxes on fuel use for heat production and energy and carbon taxes for electricity production. EU ETS Investment subsidies for: district heating activities (LIP and KLIMP, similar to the Dutch 'Green deal') and biomass based electricity production. Tradable renewable electricity certificates (stimulus for biomass-fired CHP).	The combined effect of differentiated tax rates on fuels and energy consumption have increased the relative attractiveness of district heating over other forms of heating. For a full discussion on the energy and carbon tax system and different energy investment subsidies in Sweden throughout the last decades see 'Introduction and development of the Swedish district heating systems: Critical factors and lessons learned' (Ericsson, Karin, 2009).

5.4 Denmark

Denmark is a Northern-European country with approximately 5.7 million inhabitants (The World Bank, 2015b). With a GDP of 266 billion euros in 2015 (37th highest country in the world) and a primary energy usage per capita of 130 GJ in 2013 (43rd highest country in the world) Denmark has a strong and energy-intensive economy (The World Bank, 2013, 2015a).

Historical development

At the end of the 19th century the municipality of Fredriksburg – an independent municipality situated in the western part of Copenhagen City – experienced strong population growth as a result of the development of a flourishing industry sector. The growth of the municipality caused a dire need for *waste disposal* after the landfills that served this purpose before became overfull. The Frederiksburg city council answered this need by building the first combined heat and power facility in Denmark in 1903: a waste-to-energy facility. The CHP facility produced electricity and provided heat for municipal institutions. Inspired by this feat, the first district heating system in Denmark, in the 1920's and 1930's many municipalities in Denmark started establishing district heating systems as well, fueled by the surplus heat of small and medium-sized diesel-powered electricity generating plants (DBDH, 2016).

The biggest driver for building district heating systems was the desire to capitalize on the energy-efficiency *combined heat and power* could provide. As more CHP facilities were built, gradually, district heating grew. However, during the Second World War the supply of diesel fuel became strained which made it difficult to maintain the heat supply from the CHP plants. In response heat suppliers built solid fuel heat only boilers as back-up heating facilities. When the oil supply normalized these back-up heating facilities represented excess capacity and formed the basis for expanding the district heating networks further. After the Second World War the Danish electricity sector centralized, forcing the closure of the decentralized CHPs. District heating remained, but was now supplied by large centralized CHPs. (DBDH, 2016).

Subsequently, during the 1960s, technological progress spurred the development of new district heating networks and the expansion of existing networks. Better insulated pipes made it possible to transport heat over larger distances and at lower temperatures. The combination of these two improvements unlocked the possibility to use residual heat from industry and waste incinerators, causing a boom in the establishment of both district heating networks and waste incineration plants (DBDH, 2016).

In more recent history, the 1970s till now, the growth of district heating networks continued. In the early 1970s the share of district heating in dwellings was approximately 30%, in 2014 this share was 63.3% (Euroheat & Power, 2015). The major driver that kick started the growth of district heating was the 1973 oil crisis, which caused large concern for energy-dependence in Denmark. At the time, almost all heat for district heating was fueled by oil-fired combined heat and power and heat-only installations causing prices to rise steeply. The Danish government responded by stimulating energy savings through improvements in the energy-efficiency of buildings and an increase in use of combined heat and power. Moreover, subsidies and taxes were introduced to stimulate the use of renewable energy sources for heating, most notably biomass in heat-only boilers and CHP facilities. Figure 5-4 illustrates the shift in energy sources for district heating as a result of the government energy policies. Notice that although the share of district heating more than doubled in the time period of 1970 to now, the total heat deliveries only grew slightly. This is a result of the progress that has been made in terms of energy efficiency of buildings. Figure 5-5 illustrates how the energy demand of buildings for heating, ventilation, cooling and domestic how water has dropped substantially from 1961 to present. The improvements in energy efficiency of buildings are a major step forward in terms of energy savings, on the other hand, it does make the future prospects of the business case for district heating more difficult since the heat demand per km of pipeline has diminished.

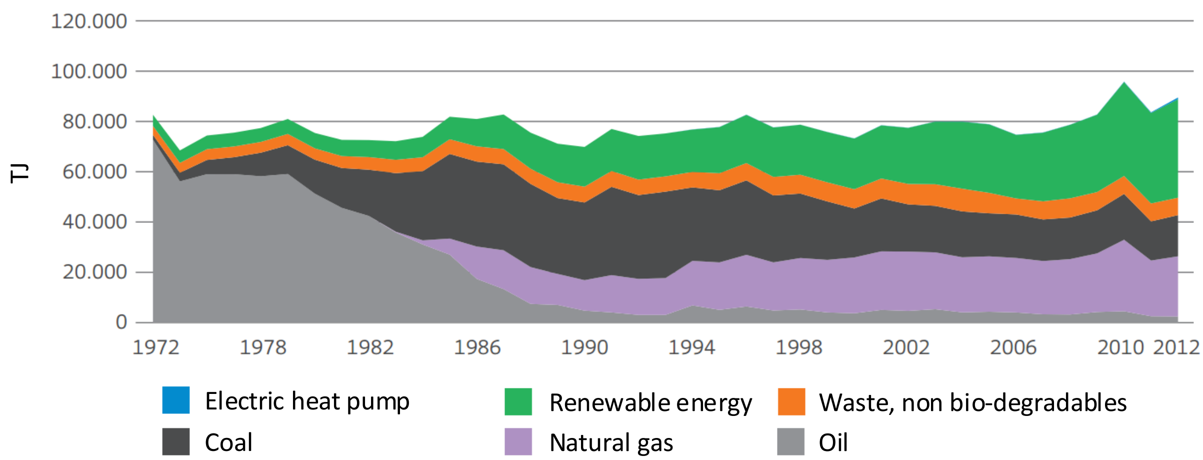

Figure 5-4: Energy sources for district heating 1972-2012 (Danish Energy Agency, 2014).

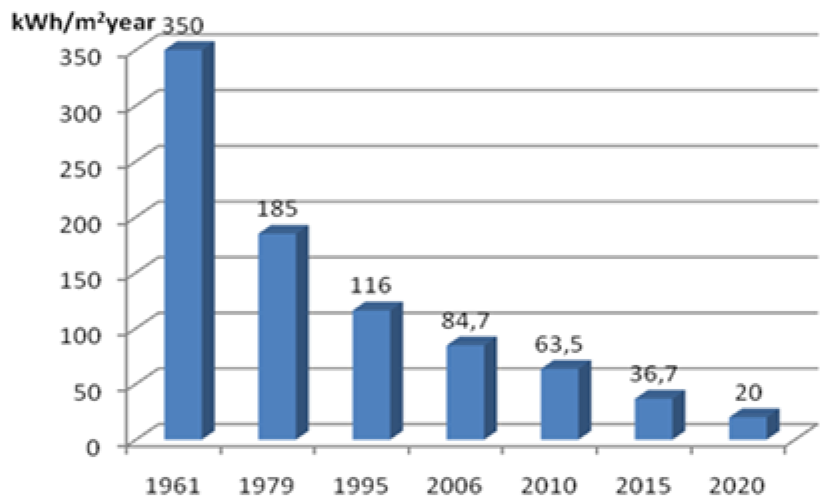

Figure 5-5: Danish building codes from 1961 to present. The bars represent the limit on the total amount of supplied energy for heating, ventilation, cooling and domestic hot water (Danish Energy Agency, 2015).

Current role of district heating in the Danish energy system

In the course of a century district heating has grown to be the largest heat technology used to satisfy the low-temperature heat demand in Denmark with a market share of 63.3% of households connected to district heating[22] (Euroheat & Power, 2015). Next to district heating other heating alternatives exist including

[22] Statistics concerning the larger low-temperature heat market are not available, but are likely to be similar.

natural gas for individual heat boilers (15.6%), oil-fired individual heat boilers (12%), direct electric heating (4.7%), biomass-fired boilers (2.7%) – oftentimes small-scale and decentralized applications, and electric heat pumps (1.7%) (Euroheat & Power, 2015). In the previous paragraph it was explained that the Danish heat sector is for a large part the result of *public planning*, being the municipalities and central government responding to events to which district heating was able to provide a solution. In this section the key factors that have determined why district heating was and is such an attractive heating alternative will be discussed. Three factors stand-out: (1) the bottom-up development of district heating with a key role for *municipalities*, (2) the favorable regulatory framework and (3) the public support for district heating.

The municipalities. As described, the municipalities played a crucial role in the early-stages of development of district heating systems in Denmark. Following that, in 1979 Denmark passed its first Heat Supply Act which gave a central role to municipalities for district heating planning which, albeit in a different form, still retain. In Denmark any interested party has the right to initiate a heat-planning project, that is, private companies such as energy companies, industry or waste management companies, as well as public parties such as local authorities. Project proposals have to be sent to the *municipality* who is responsible for project approval. The project proposals have to include a social cost-benefit analysis which includes the following three categories: (1) the prospective consumer price, (2) the district heating company's business case and (3) the social costs and benefits of the project (externalities such as emissions of greenhouse gases and other pollutants). In order to make project proposals from different applicants comparable, exogenous variables such as future fuel prices and the interest rate used are defined by the central government. In addition, after the proposals have been prepared, but before project approval, the *municipality* will invite the relevant stakeholders (e.g. supply companies or citizens) for consultation. In the past municipalities had to send the project proposals to the central government for consultation as well, but this requirement has been abolished to further solidify and clarify that the municipalities are responsible for project approval of district heating systems. The most important argument of placing heat planning in the hands of the municipalities, and also a reason for its success, is that the municipalities are best equipped to weigh the different heat alternatives against each other in their jurisdictions because to a large extent the attractiveness of district heating versus other forms of heating is determined by *local to regional conditions* (e.g. the presence of residual heat from industry, the heat demand density of a region or the expansion plans of urban areas). In addition, municipalities also play an important role in the district heating sector as owners or shareholders in district heating companies that operate in various parts of the value chain. Companies in the district heating sector are mainly either public companies owned by municipalities, private companies (with oftentimes in part public shareholders) or co-operatives oftentimes owned by citizens and municipalities.

Favorable regulatory framework. Throughout its century of development district heating was at first primarily championed by the local and central government as a means to improve Denmark's energy-independence. By exploiting the high energy-efficiencies that can be achieved by using combined heat and power and the flexibility of fuel-switching district heating offers made it an attractive alternative. In the last few decades next to energy-independence a second driver for district heating came to be, meaning the Danish climate goals. The Danish government envisions to ban the use of coal from the Danish energy sector by 2030 and all electricity and district heating in Denmark must be produced exclusively by means of renewable energy sources by 2035 (Danish Energy Agency, 2015). Furthermore, "a *large majority of the* *parliament* agreed on specific policy targets for 2020 to cater this development" (Danish Energy Agency, 2015, p.5), signaling broad public support for 'green public policy'. Accordingly, the Danish regulatory framework is organized as such that the most environmentally friendly solution is the most attractive one, given affordable costs. Three key factors were therewith instrumental in securing the position district heating holds today: (1) the system of energy and carbon taxation, (2) the variety of subsidy schemes and (3) the district heating specific regulation, most notably the 'zoning' and 'tariff regulation' of the system.

Energy and carbon taxation. In Denmark there are differentiated tax rates on the use of fuel. Energy suppliers pay the taxes and shift them to consumers. The fuels that have energy excise, carbon and Sulphur[23] tax are: petrol, gas oil, kerosene, heavy fuel oil, liquid petroleum gas, natural gas, coal, coke and lignite. Moreover, the use of electricity is also taxed at the consumption level. The combined energy, carbon, sulphur and electricity taxes are tailored as such that low-carbon fossil fuels are relatively more attractive than high-carbon fossil fuels. Moreover, the use of biomass as a fuel for district heating is not taxed, giving a clear advantage to biomass over other fuels for heating. Electric heating has a reduced tax level in order to maintain the affordability of heating for businesses and households (European Commission, 2015). Figure 5-6 illustrates the integral costs for a selection of fuels for heating production.

The energy and carbon taxation system in Denmark is designed to facilitate a transition towards more sustainable means of satisfying the energy demand, including the heating demand. As a result, biomass has become the prime energy source for heat production in district heating. "Today, almost all decentralized heat-only boilers and one in four of the decentralized CHP plants use biofuels" (Danish Energy Agency, 2015, p.4). The share overall share of biomass in heat production for district heating is 47%, which "constitutes one-fourth of the total space heat demand in Denmark" (Danish Energy Agency, 2015, p.4).

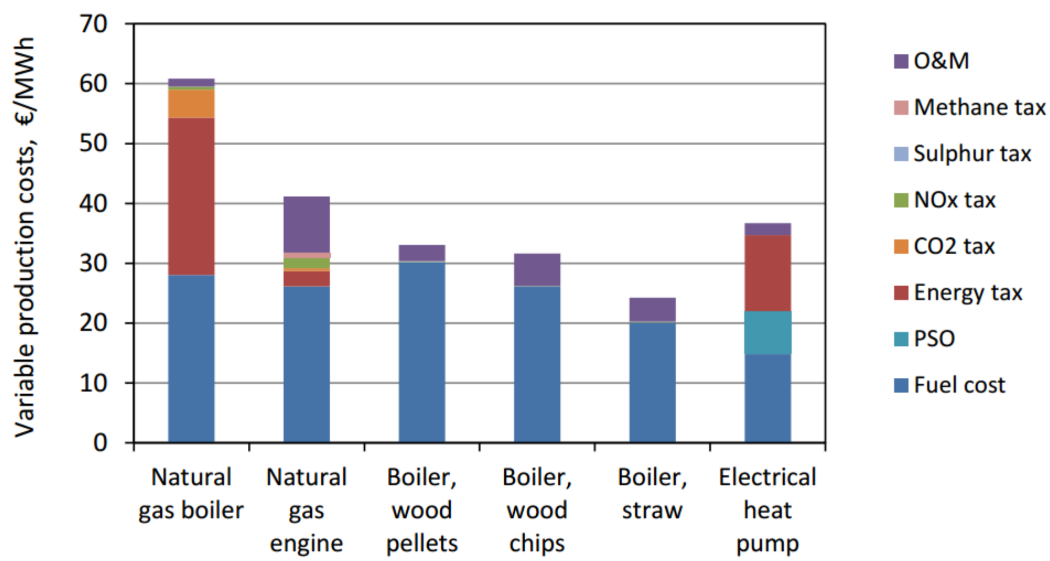

Figure 5-6: Variable costs for different fuels for heating production including fuel costs, energy, carbon and Sulphur taxes and value added tax (Danish Energy Agency, 2016).

[23] "The sulphur tax on fuels is only levied on fossil fuels containing more than 0.05 percent sulphur" (European Commission, 2015).

Subsidies. Next to the incentives for renewable heating and district heating as a technology incorporated in the energy, carbon and Sulphur taxes, Denmark also has a variety of subsidies in place that favor the use of combined heat and power and biomass. The most notable subsidies that are currently in place include the price premiums and fixed feed in tariffs that exist for electricity generation. "CHP producers receive an add-on of DKK 150 per MWh [± 20 €/MWh] to the market price of electricity for electricity produced by biomass" (Danish Energy Agency, State of Green, & DBDH, 2015, p.7). Which gives a strong incentive for electric power producers to use biomass in CHP, supporting the operation of district heating systems.

District heating specific regulation. The Danish district heating sector has no specific regulation with regards to ownership of district heating activities (D1 & D3), the type of market (D4), congestion management (D6) or about the integration with neighboring networks (D7). It does however have interesting regulations stipulated for the network access conditions (D2) and the form of tariff regulation (D5).

First of all the network access conditions. Producers may connect to an existing district heating network if it can form an agreement with the heat network owner in question and receives approval from the municipality on its project proposal according to the public heat planning process explained above. Competition between retail companies does not occur in the Danish district heating sector: there is no freedom of choice. With respect to the access conditions for consumers an interesting choice has been made, the Danish *municipality*, in negotiation with local energy utilities, makes municipal heating plans in which they apply 'zoning'. Zoning means that the municipality designates in which areas which infrastructure will service the heating demand. That means consumers have no freedom to choose which technology they would like to use for their heating service, if you are living in a district heating area, since 1982 the municipality has the power to oblige you to connect to district heating for your heating service, also in existing buildings (Danish Energy Agency, 2016). The municipality does allow grace periods however in which existing houses are "granted the possibility to postpone the connection in a period of up to 9 years, if a supply monopoly is adopted" (Danish Energy Agency, 2015, p.8). The grace period is there to account for investments households or businesses might have done in heating boilers which they likely want to depreciate first before switching to another heating service. The benefits of zoning are clear: zoning prevents duplication of infrastructures which is in many cases economically inefficient. Furthermore, the possibility of obligatory connection ensures that district heating systems have enough connections to recuperate the large investment costs of the network over a sufficient number of consumers and heat demand. Therewith, zoning has been an important instrument in enabling the growth of district heating systems.

Opponents of zoning mention however that the lack of competition will lead to a lower allocative and dynamic market efficiency. The Danish Energy Agency, however dismisses these arguments because of the benefits that zoning present: zoning allows for careful heat planning, minimizing costs through optimizing the network lay-outs of different energy networks, being electricity, natural gas and district heating (Danish Energy Agency, 2015). Furthermore, the argument that there would be no competition is not entirely true, because there is most definitely competition: the choice for an infrastructure in a certain area is based on the least socioeconomic cost principle which leads to fierce competition *for* the network, instead of competition *between* or *over* the networks or benchmarking. For proper competition *for* the network during the heat planning process to work well, municipalities are supported in performing the necessary socio-economic analyses by the 'Danish technology catalogue'. The catalogue contains a myriad of information including information regarding heating supply plants, how to calculate the distribution of heating demand over a year, how to assess the investments in gas networks and district heating networks (Danish Energy Agency, 2016). As mentioned before, future fuel prices and interest rates are supplied by the central government.

Secondly, district heating companies in Denmark must operate according to a 'non-profit' principle, meaning making a profit on heat production, transport, distribution or delivery is not allowed. Also, the tariffs for wholesale production, network activities and heat delivery are regulated by the Danish Energy Regulatory Authority (Windelin, DERA, 2015). Tariffs are calculated according to a price cap which is based on the costs of heat delivery. DERA determines a maximum price based on an estimation of the actual costs of a representative heat supplier. The district heating company is allowed to differentiate his tariffs between networks as long as he does not discriminate between consumers. Specific price caps are determined for different types of heat production plants. Furthermore, regulations stipulate how combined heat and power facilities must distribute their costs among the electricity production and heat production. The tariff regulation protects bound-consumers from possible abuse of power of their heat suppliers. Moreover, the interests of the heat suppliers are oftentimes in line with the interest of the consumers themselves because heat suppliers are oftentimes owned by either local municipalities or energy collectives (shareholders are consumers themselves and possible local municipalities as well). In Table 5-3 a summary of the full regulatory framework is given.

Note on public perception of district heating in Denmark.

According to the Danish Energy Agency the public perception of district heating in Denmark is positive. "Statistics from the Danish District Heating association show that in 2014 99% of all district heating consumers pay less for their heat compared to heat from household-based oil boilers and 73% of district heating consumers pay less for their heat when compared to individual natural gas boilers" (Danish Energy Agency, 2015, p.8). Also, the prices are stable and reflect the true cost of heating, meaning each individual consumer has his or her own heat meter. This is not only fair, but also induces an incentive for energy savings since consumers can directly see the effect on their heat bill. Furthermore, there are targeted subsidies for low-income consumers, so that heating may remain affordable for vulnerable groups as well (Danish Energy Agency, 2015).

A note on the future prospects of district heating in the Danish energy system

The district heating system in Denmark has the developed into one of the largest district heating systems in Europe in terms of the share of the heating demand it serves in the country. This paragraph briefly describes the promising opportunities and challenges the Danish district heating systems will encounter in the medium to long-term future (2030-2050).

Opportunities. In the Danish electricity sector onshore and offshore wind energy plays an increasingly large role. In 2020, wind turbines are expected to account for 50% of the domestic electricity production (Danish Energy Agency et al., 2015). Because of the intermittent character that is inherent to wind power there will be a need for balancing. Next to increased electricity market integration with neighbouring countries such as Norway, who may use its hydropower basins and production flexibility to balance part of the wind power, district heating systems can play an important role in integrating wind power in the Danish energy systems.

Three technologies that are compatible with district heating systems may contribute to coping with the intermittency of wind power: (1) heat storage, (2) electric boilers and heat pumps and, (3) the bypassing of turbines at CHP plants.

Heat storage at CHP plants may allow CHP operators to produce electricity when wind production is low and store the heat that is also produced in heat buffers. When wind production is high, CHP plants can shut-down and use the heat buffers to supply the needed for the district heating systems, thereby serving as a buffer for the electricity system.

