A conceptual model to grasp the district heating market

A study using technical, economic and institutional perspectives

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Abstract. The district heating system is currently a natural monopoly. Introducing multiple producers on district heating networks could have many benefits. By developing a conceptual model that captures the technical, economic and institutional layers of the district heating system, a solid basis for a simulation model can be made. The proposed agent-based simulation model can give insight in the behaviour of stakeholders in a new district heating market that allows competition for producers of heat.

Keywords: District heating market, conceptual model, agent-based simulation, technical economic and institutional perspectives, competition

1 Introduction

One of the basic needs of a human being is heat. Heating in households is very common, and nowadays many people take it for granted. Heating in households can be referred to as space heating. Many households have an individual gas powered boiler in the Netherlands, but space heating can be organised in different ways. For example by a collective district heating system. A collective district heating system is a network of pipes, which uses centrally produced heat to heat up households through radiators or floor heating for example.

Up until now, municipalities in the Netherlands have ensured that district heating networks have been established and expanded. After privatisation of energy companies in the Netherlands in 1995, the district heating system has been advanced through financial investments, defining concession zones and building control regulations, amongst other methods. Through these ways municipalities have been expanding connections to district heating (Hawkey & Webb, 2014). Currently, per local district heating network, one energy company supplies heat on the net.

An example of a district heating network is that in The Hague and surroundings. A portion of the city centre is connected to the district heating network. The energy company that supplies heat on the district heating network in The Hague and surroundings, is E.ON Benelux N.V.. E.ON Benelux is the division of E.ON that operates in The Netherlands and in Belgium. E.ON, the mother company, is a German company, which has divisions throughout several countries in Europe. In The Hague, 40.000 households and buildings are currently connected to the district heating network, and they are looking to increase this to 100.000 connections. E.ON Benelux now supplies the heat, but when increasing the amount of connections, room is created for more potential producers.

Having more producers on one network could have several benefits. For example, more waste heat from industrial facilities could be reused, posing environmental benefits. Also, for E.ON in this case, it would mean that they are not forced to supply heat all the time, but can make more strategic decisions when it comes to efficient use of their combined heat and power plant (CHP). Having more producers supply on one network would also mean that less additional heat from buffers our auxiliary boilers needs to be produced to meet consumer demand. Which in total would benefit the environment and could save costs for current and future producers.

The aim of this article is to research how the district heating system can be captured in a conceptual model, that can later on serve as a foundation for simulation when looking into introducing multiple independent producers on one district heating network. This will be done by looking into comparable utility markets, a theoretical framework, developing a conceptual model and providing a link to simulation.

2 Comparable markets

In many ways electricity, gas, water and district heating are similar, but to what extent can these markets be compared? In this paragraph firstly a comparison between the characteristics of electricity as a product and a service and district heating as a product and a service is made. Their value chains for example are very similar. From production to transmission/transport to distribution to consumer, the essential steps are comparable. Both make use of a large network and share natural monopoly characteristics. Since both heat and electricity are a basic need, their security of supply is highly valued and they both have to deal with seasonal and even hourly changes in demand. However, district heating is different in some ways as well. Where storage of electricity is practically impossible, storage of heat is more easily achieved, currently buffers and auxiliary boilers do so. Another difference is that for district heating the barriers to entry are even higher than for electricity. The transport network is much more expensive and transport costs and heat losses occur even if there is no demand because the water flows constantly through the system, whether it is heated up and used or not. In case of shortages, there is a difference as well. Where in case of electricity blackouts occur, for heat it causes more of a queue or traffic jam situation. It will simply take longer to reach the desired temperature, making a balancing mechanism less important than for electricity. Also district heating networks in the Netherlands are very local, where the electricity grid is connected nationally. These similarities and differences are summarised in table 2.

Due to the many similarities, the electricity market may be the most comparable market for district heating. Other markets that share the same similarities are the gas and water market. They are also basic needs, where security of supply is very important, make use of large networks and share natural monopoly characteristics and also have seasonal and hourly demand changes. Networks like telecom and rail also make use of large networks where a monopoly makes a lot of sense, however, the security of supply is strictly not as essential as for the before mentioned utilities, which is why the electricity, gas and water markets are a better fit for district heating. Since there is a lot of literature available on electricity markets, the liberalisation of electricity markets worldwide and the lessons learned, many of the discussions in this chapter will concern the electricity market. However, the differences as identified in table 2 should not be neglected. The differences between heat and electricity make heat a simpler flow to manage, but with higher transport costs a higher barriers to entry. This means that from a market design perspective, heating is easier to design, but practically, it is more difficult to attract new producers. Even though comparisons between the markets are drawn, attention should be paid what the effects of the heat characteristics are.

