Designing a new regulatory framework for the Dutch district heating sector: Combining theoretical insights with empirical evidence

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Abstract – In the context of the ongoing energy transition away from fossil fuels the Dutch government sees great potential in the district heating sector as a key sector to reduce greenhouse gas emissions from the heat provision sector. In addition, because of the fuel-flexibility of heat production facilities for district heating, district heating may also contribute to lowering the energy dependency of the Dutch energy sector. In order for the district heating sector to grow and increase its share of renewable heat production there is however a need to adapt the current regulatory framework such that the relative attractiveness of district heating versus other forms of heating is improved. In this paper a market design approach is presented for the regulatory framework of the Dutch district heating sector. The design challenge is conducted by combining theoretical insights from economic literature and empirical evidence drawn from international case-studies of alternative market models for the district heating sector. Two new, distinct, market models are suggested for the Dutch district heating sector, which both may (1) foster the growth of the district heating sector, including increasing the share of renewable heat production, and (2) facilitate the transition towards more sustainable practices in the overall heat provision system. Future research could focus on conducting more case-studies in order to improve the quality of the arguments for and against specific policy instruments in the design space. In addition, future research could also focus on improving the assessment of the expected performance of the market models in practice through modelling and simulation.

Keywords: Market design, district heating sector, international comparison, regulatory framework

1 Introduction[2]

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[3]. Driven by climate policies, a decreasing availability of domestic natural gas resources and the risks of energy import dependency from politically-unstable regions,

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[2] This paper is based on the Master thesis research of the Author, publicly defended at Delft University of Technology on the 22nd of November 2016 (Oei, 2016).

[3] 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).

the Dutch government is now investigating pathways towards a more sustainable provision of heat (Ministry of Economic Affairs, 2015a).

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).

Despite the merits and substantial potential of district heating as a means to satisfy the heat demand there exist physical/technological, institutional and economic barriers that impede the growth of the sector. Table 1 summarizes a handful of these barriers recurring in literature by briefly explaining and characterizing them.

To overcome these barriers, the relative attractiveness of district heating versus other forms of heating (e.g. natural gas-fired boilers, electric heat pumps, etc.) must be increased. In the Netherlands the current regulatory framework already stimulates district heating networks, and other more sustainable forms of heating, by means of subsidies, grants, and other favorable regulatory arrangements. Despite these regulatory arrangements, the Dutch heat vision however observes that the current regulatory framework is not sufficient to overcome the physical and institutional-economic barriers that are impeding the growth of the district heating sector and the 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.

Although the overarching goal is attaining a more sustainable heat provision sector as a whole the focus of this research 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 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."*

2 Approach

Before looking at *how* a new market model for the district heating sector may be developed, first, the concept 'market model' must be further defined. The Ministry of Economic Affairs defines a market model as *"a description of a defined market 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 1 graphically depicts which roles, relations and responsibilities are included in the market model description of the district heating sector.

Redefining the market model description of the district heating sector involves two types of legislation: (1) district heating sector-specific legislation and (2) related regulation. The first category concerns sector laws and decrees such as the degree of competition and unbundling and the regulation of access and tariffs.

Table 1: Overview of barriers to the growth of district heating networks in the Netherlands

Barriers	Explanation
Transportation costs *Nature: physical/economic*	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).
Security of supply *Nature: physical/ institutional*	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 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 *Nature: institutional*	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.
Price reference to natural gas *Nature: institutional/ economic*	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.
Payback period of investments *Nature: institutional/ economic*	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.
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

Nature: institutional/ economic	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.
Negative externalities *Nature: institutional/ economic*	Producing electricity from fossil-fuel fired thermal power plants goes hand in hand with the emissions of greenhouse gases, which constitutes a negative externality. Currently, in the Netherlands the emissions associated heating (for residential purposes) is not internalized in the price. Since 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 *Nature: physical, institutional and economic*	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).

The second category concerns regulation that is not only specific to the district heating sector, but is of influence to it such as the (energy) tax structure or specific regulation for related sectors such as policies regarding energy efficiency in the urban environment.

In summary, given the desire to overcome the institutional-economic barriers mentioned, given the physical/technological constraints, a new market model for the provision of heat is sought which will attain a more sustainable heat provision system. This new market model should contribute to unlocking the potential of the district heating sector while also being considerate for other sustainable practices. The research question 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?"

To guide the research process the research study was framed as a *design exercise.*

Structuring the design process

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 (Herder & Stikkelman, 2004). 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.