Large-scale electric boilers and electric heat pumps can be used to produce heat for district heating systems when electricity prices are low, or even negative, because of high wind power production. The quick-reaction time of electric boilers and electric heat pumps, combined with the possibility of heat storage, make electric heating facilities well-equipped to balance the electricity system.

It is possible to bypass the power turbines at CHP plants running the CHP plants as an heat-only plant, making it possible to produce heat when heat buffers only do not suffice. This possibility adds to the flexibility of district heating systems.

Another opportunity for district heating systems lies in the development of low-temperature district heating systems. Low-temperature district heating systems may attain high energy-efficiencies than higher-temperature district heating systems because of lower losses in transmission and distribution. Lower-temperature heat is cheaper because at for instance CHP plants if the heat can be coupled-out at a lower-temperature more electricity can be produced. In addition, lower-temperature heat is available from a larger variety of heat sources, adding more flexibility in terms of energy sources for the district heating systems.

A final developing opportunity for district heating systems is feeding-in large-scale solar heating. Increasingly projects are being developed that will feed-in solar heat into existing and new district heating systems, improving the environmental performance of the district heating system. Solar heating production is especially well-equipped to provide heat for low-temperature district heating systems, but as well for higher temperature district heating systems.

Challenges. There are however also challenges for the district heating sector. With electricity prices falling due to the increased share of cheaply available wind power in the electricity sector competition with individual electric boilers and electric heat pumps is increasing. In some areas it will therefore be cheaper both from an economic as a socio-economic point of view to use electric heating as opposed to district heating (Danish Energy Agency, 2016). Furthermore, the energy demand per square meter in buildings is falling rapidly due to the progress that is being made in energy savings in buildings. With lower heat demand densities, district heating systems' throughput is falling, squeezing the business case for district heating. Lowering the operating temperature of district heating systems to lower energy losses becomes therewith more important in the medium to long-term future. Finally, the falling electricity prices and increased share of renewables (mainly wind energy) in the electricity sector are also displacing thermal electricity generation capacity. Less CHP facilities means less heat production for district heating systems which will have to be covered by other forms of heating such as solar heating and electric forms of heating.

In 2014, the Danish Energy Agency foresaw the opportunities and challenges for the future role of district heating listed above and in response carried out a "comprehensive analysis of the district heating system and the future role of district heating" (Danish Energy Agency, 2016, p.22) in Denmark. The analyses were performed using the 'Balmorel' optimization model in combination with a heating atlas for Denmark (Danish Energy Agency, 2014). Three different scenarios were defined to explore possible futures for the Danish energy sector and the Danish district heating sector. The results included that in all scenarios district heating will remain important in servicing the Danish heat demand and play a key role in balancing the electricity sector's wind energy production. Figure 5-7 illustrates the projected district heating production including the energy sources used for heat production. Although the district heating production in terms of total energy produced is expected to be lower in 2050, the share of district heating in servicing the heat demand is roughly similar to that of current levels because of improvements in the energy efficiency of buildings. Notice that, the share of CHP is expected to fall strongly under changing electricity sector conditions. This is compensated by an increase in the use of heat-only boilers, heat pumps and electric boilers, excess heat and solar heating (Danish Energy Agency, 2016).

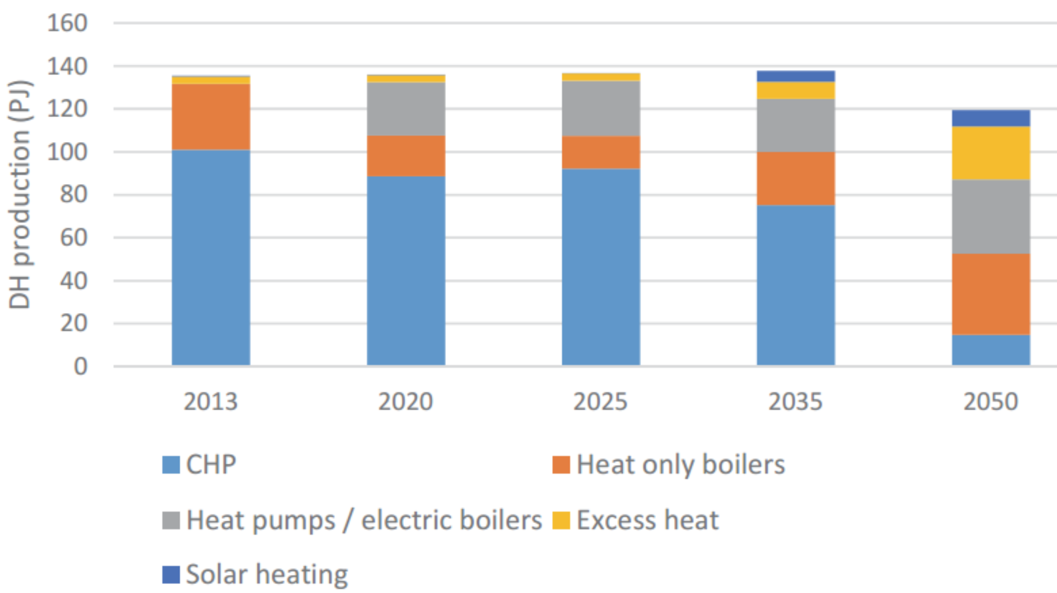

Figure 5-7: Type of heat production for district heating in Denmark as estimated in the modelling analysis performed by COWI and Ea Energianalyse (Wind-scenario) for the Danish Energy Agency (Danish Energy Agency, 2014).

Table 5-3: Regulatory framework or 'market model' of the Danish district heating sector

Design variable	Chosen policy instrument(s)	Consequences
Regulating the district heating sector		
1. Public versus private ownership	Any interested party has the right to initiate a heat project. The municipality authority is responsible for *approval* of the projects. The Danish district heating sector has different modes of organization.	The large share of public and end-user ownership in the district heating sector aligns the goals of the end-users with the goals of the energy companies. This makes it easier to secure the reliability, affordability and acceptability of heat delivery.
2. Network access conditions (for producers, retail companies and consumers)	For producers: regulated access. If an interested producer wants to connect to the network his proposal must be approved by the local municipality. For retail companies: Not regulated. For consumers: Zoning. See text.	The combination of regulated access and zoning has led to the possibility of public heat planning optimizing the socioeconomic costs of providing heat.
3. Network unbundling	Not regulated, however unbundling does occur.	An example of unbundling is the largest district heating system in Denmark: Copenhagen City. In the Copenhagen district heating system multiple heat producers feed-in heat to a transmission grid which is connected to multiple distribution grids. The owners of the production facilities, transmission grid and distribution grid(s) are all different parties.
4. Integrated versus decentralized market	Decentralized market: bilateral contracts.	
5. Tariff regulation	Non-profit principle and a price cap based on the actual costs of the district heating activity (benchmarking).	The tariff regulation provides protection for bound-consumers from possible overcharging by heat suppliers.
6. Congestion management method	Not regulated.	Although there are no integrated markets nor are their provisions for congestion management, the possibility of congestion in the Danish district heating systems is slim, because the combination public heat planning process including 'zoning' and 'municipal project approval' allows for careful planning of network lay-out.
7. Integration with neighboring networks	Not regulated.	Occurs when socio-economically beneficial on the initiative of relevant district heating stakeholders.
Steering the relative attractiveness of district heating versus other forms of heating		
8. Incentives for consumers of heat	The energy, carbon and Sulphur taxes provide incentives for consumers to make the 'sustainable choice' since that is cheaper.	Large growth of district heating and other non-oil based forms of heating (e.g. natural gas and electric forms of heating).
9. Incentives for producers of heat	The energy, carbon and Sulphur taxes provide incentives for producers to make the 'sustainable choice' since that is cheaper. Subsidies for CHP based on biomass.	Large growth of CHP and connected to that district heating systems.

5.5 Synthesis: comparison of market model performance

In this chapter an answer was sought for the third research question: "What insights can be gained from international experience with alternative market models for heat provision and the district heating sector specifically?" Section 5.3 and 5.4 showed that in both the Swedish and Danish energy sector's district heating plays a very important role. The discussion of these countries district heating sectors' historical development, current role and future outlook provided important lessons as well as inspiration for the Dutch market model design. In Table 5-4 the three market models (The Netherlands, Sweden and Denmark) are positioned next to each other for comparative purposes. Table 5-5 shows how the three countries' market models perform on the Dutch policy goals, which were operationalized in the evaluation framework of Table 3-4.

The most notable observation is that while Denmark and Sweden come from similar starting-points and have ended up at similar end-points, their respective pathways towards these end-points were very *different*. Both countries had historically a strong reliance on individual oil-fired boilers and no heat sector regulation. Driven by *similar, but also different drivers* a widespread district heating sector was developed with a key role for municipal authorities. Today, both countries have large shares of district heating in the heat sector with a strong reliance on combined heat and power fueled by both biomass and waste. The difference between the two countries' market models is the chosen form of *network access conditions* and *tariff regulation*. Although many factors have contributed to the success and relative attractiveness of district heating in the two countries the common denominator is the strong public push for the use of district heating over other forms of heating. Through taxation, subsidies and obligations the district heating sector was made to be the most attractive heating option in most areas. In discussing support mechanisms for renewable energy sources policy makers have to make a trade-off between 'keeping all the options open' and 'choosing a winner'. Choosing to keep all the options open favors development of multiple technologies which might lead to innovations that otherwise would not come to be. On the flip side, keeping all the options open might result in slow development of renewable energy sources, making it difficult to attain renewable energy goals. Choosing a winner results in one technology being developed at a strong pace, fostering learning effects and innovation for this particular technology. On the flip side, if one winner is chosen, alternative technologies that could also have contributed are at a disadvantaged position to develop further. Clearly, both the Swedish and Danish government have chosen for a market model in which all options are kept open, but district heating is favored such that it's relative attractiveness makes it the 'winner' of both countries' heating sectors.

Table 5-4: Comparison of the regulatory frameworks or 'market models' of The Netherlands, Sweden and Denmark.

Design variable	Netherlands	Sweden	Denmark
Regulating the district heating sector			
1. Public versus private ownership	Not defined.	Not defined. In practice the district heating sector is dominated by vertically integrated heat companies.	Any interested party has the right to initiate a heat project. The municipality authority is responsible for *approval* of the projects. The Danish district heating sector has a variety of modes of organization.
2. Network access conditions (for producers, retail companies and consumers)	Producers: no regulation. Retail companies: not defined. Consumers: obligation to connect to electricity and natural gas. Bound-heat-consumers *must* pay the fixed part of the connection costs.	For producers: regulated access since 2014 based on least cost principle. For retail companies: not defined. For consumers: no obligation to connect consumers.	For producers: regulated access. If an interested producer wants to connect to the network his proposal must be approved by the local municipality. For retail companies: not defined. For consumers: Zoning. See Section 5.4.
3. Network unbundling	No unbundling.	No unbundling.	Not regulated, however unbundling does occur.
4. Integrated versus decentralized market	Decentralized market: bilateral contracts.	Decentralized market: bilateral contracts.	Decentralized market: bilateral contracts.
5. Tariff regulation	End-user price regulation following the 'not-more-than-otherwise' principle.	No tariff regulation. Reliance on competition *between* networks to form competitive prices.	Non-profit principle and a price cap based on the actual costs of the district heating activity (benchmarking).
6. Congestion management method	Not defined.	Not defined.	Not regulated.
7. Integration with neighboring networks	Not defined.	Not defined.	Not regulated.
Steering the relative attractiveness of district heating versus other forms of heating			
8. Incentives for consumers of heat	Investment subsidy for renewable energy (consumers and 'small and medium enterprises'); energy taxes.	Investment subsidies: replacement of oil and direct electric heating in buildings. Energy and carbon tax system: The differentiated energy and carbon tax and value-added tax levels on oil, electricity, natural gas, district heating and wood pellets are providing consumers incentives towards the more environmentally friendly alternatives.	The energy, carbon and Sulphur taxes provide incentives for consumers to make the 'sustainable choice' since that is cheaper.
9. Incentives for producers of heat	Among others: SDE+, geothermal energy subsidies, EIA (see also Table 1-1)	Taxes on fuel use for heat production and energy and carbon taxes for electricity production. EU ETS. Investment subsidies for: district heating activities (LIP and KLIMP, similar to the Dutch 'Green deal') and biomass based electricity production. Tradable renewable electricity certificates (stimulus for biomass-fired CHP).	The energy, carbon and Sulphur taxes provide incentives for producers to make the 'sustainable choice' since that is cheaper. Fixed feed-in tariff for CHP based on biomass.

Table 5-5: Comparison of the market model performance of the Netherlands, Sweden and Denmark on the Dutch policy goals for the district heating sector

Performance indicator	Netherlands	Sweden	Denmark
More reliable district heating			
Average duration of service interruptions in minutes	Statistics not available. District heating systems are considered reliable.	Statistics not available. District heating systems are considered reliable.	Statistics not available. District heating systems are considered reliable.
Number of service interruptions per year over 1000 connections			
Percentage of heat provision based on natural gas	Irrelevant for now.	Irrelevant for now.	Irrelevant for now.
Coverage level of potential heat consumers	4% (Euroheat & Power, 2015)	52% (Euroheat & Power, 2015)	63% (Euroheat & Power, 2015)
More affordable district heating			
Variable heating costs (including VAT)	Maximum price: 22,66 €/GJ (ACM, 2016) No price differentiation.	Average in 2013: 19,9 €/GJ (Euroheat & Power, 2015) Price differentiation for 2011: lowest: 13.6 €/GJ highest: 29.9 €/GJ (Swedish Energy Agency, 2012)	Average in 2013: 34,9 €/GJ (Euroheat & Power, 2015) Price differentiation for 2015[24]: Lowest: 12.1 €/GJ Highest: 48.2 €/GJ (Dansk Fjernvarme, 2015)
More acceptable district heating			
Percentage of renewable heat production	80% (Euroheat & Power, 2015)	95% (Euroheat & Power, 2015)	99.8% (Euroheat & Power, 2015)
Fraction of energy used usefully in heating systems	Irrelevant for now.	Irrelevant for now.	Irrelevant for now.
Emissions of CO_2 in ton per year*	Irrelevant for now.	Irrelevant for now.	Irrelevant for now.

*Polluting gases are the issue. Focus will lie on greenhouse gases however.

[24] Prices were estimated using data from Dansk Fjernvarme regarding the variety in prices for different types of heat production facilities. Variable prices were given excluding the costs of heat losses and Danish value-added tax. In order to make the figures comparable these costs were added to the figures found on page 9, assuming 15% heat losses and the Danish value-added tax of 25% (SKAT, 2016).

6 Market model design

In this chapter alternative market models for the Dutch district heating sector are designed. First, the process of selecting promising market model elements for the Dutch district heating sector is explained (Section 6.1). 'Good' market model designs must be feasible market model designs that are likely to support the policy goals of the Dutch government for the district heating sector. In addition, the market model designs must however also be in accordance with 'principles of good governance' which ensures that the market model will be efficient, effective and 'fair' (Section 6.2). A 'good' market model design must also be future proof, which means that it is robust to developments that might occur. These developments can be of a technological, institutional-economic or political nature (Section 6.3). Using the selection process detailed in Section 6.1 and taking into account the topics described in Section 6.2 & 6.3 alternative market models for the Dutch district heating sector are defined (Section 6.4). Finally, the alternative market models' expected performance is compared and discussed (Section 6.5).

6.1 Selecting promising market model elements for the Dutch district heating sector

In Chapter 4 the nine design variables for a new market model design for the Dutch district heating sector were identified. For each of the nine design variables the policy maker must make a decision regarding how the design variable should be filled in. The design options that the policy maker has per design variable represents the 'design space' which was presented in full in Table 4-4. A market model design is defined by choosing one (or in some cases multiple) policy instrument(s) that together form an internally consistent 'package'.

For the purpose of readability and clarity Table 4-4 summarizes the most important policy instruments per design variable without going into depth about the degrees of freedom that exist within those policy instruments. Still, however, the number of possible designs when combining policy instruments into packages is huge. Assuming there were only 3 design options for the 9 design variables the number of possible combinations would be 3^9 which equals 19683. In reality, not all of the possible combinations are *feasible* designs because of the interdependency between the design variables and policy instruments (see Section 4.4). Nevertheless the number of feasible design combinations remains too large to tackle directly, therefore the design space has to be brought back to a manageable size first.

Inspired by the discussion in *Dym et al.* (2009, p. 108-109) about 'limiting the design space to a useful size' three steps will be undertaken to prune the design space: (1) test policy instruments against stakeholder preferences, (2) assess the experience with the listed policy instruments to assess their potential, and (3) make use of 'common sense' to assess whether a policy instrument should be considered for further analysis or not. In step 1, per design variable the available policy instruments are compared with the interests of the relevant stakeholders ('the players') that were identified during the stakeholder analysis (see Figure 3-9). The policy instruments that are deemed to be the most likely to be accepted by the relevant stakeholders are taken into account for further analysis. Subsequently, in step 2 the insights gained from the case studies is used to select the most promising policy instruments for further analysis. Policy instruments for which negative experiences exist are either excluded or adapted for further analysis. Finally, in step 3 the policy instruments are subject to the test of 'common sense'. The policy instruments are ordered, in order to improve readability of the design space and as Dym et al. (2009) call it, it is time to "get real". Which basically means that the policy instruments that are deemed unlikely to succeed in the Dutch institutional-economic context or are unlikely to adequately support the Dutch policy goals for the district heating sector are excluded for further analysis. For this last step, the constraints and objectives that followed from Section 3.4 are used. Table 6-1 illustrates the design space for a new market model for the Dutch district heating sector in the form of a 'morphological chart'. On the vertical axis the nine design variables are listed and on the horizontal axis the selected policy instruments per design variable are presented. Combining policy instruments for each of the design variables into packages results into market model designs.

Composing feasible market model designs using the morphological chart.
Selecting the market model elements per design variable and combining them into 'packages' is guided by the FULDA Method. 'FULDA' is an abbreviation for the 'function-based legal design & analysis method', developed by Knops (2008). The method was originally developed in order to facilitate the design of the legal organization of *technical functions* of energy infrastructure systems. In this thesis, the method is used to design the legal organization of the *institutional-economic functions* (represented by the design variables) of an energy infrastructure system, specifically the district heating system. The FULDA-method is comprised of three main steps, Figure 6-1 illustrates these steps.