Table 1. Similarities and differences between electricity and heat as a product and service

Similarities	Differences (from the heat perspective)
Value chain from production-consumer	Storage is possible
Make use of a large network	Higher barriers to entry
Natural monopoly characteristics	Transport costs and heat losses when there is no demand
Security of supply important	Balancing mechanism less important
Both a basic need/utility	More local networks
Hourly/seasonal changes in demand	

3 The technical, economic and institutional perspective

Opening the market for more than one producer poses technical as well as economic and institutional issues. Groenewegen (2005) has discussed these three aspects in his ‘designing markets in infrastructures’. The technology domain encompasses “how to engineer the physical environment” (Groenewegen, 2005, p. 2), the economic domain is said to include the production of goods and services and the different economic levels that occur with that. The institutional domain contains values, norms, laws and other arrangements that are linked to coordinating transactions. Groenewegen also states that this is “the domain of designing markets” (Groenewegen, 2005, p. 3), which is relevant for this thesis. When analysing the district heating network, focus should be an all three perspectives. The three domains and how they relate are shown in figure 1.

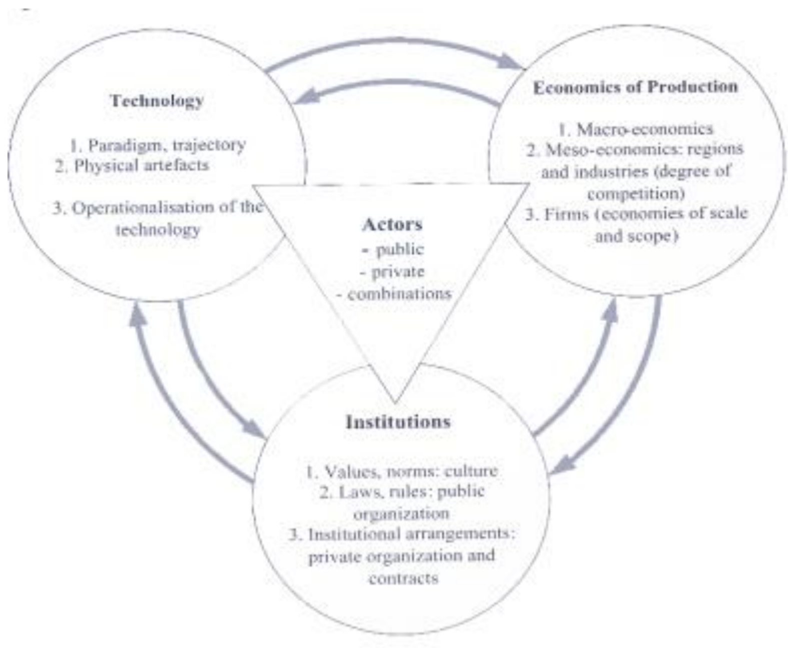

Fig. 1. A multi-disciplinary, multi-level and multi-actor system (Groenewegen, 2005)

4 Systems analysis

The current situation of the district heating system in The Hague is described. This is done by keeping to the technical, economic and institutional domains. By means of this structure the district heating system is described.

4.1 Technical domain

The technical structure of a district heating network is very complex. A brief overview of temperature requirements, capacity of the pipeline and the complexities these bring are given. Firstly, the supply temperature of heat at households should always be 90°C, in order to reach a room temperature of 21°C with the standard radiators in The Netherlands. Taking the 90°C as a given, the temperature at which heat leaves the plant varies between 120°C and 95°C, dependent on the outside temperature. The return temperature is then dependent on how much a household uses, but is generally measured to be 68-70°C. This gives us a temperature difference, also known as ΔT. This difference is important, because it co-determines the capacity of the pipeline. The larger ΔT, the more capacity the pipeline can hold.