In the next section, first, the results of the first two research activities is given: what are the goals, objectives and constraints for the design task at hand and what is the design space? Then, informed by the international case studies the design space is assessed in section 4. By combining the theoretical insights for market design, presented in the design space, with the empirical evidence drawn from the international case studies the basis for designing new market models is complete. In section 5, two new, distinct, market models are designed for the Dutch district heating sector. Finally in section 6 the conclusions and discussion of this research study are presented.

3 Identifying the goals, objectives and constraints and the design space

In subsection 3.1 the goals, objectives and constraints or 'motives' behind searching for a new market model for the district heating sector are presented. Subsection 3.2 presents the design space or 'toolbox' for shaping such a new market model.

3.1 Goals objectives and constraints

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*[4], *affordable* and *acceptable* heat provision. In Appendix 1 the goals of reliability, affordability and acceptability are operationalized in measurable performance indicators which may be used to evaluate the system's performance. As such, the table of Appendix 1 represents the evaluative framework against which the performance of the district heating sector may be measured.

3.2 Design space

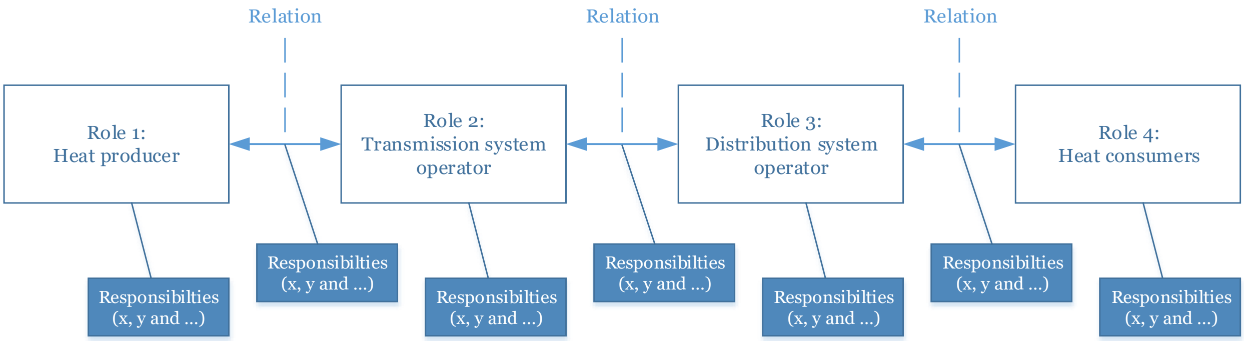

Figure 1: Illustration of the elements included in a market model description – roles, relations and responsibilities.

The design space represent the toolbox of options government has to change the 'rules of the game' so that businesses and households will invest in and choose for more sustainable practices in the (district) heating sector. This toolbox consists of the 'design choices' that have to be made and the 'design options' available for these choices. Nine design choices, or variables were identified for the district heating sector based on an extensive literature review. The design variables are listed in Table 2 – for more background on these design choices see Oei (2016). Consequently, the most promising design options were identified which are presented in Appendix 2 in a 'morphological chart' alongside their respective design variables.

The design variables themselves can be split up into two categories: the variables that

[4] 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.

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.

Table 2: 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

4 International case-studies

In economic literature arguments for and against the policy instruments listed per design variable may be found. It is however difficult to assess the weight of these pro's and con's which makes it hard to make choices between different policy instruments for the design choices. Therefore, international case-studies of alternative market models for the district heating sector were conducted to learn what works, and what doesn't. By inquiring in-depth into why different countries chose for different types of market models for the district heating sector and assessing the performance of these different market models lessons can be drawn about the performance of specific policy instruments. In the following three subsections respectively the Dutch, Swedish and Danish district heating sectors market models are briefly described and analyzed.

4.1 The Dutch district heating sector

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.

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.

What is interesting is that the current regulatory framework for the district heating sector allows for a large variety of different market models. Appendix 3 gives a brief overview of the choices the Dutch government made on the nine design variables of interest for this study and the consequences these choices have for the performance of the district heating sector.

4.2 The Swedish district heating sector

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. Consequently, in the 1970s, driven by the occurrence of two sever oil crises the Swedish government continued her efforts to become more energy independent. District heating was seen as an important enabler for this goal.