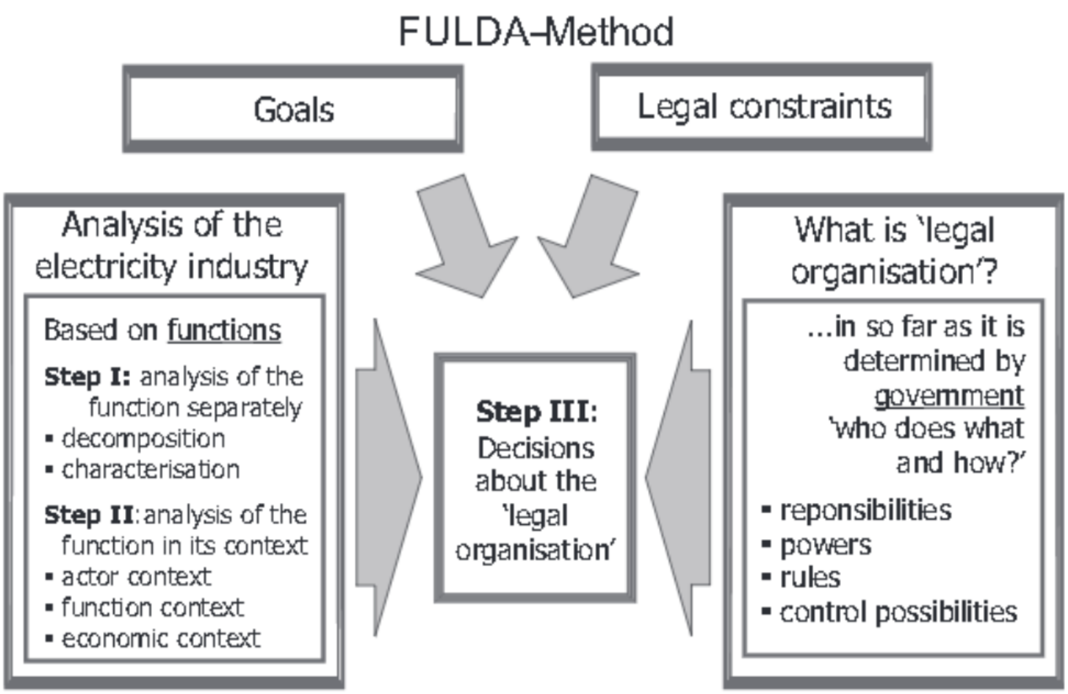

Figure 6-1: Schematic representation of the FULDA-Method (Knops, 2008)

Table 6-1: 'Morphological chart' for designing a new market model for the Dutch district heating sector

Policy instruments / Design variables	1	2	3	4	5
1. Public versus private ownership - Production activities - Network activities - Delivery activities	No regulation	Public ownership	Private ownership		
2. Network access conditions - For producers - For retail companies - For consumers	No regulation	Negotiated access	Regulated access		
3. Network unbundling	No unbundling	Non-ownership unbundling (separate accounting, administrative separation or juridical separation)	Ownership unbundling		
4. Integrated versus decentralized market	Nodal pool (integrated)	Bilateral market (decentralized)	Independent exchange plus bilateral market (decentralized)		
5. Tariff regulation - Wholesale price - Network tariffs - Tariffs for retail services	No regulation	Price cap (external benchmarking)	Price cap (based on costs of heat delivery)	Cost-plus	Standardized cost-plus
6. Congestion management method	No regulation	Integrated markets	Dynamic transport tariffs	Explicit (capacity auctions)	
7. Integration with neighboring networks	No regulation	Regulating the interconnection of district heating networks			
8. Incentives for consumers of heat	Subsidies	Taxes	Obligations		
9. Incentives for producers of heat	Subsidies	Taxes	Obligations		

The FULDA-method starts off with identifying the various functions of the energy infrastructure system of interest. Subsequently, the three main steps of the method can be applied to a single function. The first two steps serve as information gathering activities and the third step concerns the decision make stage. During the first step the function of interest is analyzed in isolation. The analysis is comprised of a decomposition of the function into the sub functions and tasks the function fulfills and a brief characterization of the function. During the second step, the function's context is analyzed, which is comprised of an analysis of its actor context, function context and economic context. Finally, informed by the information gathered in steps 1 & 2, the goals and legal constraints imposed on the system and the definition of what is considered 'legal organization' choices can be made in step three regarding which policy instrument is deemed appropriate to fulfill the function of interest. In this thesis, step one and two have been conducted for all functions together, instead of in isolation, in Chapter 3 where the system functions' physical layer, institutional-economic layer and context where thoroughly investigated. The goals and constraints imposed on the district heating sector were discussed in Section 3.4 and have to be taken into account during the execution of step 3. What is considered 'legal organization' is discussed in Section 2.1. This chapter builds on these foundations and will make use of the guidelines described in step 3 of the FULDA method to make choices for the policy instruments per design variable.

During step 3 of the FULDA method four questions are asked for each of the institutional-economic functions, or design variables. The answers to these questions result in a choice of a policy instrument per design variable. The four questions are:

A. Should someone be made explicitly responsible for this function?
B. Who should be made responsible? Or: who should be allowed to perform this function?
C. How should the function be further organized?
D. What control possibilities for governments should be implemented?

A. Should someone be made explicitly responsible for this function?

Per design variable the policy maker must decide whether government intervention may be justified. Each design variable governs institutional-economic aspects of the district heating sector which in turn govern the physical aspects of the district heating sector. Taking this in mind, government intervention may be justified if (1) it is considered *necessary* for the adequate functioning of the district heating sector and (2) there is a need to *explicitly* appoint someone responsible. The second requirement is met when "central provision or coordination of the service is required, or if the desired level of service provision is not to be expected to be provided by the 'market' "(Knops, 2008, p. 541).

B. Who should be made responsible? Or: who should be allowed to perform this function?

If the answer to question A. is positive, question B. becomes 'who should be made responsible?' For example, suppose that it is decided that for design variable 1 (public versus private ownership) that it is *necessary* to *explicitly* appoint the ownership of the different roles in the district heating value chain. Answering question B. will then determine *who* will be responsible for fulfilling the different roles in the district heating value chain. Alternatively, if the answer to question A. is negative, question B. becomes 'who should be allowed to perform this function?' The point of departure is in this case that "anyone is allowed to perform the function concerned. Therefore, the main issue is whether there is a need to introduce 'positive' or 'negative' requirements for the actors" (Knops, 2008, p.542).

C. How should the function be further organized?
Question C pertains to whether or not, and to what extent, it is necessary "for government to determine the organization of the function and to pre-specify rules for it" (Knops, 2008, p.542). Two issues are of importance: (1) *who* determines the further organization of the function, and (2) *how* is it further organized (Knops, 2008, p.542).

D. What control possibilities for governments should be implemented?
When defining what is allowed, what is not allowed, and what should be further regulated government must also consider how she would like to *control* the performance of the particular function. Four classes of control can be distinguished: (1) government uses *ex ante* control powers, (2) enforcement, (3) change of the legal framework and (4) direct government intervention (Knops, 2008). The choice for which means of control is used depends on the suitability of the control class for the task at hand and also at the choices made for other design variables.

Once the four questions of step 3 of the FULDA method are answered, an informed choice can be made for the most suitable policy instrument to govern the design variable of interest. The process of answering the four questions of step 3 is repeated for all nine design variables, but not in a random order, the interdependency of design choices makes it necessary to follow a certain *order of preference* when defining the legal organization, or in other words, the 'market model choices'. Figure 4-2 prescribes this order of preference. In addition, Table 4-5 aids the policy maker in taking into account the necessary interdependencies between the other design variables when choosing an appropriate policy instrument for a particular design variable.

The creative endeavor of designing new market models
In this subsection the design space has been brought back to a manageable size by pruning the larger design space presented in chapter 4. Subsequently, the 'guideposts' for composing new market model designs have been placed, being the FULDA questions and the considerations regarding the interdependency of the design choices. Despite all these steps, there are however still a large number of feasible market model designs possible. Therefore, although the design process is structured in the best possible manner, in part designing new market models remains a *creative endeavor* (Dym et al., 2009).

6.2 Principles of good market governance

The alternative market models that are designed in this chapter have to contribute to the *policy goals* outlined in Table 3-4 as well as meet the constraints that are attached to those policy goals. In addition, the market models should also meet a set of 'principles of good market governance' in order to ensure a good-functioning regulatory framework. A good-functioning regulatory framework fosters investment security through regulatory stability and supports the realization of an efficiently working market. The 'principles of good market governance' are "a set of best practices for laws, regulations, processes and regulatory arrangements" (Knops, 2008, p.103) that together support the design of a good-functioning regulatory framework. Meeting these principles is especially important for the district heating sector where regulatory stability is necessary for businesses to be able to engage in the long-term investments that characterize the district heating sector[25] (Hancher et al., 2003). Furthermore, "the interests of end-users (consumers) are likely to be better served with appropriate supply and a dynamic market when the regulatory framework functions well and secures stability (see (Berg, 2001))" (Hancher et al., 2003, p. 341). Of course, good governance is only one determinant for market model performance, albeit a determinant of great importance.

Based on an extensive literature review[26] Hancher et al. (2003) compiled a list of ten principles that should be followed to enable the design of good-functioning regulatory frameworks. These ten principles are: (1) transparency, (2) independent supervision of the market, (3) clear legislative mandate, (4) proportionality, (5) predictability, (6) accountability, (7) consistency, (8) respect for general competition policy, (9) respect for European law and co-operation and (10) flexible powers.

In essence, the ten principles aim to contribute to the following three goals: (A) to minimize the regulatory uncertainty for market parties, (B) to ensure the internal and external consistency of the legal organization, and (C) to equip government with the flexibility needed to cope with the dynamics of both market performance and policy objectives. Table 6-2 summarizes the meaning of the ten principles and to what goals these principles contribute. The 'principles of good market governance' will be taken into account when composing new market models for the district heating sector. Moreover, the three goals listed in Table 6-2 are added to the evaluation framework of Table 3-4 so that the market models' compliance with the principles of good market governance may be assessed.

A note on interrelatedness

The principles of good market governance are interrelated and sometimes at odds with each other. For example, a *clear legislative mandate* entails that government follows strict rules on what she may, and may not do. This is directly at odds with the principle of *flexible powers*, which argues that government should have the discretionary room to act in the manner she deems most conducive to attain her policy objectives. In line with the interrelation of the ten principles also the three goals are interrelated. For example, albeit possibly indirectly, a more consistent regulatory framework is likely to contribute to less regulatory uncertainty. Also, the government's *flexible powers* in 'changing the rules during the game' makes it possible to align the regulatory framework with developments in market performance and policy goals. This may however be either conducive or unconducive to the regulatory certainty of the market. Similarly, the manner in which the government uses its flexible powers will contribute to a deviation or conformity to the consistency of the regulatory framework with its institutional context.

[25] The economic lifetimes of district heating projects are oftentimes over 30 years with technical lifetimes being even longer, oftentimes over 40 years.

[26] Hancher et al. (2003) base their analysis mainly on the following four pieces of literature: (OECD, 1995), (COM, 2001), (Better Regulation Task Force, 2000) and (AURF, 1999).

Table 6-2: The ten principles of 'good market governance' and the overarching goals to which they contribute. For a more extensive discussion on the ten principles see Hancher et al. (2003).

Principles and overarching goals	Explanation
Goal A: "To minimize the regulatory uncertainty for market parties."	
1. Transparency	Transparency is an umbrella term requiring public bodies to operate in an open manner, explain their reasoning behind decisions and making those decisions easily accessible. This requirement applies to all public bodies including both the legislative and executive branch, including the authorities that are responsible for implementation of a decision. Transparency fosters understanding from regulated firms and citizens which in turn makes it more likely that regulation is both accepted and considered legitimate (Hancher et al., 2003).
2. Independent supervision of the market	Supervision of the market should be independent first, from stakeholders and secondly, from politics. In order to ensure that the regulation is 'fair' and the level playing field is secured market parties should not be able to exert unduly influence on the regulator. With regards to the independence of supervision from politics two arguments are of important. First of all the economic regulation should be consistent, so that the investment security of companies and innovation and efficiency incentives for companies are not endangered by undue political interference. Secondly, politics should only concern itself with decisions based on political choices, such as the distribution of wealth, and leave decisions of a technical nature to the administrative agencies which possess over the necessary expertise to make such decisions (Hancher et al., 2003).
3. Clear legislative mandate	"This principle is strongly related to the principle of transparency. Although it is not always mentioned as a separate principle, this thesis subscribes to the reasoning of Baldwin and Cave (1999) that it deserves separate attention" (Hancher et al., 2003, p. 345). A clear legislative mandate guides the independent administrative agencies to what the agency should, and what she should not do. The mandate should not be formulated in minute detail, but should state the purposes and objectives the agency must pursue as clearly as possible (Hancher et al., 2003).
4. Proportionality	"The principle of proportionality entails that regulatory action is only taken when really *necessary*, that the measures chosen are *appropriate* to achieve their goals and that the effects of the measures chosen are *proportionate* to the objectives" (Hancher et al., 2003, p. 347). Drafting regulation from necessity in an appropriate and proportionate manner aims to minimize the regulatory interference with the market as much as possible. Regulatory Impact Assessments are useful tools that may aid governments to assess ex-ante what the impact of an intervention in the market will be (Hancher et al., 2003).
5. Predictability	The predictability of regulation is crucial for the investment climate in network industries such as the district heating sector. With long economic and technical lifetimes of projects it is necessary for companies to be able to predict government policies with respect to among others tariff regulation and externalities. Securing predictability requires transparent decision-making procedures with clearly defined decision-making criteria and timetables (Hancher et al., 2003).
6. Accountability	The principle of accountability "protects the interests of the regulated firms, citizens and the legislative (when the decision emanates from the executive or an agency)" (Hancher et al., 2003, p.349). In short, "regulatory authorities should be accountable to politicians through political *control* instruments, to the citizens by *explaining and publishing* policies, to the

	interested parties through *public consultation* procedures and to the judiciary through *legal procedures*. Hence the principle of accountability is strongly related to transparency" (Hancher et al., 2003, p.349-350).
Goal B: "To ensure the internal and external consistency of the legal organization."	
7. Consistency	Regulation should be consistent "across different utility sectors, and over time as a means of improving confidence in the regulatory regime" (Hancher et al., 2003, p.348-349). In order to secure a level playing field in the district heating sector government should not take disproportionate action which could go at the expense of a selected number of stakeholders. Attaining consistency also requires the formulation of clear substantive rules and transparent procedures (Hancher et al., 2003).
8. Respect for general competition policy	To prevent the duplication of regulation and possible conflicts between the general competition authority and a Ministry or other legislative or executive body, government should respect general competition policies when drafting sector-specific regulation. The principles of consistency, proportionality and predictability contribute to securing this principle. Because of the importance of competition effects on a market it is however useful to state this principle as a separate principle (Hancher et al., 2003). The Ministry of Economic Affairs adheres to this principle by only adopting additional sector-specific competition policies when general competition policy does not address an issue that pertains to competition policy adequately or sufficiently in a given sector.
9. Respect for European law and co-operation	Similar to principle number eight national, regional and local government should respect European law and co-operation. In fact, government should not only 'respect' European law, it is a government's duty to follow EU treaties, ratify EU directives in national law and follow the binding and directly applicable EU regulations and decisions. Moreover, in line with the further harmonization of particularly energy policy in the European Economic Area governments should not only look at the European Commission for what is 'expected of them', but also look sideways to other member states to learn from best practices and help those which require or request assistance (Hancher et al., 2003).
Goal C: "To equip government with the flexibility needed to cope with the dynamics of both market performance and policy objectives."	
10. Flexible powers	The principle of 'flexible powers' is intimately connected to the principle of a 'clear legislative mandate'. Although flexibility might seem to be at odds with clarity, it is actually more complimentary than conflicting. Flexible powers means that government should have the discretionary room to operate in such a way she deems most conducive to carrying out her function and attaining the objectives imposed on the government body. Having the necessary discretionary room in making decisions enables a policy maker to react to developments in market performance and policy goals swiftly so that the regulatory framework may adhere to these developments in the best possible manner. In practice this means that policy makers should be able to change the 'rules of the game' when necessary and interpret her legislative mandate in a broad manner rather than in narrow manner. Of course this does require accountability and transparency of the policy maker to prevent flexibility of powers to be abused, or cause regulatory uncertainty due to arbitrariness of policy makers. Therefore the principle of flexible powers is closely connected to all other nine principles of good market governance. The principle deserves special attention because it plays a crucial role if one wants to attain policy objectives at the desired pace (Hancher et al., 2003).

6.3 Designing robust market models: incorporating the trends in the heat sector through scenario-analysis

The business case for district heating is for a large part determined by the market model for the district heating sector. There are however also a great number of *exogenous factors* that affect the relative attractiveness of district heating versus other forms of heating. These exogenous factors can be of a physical, economic, social, or political nature (A. C. Correljé & de Vries, 2008). Taking these exogenous factors into account during the design process is crucial for the robustness of the market models to be designed.

An adaptation of PwC's 'energy transformation framework' provides a useful lens to look at how these exogenous factors influence the market design process (PwC, 2014). The adapted framework consists of four blocks. The **first block** consists of the 'megatrends' or 'drivers' which are at the root of the exogenous factors impacting the energy sector. The **second block** concerns the exogenous factors themselves, which together could potentially disrupt how the future heat provision system will look like in the Netherlands. The sheer number of exogenous factors and the uncertainty regarding both their development and impact on the district heating sector however presents a problem for the design effort. Therefore in the **third block** three possible scenarios are defined which sketch how the megatrends will develop into the medium-future and how, as a result of that, the disruptive factors will develop. Finally, the **fourth block** represents the impact the possible future scenarios have on the market model performance and how businesses (district heating companies) will form their strategies. Figure 6-2 illustrates the adapted framework as applied to the district heating sector. The analyses underlying Figure 6-2, including the identification and brief characterization of the disruptive factors may be found in Appendix E.

Assessing the potential impact of the three possible future scenarios on the district heating sector's market model performance fosters insight into possible vulnerabilities in the market model design. By being aware of these vulnerabilities while designing new market models more robust market models can be designed. Possible insights gained could be for instance to what extent the government should have *flexible powers* in order to be able to cope with the dynamics of the disruptive factors. In case of tariff regulation for example, is it necessary to define the tariffs for heat delivery quarterly, or does once a year suffice? How often should government assess the competitiveness of the market and the efficiency with which the market supplies heat? And so forth. In Table 6-3 to Table 6-5 a brief summary of the three scenarios is sketched.

Table 6-3: Future scenario of the district heating sector's market model performance – base scenario.

Base scenario	
Characteristics	**Consequences**
- Moderate technological breakthroughs - Moderate development of climate change and resource scarcity - Moderate demographic changes - Moderate shift in economic power - Moderate progression of urbanization	An increasing political awareness and understanding of sustainability issues combined with the availability of better heat distribution and storage technologies causes the district heating sector to grow. At the same time the public also becomes more aware of the need to satisfy their heat demand in a more sustainable manner which leads to the growth of electric heat pumps and increased application of heat savings measures. Due to moderate economic growth and synergies in heating due to increasing urbanization the costs of heating remain affordable.

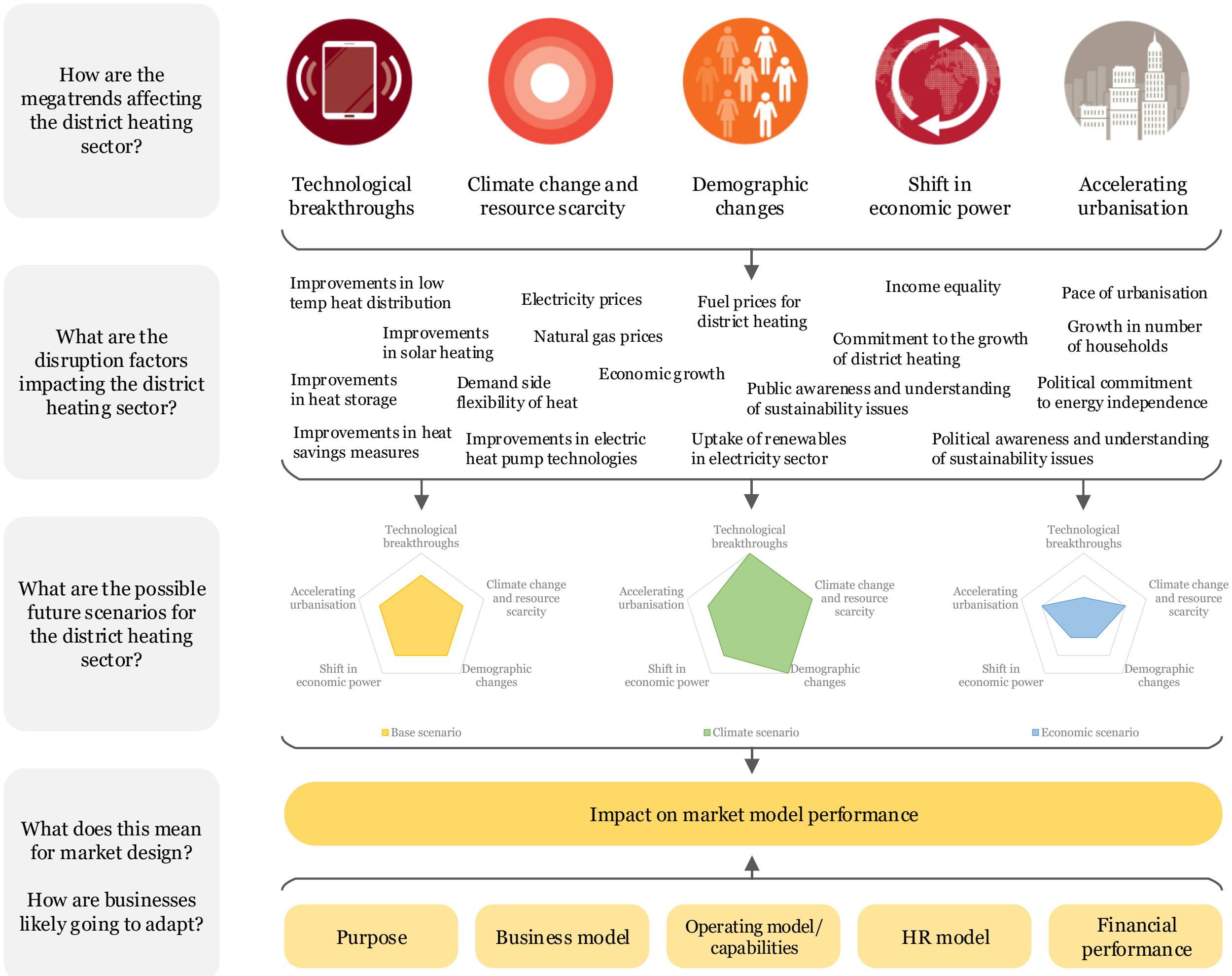

Figure 6-2: Illustration of how the megatrends are driving change in the disruptive factors impacting the district heating sector. Three scenarios illustrate how the megatrends might develop in the future. Depending on the scenario, the impact of the megatrends on the district heating sector's market model performance differs (adapted from: PwC, 2014).