The pressure in the network is controlled with the use of booster stations. As the name suggests it boosts the pressure of the water flow, since there is a certain pressure drop over the distance travelled. Then there is also the flow, with which the heat travels through the pipeline. The flow is the volume per time unit. This is dependent on the diameter of the pipeline. Together with the pressure, pressure drop and ΔT the capacity of the pipeline can be determined. The pressure, pressure drop and diameter of the pipeline are stable, however the ΔT changes daily, seasonally and so forth with demand and outside temperature for example. Therefore, the capacity of the pipelines varies over time.

The fact that the capacity varies over time and is dependent on ΔT, brings technical complexity. From the producers and distributors point of view on efficiency, it is desirable to have a large ΔT so that smaller pipelines can be installed that can still hold the capacity that is necessary to meet demand. This would lower the barrier to entry significantly. At the same time, it is more efficient from a societal and consumer point of view, to have a lower ΔT. This would mean households use less heat, because their homes are well isolated, or make use of floor heating for example. This lowers their costs of heat use, and since a smaller amount of heat is used, this is more efficient for them as well. Because there are multiple points of view on the ΔT, this is an important factor to take into account when designing a new market for district heating.

4.2 Economic domain

There are several economic principles that are used in practice in district heating systems in The Netherlands. The two design choices from theory that are economically relevant are the end-user price regulation and the capacity mechanism. The current situation only has an end-user price regulation in place, and does not have a capacity mechanism installed. In this paragraph, only the organisation of the end-user price regulation is discussed.

Since consumers cannot choose within district heating who supplies them, or even choose another form of space heating. Consumers are completely surrendered to the one supplier of district heating in their area. To reduce the negative effects of this monopoly position for the consumer, a maximum price is set that suppliers can ask. This price calculation is divided into a connection fee and a variable cost that is dependent on the Gigajoules (GJ) of heat used per consumer, the exact calculation is demonstrated in the theory exploration chapter.

E.ON and Eneco as producer and distributor have agreed upon a price per GJ. The basis in this calculation finds itself in the heat law as well. In this law, it is established that a producer can receive a reasonable return on the heat delivered. The costs made by Eneco are therefore based on the costs made by E.ON for production in addition with a reasonable margin for E.ON. Dispatch is calculated using the established price agreement. Because prices are constrained by the NMDA principle in the heat law, it is less likely that producers will invest in generation capacity. In order to stimulate investments in generation capacity, a capacity mechanism could be installed.

4.3 Institutional domain

In order to define the institutional context, Williamsons (1998) layer model is used. This model maps four different layers of institutions, varying from those that are completely embedded in society to temporary agreements that are made, as shown in the literature chapter. In the figure below, this framework is applied to the case of district heating in the The Hague area.

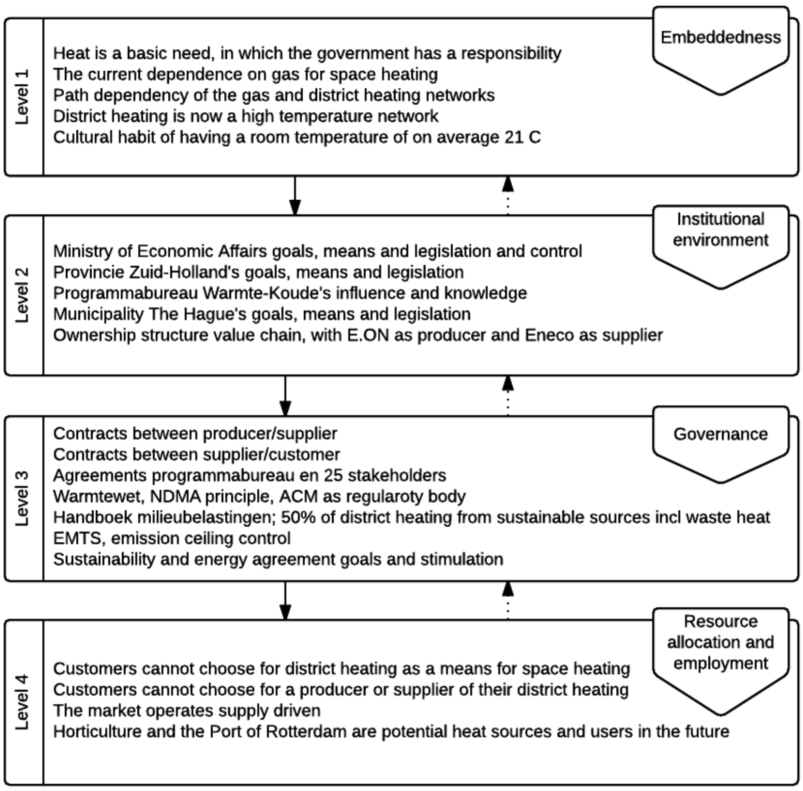

Fig. 2. Institutional layers of the current district heating system, framework by Williamson (1998)