What is interesting to see is that the primary reason for choosing district heating in Sweden was energy-independence, sustainability came second. Also, the push the outlay of the sector was mainly driven by the public sector, specifically the municipalities. It was only later, starting in 1996 the sector was privatized and private companies entered the sector also. Nowadays, the district heating sector competes with electric heat pumps and conventional heat-stoves for servicing the heat demand in the residential and services sector. District heating however holds the largest market share – 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). Appendix 3 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.

4.3 The Danish district heating sector

The first district heating network in Denmark was realized already in 1903 in the municipality of Fredriksburg. The main heat source for the district heating network was a waste-to-energy facility. 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. 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.

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[5] (Euroheat & Power, 2015). Next to district heating other heating alternatives exist including natural gas for individual heat boilers (15.6%), oil-fired individual heat boilers (12%), direct electric heating (4.7%), biomass-fired boilers (2.7%), and electric heat pumps (1.7%) (Euroheat & Power, 2015). 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 Appendix 3 a summary of the full regulatory framework is given.

5 Designing new market models for the district heating sector

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) the 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,

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

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 Appendix 4.

6 Conclusions and discussion

In this paper 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.

Appendix 1. Evaluative framework for the goals for the district heating sector. Main goal of the Ministry: 'Securing a sustainable heat provision' – see Oei (2016) 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[6].
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[7]	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 <

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

[7] 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.

Appendix 2. '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		

Appendix 3. 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: negotiated access. 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 **Error! Reference source not found.**.
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 **Error! Reference source not found.**)	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.

Appendix 4. 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: negotiated access. 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 **Error! Reference source not found.**)	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.	

References

CBS. (2012). *Het energieverbruik voor warmte afgeleid uit de Energiebalans: Update 2010*.

CE Delft. (2014). *Kansen voor warmte*.

Correljé, A. C., & de Vries, L. J. D. (2008). Hybrid electricity markets: the problem of explaining different patterns of restructuring. Competitive Electricity Markets, Design, Implementation, Performance.

DBDH. (2016). District heating history. Retrieved August 14, 2016, from http://dbdh.dk/district-heating-history/

ECN. (2015). *National Energy Outlook 2015*.

Ecorys. (2016). *Onderzoek evaluatie Warmtewet en marktmodellen warmte*.

Euroheat & Power. (2015). *District Heating and Cooling Country by Country Survey 2015*. EuroHeat & Power. Retrieved from http://www.euroheat.org/Statistics-69.aspx

Gent, C. van, Bergeijk, P. A. G. van, & Heuten, H. . (2004). *Basisboek markt- en micro-economie: met de praktijk van het mededingingsrecht [Leerlingenboek]. [Leerlingenboek]*. Groningen: Wolters-Noordhoff.

Herder, P. M., & Stikkelman, R. M. (2004). Methanol-Based Industrial Cluster Design: A Study of Design Options and the Design Process. *Industrial & Engineering Chemistry Research*, *43*(14), 3879–3885. https://doi.org/10.1021/ie030655j

Knops, H. P. A. (Ed.). (2008). *A functional legal design for reliable electricity supply: how technology affects law*. Antwerp: Intersentia.

Ministry of Economic Affairs. Heat vision (2015a). Retrieved from https://www.rijksoverheid.nl/documenten/kamerstukken/2015/04/02/kamerbrief-warmtevisie

Oei, A. H. G. (Alexander). (2016, November 22). *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* (Master Thesis). Delft University of Technology, Delft. Retrieved from http://repository.tudelft.nl/

PwC. (2015). *The possibilities for Third Party Access on heat networks: Report for NV Nuon Heat*.

RIVM. (2014). *National Inventory Report 2014: Greenhouse Gas Emissions in the Netherlands 1990-2012*.

RLI. (2015). *Rijk zonder CO2: Naar een duurzame energievoorziening in 2050*.

Swedish Energy Agency. (2012). *Energy in Sweden 2012*. Retrieved from https://www.energimyndigheten.se/Global/Engelska/Facts%20and%20figures/Energy_in_sweden_2012.pdf

Vos, J., & Leegte, R. W. Motie van de leden Jan Vos en Leegte over een samenhangend plan van aanpak, TweedeKamer.nl (2014). Retrieved from https://www.tweedekamer.nl/kamerstukken/detail?id=2014Z20871&did=2014D42226

Warringa, G. E. A., & Rooijers, F. J. (2015). *Verkenning functionele energievraag en CO2-emissies tot 2050*. CE Delft.