Table 6-4: Future scenario of the district heating sector's market model performance – climate scenario.

Climate scenario	
Characteristics	**Consequences**
- Strong technological breakthroughs - Strong development of climate change and resource scarcity - Strong demographic changes - Moderate shift in economic power - Moderate progression of urbanization	Due to substantial improvements in low temperature heat distribution technologies and solar heating the costs of district heating using renewable energy sources is falling rapidly. Combined with a strong sense of urgency from both politics and the public is causing rapid growth in district heating networks and other more environmentally friendly forms of heating. Prices of heating rise moderately, but not to unacceptable levels. Thanks to moderate economic growth only vulnerable consumer

	groups require financial assistance to keep heating costs affordable.

Table 6-5: Future scenario of the district heating sector's market model performance – economic scenario.

Economic scenario	
Characteristics	**Consequences**
- Weak technological breakthroughs - Moderate development of climate change and resource scarcity - Weak demographic changes - Weak shift in economic power - Moderate progression of urbanization	Economic decline causes the public and politicians to place their priorities away from climate change and sustainability. Because of only minor investments into clean technologies and district heating systems technological breakthroughs remain out of reach. Therefore, the low temperature heat demand remains dominated by natural gas fired individual heating boilers with only small developments in the direction of sustainability. In the meantime the carbon footprint of the heating sector remains largely unchanged and the energy-dependency on natural gas imports for heating increases as domestic natural gas production declines.

6.4 Designing new market model configurations

In Section 2.6 the process of designing a new market model for the Dutch district heating sector was structured by using the 'meta-model' for design (see Figure 2-3). The meta-model consists of 5 research activities[27] of which 'designing alternative market models' is the fourth activity. The results of the first three research activities serve as inputs for the fourth research activity and have been described in chapter 3 to 5. Subsequently, in this chapter the guideposts for the actual 'design part' of the fourth research activity have been laid out being the manner in which the design effort is conducted (Section 6.1), the *principles of good market governance* to which the design effort must adhere (Section 6.2) and finally the considerations regarding how to design a market model that is *robust* to change (Section 6.3). In this section these guideposts are used to present *two new, distinct, market models* for the Dutch district heating sector which may facilitate the transition towards a more sustainable heat provision system with a key role for the district heating sector.

The FULDA-method questions aim at providing guidance to find the most optimal legal organization for the district heating sector. However, depending on the assumptions a policy maker makes regarding which arguments to adhere to, and which to dismiss, the FULDA-method questions may be answered in different ways. For example, a policy-maker could adopt the principle that heat, as a merit good, is of such an importance that large parts of the provision should be performed by public organizations. By choosing for public provision one can ensure that the policy goals for the district heating sector are met via direct control, but possibly the lack of competition between private firms will yield a lower market efficiency. Alternatively, a policy-maker could seek to stimulate competition there in the value chain that competition is possible, under the assumption that 'the market' is better equipped at providing heat efficiently than government is.

[27] The 5 research activities: (1) developing the goals, objectives and constraints, (2) developing the design space, (3) assessing the design space, (4) designing alternative market models, and (5) selecting the most promising market model (see Section 2.6).

The perspective on public provision is just one example of many, where answering the FULDA-method questions may differ according to the adopted perspective. Therefore, in this section two distinct perspectives are adopted which results in two new, distinct, market models for the Dutch district heating sector. These two perspectives are: (1) the 'Danish+ perspective' and (2) the 'Swedish+ perspective'. The perspectives taken and the resulting market models are described in Section 6.4.1 and Section 6.4.2 respectively.

6.4.1 Market model 1: 'Danish+ perspective'

The first market model is titled 'Danish+ perspective'. In this market model the Danish perspective on district heating is adopted. The plus sign indicates that in order to make the Danish perspective applicable to the Dutch district heating sector the perspective is adjusted for the Dutch institutional-economic and physical context. Choosing policy instruments for all the nine design variables was conducted according to the process described in Section 6.1. The 'Danish+ perspective' served as a starting-point and the 'principles of good market governance' and the 'considerations regarding designing robust market models' were also taken into account. The selection chart for market design of network industries (Figure 4-2) prescribes a certain order of preference in choosing policy instruments for the design variables. Although this was useful while designing the new market model, reporting in this section follows the order of the design variables for clarity and readability. In Table 6-6 an overview of the 'Danish+ perspective' market model is given. Below, the four FULDA-questions are answered for the nine design variables.

The FULDA-questions:

A. Should someone be made explicitly responsible for this function?
B. Who should be made responsible? Or: who should be allowed to perform this function?
C. How should the function be further organized?
D. What control possibilities for governments should be implemented?

1. Public versus private ownership

A. Within the district heating value chain three different roles may be distinguished: (1) production, (2) transmission, (3) distribution and delivery. For each of these roles one may ask: should someone be made explicitly responsible for this function? Although heat is considered a merit good in the Netherlands, there is no indication that public heat provision will perform higher service provision levels than private heat provision. Second, different modes of organizations exist in the Netherlands including vertical integration, single-buyer models and joint-venture models. There is no indication that one of these different modes of organization performs better than the other. Hence, it seems not *necessary* to make one organization *explicitly* responsible for a function. **B.** Moreover, all parties should be allowed to perform the different roles in the district heating value chain with one exception: electricity and natural gas distribution companies are not allowed to be active in the competitive activities of the district heating sector (production and retail) as this goes against their mandate found in law. **C.** Ownership regulation does not include considerations regarding how activities in the district heating sector must be conducted as this is included in other design variables. Since there are no parties excluded from ownership in the district heating sector there is no need for further organization. One exception is made for the network companies again who are supervised by the ACM. The ACM will control that network companies do not engage in the competitive activities of the district heating sector. **D.** Further control possibilities for government are not necessary.

2. Network access conditions (for producers, retail companies and consumers)

A. Three different parties require access to district heating networks: producers, retail companies and consumers. It is *necessary* to regulate the access conditions for producers and consumers because it is expected that their negotiation position is unequal to district heating network owners since these network owners hold a natural monopoly. Access by retail companies is not regulated because there is no indication that retail competition should be stimulated. The Danish+ perspective adheres to the argument that retail competition will not yield lower social costs because the relatively low number of connections causes it to be impossible to cover the increased overhead costs of having multiple retail companies. **B.** Requests from prospective producers to gain access to an existing district heating network should be assessed based on a lowest social costs principle. This means that prospective producers should gain access to existing district heating networks from network owners if prospective producers can provide heat at lower social costs than the existing heat producers can and that entering the market will lower social costs for consumers. Assessment of access requests by prospective producers should be assessed by the municipality because the assessment should be done by a neutral party which holds local knowledge of the heat provision system. Consumers should hold the right for access on a non-discriminatory basis to an infrastructure that can supply them with heat. Zoning is used to designate which areas receive district heating and which areas receive electricity or natural gas for their heating. The zoning decision is placed at the municipality as well who must consult the network companies for electricity and natural gas and the district heating companies in drafting their heat zoning plans. **C.** Assessment of access requests by prospective producers should be based on social cost benefit analyses that adheres to a standardized process defined on the national level, by the Ministry of Economic Affairs, in order for assessments to be conducted fair and transparent. Actual assessment of the project initiative itself should occur on a local level, because district heating projects are of a local to regional nature which requires local knowledge. Municipalities are the choice of government authority for this responsibility because they are both neutral and knowledgeable about their heat systems. Municipalities that lack the expertise should be supported by knowledge centers (at for example RVO) and larger municipalities with professional heat-and-cold policy departments such as the larger municipalities of Rotterdam and Amsterdam. Consumers do not have freedom of choice when zoning is used. Therefore, periodically consumer satisfaction surveys should be conducted to pick up signals of where service levels are performing well, and where attention is needed to improve the level service provided by the heat suppliers. **D.** The proposed system requires heavily on the well-functioning of the heat policy departments at municipalities. If such a department appears to be unequipped to handle access requests of prospective producers adequately, the Ministry of Economic Affairs should be able to *intervene*. Intervention could take the form of larger municipalities with more professional heat-and-cold policy departments supervising the work of smaller municipalities that are underperforming, or, even taking over the work of underperforming municipalities. The same holds for the zoning planning by municipalities. If government finds that zoning plans are inefficient or possibly even biased in favor of certain companies, the Ministry of Economic Affairs must be able to intervene in an appropriate and proportionate manner.

3. Network unbundling

A. In line with design variable one there is no indication that it is *necessary* to *explicitly* appoint a responsible actor for the network activities vis-à-vis the actors responsible for heat production and heat distribution and delivery. On the contrary, the relatively small number of connections limit economies of scale and require district heating companies to manage their risks carefully. One manner of doing this is vertical integration. Unbundling is however allowed, by the example of the Danes, so that companies who wish to use this mode of organization may do so freely. **B.** Both unbundling and vertical integration should be allowed. **C.** There is no need for further organization. **D.** There is no need for further control possibilities from government.

4. Integrated versus decentralized market

A. Different market matching mechanisms exist to match the heat demand and heat supply to each other. If there is no regulation, the default option is a decentralized market where demand meets supply through bilateral contracts. The question therefore here is: is it *necessary* to make an *explicit* choice between the default option and the other market matching mechanism possibilities? Because of the choices made in design variable two it is unlikely that congestion will occur because zoning allows for informed heat network dimensioning and lay-out. There is therefore no direct need to directly couple the technical and economic aspects of heat trade, hence the default option suffices. **B.** Not applicable. **C.** Rules should be added regarding the transparency of contracts from heat suppliers for bound-consumers. The contract requirements should be formulated in detail by the ACM. **D.** There is no need for further control possibilities of the government. If at some point in time the market matching mechanisms no longer satisfies the needs of the market, it may be re-evaluated (change of the legal framework).

5. Tariff regulation

A. It is *necessary* to *explicitly* regulate tariffs because with district heating bound-consumers are exposed to the risk of overcharging by their monopolist district heating suppliers. With respect to wholesale tariffs regulation is not deemed *necessary* because wholesale trade occurs between large producers and large consumers who have a better negotiation position than the oftentimes small bound-consumers. For the same reason network tariffs are also not regulated, however, for the network tariffs there should be supervision for non-discrimination. **B.** Regulating tariffs for protection of bound-consumers is a task for the ACM, guided by a legal framework and legislative mandate from the Ministry of Economic Affairs. For network tariffs supervision the same holds true. **C.** The institutional-context of the Dutch heat provision sector makes it hard to deviate from the price-cap regulation that is currently in place, the external benchmark of the NMDA principle. The case-studies of Denmark and Sweden and the conceptualization of the Dutch district heating sector have however shown that there is a need for tariff differentiation. Over the course of a certain time period tariff differentiation should be allowed by district heating companies within the bounds of a price-cap based on the costs of district heating (benchmarking). The time period may be the result of a negotiation between consumer organizations (owners associations and housing corporations) and district heating suppliers (e.g. Eneco & Nuon), moderated by the regulator (ACM). **D.** Government should be able to (1) set the tariffs in advance so that consumers and heat suppliers know what prices will be, (2) enforce the maximum costs defined by the ACM and (3) change the legal framework if it turns out that the new tariff structure causes problems for district heating companies or other stakeholders or strong discontent among consumers.

6. Congestion management method

A. From a theoretical point of view it is *necessary* to add a congestion management mechanism to the market design of an energy only market in order to provide sufficient incentives for adequate usage of the available transport capacities and investments into transport capacity expansion. Because of the decisions made in design variable two it is however unlikely that congestion will occur. Zoning allows for informed heat network planning and lay-out which makes it possible to dimension the networks as such that congestion will not occur. In addition, district heating allows for heat storage and heat flows are more easily predicted which makes it easier to design more robust network lay-outs. Hence, it is not necessary to add a congestion management method to the market model design. **B.** Not applicable. **C.** Not applicable. **D.** Government should monitor the usage of transport and distribution networks and if it seems that congestion does occur on a regular basis, especially in networks using the single-buyer model with multiple heat producers, government should be able to intervene: that is, consider the implementation of a congestion management method after all. This power should be located at the ACM, since congestion could form an inhibitor for wholesale competition and cause the network manager to have an unfair advantage over third party heat producers.

7. Integration with neighboring networks

A. The Danish case study informs that linking neighboring networks occurs when it is socioeconomically attractive. That is, when linking neighboring networks leads for example to economies of scale, the possibility of increasing the number of connections or increasing the environmental performance of the district heating companies (by unlocking renewable heat production). Given the fact that it is likely to occur on its own there is initially not a concern that is needed to regulate the integration with neighboring networks. It should however be stimulated because of the potential socio-economic benefits of linking neighboring networks to each other. **B.** Stimulation should be done as a multi-level-governance initiative with the Ministry of Economic Affairs as a coordinator. **C.** The already existing 'Green Deal' could be conducive in taking away barriers to linking networks (e.g. facilitating building permits or providing grants). **D.** No further control possibilities are deemed necessary.

8. Incentives for consumers of heat

A. Given the energy and climate goals of the Dutch government it is *necessary* to *explicitly* make an organization responsible for this design variable. **B.** The consumption of heat is a matter that falls under the responsibility of two Ministries: the Ministry of Economic Affairs and the Ministry of the Interior and Kingdom Relations. The Ministry of Economic Affairs is responsible for shaping the market conditions as such as is in her power so that 'the sustainable heating choice' is the most attractive one for consumers. The same holds for the Ministry of the Interior and Kingdom Relations, but is mainly directed at policies regarding buildings' energy efficiency as opposed to overall market conditions. **C.** The Danish case study made it unequivocally clear that attaining a more sustainable heat provision system and a larger district heating sector requires *commitment* from politics and the public. Energy prices must be adjusted using energy taxes as such to make district heating, but also electric heating, more attractive than natural gas fired heating. The recently implemented 'Investment Subsidies for Renewable Energy' for consumers (ISDE) and already existing energy efficiency building standards for new buildings may provide an additional stimulation for a transition to more sustainable alternatives for satisfying the heat demand. **D.** The government should periodically assess the performance of the market in terms of affordability, reliability and acceptability in order to gage whether it is necessary to change the regulatory framework. Possibly, the expected increases in energy prices may make it necessary to support vulnerable consumers financially in order to keep heating costs affordable.

9. Incentives for producers of heat

A. For the same reasons as for design variable eight it is *necessary* to *explicitly* make an organization responsible for this design variable. **B.** The production of heat is associated with the emissions of greenhouse gases and other polluting gases and the consumption of scarce resources. It is the domain of two Ministries: The Ministry of Economic Affairs and the Ministry of Infrastructure and the Environment. The Ministry of Economic Affairs is responsible for energy policy whereas the Ministry of Infrastructure and the Environment is responsible for climate policy and air and soil quality. **C.** The Ministry of Economic Affairs should adjust energy and coal taxes for heat producers as such to provide incentives to make the 'sustainable choice'. In addition, an obligation to use residual heat from industry and power plants usefully when economically feasible should be implemented. This should yield growth of CHP and connected to that district heating systems. Especially CHP based on biomass fuels, and possibly natural gas, are expected to perform well under such a regulatory framework. To support the growth of biomass CHP and biomass heat-only boilers the SDE+ could be used to compensate for the financial gap between biomass fired heat production and cheaper heat production alternatives. Moreover, two technologies should be added to the SDE+ which are geothermal heat production and large-scale solar heating. Large-scale heat producers that use fossil fuels as an energy source fall under the EU ETS. The Ministry of Infrastructure and Environment who manages the EU ETS dossier for the Netherlands should strengthen its efforts for a strong European Union Emission Allowance price for carbon so that a transition to non-carbon fuels may be stimulated. **D.** Government should continually monitor energy prices so that intervention in the regulatory framework may be conducted if need be. Coordination between the two Ministries is of great importance in this.

Table 6-6: Market model 1: 'Danish+ perspective'. The design variables that are shaded blue draw inspiration from the Danish market model, but are adapted to the Dutch institutional-economic and physical context.

Design variable	Chosen policy instrument(s)	Consequences and explanation
Regulating the district heating sector		
1. Public versus private ownership	Any interested party has the right to initiate a heat project. The municipality authority is responsible for *approval* of the projects. The market model allows for different modes of organization.	Currently, different modes of organization exist in the Dutch district heating sector, some with publicly owned heat suppliers, others with mainly privately owned heat suppliers. There is no indication that publicly owned heat suppliers deliver a better service provision level than privately owned heat suppliers, hence both shall remain allowed. The Danes have shown however that end-user ownership through energy collectives may increase the acceptance of district heating. Therefore, initiatives to form new energy collectives that will serve as heat suppliers or heat producers should be stimulated by municipalities.
2. Network access conditions (for producers, retail companies and consumers)	For producers: regulated access. If an interested producer wants to connect to the network his proposal must be approved by the local municipality. For retail companies: Not regulated. For consumers: Zoning.	Regulated access provides prospective district heating producers with the opportunity to connect to an existing district heating network if they meet certain criteria. Benefits include an increase in district heating because of the possibility to use untapped heat production capacity and lower social costs of district heating because of wholesale competition. On the other hand, there is the risk of crowding-out existing heat production capacity which may or may not lead to higher social costs than if there was no regulated access. Retail competition is allowed, but not stimulated since it is unlikely to cause lower tariffs because of the increase in transaction costs and the relatively low number of connections to compete over. Following the example of the Danes, zoning is used to prevent inefficient duplication of infrastructures and lay out district heating grids where it is economically most efficient, and natural gas and electricity grids where the latter are economically most efficient. Public concessions issued by the *municipality* enable *competition for the network* between different infrastructure and energy companies (electricity versus natural gas versus district heating).

3. Network unbundling	Not regulated. Unbundling is however allowed.	Network unbundling is not enforced. There is no indication that unbundling will lead to lower social costs in the district heating sector.
4. Integrated versus decentralized market	Decentralized market: bilateral contracts.	Same system as exists currently.
5. Tariff regulation	Price-cap regulation (external benchmarking: NMDA-principle) transitioning into price-cap regulation based on the costs of district heating (benchmarking). Allow for tariff differentiation in medium future.	The tariff regulation provides protection for bound-consumers from possible overcharging by heat suppliers. The time period of transitioning may be the result of a negotiation between consumer organizations (owners associations and housing corporations) and district heating suppliers (e.g. Eneco & Nuon), moderated by the regulator (ACM).
6. Congestion management method	Not regulated.	The possibility of congestion is slim, because the combination of public heat planning including 'zoning' and 'municipal project approval' (regulated access assessed by municipality) allows for careful planning of network lay-out.
7. Integration with neighboring networks	Not regulated, but certainly stimulated when deemed conducive for lowering the social costs of district heating or increasing the reliability of the service provision.	Occurs when deemed socio-economically beneficial on the initiative of relevant district heating stakeholders. 'Green deals' from the Ministry of Economic Affairs may be used to smooth the road towards integration if need be.
Steering the relative attractiveness of district heating versus other forms of heating		
8. Incentives for consumers of heat	Adjust the energy taxes as such to provide incentives for consumers to make the 'sustainable choice'. Evaluate the performance of the Investment Subsidies for Renewable Energy for consumers (ISDE).	Large growth of district heating and other alternatives to natural gas fired heating (e.g. electric heat pumps, heat and cold storage systems and solar heating).
9. Incentives for producers of heat	Adjust the energy and coal taxes as such to provide incentives for producers to make the 'sustainable choice'. Strengthen the subsidies for renewable heat in the SDE+ for biomass-based CHP and add geothermal heat and solar heating. Also include an *obligation* to use residual heat from industry and power plants usefully if economically feasible.	Foster the growth of CHP and connected to that district heating systems. Phase out CHP based on coal and increase share of CHP based on natural gas, biomass and waste. Because of the low amount of biomass fuel available domestically, reliance on CHP must not be too dominant. Geothermal heat and large-scale solar heating could offer promising energy sources instead.

6.4.2 Market model 2: 'Swedish+ perspective'

The second market model is titled 'Swedish+ perspective'. In this market model the Swedish perspective on district heating is adopted. The plus sign indicates that in order to make the Swedish perspective applicable to the Dutch district heating sector the perspective is adjusted for the Dutch institutional-economic and physical context. Choosing policy instruments for all the nine design variables was conducted in the same manner as was done for the 'Danish+ perspective' market model. In Table 6-7 an overview of the 'Swedish+ perspective' market model is given. Again, the FULDA-questions were useful in arriving at the choices for policy instruments for the nine design variables. For the purpose of brevity only the design variables that deviate from the Swedish market model are discussed here below.