To elaborate upon the figure, a few institutions will be explained. The first layer includes norms, values, cultural habits and other completely embedded institutions. Heat is seen as a basic need for human beings, and therefore the government is responsible for the availability for citizens. This means they have to ensure even households with the lowest income can afford this service. In the past, much of space heating in houses has been provided by gas. Generally, each house has a gas connection, which though an individual boiler heats up water for radiators and tap water. Simultaneously, many houses therefore have a gas stove as well. Since the Groningen gas field was discovered, this has become the norm in The Netherlands. The effects of these norms on district heating have been that all houses are built based on 90°C water running through radiators and the cultural norm of an average 21°C room temperature, and that therefore district heating water also has to supply 90°C water in order to reach that room temperature. To illustrate, for example in Sweden, radiators are larger by default and due to the larger surface area only require 72°C water in order to reach the similar 21°C average room temperature.

Then on to the second layer, which includes the institutional environment, or the formal rules of the game so to say, with especial attention to property, in the polity, judiciary and bureaucratic sense. Formally speaking, the value chain is divided as illustrated at the beginning of this section, where the Ministry of Economic Affairs, Programmabureau Warmte-Koude Zuid-Holland, Province Zuid-Holland and the Municipality of The Hague have chain-wide interests and control. Others, like E.ON, Eneco, own a specific part of the chain, production and transportation, and distribution respectively.

The second layer has direct effects on the third layer, which includes governance, or so-called play of the game, with especially contracts and aligning governance structures with transactions. In this layer, the contracts within the chain are important, physical and verbal agreements included. Not only the contracts, but also the laws and regulations that apply to district heating are in this layer. Some of them are applicable specifically to the economics of the system, they have been explained in the previous paragraph. Sustainability goals are applicable for district heating as well, this influences which sources should be used in the near future. The EMTS system is also included in this diagram, because the Port of Rotterdam is one of the potential producers of district heating. They reach their maximum allowance of the allowed emissions, and up until now reusing waste heat for district heating does not count as a saving on the emissions. If it would, they would be far more likely to want to connect to the district heating system for example.

The fourth and last layer includes the institutions on resource allocation and employment. For this system, this means the fact that consumers cannot choose their supplier, or for district heating as a form of space heating at all. The market thus far has been focussed on ‘there is heat supply’ and not ‘there is heat demand’, which has made it supply driven. Lastly, horticulture and the Port of Rotterdam are seen as potential producers, so knowingly or not any plans made are already focussed on these parties.

5 The conceptual model

From the systems analysis the design area can be demarcated. The conceptual model should include all elements from the design area.

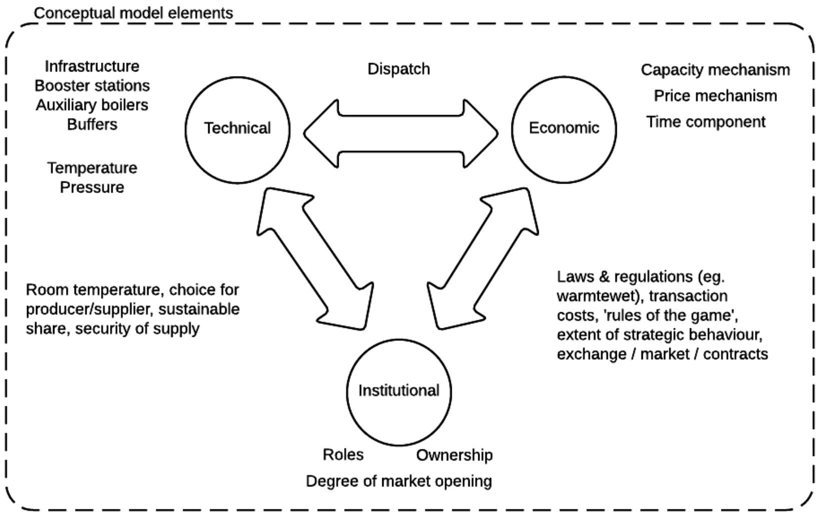

Fig. 3. The conceptual model design area

The idea behind this conceptual model is to map the system as a whole and the relations between different variables in the system. The conceptual model consists of three layers: a technical layer, an institutional layer and an economic layer. Each layer describes a different aspect of the market design, occuring at the same physical stage of the markt. The physical stage guiding the other layers consists of the four main activities, namely: production, transport network, distribution networks and load, representing the different activities in the value chain through which heat passes from production to consumer. The technical, institutional and economic layers each have their influence on eachother and share an interface where the layers interact.

The layers include the following:

- The institutional layer indicates who or what type of organisation is active within each stage, or the roles they have with respect to the physical stage in which the heat is located. This can be different with respect to each market design, depending on the configuration, which is indicated by the dashed box around the elements.
- Then the economic layer indicates how the heat is traded from each stage to the next. This could also vary, depending on the institutional desgin of the structure, and the technical interpretation of the system.
- The technical layer shows what technically needs to happen to get the heat from the place where is generated to where it is being used. This structure is not likely to vary, but the implementation may differ in temperatures, losses, kilometers etc.

As is already becoming clear, the layers are very dependent on eachother and cannot be seen seperately. Therefore the interfaces are also included in the diagram. The interfaces show aspects that will need to be balanced between the layers, being influenced from both sides. As an example, the room temperature. This is a cultural habit, and will be different per country or region, or even differ within cities where communities with different cultural backgrounds live together in neighbourhoods. In The Netherlands, a room temperature of 21°C is maintained. From the technical side, this means that the supply temperature must be high enough to heat households to this temperature, either through radiators or floor heating or otherwise. As is illustrated a quite simple aspect such as room temperature can have a big impact within different layers of the system.

5.1 Technical layer

First off, the technical layer. This layer encompasses the actual heat or energy flow and its characteristics. The temperature, the pressure, the pipeline, the network, and the return flow of water. This is comparable with the paragraph 'technical structure' in the systems analysis chapter. Not much is likely to change within this structure for district heating when more producers are added to one network of district heating. There will still be a generator, booster stations, distribution and the use of heat and between the elements, the heat will flow with a certain temperature, pressure and over a certain distance. The distances may change, and the amount of generators, booster stations might change, but this does not alter the fundamental technical structure. There is one aspect in the technical layer that does have an impact when changed, this is the supply temperature. Therefore this is demarcated with a dotted line.

5.2 Economic layer

The economic layer is already more subject to change than the technical layer. Trading and investments can be done in many ways. Through an exchange, a market, or contracts and these are just some general configurations. This conceptual model shows that in the transport and distribution network sections of the value chain, the economic counterparts are not set in stone. These are to be filled in, when designing alternatives for the market. These elements in the economic layer are related to the institutional layer and the structure that is designed there. It must be kept in mind that these cannot be seen completely separate. Within this layer, there is one design choice that is very important, namely the capacity mechanism. A capacity mechanism is a policy instrument to give incentive to investments. Especially in potential new market situations, a big question is 'who is responsible for investments in which parts of the value chain' and how can be made sure that investments are made?

5.3 Institutional layer

The institutional layer is perhaps the most intricate of all, since these elements are mostly variables you cannot calculate or give a value to, for example elements like roles, responsibilities, and ownership. Looking back at the institutional analysis in the system analysis, there are four layers that can be identified. All these institutions do not necessarily operate on the institutional layer itself, but also either in the economic & institutional interface or the technical & institutional interface, since institutions can be nested everywhere. The most change can be made in this layer. Rules, regulations, ownership, relationships, many elements can be designed for a market. They are all closely linked together, so any institutional design must be well thought out, also in combination with the economic layer. When looking at the institutional layer, the degree of market opening is marked as a design choice.

5.4 Interfaces

Variables that either influence elements from two layers, or themselves are influenced by elements in two different layers, are placed in the interfaces. Three different interfaces can be identified. The I&E, E&T, T&I interfaces include many variables. Many of these variables are actually institutions, but since these are important for more that the institutions layer, they intervene on the interfaces. The variables on the I&E interface are the laws & regulations, transaction costs, and the institution through which trading takes place, for example contracts, an exchange or a market. The E&T interface includes only one variable, which is the dispatch. How the dispatch is calculated depends on the economic and technical configuration, which is why it is on that interface. On the third and last interface, the T&I interface, room temperature, whether there is a choice for producer or supplier for consumers, the sustainable share and the security of supply are situated. This is all summarised in figure 4.