Design variables 1, 2, 3, 4, and 6 follow the Swedish market model choices. The reason for that is because both the institutional-economic and physical context of the Dutch district heating sector do not form any objections to follow the same choices the Swedes have made for these design variables. For design variables 5, 7, 8 and 9 the Dutch institutional-economic and physical context do however lead to different answers on the FULDA-questions. Below, the arguments for the choices made for the latter four design variables are described.

5. Tariff regulation

A. It is *necessary* to protect bound consumers from potential overcharging by their heat suppliers. **B.** The ACM must define maximum prices based on an external benchmark so that heat may remain affordable. **C.** On the other hand, heat suppliers require room to differentiate their tariffs because the costs of heat delivery vary widely based on local conditions. Competition between networks will serve as a means to form competitive prices and products in the district heating sector. The price-cap serves as a maximum price which may not be exceeded. **D.** Periodic consultations of consumer organizations must show whether the prices that arise in the market are considered affordable. If not, the ACM must assess whether possible concerns justify government intervention.

6. Integration of neighboring networks

Adjusted to the Dutch institutional-economic and physical context in the same manner as was done in the 'Danish+ perspective' market model.

7. Incentives for consumers of heat.

Adjusted to the Dutch institutional-economic and physical context in the same manner as was done in the 'Danish+ perspective' market model.

8. Incentives for producers of heat.

Adjusted to the Dutch institutional-economic and physical context in the same manner as was done in the 'Danish+ perspective' market model.

Table 6-7: Market model 2: 'Swedish+ perspective'. The design variables that are shaded blue draw inspiration from the Swedish market model, but are adapted to the Dutch institutional-economic and physical context.

Design variable	Chosen policy instrument(s)	Consequences and explanation
Regulating the district heating sector		
1. Public versus private ownership	Not prescribed. Public and private ownership are both allowed.	Flexibility in modes of organization.
2. Network access conditions (for producers, retail companies and consumers)	For producers: regulated access based on lowest cost principle. For retail companies: not regulated. For consumers: no *obligation* to connect consumers, but consumers may *request* access against non-discriminatory terms.	Removes entry-barrier for heat producers and opens the door for wholesale competition along the lines of the single-buyer model. The lack of an *obligation* to connect leads to the most economically attractive consumers to be connected whereas other are not. These consumers can then choose to use an alternative form of heating or negotiate terms of access with their local heat supplier.
3. Network unbundling	Not regulated. Unbundling is however allowed.	Network unbundling is not enforced. There is no indication that unbundling will lead to lower social costs in the district heating sector.
4. Integrated versus decentralized market	Decentralized market: bilateral contracts.	Same system as exists currently.
5. Tariff regulation	Hybrid-system. Price-cap based on external benchmark which is set such that district heating suppliers can recuperate their costs. In addition, tariff differentiation is allowed and competition *between* networks serves as a means to form competitive prices and products in the district heating sector. The competition between networks serves to protect consumers to being overcharged by their monopolistic heat suppliers.	Price differentiation is also allowed, but discrimination is not. Therewith the district heating companies may charge different prices over pre-defined 'price regions' as long as these prices and terms are the same for all consumers within a price region. Prices may be lower than the price-cap, but not higher.
6. Congestion management method	Not regulated.	Congestion could arise in the future. The ACM should monitor the effects of possibly congested networks and assess the necessity of intervention periodically.
7. Integration with neighboring networks	Not regulated, same as 'Danish+ perspective'.	Same as 'Danish+ perspective'.
Steering the relative attractiveness of district heating versus other forms of heating		
8. Incentives for consumers of heat	Same as 'Danish+ perspective'.	Same as 'Danish+ perspective'.
9. Incentives for producers of heat	Same as 'Danish+ perspective'.	Same as 'Danish+ perspective'.

6.5 Synthesis: comparing the alternative market models' expected performance.

In this chapter an answer was sought for the fourth research question: "What market model designs for the Dutch district heating sector are expected to contribute best to the climate and energy goals of the Dutch government?" In pursuit of an answer to that question two market models were designed by using the FULDA-method while at the same time using the insights from the international case studies. Adopting respectively the Danish and Swedish perspectives on district heating two optimized market models were designed for the Dutch institutional-economic and physical context. In this section the resulting market model designs, the 'Danish+ perspective' and the 'Swedish+ perspective' are compared to each other to facilitate decision-making for policy makers. In addition, an assessment of the expected market model performance of the 'Danish+ perspective' and the 'Swedish+ perspective' is given. In Table 6-8 the two proposed market models are positioned next to the current Dutch market model for comparative purposes. Table 6-9 shows how the three distinct market models are expected to perform on the Dutch policy goals and on the 'principles of good market governance'.

In Table 6-8 the proposed market models' differences with the Dutch market model are shaded in blue when unique to the proposed market model and orange when different from the Dutch market model, but similar to the other proposed market model. This distinction illustrates that for four design variables no changes are suggested with respect to the current Dutch market model. These design variables are (3) network unbundling, (4) integrated versus decentralized markets, (6) congestion management, and (7) integration with neighboring networks. Answering the FULDA-questions for these four design variables resulted in the same answer that is currently adhered to in the current Dutch, Swedish and Danish market model: there is no further regulation needed (see Table 5-4). For the other five design variables the proposed market models *do* prescribe to change the policy instruments chosen.

Public versus private ownership. In all three market models both public and private actors are allowed to own and operate all parts of the district heating value chain. In the 'Danish+ perspective' market model ownership and operation is however dependent on *municipal approval*. The Dutch municipalities are made responsible for making heat plans in which the municipality assesses which (1) heat provision alternative to provide to which area (see zoning under network access conditions) and (2) which district heating project is approved, and which is not. Public heat planning has as benefit that the district heating sector's business case and investment security increases because of a higher level of security of demand and supply. In turn, this is expected to lead to growth of the district heating sector. On the other hand, it is uncertain whether public heat planning will yield the most cost efficient distribution of heat provision alternatives.

Network access conditions. The 'Danish+ perspective' market model choice could be characterized as a form of *public push* of district heating whereas the 'Swedish+ perspective' market model choice could be characterized a form of *private carte blanche* for district heating companies. The first market model will likely result in strong growth of district heating networks that occurs in a *planned* manner, whereas the second market model will likely also result in growth of the district heating network, but in a much more *emergent* manner. Energy companies will assess the economic attractiveness of district heating per area and as a result of that assessment district heating will grow in only these areas where it can outcompete natural gas and electric alternatives. The first market model therefore provides more control for the government whereas the second market model holds a more emergent character for the district heating sector.

Tariff regulation. The most important difference between the two market models arguable lies in the manner of tariff regulation. Both proposed market models acknowledge the legacy of the price-cap based on the external benchmark based on the not-more-than-otherwise-principle and propose a transition to a system that is more appropriate for the Dutch energy and climate goals for the heat provision sector. However, whereas in the first market model the heat price is set by the ACM, in the second market model the heat price will be a result of *competition between networks*, although capped by a maximum price set by the ACM. The latter system is expected to be more profitable for district heating suppliers, but the first provides more security because of the choice for zoning.

Incentives for consumers and producers of heat. In both proposed market models the same instruments are recommended to steer the relative attractiveness of district heating versus alternative forms of heating. By implementing a favorable mix of taxes, subsidies and obligations the attractiveness of district heating may be increased. The height of the taxes and subsidies and the stringency of the obligations will determine the pace of the growth of the district heating sector. This is however for a large part a *political choice*. How much will the heat price be allowed to rise? But also, related to the choice of tariff regulation: what level of tariff differentiation will be considered acceptable? How ambitious are the targets for increasing energy independence and lowering emissions greenhouse gases?

Concluding remarks

This chapter has presented two new market models for the district heating sector of the Netherlands which will facilitate a transition towards a more sustainable heat provision sector. Within the proposed market models there is still substantial room for differentiation, for instance with regards to political choices such as the height of taxes. Choosing a 'winner' between the two proposed market models remains however difficult. The expected performance of the proposed market models detailed in Table 6-9 is insufficient to appoint a 'clear winner'. Furthermore, the assumptions underlying the 'Danish+ perspective' and the 'Swedish+ perspective' are different. Depending on the assumptions one holds regarding the feasibility and implications of design choices one may be more inclined to adopt either the 'Danish+ perspective' or the 'Swedish+ perspective' as the most promising market model for attaining the Dutch climate and energy goals. In this thesis I therefore refrain from selecting 'the most promising market model'. Instead, this thesis offers policy makers two perspectives which will both lead to the growth of the district heating sector and facilitate the transition towards more sustainable practices in the larger heat provision system.

In order to arrive at more precise expectations of the proposed market models' performance one must go beyond the theoretical and empirical insights provided in this thesis. An appropriate approach would be to assess the impact of the proposed market models on the district heating sectors' performance by means of *modelling and simulation* or *real-world pilots*. This is a task for future research which will be reflected on in Chapter 8.

Table 6-8: Comparison between the proposed market models and the Dutch market model. The blue-shaded cells represent choices for the design variables that differ from the Dutch market model. The orange-shaded cells represent choices for the design variables that differ from the Dutch market model, but are the same in Market model 1 and Market model 2.

Design variable	Dutch market model	Market model 1 'Danish+ perspective'	Market model 2 'Swedish+ perspective'
Regulating the district heating sector			
1. Public versus private ownership	Not prescribed. Public and private ownership are both allowed.	Any interested party (both public and private) has the right to initiate a heat project. The municipality authority is responsible for *approval* of the projects.	Not prescribed. Public and private ownership are both allowed.
2. Network access conditions (for producers, retail companies and consumers)	Producers: no regulation. Retail companies: not defined. Consumers: obligation to connect to electricity and natural gas. Bound-heat-consumers *must* pay the fixed part of the connection costs.	For producers: regulated access. Access request/ project proposal must be approved by the local municipality. For retail companies: Not regulated. For consumers: Zoning.	For producers: regulated access based on lowest cost principle. For retail companies: not regulated. For consumers: no *obligation* to connect consumers, but consumers may *request* access against non-discriminatory terms.
3. Network unbundling	Not regulated. Unbundling is however allowed.	Not regulated. Unbundling is however allowed.	Not regulated. Unbundling is however allowed.
4. Integrated versus decentralized market	Decentralized market: bilateral contracts.	Decentralized market: bilateral contracts.	Decentralized market: bilateral contracts.
5. Tariff regulation	End-user price regulation following the 'not-more-than-otherwise' principle.	Price-cap regulation (external benchmarking: NMDA-principle) transitioning into price-cap regulation based on the costs of district heating (benchmarking). Allow for tariff differentiation in medium future.	Hybrid-system. Price-cap based on external benchmark which is set such that district heating suppliers can recuperate their costs. In addition, tariff differentiation is allowed and competition *between* networks serves as a means to form competitive prices and products in the district heating sector. The competition between networks serves to protect consumers to being overcharged by their monopolistic heat suppliers.
6. Congestion management method	Not regulated.	Not regulated.	Not regulated.
7. Integration with neighboring networks	Not regulated, but certainly stimulated. Example: the heat roundabout South-Holland.	Not regulated, but certainly stimulated.	Not regulated, but certainly stimulated.
Steering the relative attractiveness of the district heating sector			
8. Incentives for consumers of heat	Investment subsidy for renewable energy (consumers and 'small and medium enterprises'); energy taxes.	Adjust the energy taxes as such to provide incentives for consumers to make the 'sustainable choice'. Evaluate the performance of the Investment Subsidies for Renewable Energy for consumers (ISDE).	
9. Incentives for producers of heat	Among others: SDE+, geothermal energy subsidies, EIA (see also Table 1-1)	Adjust the energy and coal taxes as such to provide incentives for producers to make the 'sustainable choice'. Strengthen the subsidies for renewable heat in the SDE+ for biomass-based CHP and add geothermal heat and solar heating. Also include an *obligation* to use residual heat from industry and power plants usefully if economically feasible.	

Table 6-9: Comparison of the expected performance of the proposed market models with the performance of the Dutch market model.

Performance indicator	Dutch market model	Market model 1 'Danish+ perspective'	Market model 2 'Swedish+ perspective'
More reliable district heating			
Average duration of service interruptions in minutes Number of service interruptions per year over 1000 connections	Statistics not available. District heating systems are considered reliable.	Statistics not available. In Denmark District heating systems are considered reliable.	Statistics not available. In Sweden District heating systems are considered reliable.
Percentage of heat provision based on natural gas	Irrelevant for now.	Irrelevant for now.	Irrelevant for now.
Coverage level of potential heat consumers	4% (Euroheat & Power, 2015)	Strong growth expected.	Strong growth expected.
More affordable district heating			
Variable heating costs (including VAT)	Maximum price: 22,66 €/GJ (ACM, 2016) No price differentiation.	Judging the performance of the Danish market model the prices for heating are expected to rise (see Table 5-5 for indication Danish market model performance).	Judging the performance of the Swedish market model the average price is expected to remain stable, but price differentiation will be relatively large. (see Table 5-5 for indication Swedish market model performance).
More acceptable district heating			
Percentage of renewable heat production	80% (Euroheat & Power, 2015)	Strong growth expected. More (biomass) CHP and use of renewable heat sources.	Strong growth expected. More (biomass) CHP and use of renewable heat sources.
Fraction of energy used usefully in heating systems	Irrelevant for now.	Irrelevant for now.	Irrelevant for now.
Emissions of CO_2 in ton per year*	Irrelevant for now.	Irrelevant for now.	Irrelevant for now.
Principles of good market governance			
Goal A: "To minimize the regulatory uncertainty for market parties."	Good	Good	Good
Goal B: "To ensure the internal and external consistency of the legal organization."	Moderate	Moderate	Moderate
Goal C: "To equip government with the flexibility needed to cope with the dynamics of both market performance and policy objectives."	Moderate	Good	Moderate

7 Conclusions and recommendations

Driven by climate policies, a decreasing availability of domestic natural gas resources and the risks of energy import dependency from politically-unstable regions, the Dutch government is investigating pathways towards a more sustainable provision of heat. To that end, in this thesis two new market models for the district heating sector were developed. Both proposed market models will (1) facilitate the growth of the district heating sector including the use of more renewable heat production, and (2) provide an appropriate regulatory framework for the district heating sector taking into account the interests of key stakeholders. In this chapter the conclusions (Section 7.1) and recommendations (Section 7.2) of this thesis are discussed.

7.1 Conclusions

The aim of this thesis is to develop a new market model for the Dutch district heating sector that is aimed at facilitating a transition towards a more sustainable heat provision system. In the *central research question* this is formulated as follows:

> **What should a new market model for the district heating sector of the Netherlands look like so that it will facilitate a transition towards more sustainable practices?**

In order to find an answer to the central research question four additional research questions were defined. These research questions are:

1. What are the *goals*, *objectives* and *constraints* for which a market model for the Dutch district heating sector has to be designed?
2. What is the design space for reshaping the market conditions for heat provision as a whole and restructuring the market design of the district heating sector?
3. What insights can be gained from international experience with alternative market models for heat provision and the district heating sector specifically?
4. What market model designs for the Dutch district heating sector are expected to contribute best to the climate and energy goals of the Dutch government?

The *goals, objectives and constraints* for which a market model for the Dutch district heating sector was designed are an operationalization of the public goals of *reliability, affordability* and *acceptability (*the three A's). By operationalizing the three A's it was possible to define the performance indicators against which the market models were assessed. Together, the performance indicators form the *evaluative framework* of the market model performance of the district heating sector.

Developing the *design space* for the district heating sector led to the identification of nine *design variables* for which choices have to be made to define new market models. Of these nine design variables the first seven are directed at *regulating the district heating sector* while the last two are directed at *steering the relative attractiveness of district heating versus other forms of heating*. Table 7-1 gives an overview of the design variables. In addition to the design variables, the most relevant policy instruments between which choices had to be made per design variable were identified. Together, the design variables and their respective policy instruments form the design space for a new market model for the district heating sector.

Table 7-1: Design variables for the design of a new market model for the Dutch district heating sector.

Design variables
Regulating the district heating sector
1. Public versus private ownership
2. Network access conditions (for producers, retail companies and consumers)
3. Network unbundling
4. Integrated versus decentralized market
5. Tariff regulation
6. Congestion management method
7. Integration with neighboring networks
Steering the relative attractiveness of district heating versus other forms of heating
8. Incentives for consumers of heat
9. Incentives for producers of heat

In order to go beyond the theoretical insights provided by the identification and exploration of the design space *international case studies* were conducted. The case studies served to learn more about how the policy instruments identified in the design space performed in practice. These insights provided empirical arguments for choosing the most promising policy instruments for a new market model for the Dutch district heating sector. In addition the case studies provided inspiration to both expand and prune the design space and enriched the arguments for and against specific policy instruments. The district heating sectors of Sweden and Denmark were thoroughly investigated for this purpose.

Finally, two new, distinct, market models for the Dutch district heating sector were designed directed at (1) facilitating the growth of the district heating sector including the use of more renewable heat production, and (2) providing an appropriate regulatory framework for the district heating sector taking into account the interests of key stakeholders. The reason for designing two distinct market models instead of one optimized market model is because depending on the assumptions one makes regarding the arguments for and against specific policy instruments, one may come to different conclusions. Two sets of assumptions, or perspectives, were taken as input for the designs: the 'Danish+ perspective' and the 'Swedish+ perspective'. An overview of the two market models that resulted from adopting these perspectives is given in Table 7-2.

Market model 1: 'Danish+ perspective'.

In this market model the Danish perspective on district heating is adopted. The plus sign indicates that in order to make the Danish perspective applicable to the Dutch district heating sector the perspective is adjusted for the Dutch institutional-economic and physical context. Assumptions in the Danish+ perspective include that heat is a 'merit good' and as such the government should play an important role in securing its provision. In the designing process this meant that 'public provision' options were preferred over 'private provision' options, e.g. 'zoning' versus no obligations or regulation regarding the network access conditions for consumers.

Table 7-2: Overview of the proposed market models and the Dutch market model. The blue-shaded cells represent choices for the design variables that differ from the Dutch market model. The orange-shaded cells represent choices for the design variables that differ from the Dutch market model, but are the same in Market model 1 and Market model 2.

Design variable	Dutch market model	Market model 1 'Danish+ perspective'	Market model 2 'Swedish+ perspective'
Regulating the district heating sector			
1. Public versus private ownership	Not prescribed. Public and private ownership are both allowed.	Any interested party (both public and private) has the right to initiate a heat project. The municipality authority is responsible for *approval* of the projects.	Not prescribed. Public and private ownership are both allowed.
2. Network access conditions (for producers, retail companies and consumers)	Producers: no regulation. Retail companies: not defined. Consumers: obligation to connect to electricity and natural gas. Bound-heat-consumers *must* pay the fixed part of the connection costs.	For producers: regulated access. Access request/ project proposal must be approved by the local municipality. For retail companies: Not regulated. For consumers: Zoning.	For producers: regulated access based on lowest cost principle. For retail companies: not regulated. For consumers: no *obligation* to connect consumers, but consumers may *request* access against non-discriminatory terms.
3. Network unbundling	Not regulated. Unbundling is however allowed.	Not regulated. Unbundling is however allowed.	Not regulated. Unbundling is however allowed.
4. Integrated versus decentralized market	Decentralized market: bilateral contracts.	Decentralized market: bilateral contracts.	Decentralized market: bilateral contracts.
5. Tariff regulation	End-user price regulation following the 'not-more-than-otherwise' principle.	Price-cap regulation (external benchmarking: NMDA-principle) transitioning into price-cap regulation based on the costs of district heating (benchmarking). Allow for tariff differentiation in medium future.	Hybrid-system. Price-cap based on external benchmark which is set such that district heating suppliers can recuperate their costs. In addition, tariff differentiation is allowed and competition *between* networks serves as a means to form competitive prices and products in the district heating sector. The competition between networks serves to protect consumers to being overcharged by their monopolistic heat suppliers.
6. Congestion management method	Not regulated.	Not regulated.	Not regulated.
7. Integration with neighboring networks	Not regulated, but certainly stimulated. Example: the heat roundabout South-Holland.	Not regulated, but certainly stimulated.	Not regulated, but certainly stimulated.
Steering the relative attractiveness of the district heating sector			
8. Incentives for consumers of heat	Investment subsidy for renewable energy (consumers and 'small and medium enterprises'); energy taxes.	Adjust the energy taxes as such to provide incentives for consumers to make the 'sustainable choice'. Evaluate the performance of the Investment Subsidies for Renewable Energy for consumers (ISDE).	
9. Incentives for producers of heat	Among others: SDE+, geothermal energy subsidies, EIA (see also Table 1-1)	Adjust the energy and coal taxes as such to provide incentives for producers to make the 'sustainable choice'. Strengthen the subsidies for renewable heat in the SDE+ for biomass-based CHP and add geothermal heat and solar heating. Also include an *obligation* to use residual heat from industry and power plants usefully if economically feasible.	

Market model 2: 'Swedish+ perspective'.
In this market model the Swedish perspective on district heating is adopted. The plus sign indicates that in order to make the Swedish perspective applicable to the Dutch district heating sector the perspective is adjusted for the Dutch institutional-economic and physical context. Assumptions in the Swedish+ perspective include that although heat is considered a 'merit good', the private sector is thought to be able to provide heat services in the most efficient manner. In the design process this meant that 'private provision' options were preferred over 'public provision' options. An example includes the choice that *competition between networks* determines which infrastructure serves which customers and must secure appropriate tariffs and heat delivery services as opposed to public variants such as zoning and tariff regulation (e.g. cost-plus).

Expected market model performance and limitations
In both market models the district heating sector is expected to grow with the share of renewable heat production increasing as well. Furthermore, the average price is expected to rise in the 'Danish+ perspective' market model and a moderate amount of tariff differentiation will be introduced. In the 'Swedish+ perspective' market model the average price of heat remains relatively stable, but a larger amount of tariff differentiation is expected. The expectations about the future performance of the Dutch district heating sector presented in this thesis are however insufficiently substantiated and precise to be able to compare which perspective will perform better. Furthermore, the performance of the market models is largely dependent on political choices and trade-offs between variables which could not be incorporated in the design and thus also not in the market models' expected performance. Therefore this thesis does not choose a 'winner' out of the two proposed market models, but instead shows two feasible market models which both are able to attain the Dutch energy and climate goals if there is sufficient *political commitment*.

The two proposed market models do however leave room for *differentiation* within the chosen policy instruments regarding choices such as the height of subsidies and taxes or the manner in which the chosen tariff regulation system is further defined. Therefore, the market models should not be interpreted as blue-prints for the new market model for the Dutch district heating sector, but instead, as regulatory frameworks with clear lines which may be colored in further. Policy makers should define the further regulation in a *transparent* manner by making use of *stakeholder consultations* and clearly presented arguments.

Empirical contributions
The process of designing the two new proposed market models for the Dutch district heating sector was based on both theoretical insights and empirical insights from the international case studies. It was the latter that provided a novel view on how to regulate the Dutch district heating sector. The most important contributions from the case studies were:

- The empirical evidence for the actual benefits and costs for a selection of policy instruments when applied in practice.
- Inspiration for the combination of policy instruments which go well together.
- An enriched understanding of Dutch, Swedish and Danish district heating stakeholder views on the benefits and costs of a selection of policy instruments for the district heating sector.
- An enriched understanding of what 'makes or breaks' the business case of district heating according to Dutch, Swedish and Danish district heating stakeholders.

Scientific contributions

In his dissertation Knops postulated that the FULDA-method could not only be used for the legal design of *technical functions*, but also for the legal design of *institutional-economic functions*. This thesis tested the practicability and usefulness of the FULDA-method by applying it to the design variables for the market model for the Dutch district heating sector. Although the design variables are not *institutional-economic function* in a strict sense, the FULDA-method was still very useful in guiding the selection of the most appropriate policy instruments per design variable to regulate the district heating sector. It also showed however that the FULDA-method is not able to yield a 'best design' when the assumptions underlying the design choices are not fully free from ambiguity – that is, when there exists discussion on which assumptions should be made regarding the pro's and con's of specific policy instruments. The method still proved useful, but the design process had to be conducted twice to account for conflicting perspectives on what is the appropriate manner in which the district heating sector should be regulated.

In addition, this thesis has reaffirmed the usefulness of the meta-model design approach in structuring the design process and providing a systematic method to attain an institutional design for a complex (infrastructural) socio-technical system. Moreover, the sector in question, the district heating sector, is a sector for which the meta-model design approach had not been applied before very often.

7.2 Recommendations

This section discusses two topics (1) how to optimally use the results of this thesis and (2) next steps policy-makers and researchers could take to build on the presented research.

1. **How to optimally use the results of this thesis**

Despite the fact that there are insufficient substantiated arguments to state that the expected performance of one of the proposed market models is better than the other, it is possible for policy-makers to choose one of the proposed market models to work with and define further since both models support the realization of the Dutch energy and climate goals. I would recommend the policy maker to assess which assumptions underlying the two market models the policy maker deems the most accurate representation of reality. Consequently, the policy maker can choose to work with either the 'Danish+ perspective' or the 'Swedish+ perspective'.

Defining the further regulation of a chosen market model, or in other words, filling in the still present room for differentiation should be done in a *transparent* manner. Consultations with stakeholders in the district heating sector may provide feedback to the policy maker on what issues should be incorporated in the further regulation, and which should be omitted. Stakeholders inquired should include both public and private stakeholders.

2. **Next steps for policy-makers and researchers**

In order to improve the assessment of the expected performance of the proposed market models one must go beyond the theoretical insights and empirical evidence given in this thesis. One promising approach is the use of *modelling and simulation*. Currently, the Ministry of Economic Affairs is developing a calculation model in cooperation with relevant district heating stakeholders called the VESTA+ model. VESTA+ will allow the assessment of the impact of district heating projects on all the performance indicators mentioned in the evaluative framework. The Ministry should consider adapting the VESTA+ model such so that the proposed market models' impact may be tested in the model.

In order to gain more empirical insights from alternative market models researchers could perform more international case-studies. Building on the presented research two approaches could be adopted:

1. Conducting case studies on the same level in order to gain more insights regarding the pro's and con's of the policy instruments from the design space in practice. Possibly these insights could also provide inspiration for expansion of the design space and/or morphological hart.
2. Conducting case studies that focus on specific design variables. Case studies directed at specific design variables such as for instance tariff regulation can yield more insights on how to define the further regulation of a selected policy instruments.

Countries that are eligible for further case-studies include, but are not limited by, Germany, Austria and Poland. Moreover, when zooming in on specific design variables (approach 2) Denmark and Sweden also still offer more insights to learn from.

8 Reflection

In this chapter I reflect on the research presented in this thesis. The reflection consists of two parts: (1) a reflection on the research results, (2) a reflection on the quality of the results – described respectively in Section 8.1 & 8.2.

8.1 Reflection on the research results

In order to reflect on the success of the research study we must revisit the goal of this research study, which was formulated as follows:

"To contribute to the development of a new market model for the district heating sector of the Netherlands that is aimed at facilitating a transition towards a more sustainable heat provision system".

Through an extensively described, structured, design process I was able to design two new alternative market models for the Dutch district heating sector that will facilitate the growth of the district heating sector, including more renewable heat production, and the transition towards a more sustainable heat provision system in general. Based on the presented research it was however not possible to select one 'best' design. The reason for that was that the expected performance of the two proposed market models was insufficiently substantiated and precise to enable me to conduct a proper semi-quantitative multi-criteria decision analysis, which was initially the plan. In addition, I found that for a large part the expected performance of the proposed market models is dependent on political choices, which I cannot make in this thesis, nor give reliable future predictions about.

Although there were good reasons not to select a preferred design, I was able to give recommendations on how to cope with this 'limitation' of the research study. Two practical recommendations were given. The first advice is to assess to which assumptions about the pro's and con's for specific design choices the policy maker adheres to best, and on the basis of that choose his or her preferred market model design. The second advice is to use modelling and simulation to gain more substantiated and precise expectations about the future market model performance of the proposed market models. Since the Ministry of Economic affairs is currently already developing a model which will be suitable for this purpose with only minor adaptations (the VESTA+ model) this advice is very much practicable.

This research distinguishes itself from most other research studies into how to design the market model for the district heating sector of the Netherlands through its *scope*. Where many other research studies focus on specific design variables such as third party access (Lisa, PwC) or tariff regulation (…), this research study aimed to conceive a new market model design spanning the entire regulatory framework of the district heating sector. This research choice is a strength of the research as it provides a comprehensive overview of the regulatory framework of the district heating sector which made it possible to take into account interdependency issues between design variables and shed new light on which design choices really matter, and which are of less importance. On the other hand, the scope of the research made it *necessary* to design on a higher level of the regulatory framework, meaning that the further regulation is not fully defined in this research which leaves room for differentiation. As a result, the proposed research designs are not blue-prints which policy makers can implement directly in the district heating sector. However, I argue that this is not a flaw but a strength. The remaining room for differentiation offers an opportunity to define the further regulation further in consultation with the district heating sector instead of top-down prescribing the new regulatory framework. Consulting the district heating stakeholders for this part of the regulatory framework will lead to more informed policy choices and a higher likelihood that the new regulatory framework will be accepted by the majority of stakeholders. This will likely result in a better functioning regulatory framework.

8.2 Quality of the results

In this section I reflect on the reproducibility and the internal and external validity of the presented research. The internal validity of the research pertains to whether the design choices and conclusions follow logically from the presented arguments. The external validity of the research pertains to whether the design choices and conclusions are valid not only in theory, but also in practice.

Reproducibility

Scientific research must be reproducible which means that other researchers should be able to repeat the research study and be able to check whether they arrive at the same results. To that end, the design process in this research study was structured using the proven 'meta-model for design'. The meta-model for design consists of five research activities which together guided the process of designing a new market model for the district heating sector. These research activities made it easier to work in a systematic way towards conceiving a new market model for the district heating sector. Moreover, it also supported the reporting of the design process in a logical manner.

The most important design choices in the design process involved selecting the policy instruments for each of the nine design variables and combine the selected policy instruments into coherent 'packages' to form new market models. To guide this selection process the FULDA-method was used. Every design choice for the new market models was justified by answering the four FULDA-method questions of step 3 of the FULDA-method and was extensively reported fostering reproducibility of the research study.

The sources used to make the design choices and eventually arrive at the conclusions and recommendations were mostly public sources and for a small part confidential documents. A mixture of academic sources and grey literature (reports, white-papers, opinion statements, etc.) were used. In addition, four semi-structured interviews were conducted with Swedish district heating stakeholders and a range of informal interviews with Dutch district heating stakeholders were conducted as well. The interviews with the Swedish district heating stakeholders were recorded and are available with the author.

Internal validity

The results of the research study must logically follow from the arguments given during the design process. To that end, I periodically checked my design choices and initial findings with my academic supervisor (Laurens de Vries) and policy supervisor (Mark Driessen). The discussions and feedback both supervisors provided me with enriched my understanding of the district heating sector and its regulatory framework which allowed me to sharpen my analyses and improve my justifications for design choices.

Next to discussions with my direct supervisors I have also checked my initial hypotheses about how the district heating sector should be regulated with district heating stakeholders through informal discussions and the semi-structured interviews. For example the questionnaire submitted to the Swedish district heating stakeholders was informed by my analysis of the Swedish district heating sector. This allowed me to check whether my analysis was correct, and whether it was complete. This enabled me to conduct the design process in a reflective manner in such a way that as insights progressed previous design choices could be improved.

To test my initial findings in a more formal manner I gave a presentation to the 'power rangers-team' of the section of Energy & Industry at the Faculty of Technology, Policy and Management. The power rangers team is a group of researchers that conducts research regarding a range of topics related to the electricity sector, but also the larger energy sector as a whole. The feedback the researchers provided me with allowed me to reassess the focus of the research study and realign my research priorities. Specific feedback included for example which design variables to include and which I could also omit.

External validity

Assessing whether the arguments made for the two proposed new market models hold in practice is a difficult task. To that end, two approached were taken. The first approach was to ensure that the internal validity of the research was as high as possible, which has been described in the previous paragraph. The second approach was to assess the *expected* market model performance of the two proposed market models for the Dutch district heating sector.

The expected performance of the policy instruments was formulated based on *theoretical arguments* drawn from literature and *empirical evidence* drawn from the international case studies. The problem with that is that both types of arguments can only in part account for the Dutch institutional-economic and physical context in which the proposed market models have to perform. Therefore, the expected performance was judged as insufficiently substantiated and precise to draw hard conclusions and enable selection of a 'best' design. However, as mentioned before, this research does give practicable recommendations how to improve the assessment of the expected performance of the proposed market models. Due to time and scope constraints these recommendations are however a topic for further research and are not worked out further in this thesis.

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Appendix A: Stakeholder analysis

In this Appendix first the goals and means of the dossier owner, the Ministry of Economic Affairs (specifically the Directorate General Energy, Telecom and Competition, hereafter abbreviated as DG-ETC) are discussed in Appendix A-1. Subsequently, the main stakeholders regarding the reforms in the market model of the (district) heating sector are identified in Appendix A-2. Finally, the main stakeholders are organized in a power/interest matrix to better understand how to approach the different stakeholders.

Appendix A-1: The goals and means of the Ministry of Economic Affairs' DG-ETC

Within the Ministry of Economic Affairs the 'Directorate General Energy, Telecom and Competition' (DG-ETC) is responsible for national energy and therewith heat policy. Figure A-1 schematically depicts in a goal tree how the Ministry interprets the public goals of *availability, affordability and acceptability*, also known as the '3 A's'. At the top the main goal of the Directorate is shown being 'securing sustainable heat provision'. By moving down the 'tree' from the top to the trunk, the goals of the Directorate are explicated via sub-goals and eventually operational goals. The operational goals are *measurable* goals which may be used as *performance indicators* to measure the system's performance. The arrows indicate the relations between the goals, that is, to which higher goal the lower goals contribute.

To achieve the goals for the heat sector depicted in Figure A-1 the Dutch government employs a great number of policy instruments – see Table 1-1 for examples of policy instruments used per sector. Figure A-2 schematically depicts specific policy instruments and categories of policy instruments which are at the Dutch government's disposal to steer the (district) heating sector. Some of these policy instruments are under direct control of the Ministry of Economic Affairs, others, are owned by other public organizations such as the Authority, Consumer and Markets (e.g. setting the tariffs in the district heating sector) and the Ministry of the Interior and Kingdom Relations (e.g. instruments directed at stimulating energy efficiency in the built environment). What all these means however share in common is that they are all part of the description of the 'market model' of the Dutch heat provision system and in particular the district heating sector.

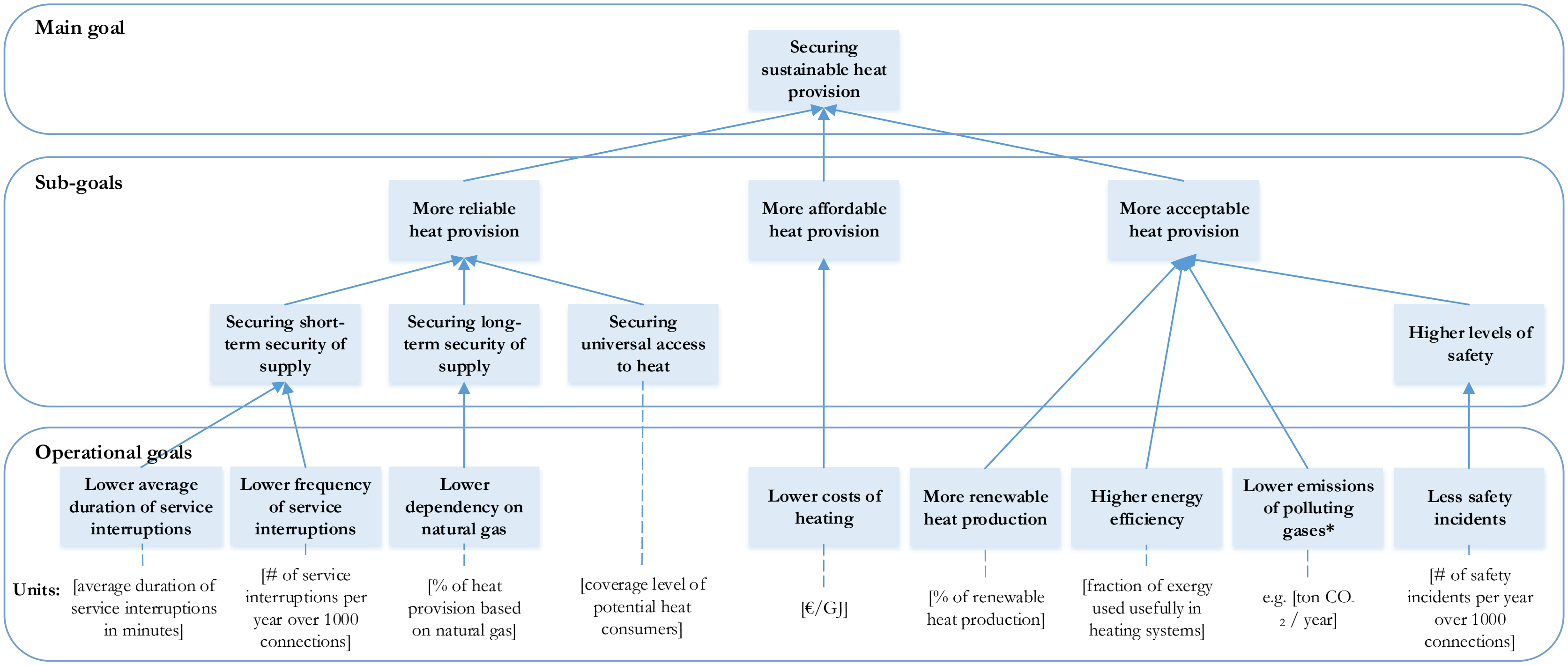

Figure A-1: Goal tree for the Directorate General Energy, Telecom and Competition with respect to heat policy.

**Polluting gases include NO_x, CO_x (particularly CO_2), PM_x (particulate matter) and other gases such as SO_x. The allowed emissions for these gases are defined by the Ministry of Infrastructure and Environment. The Directorate General must take into account the aim to lower emissions of polluting gases when designing policies for the heat sector.*

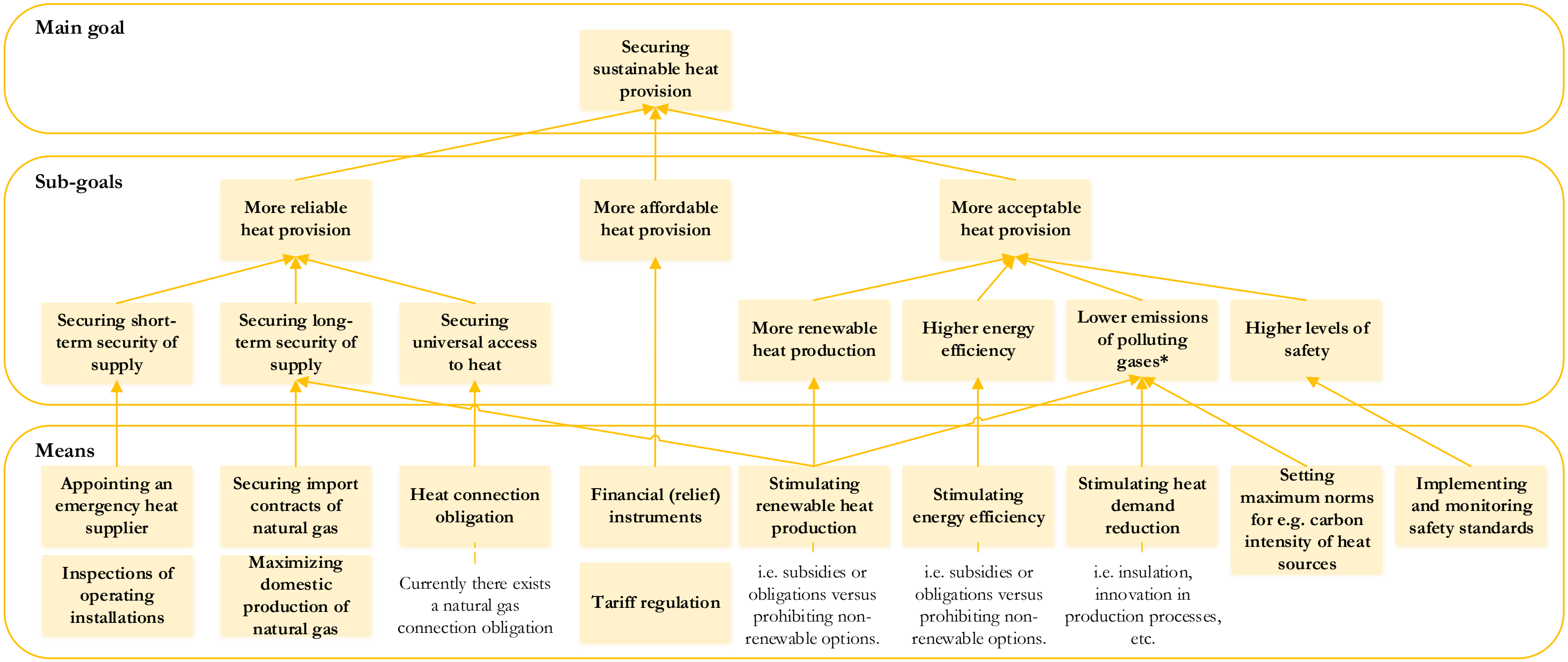

Figure A-2: Means-ends diagram for the Directorate General Energy, Telecom and Competition with respect to heat policy.