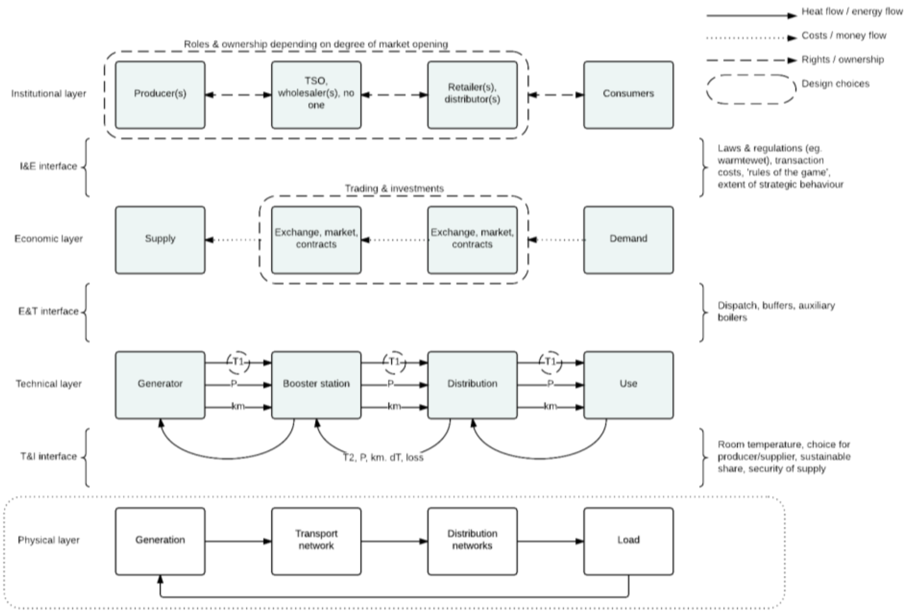

Fig. 4. The conceptual model for district heating

6 From conceptual model to simulation

Agent-based modelling of socio-technical systems (van Dam, Nikolic, & Lukszo, 2013) will be used to guide this chapter of how to go from the alternatives sketched to a simulation model. Firstly, it should be established that the district heating system meets the requirements to be modelled in an agent-based manner. The book describes three conditions for modelling complex systems using agent-based concepts (van Dam et al., 2013). How the district heating system meets these conditions is described in table 7.

- "The problem has a distributed character; each actor is to some extent autonomous.
- The subsystems (agents) operate in a highly dynamic environment.
- Subsystem interaction is characterised by flexibility: it can result from a reactive or pro-active attitude, from a propensity to co-operate or to compete, or it can be the result of social interaction (including, for example, trust or empathy)" (van Dam et al., 2013, p. 5).

Table 2. How district heating meets the conditions for agent-based modelling

Agent-based modelling conditions	District heating system
The problem has a distributed character; each actor is to some extent autonomous.	The distributed character is present in the district heating system. Each actor, producers as well as distributors have their own plans, actions, behaviours and independent from others to a certain extent.
The subsystems (agents) operate in a highly dynamic environment.	The environment of district heating is highly dynamic. Especially now, with so many stakeholders that want to make a change. The ministry of economic affairs with their proposed heat vision, the Programmabureau with the steps towards a heat roundabout. Also E.ON itself is undergoing organisational changes. With energy policy high on the agenda, a dynamic environment is a given.
Subsystem interaction is characterised by flexibility: it can result from a reactive or pro-active attitude, from a propensity to co-operate or to compete, or it can be the result of social interaction (including, for example, trust or empathy).	Interactions between the different actors, whether producers or distributors, is very much a result of their different attitudes and social interaction. Currently this is already the case between E.ON and Eneco, who have a certain trust relationship amongst each other for example. In a new market situation, interactions only increase and will be even more flexible since there is more choice of producers and distributors.

From this table we can conclude that the district heating system does meet the conditions and can therefore be modelled using agent-based concepts. Some further steps in the process are proposed in this chapter. The steps in the same book will be used. Step 1 and 2 of a total of 10 steps will be completed, namely the problem description specific to the model and also a system demarcation including a design of experiments.