Appendix A-2: Identifying the main stakeholders in the District Heating sector

The stakeholder identification showed that there are a large number of actors from different fields that have stake in the (district) heating regulation. Based on the importance the (district) heating regulation holds to these different actors and their respective power to influence the policy process *seventeen* different stakeholders/stakeholder groups were identified. Table A-1 introduces the stakeholders and organizes them based on three types being *public actors, semi-public actors,* and *private actors.*

Table A-1: Overview of the interests and power of the main stakeholders in the Dutch district heating sector

Stakeholders	Desired situation/ goals	Gap with the existing situation	Causes	Approach for a solution
Public actors				
European commission	Idem with the Ministry of Economic Affairs.	Emphasis on the impacts of the energy use of EU's heating sector on the energy independence of the EU area and its climate footprint.	Decreasing EU fossil fuel reserves and growing geopolitical instability at current important regions.	EU Heating and cooling strategy
Ministry of Economic Affairs *Directorate General Energy, Telecom and Competition*	Securing a sustainable heat provision – See Figure A-1 and A-2	The security of supply of the heat provision system is becoming less reliable. The heating demand is largely satisfied by unrenewable carbon emitting energy sources which is not sustainable on the medium to long-term.	Decreasing domestic natural gas resource availability and growing geopolitical instability at current import regions. Natural gas was/is the cheapest, most reliable energy source for heating for decades.	The implementation agenda of the heat vision of which designing a new market model for the district heating sector is a part of.
Ministry of the Interior and Kingdom Relations *Directorate General Governance and housing*	Securing a well-functioning and sustainable housing market and built environment	The energy efficiency of the Dutch building stock must be improved to meet climate and energy efficiency goals.	Historically most building have been connected to the nation-wide natural gas grid, which is becoming increasingly undesirable. Moreover, the Dutch building stock has a relatively long lifetime (30-50+ years) and therewith a slow replacement rate. Because of this the Dutch building stock is relatively old. In general, older buildings are less energy efficient than newer buildings and combined with a slow replacement rate the building stock is only slowly advancing towards a higher energy efficiency.	Energy label; Energy index (EI) – STEP, FEH, NEF, Energy performance and rent points system; Energy conservation programs (e.g. Zero on the meter); Connection obligation; Energy Performance Coefficient (EPC); Energy performance measures on a regional level (EMG) And also, subsidies for small renewable heat options (Ministry of Economic Affairs).
Ministry of Infrastructure and the Environment	Reduction of the heating sector's carbon emissions.	No specific targets for the heating sector's emissions exist, but for the energy sector as a whole the CO_2 equivalent emissions must be reduced by 16% compared to 1990 levels by 2020.	Too weak incentives to shift to less carbon-intensive and more sustainable means of heating.	EU ETS and sectoral targets (which have not been defined for the heating sector)

Netherlands Enterprise Agency	Idem with the Ministry of Economic Affairs.	Idem with the Ministry of Economic Affairs.	Idem with the Ministry of Economic Affairs.	Encouraging and supporting public bodies, such as provinces and municipalities, and private actors in realizing sustainable heating projects by providing knowledge and expertise and issuing subsidies (e.g. SDE+, geothermal energy exploration guarantees)
Authority Consumer and Markets	Securing the highest possible market efficiency for the market for heat delivery within the current market model.	Lack of knowledge about the actual profitability of district heating in the district heating sector and of the markets efficiency.	Only recently started the systematic collection of data (2009) on heat supplier profitability.	Profitability monitor Inspection of heat suppliers tariffs and service level quality
Provinces	Reaching their targets for carbon emission reduction and renewable energy production	Efforts are still in progress	Too weak incentives to shift to less carbon-intensive and more sustainable means of heating.	Support regional sustainable heating projects where possible and lobby at the Ministry for green deals and a more 'green' market model design.
Municipalities	Reaching their targets for carbon emission reduction and renewable energy production	Efforts are still in progress	Too weak incentives to shift to less carbon-intensive and more sustainable means of heating.	Heat plans and support of local sustainable heating projects where possible and lobby at the Ministry for green deals and a more 'green' market model design.
Semi-public actors				
Network companies - Stedin, Alliander, Enexis, etc.	Securing the reliability and affordability of their distribution networks.	District heating is both an opportunity and a risk for the network companies.	Opportunity: new means of servicing heat to their customers in a more sustainable manner. Risk: decreasing revenues from existing networks as district heating zones cannibalize on network usage levels (ultimately possibly making parts of natural gas grids in the built environment obsolete).	Explore possibilities for network companies to build and/or operate and/or own new district heating networks. Incorporate district heating developments in maintenance and design considerations for existing grids.
Private actors 'heat field'				
Integrated heat companies - Eneco, Nuon, Ennatuurlijk, Warmtebedrijf Rotterdam etc.	Profitable growth of district heating areas	Profitability of the district heating service is weak. This makes it difficult to expand existing networks and lay new networks.	On the one hand sales prices are capped at the natural gas reference level (NMDA), which is too low to secure a 'reasonable' profit and on the other hand the costs are for a large part inflexible network costs with only limited room for cost reductions.	Lobby for a change in the current market model. Wish list: increasing the regulated sales prices, subsidizing investments in new networks and/or remain favorable regulatory choices such as allowing vertically integrated companies and their monopolies to exist without enforcing competition through for instance unbundling and/or regulated third party access.
Independent heat producers	Profitable sales of residual or drain heat without too large risks related to security of supply obligations.	No real gap with the existing situation. Perhaps the desire for district heating networks to grow which will increase sales markets.	The lack of district heating networks close to large potential heat sources form a source of untapped economic potential.	Lobby for growth of the district heating sector.
Small heat consumers	Affordable, reliable heat provision, if possible in the most sustainable manner.	Most small heat consumers are content with their heat provision. However, some are aware that their heat provision is in some cases	The heat is provided reliably, safe and more environmentally friendly than the alternative. Despite the fact that most small heat consumers are aware of	Small heat consumers themselves have only little bargaining power about their terms of heat provision. That doesn't mean they can't be loud however. On the contrary, dissatisfied small heat

		more expansive than the natural gas alternative which breeds dissatisfaction.	price differences with the natural gas alternative, most are not because they are either uninformed or not interested enough.	consumers often organize themselves in larger groups through e.g. consumer organizations through which they may successfully lobby for altering their terms for their heat provision.
Large heat consumers	Affordable, reliable heat provision, if possible in the most sustainable manner.	No real gap with the existing situation. There are however large heat consumers that are looking for ways to satisfy their heat demand more sustainably, but see their ambitions beach on affordability or technological possibility.	The transport of heat is relatively expensive. Therefore, heat consumption must be in close geographical proximity to the heat source. Also, depending on the temperature requirements of the heat demand not all heat sources are eligible.	If the negative externalities of using unrenewable/carbon intensive energy sources for heat provision are incorporated in their prices more sustainable means of heating become more competitive. To some extent this already occurs through the EU ETS (e.g. steel industry, cement industry and power sector, etc.).
Consumer organizations - Housing corporations, Owners associations ('Vereniging Van Eigenaren' and 'Vereniging eigen huis')'	Secure that energy costs remain affordable in order to protect their constituents living costs.	Dissatisfaction among district heating clients about prices and freedom of choice. Costs of district heating compared to natural gas fired individual boilers make it difficult to choose for the sustainable option.	The NMDA price level does not in all cases reflect an adequate price of the actual costs of district heating. Due to low natural gas prices district heating is oftentimes the cheaper alternative.	Lobbying for: Stimulating the usage of district heating through financial instruments to make it the economically attractive option as well was the environmentally attractive option (e.g. increasing natural gas prices through increasing the energy tax on natural gas). Preventing regulatory choices to impact their costs.
Gasindustry - Gasunie, Gasterra, gastransportservices	Securing their sales markets and the profitability of their assets being natural gas production facilities and transport infrastructure.	No real gap with the existing situation. However, developments of the district heating sector are closely monitored as they directly impact the natural gas infrastructure system.	When the district heating sector grows, parts of the existing natural gas infrastructure may generate less revenues or even become obsolete.	Lobbying for: An adequate integral comparison between different heat options so that heat may be provided in the most cost-efficient manner. That means, natural gas versus district heating versus electric heating where it is most efficient. This also includes heat demand reduction measures such as insulation and production process innovations.
Horticulture sector - Horticulture companies & branch organizations	Secure that energy costs remain affordable in order to protect their constituent's profitability.	Would like more support for renewable heat project such as geothermal energy extraction and district heating networks.	Oftentimes horticulturists want to move towards more sustainable practices but economic reasons inhibit them. A change in market circumstances could tip that balance.	Lobbying for: Geothermal energy exploitation guarantees (subsidies). Direct subsidies for renewable heat projects.
Installation sector - UNETO VNI	Securing the interests of installation employers and employees in the heat provision sector.	Depending on the new market model the district heating sector may be a threat for the amount of work for small to medium enterprises (SME) in the installation sector.	Due to a possibly steep decrease in the number of households and businesses having a natural gas fired boiler which needs to be replaced and maintained a large part of their market will disappear.	Incorporate the possibility for the SME sector to partake in the installation of the to be built district heating infrastructure. This will require some form of agreement between UNETA VNI and the large heat companies as the most likely practical situation otherwise would be that large heat companies contract large construction companies (e.g. BAM) to build the install the necessary instructure equipment.

Appendix A-3: Structuring the main stakeholders in the District Heating sector

In Figure A-3 the stakeholders identified in Table A-1 are organized based on how important the district heating regulation is to them, in other words how strong is their *interest*, and on how strong their *power* is to influence the policy process that forms the district heating regulation. The resulting matrix is called a power/interest matrix which helps the policy maker to see which stakeholder interests *must* in all cases be taken into account.

The matrix consists of four quadrants: *subjects*, *players*, the *crowd* and *context setters*. Stakeholders belonging to the 'subjects' quadrant are those to which district heating (regulation) is a highly important matter but they only have low to moderate power to influence the policy process surrounding the formation of the district heating regulation. Then, the 'players' are those stakeholders that also consider district heating a highly important matter, but they also have moderate to high power to influence the policy process. These stakeholders are the most important ones and their interest *must* be taken into account when designing policies for the district heating sector. The 'crowd' are the stakeholders of which their interest in the district heating regulation is only low to moderate and they also have very little power to influence the process. This however doesn't mean that the policy maker may ignore or neglect the interests of the crowd – the crowd may very well become more interested if their interests are harmed and may even form coalitions with stronger stakeholders to influence the policy process. Finally there are the 'context setters'. These stakeholders are generally powerful actors that could potentially be influential in the formation of the district heating regulation, but it is not in their interest to be highly involved. Their interest should be taken into account to the extent that they will not become opposed to possible proposed changes to the district heating regulation.

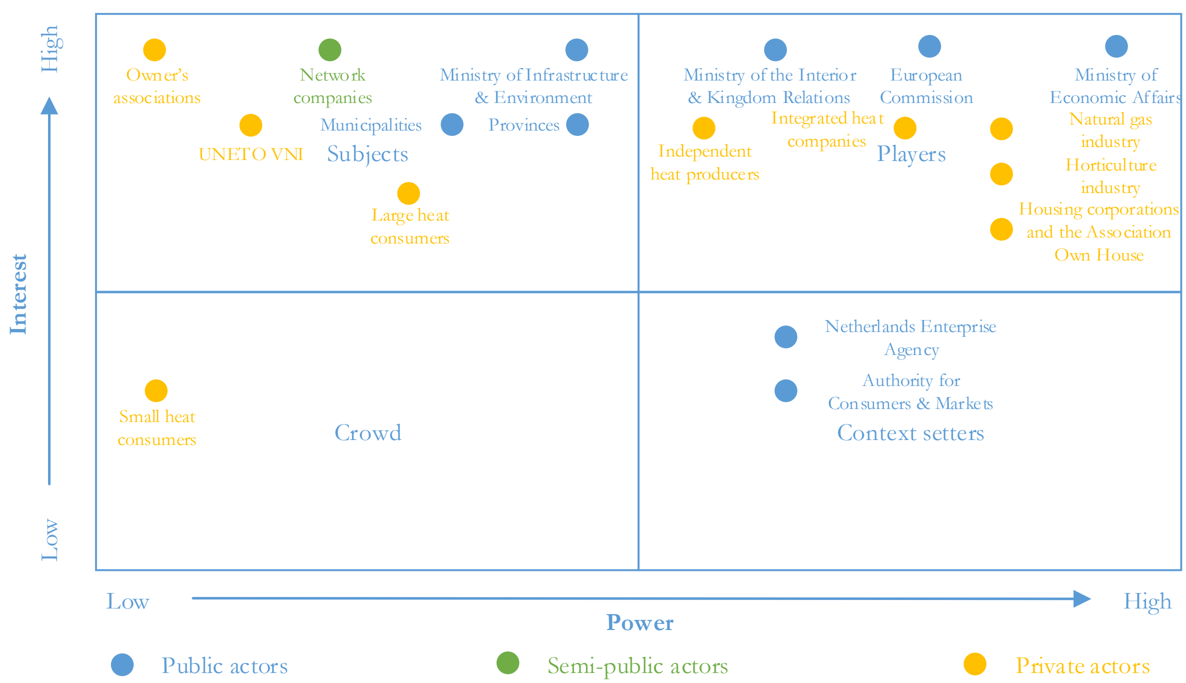

Figure A-3: Power-interest grid of the main stakeholders in the Dutch district heating sector

Appendix B: Design space

Further explanation by Figure 4-1: the degrees of market opening

The most closed version of a market is a fully regulated one. Historically most district heating systems where developed as such, where a *vertically integrated, publicly-owned utility company* would own and operate the system. Oftentimes these vertically integrated utility-companies would in fact not be an actual 'company', but instead the district heating system would be managed by an administrative arm of a public actor such as for instance a municipality.

A first step towards loosening the regulatory control of the government and implementing market forces is by the *corporatization* of such administrative bodies. By moving the district heating systems in dedicated utility companies the operation and management of the systems may become more similar to private company operation and management and therewith less dependent on the caprice of politics.

Next up is the introduction of *independent heat producers (IPPs)*. Independent heat producers sell their heat to a publicly-owned heat utility company (called the single-buyer) which owns and operates the district heating network as well as supplies the heat to its consumers. Oftentimes the utility company remains its own heat production facilities as well. Although in this case the district heating system is still a monopolistic one, the "IPPs may provide benchmarks for performance and may increase their influence over time (A. C. Correljé & de Vries, 2008, p. 7)".

Subsequently, actual competition between multiple heat producers may be introduced (wholesale market competition) by removing the single buyer. These heat producers can sell their heat directly to large consumers and/or to district heating suppliers with a retail franchise.

Finally, the most open market organization follows the introduction of retail market competition where heat suppliers may compete with each other on the same network for the graces of the consumer.

The desired degree of market opening is primarily dependent on *(1) exogenous factors* (e.g. the natural endowment of energy sources or the variety and dynamics of technology costs) and *(2) the goals* of the government for the (district) heating sector. Also, one should remember that competition per se should never be a goal on its own. The goal is to pursue a higher level of social welfare, which is expressed in terms of the reliability, affordability and acceptability of the heat provision (see Table 3-4). Competition may be used as an efficient tool to attain that higher level of social welfare through its driving force towards market efficiency.

Appendix C: Selection of countries

The purpose of the case studies is to provide an increased insight into which policy instruments from the design space seem promising in attaining the goals for the Dutch district heating sector. The case studies make it possible to go beyond theoretical insights regarding the benefits and costs associated with the policy instruments. They make it possible to gain insight into how the policy instruments perform in practice and how they are viewed by the stakeholders that they govern. For the case studies to be useful they will require a certain level of depth. Given the time constraint imposed on this research study no more than two countries have been selected for review.

The selection process is based on four criteria:

1. Institutional context: comparability of the laws and regulations of the country with respect to heat and energy policies.
2. Institutional variety: the distinctiveness of the market model as compared to the Dutch market model for the district heating sector.
3. Current level of district heating as compared to the Netherlands: comparability of the heat demand and the heat sources used and or available in the country of interest.
4. Availability of information and data.

1. Institutional context

Designing a market model is context-dependent and if the insights gained from the case-studies are to be generalized to insights for the design of a new market model for the Dutch district heating sector the institutional context should be comparable. Since the design space of the market model to be designed will be influenced and constrained by EU law & regulations only countries within the European Economic Area have been considered for analysis.

2. Institutional variety

The market model for the district heating sector of the country of interest should be clearly distinct from the market model of the Dutch district heating sector. In order to maximize learning it is useful to look at market models that have used different combinations of policy instruments than were chosen in the Netherlands.

3. Level of district heating

An important underlying goal behind the design of a new market model is that it must facilitate the transition towards a more renewable heat provision system. District heating is well equipped to play an important role in such a system. Taking this goal in mind, countries with high levels of district heating will be considered. Moreover, preferably the heat produced for these district heating systems stems from renewable energy sources or from other low-carbon heat sources such as heat from waste incinerators or combined heat and power facilities.

The branch organization for the combined heat and power, district heating and cooling sector, *EuroHeat & Power*, has identified five indicators for the state of a country's district heating sector: (1) energy supply composition for district heating, (2) district heating sales to customers, (3) district heating sales turnover, (4) share of citizens served by district heating and (5) trench length for the transport and distribution network (Euroheat & Power, 2015). Together these five indicators can give an idea of how 'big' district heating is in a country. The first, second and fourth criteria are deemed of primary interest for the selection of countries because these indicate respectively the renewability, magnitude and importance of the district heating sector for a country. The information from the third criterion (partly captured in criterion 2) and fifth criterion (primarily tells something about the heat density of the networks, not per se something about the magnitude of the sector) are deemed irrelevant for this selection process.

The first indicator, energy supply composition for district heating, details the energy split for the district heating system in terms of use of 'recycled heat', 'direct renewables' and 'other'. Recycled heat includes heat drawn from combined-heat and power facilities, waste incinerators and industry (irrespective of whether the primary fuel is renewable or fossil). Direct renewables includes heat drawn from heat-only boilers fueled by biomass, geothermal and solar installations. Finally the category 'other' includes heat-only boilers based on fossil fuels, electricity, and the electricity consumed by heat pumps. This indicator is relevant for the *renewability* of the district heating sector to be studied. For this purpose recycled heat will also be considered as 'renewable' because it is in most cases more environmentally friendly than alternatives to district heating.

The second indicator, district heating sales to customers, gives an idea of the *magnitude* of the district heating sector and therewith serves as an indication of the experience with district heating and possibly district heating *regulation*.

The fourth indicator, share of citizens served by district heating, gives an idea of the *importance* of the district heating system in the overall heat provision system. Again this may serve as an indication of the experience with district heating *regulation*.

Biannually Euroheat & power sends out a statistical survey to 29 countries that use district heating as a means to satisfy their heat demands (Euroheat & Power, 2015). In these statistical surveys the level of district heating of the countries are reported as well as details on their national legislative frameworks. Twenty three of the twenty nine countries[28] belong to the European Economic Area. Table C-1 presents how these twenty three countries score on the three aforementioned criteria that are indicative for the level of a country's district heating sector.

When reviewing Table C-1 it is clear that there are large differences between the countries that were reviewed. The shares of direct renewables range from 0% (Bulgaria and Croatia) to 76% (Iceland) whereas the shares of direct renewables plus recycled heat lie closer to each other. The sales of district heating to consumers also show large differences ranging from 7744 TJ per year (Slovenia) to 254839 TJ per year (Germany). Finally, the share of citizens who are served by district heating ranges widely also from only 1% in Norway to 92% in Iceland. The coloring in the cells of Table C-1 aims to help the reader to see the relative variety between the countries with green being the highest value on the indicator and red the lowest.

In table C-2 the data of Table C-1 is interpreted further to see which countries stand-out in terms of how renewable, large and important the district heating sectors are for their countries. Three questions were

[28] European Economic Area member countries included in the statistical review are: Austria, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Iceland, Italy, Latvia, Lithuania, Netherlands, Norway, Poland, Romania, Slovakia, Slovenia, Sweden, Switzerland and the United Kingdom.

asked: (1) does the country stand out in renewability compared to its peers? ; (2) is the country's district heating market large in terms of heat sold per year compared to its peers? ; and (3) how important is the district heating market for satisfying the heat demand in the particular country? –
Which is expressed in the share of citizens that are served by district heating. The thresholds for 'standing out' were as follows: a renewable plus recycled heat production of more than 60%, a district heating sector's heat sales of more than 50,000 TJ per year, and finally a share of citizens served by district heating of more than 50%. Four countries stand out based on these criteria which are the district heating sectors of: Denmark, Finland, Poland and Sweden.

4. Availability of information and data.
And finally fourth, in order for the analysis of the countries district heating sectors' regulatory framework to be useful the necessary information and data has to be available. Of the four countries that stand out the most the district heating sectors of Sweden and Denmark were chosen for further review because the available information and data was judged as best for these two countries. Also, the market models of Sweden and Denmark are clearly distinct from the market model of the Netherlands and distinct from each other as well.

Table C-1: Overview of the level of district heating for a selection of European countries that meet the first and second criteria.*

	AT	BG	HR	CZ	DK	EE	FI	FR	DE	HU	IS	IT	LV	LT	NL	NO	PL	RO	SK	SI	SE	CH	UK
Energy supply composition for District Heating [%]																							
Recycled heat	58	68	74	74	54	37	76	21	87	68	24	61	78	53	79	12	55	98	75	87	67	53	N/A
Direct renewables	23	0	0	2	46	15	9	39	1	2	76	16	12	20	1	61	6	2	3	2	28	31	N/A
Subtotal: recycled heat plus direct renewables	81	68	74	76	100	52	85	60	88	70	100	77	90	73	80	73	61	100	78	89	95	84	N/A
Other	18	32	26	24	0.2	48	16	40	12	30	0	23	10	27	20	27	38	0	22	10	5	16	N/A
District Heat Sales to customers (2013) [TJ]	80747	18002	N/A	89417	105563	23025	114160	86112	254839	30967	28181	33119	21464	27100	26100	16920	248693	N/A	82726	7744	175972	17890	N/A
Share of citizens served by District Heating [%]	24	18	10	38	63	62	50	7	12	15	92	6	65	57	4	1	53	23	35	15	52	4	2

*Country codes: AT (Austria), BG (Bulgaria), HR (Croatia), CZ (Czech Republic), DK (Denmark), EE (Estonia), FI (Finland), FR (France), DE (Germany), HU (Hungary), IS (Iceland), IT (Italy), LV (Latvia), LT (Lithuania), NL (Netherlands), NO (Norway), PL (Poland), RO (Romania), SK (Slovakia), SI (Slovenia), SE (Sweden), CH (Switzerland), UK (United Kingdom).

Table C-2: Data interpretation table. Ranking countries' level of district heating by comparing their scores on renewability, the magnitude of the heat delivery sector (heat sales) and the share of district heating in urban heating (share of citizens served by district heating).

	AT	BG	HR	CZ	DK	EE	FI	FR	DE	HU	IS	IT	LV	LT	NL	NO	PL	RO	SK	SI	SE	CH	UK
Stand out renewability?*	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Stand out heat sales?*	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	No	No	No	No	No	Yes	No	Yes	No	Yes	No	No
Stand out large share of citizens?*	No	No	No	No	Yes	Yes	Yes	No	No	No	Yes	No	Yes	Yes	No	No	Yes	No	No	No	Yes	No	No
Stand out how many times?*	2	1	1	2	3	1	3	2	2	1	2	1	2	2	1	1	3	1	2	1	3	1	0

*The thresholds used were: renewability >= 60% (Recycled heat + direct renewables), heat sales >= 50,000 TJ and share of citizens connected to district heating >=50.

Appendix D: Structured-interviews with Swedish district heating stakeholders

Complementing the desk-study into the historical development, the current role, regulatory framework and future prospects of the Swedish district heating sector four semi-structured interviews were conducted. The interviews helped to better understand the context of the found literature, validate the conclusions of the found literature, and fill the gaps in the found literature. The interviews were conducted on Tuesday the 13th and Wednesday the 14th of October 2015 in Stockholm Sweden. Together with a colleague from the Ministry of Economic affairs, Wouter Schaaf, we interviewed four Swedish district heating stakeholders: (1) the Swedish energy policy-maker, the 'Swedish Energy Agency', (2) the Swedish energy regulator, the 'Energy Markets Inspectorate', (3) the Swedish branch organization for district heating, the 'Swedish District Heating Association' and (4) the district heating supplier of the Stockholm district heating grid, 'Fortum Värme'. Appendix D-1 presents the survey that was sent to the interviewees in advance of the interviews. The survey was used to guide the interviews while at the same time also room and time was used to deviate from the exact questions to learn more about topics the stakeholders discussed during the interviews. The full interviews are available as '.mp3 files' with the author of this thesis. Appendix D-2 contains a list with the contact details of the four interviewed stakeholders.

Appendix D-1: List of inquiries District Heating in Sweden

Interviewers: Alexander Oei and Wouter Schaaf – Ministry of Economic Affairs of the Netherlands
Interviewees: Swedish Energy Agency, Energy Markets Inspectorate, Swedish District Heating Association (Svensk Fjärrvärme) and Fortum Värme

Technology and economy related questions

According to publications from Euroheat & Power and the Swedish Energy Agency district heating is widespread in Sweden. In the residential and services sector more than half of the heat demand is provided through district heating. This is mainly apartment buildings (market share of 93%), commercial and other premises (market share of 83%), but also detached houses (market share of 12%).

1. **Historical development: What were the main drivers in the transition from oil based heating towards district heating, electric heating and biomass-based heating?**
    a. Could you sketch the relative importance of energy prices and tax measures, such as the carbon tax and energy tax, in the transition?
    b. What were the success factors for the high penetration rates in apartment buildings and commercial and other premises? Has the limit now been reached or are higher markets shares still possible?
        i. Heat demand per household [GJ/household], heat demand density [GJ/km pipe length]?
    c. What are the most important success factors and barriers for the expansion of district heating in detached houses?

            i. Heat demand per household [GJ/household], heat demand density [GJ/km pipe length]? Institutional barriers? Cost of alternatives to district heating?)

2. **Profitability of district heating in Sweden**
    a. The Swedish climate is relatively cold in a European context. This is reflected in the heat demand profiles of the Swedish building stock. How important is the relatively higher heat demand in Sweden for the profitability of district heating grids?
        i. In the Netherlands 56 GJ/year
    b. In the Netherlands currently there is much debate about were to use district heating in connection with the trade-off between the cost of heat supply and building insulation. Is the same debate present in Sweden in regions where district heating is not present yet? Was this debate present during the time district heating grids were laid out in Sweden?
3. **Present situation and future outlook: In Sweden district heating competes with oil-fired heating, electric heating, heating based on biomass with for instance wood-fired stoves, and insulation.**
    a. How important is the price today in the decision which heat provision options to apply?
        i. Energy prices (natural gas, oil, logs, pellets)
        ii. Taxes (carbon tax, EU ETS, energy tax)
4. **Energy sources used today and in the future for district heating**
    a. In the Netherlands the sustainability of biofuels is often times under discussion, also because the Netherlands only possesses over limited biofuel resources itself. Is this debate present in Sweden as well?

Governance of district heating grids

The Swedish District Heating sector is only 'lightly' regulated. There is no tariff regulation and basically all market structure settings are allowed. The Energy Markets Inspectorate sees to it that relevant regulations from the District Heating Act followed governing price information and reporting obligations to the EI. The Swedish District heating board arbitrates in the negotiation between district heating companies with consumers and third parties that want to access the grid. Negotiation is obligatory for district heating companies.

5. **How does arbitration from the Swedish District Heating Board work in practice?**
    a. Do often do (individual) *consumers* ask for a negotiation with their district heating supplier? And when they do, how often is it necessary for the Swedish District Heating Board to get involved and arbitrate?
    b. How often do potential district heating *producers* ask for a negotiation with the operator of an existing district heating grid, or a planned district heating grid? And when they do, how often is it necessary for the Swedish District Heating Board to get involved and arbitrate?
6. **How were decisions made where to provide district heating?**
    a. Are areas designated as district heating areas and are consumers then obliged to connect? Do they have a choice in the matter? Were they involved in the decision to construct district heating grids?

b. And, the other way around: Are district heating companies obliged to connect households if they ask for a connection to the district heating grid?

7. **Is it correct that most district heating grids in Sweden are managed by vertically integrated companies who own the production facilities, district heating grid and deliver heat to consumers?**
    a. If so, how did this development come to be?
    b. Who owns the district heating grids? How were they financed?
    c. What are the main reasons that it is difficult for third parties to get access to already existing district heating grids?
        i. Market power/ strategic behavior from existing grid owners?, or technical reasons?

Prelude to question 8

In 2009 a special commission led by Peter Nygård was formed to investigate obligatory Third Party Access to Swedish District Heating grids. The results of this investigation (SOU 2011:44) called for further research which was conducted by the Energy Markets Inspectorate. The EI finished her report in 2013 (EI R2013 07). The initial report from the special commission proposed to divide up the market (unbundling) to enable wholesale and retail competition in the district heating sector similar to the market structure in the electricity sector. This would enable third party access for e.g. industrial waste heat. However, uncertainties regarding the effects and costs of introducing obligatory third party access asked for more research.

8. **Third party access: Why was the decision ultimately taken not to implement obligatory (regulated) third party access?**
    a. What were the uncertainties and costs that made the commission reluctant to advise to implement third party access?
    b. Is the debate around whether to implement Third Party Access still present?

District heating in Sweden from the perspective of the consumer

9. **What is the public opinion of district heating grids in Sweden?**
    a. Are district heating companies generally regarded as customer friendly?
    b. Do district heating consumers have freedom of choice? That is, can they choose to disconnect from district heating and use electric heating or wood-fired stoves instead if they want to? And if not, do district heating consumers have any problems with their lack of freedom of choice?
    c. How important is the price of district heating in the public opinion of district heating?

Appendix D-2: Contact details of the interviewed Swedish district heating stakeholders

Swedish Energy Agency, Energimyndigheten

The Swedish Energy policy maker. The Agency is an independent governmental body, subordinate to the Ministry of the Environment and Energy.

Contact person: Daniel Friberg, Policy officer
Phone number: +46 (0)16 544 20 06
E-mail address: Daniel.Friberg@energimyndigheten.se

Svensk Fjarrvärme

The Swedish District Heating Association

Contact person: Patrik Holmström, Area Manager Business Development
Phone number: +46 8 677 25 50
E-mail address: patrik.holmstrom@svenskfjarrvarme.se

Energimarknadsinspektionen

The Energy Markets Inspectorate (Swedish energy regulator)

Contact person: Katarina Abrahamsson, Coordinator District Heating
Phone number: +46 16 16 27 49
E-mail address: katarina.abrahamsson@ei.se

Contact person: Erik Schrammel
E-mail address: erik.schrammel@ei.se

Fortum Värme

One of the large district heating companies in Sweden. Is the heat supplier of the district heating network in Stockholm.

Contact person: Lena Gunnarsson, Product manager district heating
Phone number: 072-232 25 70
E-mail address: Lena.Gunnarsson@fortum.com

Appendix E: Scenario analysis

In this Appendix the supporting analyses for the adapted version of the 'energy transformation framework' are described. The 'energy transformation framework' posits that all external developments to the energy sector find their root cause in five drivers of change. The external developments are called the 'disruptive factors' in the framework and the drivers of change the 'megatrends'. These so called disruptive factors may be of a physical, economic, social or political nature. In Table E-1 the disruptive factors that were identified are listed, according to their nature. Also, the factors through which they affect the market performance of the district heating sector are listed. The root causes, or megatrends, behind the disruptive factors are identified in Table E-2. Some of the disruptive factors are driven by more than one megatrend.

Table E-1: Characterization of through which factors of interest the disruptive factors cause change in the district heating sector

External developments / disruptive factors	Factor of interest for district heating
Physical developments	
Improvements in low temperature heat distribution technologies	Cost of district heating; Environmental performance of district heating
Improvements in heat storage technologies	Value of district heating for district heating companies with CHP-facilities.
Improvements in electric heat pump technologies	Relative attractiveness of electric heating
Improvements in solar heating pump technologies	Relative attractiveness of district heating; total heat demand per household
Improvements in heat savings measures	Relative attractiveness of district heating; total heat demand per household
Demand side flexibility of heat	Cost of district heating; Environmental performance of district heating
Uptake of renewables in electricity sector	Value of district heating for district heating companies with CHP-facilities.
Economic developments	
Electricity prices	Relative attractiveness of electric heating versus district heating
Natural gas prices	Relative attractiveness of natural gas fired heating versus district heating
Fuel prices for district heating (natural gas, coal and biomass)	Relative attractiveness of district heating; cost of district heating
Economic growth level	Room for potential heat price increases
Income equality	Room for potential heat price increases; Need for distributive correction of heating costs among vulnerable consumers
Social developments	
Pace of urbanisation	Relative attractiveness of district heating; cost of district heating; total heat demand per hectare
Growth in number of households (population growth and one-person households)	Total heat demand
Public awareness and understanding of sustainability issues	Relative attractiveness of district heating

Political developments	
Political awareness and understanding of sustainability issues	Strength of RES-E and RES-H support; Strength of support schemes for heat savings measures and decentralized forms of heat production (e.g. solar heating, biomass stoves, etc.)
Political commitment to energy independency	Strength of support to non-fossil fuels and especially non-natural gas fuels for heating
Commitment to the growth of district heating	Next to support schemes described above, strength of public push for the realization of new district heating systems

Table E-2: Megatrends driving the disruptive factors.

External developments / disruptive factors	Driving forces / megatrends
Physical developments	
Improvements in low temperature heat distribution technologies	Technological breakthroughs
Improvements in heat storage technologies	Technological breakthroughs
Improvements in electric heat pump technologies	Technological breakthroughs
Improvements in solar heating pump technologies	Technological breakthroughs
Improvements in heat savings measures	Technological breakthroughs
Demand side flexibility of heat	Technological breakthroughs
Uptake of renewables in electricity sector	Technological breakthroughs; climate change and resource scarcity
Economic developments	
Electricity prices	Climate change and resource scarcity
Natural gas prices	Climate change and resource scarcity
Fuel prices for district heating (natural gas, coal and biomass)	Climate change and resource scarcity
Economic growth level	Shift in economic power
Income equality	Shift in economic power
Social developments	
Pace of urbanisation	Accelerating urbanisation
Growth in number of households (population growth and one-person households)	Demographic changes; accelerating urbanisation
Public awareness and understanding of sustainability issues	Demographic changes
Political developments	
Political awareness and understanding of sustainability issues	Climate change and resource scarcity; demographic changes
Political commitment to energy independency	Climate change and resource scarcity; demographic changes; shift in economic power
Commitment to the growth of district heating	Climate change and resource scarcity; demographic changes; accelerating urbanisation; technological breakthroughs

The future development of the megatrends in the medium-future (2030) are characterized by large uncertainty. Technological breakthroughs may come swift and may prove to be disruptive, or, might come slow and have only a minor impact on the district heating sector. Similarly, demographic changes such as an increasing awareness and understanding of sustainability issues may prove to be disruptive to the extent that many households become energy-neutral buildings, or, only have a minor impact on the behavior of consumers. In other words, the development of the five megatrends is unclear and their exact impact through the disruptive factors also remains to be seen. Moreover, there can be many different combinations of developments. One example is for instance strong technological breakthroughs combined with a strong shift in economic power and only moderate developments in the other megatrends. The large number of possible combinations of the future developments of the megatrends can be illustrated in a 'development space' (See Figure E-1). The numbers in the diagram represent low, weak, or strong development of the megatrend (1, 2 or 3). By drawing lines between the corner points of the three pentagrams for each of the megatrends a shape appears. This shape represents a scenario of megatrends development. Depending on how the five megatrends will develop, their impact through the disruptive factors on the district heating sector's market performance will differ.

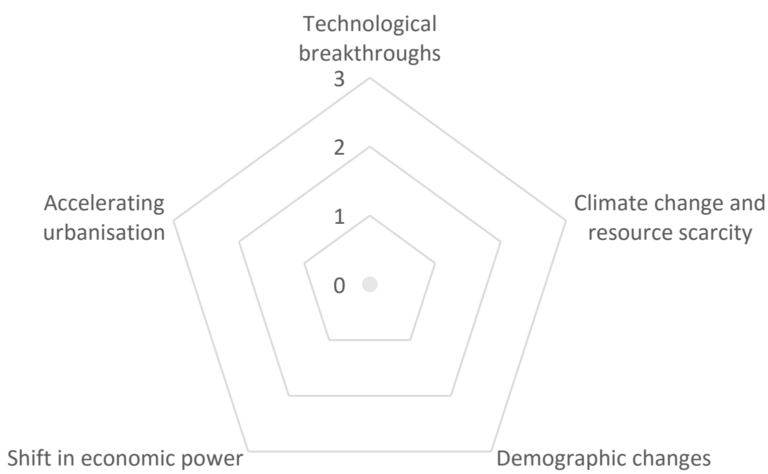

Figure E-1: Development space of the five megatrends driving change in the district heating sector

In order to gain insight into how the five megatrends might affect the future market performance of the district heating sector through the developments of the disruptive factors three scenarios are defined. The scenarios represent internally consistent and likely combinations of developments in the megatrends which in turn represent developments in the disruptive factors as well. The three scenario choices are described in Table E-3 and illustrated in the development space in Figure E-2.

Table E-3: Definition of the three scenarios.

Driving forces	Base scenario	Climate scenario	Economic scenario
Technological breakthroughs	Moderate	Strong	Weak
Climate change and resource scarcity	Moderate	Strong	Moderate
Demographic changes	Moderate	Strong	Weak
Shift in economic power	Moderate	Moderate	Weak
Accelerating urbanization	Moderate	Moderate	Moderate

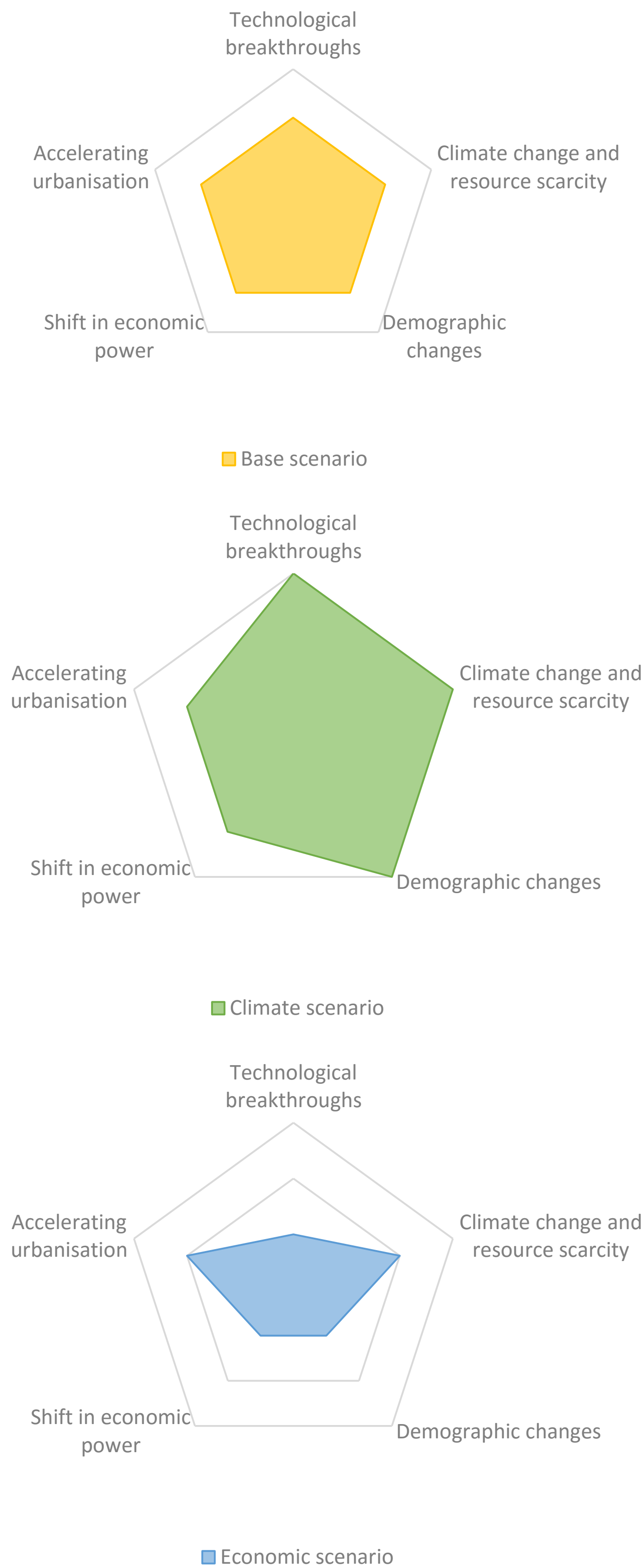

Figure E-2: Graphic representation of the three scenarios in the development space.