6.1 The modelling problem description

In order to look further into how to simulate the district heating market alternative, a problem description is necessary. The problem description consists of several parts, a lack of insight, an observed emergent pattern, a desired emergent pattern and an initial hypothesis. To complete the problem context, a problem owner is identified, the other actors that are involved are mentioned and the role of the modeller is briefly pointed out. Together this will complete step 1 of the agent-based modelling process (van Dam et al., 2013).

The lack of insight the agent-based model should address is therefore:

Which combination of design choices suit the district heating system the most?

Where the design choices are the degree of market opening, a capacity mechanism and the supply temperature of the system.

The observed emergent pattern of interest follows from the current situation as described in chapter 4, the systems analysis. The observed emergent pattern of interest is the monopolistic division of activities, a closed market with one producer, one distributor where laws are needed to prevent monopolistic prices. There is also not a lot of incentive to invest and path dependency has determined a high temperature network. The desired emergent pattern if interest follows from the desired situation and the interviews held with certain stakeholders. This is an open and demand driven market, with multiple producers and a choice for consumers.

The initial hypothesis for the difference between the observed pattern and the desired pattern is that a degree of market opening where producers are in competition with each other in a single-buyer market structure, a capacity payment mechanism and a low supply temperature network should lead to the open market as desired. However, we are not entirely sure that this configuration of design choices is the one leading to the desired emergent pattern.

The further research in terms of an agent-based model continues to address E.ON Benelux as the problem owner. However, an agent-based model of the district heating system could also be interesting for other involved stakeholders. The simulation model provides insights into the behaviour of these stakeholders and the market as a whole. The stakeholders in the model that are the most important are producers and distributors. Their behaviours are of interest in case of the new market.

Additionally, the conceptual model made in this thesis can be used to structure the modelling process. The advantages of having the conceptual model of the alternative is that it is easily visualised and forms a good starting point to depart from. It offers a way to structure the agent-based model in future steps.

6.2 System identification and decomposition

In step 2 of the agent-based modelling steps, the system to be modelled is described and demarcated. This paper has made many steps regarding this aspect already. The conceptual model provides a clear demarcation of the concepts in the system. Furthermore the final alternative for a new district heating market provides the exact system to be modelled in a future study. This will be discussed in the system demarcation. After this, an inventory will follow including all the entities of the system. Lastly, this inventory is structured including several iterations, and summarised in a figure.

System demarcation.

The system is defined as the technical, economic and institutional aspects that are relevant to the problem. As the focus has already been on the three design choices, the degree of market opening, a capacity mechanism and the supply temperature, these are also the focus for this model. The goal is to find out the type of behaviour these aspects generate in the market for district heating. This behaviour that emerges is what we are interested in, the behaviour of the agents in an open market.

The interviews done in phase A of this research have shown that the stakeholders in the situation of E.ON and The Hague have certain ideas about the new system. There are several factors of interest in the system, that the agent-based model could provide insight into. These are:

- The security of supply [ratio]
- The price of 1 MWh of heat [€/MWh]
- The demand for heat [capacity, volume]
- The number of producers in the market [1…10]
- The market share per producer [%]

Design of experiments.

With the model, certain experimental setups can be simulated in order to measure the difference of each setup on the outputs of the model. In such an experimental setup, different degrees of market opening, capacity mechanisms and supply temperature can be used as inputs. The combined effect of these alternatives can then be measured on the output variables, in order to suggest the best alternative market design for district heating. The optimum values or range of optimum values must be determined of each output variable, in order to see which experimental setup has the best results.

The first experimental setup that is proposed to test, is that of the best alternative resulted from this study (van Woerden, 2015). Which means, a certain degree of market opening, together with a capacity mechanism and a supply temperature will be tested. Secondly, other configurations of the design choices can be experimented with, to see when the observed security of supply, price, demand, n# producers, and market share per producer reach their optimum values. And thus which is the best market design for the district heating system.

All of the above can be summarised in the following figure.

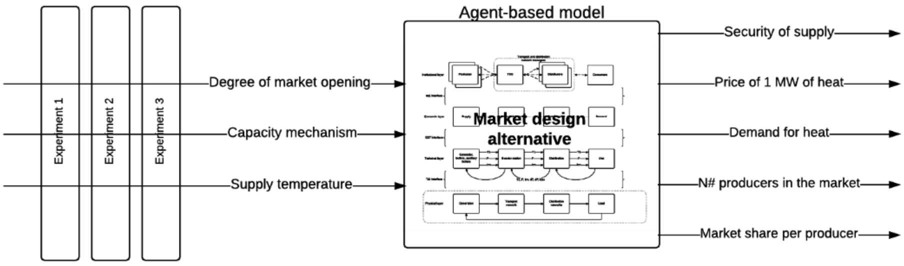

Fig. 5. Inputs, outputs and experiments of the agent-based model

7 Discussion

With the conceptual model, it has been difficult to determine the effects of a certain degree of market opening, capacity mechanisms and the supply temperature on the five objective variables (security of supply, the price of 1 MWh of heat, the demand for heat, the number of producers in the market and the market share per producer). This has been difficult, because the conceptual model captures the different flows in the system, and not the relations per se. Relations between elements are generally quantifiable, meaning a number or equation can be given. However, that was not the goal of this conceptual model. The goal of the conceptual model was to capture the district heating system and all the elements on different layers. The simulation model will have to look at the relations and quantify these. For example, the simulation model should not only determine the effect of the single-buyer market structure on the costs for the consumer, but the combined effect of the single-buyer design, the capacity payments and the lower supply temperature. And not only the effect on the consumer price, but also on the other four objective variables. Since this is becoming very complex, a simulation model is needed to define and quantify the relationships.

The relation between the model and its use in agent-based modelling of complex adaptive systems is that the conceptual model can be used to guide the development of the simulation model. From the conceptual model it is known that there are three flows: heat, costs and ownership. This is also what should flow through the agent-based model, from producer to consumer. It is also known from the conceptual model that there is a market structure, for example the single-buyer structure, and that this is what the market should look like. That is why not only the suggested alternatives, but the conceptual model is of the essence. It could be that the suggestions made for market design alternatives are not adequate, and that different design of experiments are needed. The conceptual model gives the framework to think of different options, within the district heating system.

8 Conclusion

Complex systems, such as the district heating system, where multiple actors are involved from both public and private nature, are best described from three different perspectives. In such systems the technological component determines the working of the system to a lesser extent, but the behaviour of actors that take certain decisions have a greater influence on the system. The three layers, technical, institutional and economic are all essential to design a complete market for district heating.

The conceptual model that is made for the district heating system shows the three design choices and the three different perspectives, namely the technical, economic and institutional layers of the district heating system. Since this is a design study, it is important to note that the model is an interpretation of the designer of the district heating system. In order to mitigate this potential flaw, validating the design is an important step. Experts in the field have contributed to this. Due to the extensive involvement of both theory and practice, the effect of the potential biased perspective of the designer is reduced to a minimum. The conceptual model has several advantages, it namely:

- Creates awareness of all concepts involved;
- Gives insight in all three layers, which adds value;
- Provides the means to represent the different flows, for it is not only heat going from A to B and back;
- One layer cannot advance/change without the others, which means looking at one perspective is not sufficient;
- When applied to a specific situation, this can form a complete picture and a basis for simulation.

It is also important to note some disadvantages or limitations of the conceptual model. During the process of designing, the following findings were noted:

- Difficult to capture all relations and dynamics in a diagram which does not advance in time like a simulation model would;
- The design area demarcates the research, but limits the depth in which the model has been built;
- The boxes in the institutional layer only contain stakeholders, the actual institutions are either represented by arrows or take place in the interfaces;
- The model and the current situation are focussed on households as customers and do not include large consumers;
- There are many details that are not included in the model, it does not cover a lot of detail but it focusses on concepts and high level aspects only;
- The step from going from concepts to using it to represent the current system is quite wide, this could pose difficulties for the usability of the conceptual model.

These limitations should be taken into account when using the general conceptual model for future purposes. The purpose of the conceptual model for this study is to use the conceptual model to develop alternative market designs. The different implementations of the design choices in the conceptual model are combined into alternatives.

In this case, agent-based simulation is the best simulation method for the district heating system. Agent-based modelling as a method that creates insight into behaviour of the system as a whole, as well as its individual parts. These insights are necessary in order to evaluate the alternatives in case of introducing a new market structure for district heating in The Hague. The model can contribute to the decision making process by simulating different configurations of design choices and their resulting outcome. This outcome is measured in form of the security of supply, the price per MWh of heat, the demand for heat, the number of producers in the market, and the market share per producer. Theory goes a long way, especially in this stage of developing an new market for district heating, but a simulation model can take the results from this research to the next level.

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