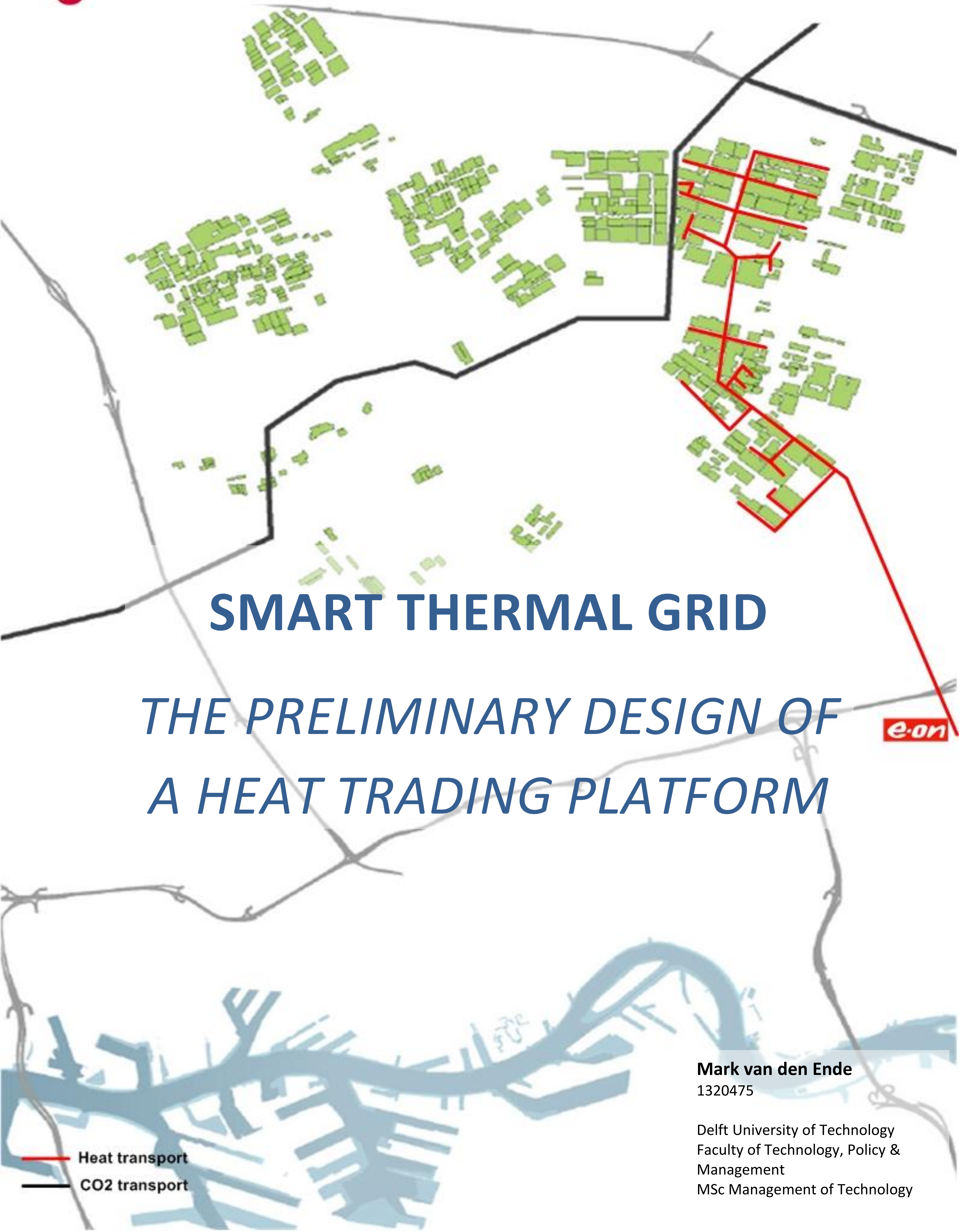

SMART THERMAL GRID

THE PRELIMINARY DESIGN OF A HEAT TRADING PLATFORM

Mark van den Ende
1320475

Delft University of Technology
Faculty of Technology, Policy & Management
MSc Management of Technology

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Author Mark van den Ende

Student ID 1320475

Institutions

Delft University of Technology

Faculty of Technology, Policy & Management

Jaffalaan 5

2618 BK Delft

The Netherlands

Eneco

Department Eneco Warmte & Koude

Marten Meesweg 5

3068 AV Rotterdam

The Netherlands

Program MSc Management of Technology

Section Energy & Industry

Course MOT2910 MSc Thesis Project

Graduation Committee

Delft University of Technology

Prof. Dr. Ir. P.M. Herder (chair)

Dr. Ir. Z. Lukszo (1st supervisor)

Dr. Ir. M. de Weerdt (2nd supervisor)

Dr. MSc. S. Cunningham(2nd supervisor)

Eneco

Drs. S.C. van Vooren (external supervisor)

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ABSTRACT

Due to changing market conditions on the energy market, profit margins of energy companies are under pressure. An example of these decreasing profit margins is the thermal grid in the B3-hoek, an area near the city of Rotterdam, partly owned and operated by Eneco Warmte & Koude (Heating & Cooling). To improve the profitability of the thermal grid Eneco W&K are investigating the possibility of transforming the thermal grid into a smart thermal grid. The investigation is done by Eneco W&K in cooperation with Eneco AgroEnergy, E.ON and the TU Delft. Currently, there is only one heat supplier. However, with the dispatch multiple production units in operation, the thermal grid will be more flexible and requires it to be more 'smart' .

The decision problem concerning the smart thermal grid is unclear. The decision problem is defined as the organization of the decision process involving many stakeholders. This research has developed a decision problem formulation regarding the smart thermal grid in the B3-hoek. This leads to the main research question:

How can the decision problem regarding the smart thermal grid in the B3-hoek be formally described?

To describe the decision problem, a preliminary design of a heat trading platform is developed. This heat trading platform organizes the decision process involving all the relevant aspects of decision making in the smart thermal grid.

To develop the preliminary design of the heat trading platform, the smart thermal grid has to be analysed first. This analysis is based on Groenewegen's framework which defines complex systems (Groenewegen, 2005). The method of analysis divides the system into different domains: technology, actors, economics and institutions. The different domain analyses create a perspective on the different domains. These perspectives are combined in an aggregated view, or in this case the preliminary design. This design is also based on engineering economics, since the heat trading platform has to be both technically and economically viable. Subsequently, an illustrative example, based on engineering economic techniques, is presented to investigate the economic feasibility of the smart thermal grid and the heat trading platform.

Analyses

Since the transformation to a smart thermal grid is investigated, it was to be expected that the heat demand is important. However, greenhouse growers are connected to this thermal grid, therefore also CO_2 and electricity have their influence on the system. The three sources needed by greenhouse growers (heat, CO_2 and electricity) are all interrelated and therefore they cannot be treated separately.

The use of decentralized heat production will create new technical constraints appertaining to production, transportation and the switch to prosumers. These constraints, discussed in this thesis, need to be taken into account as boundaries of the dispatch of the production units.

Moreover, the change to decentralized production will change the roles and responsibilities of some of the thermal grid participants. The decentralized character of the smart thermal grid requires trust in the system and in other system participants. Especially, considering that the dependency of participants on the system and other participants increases. the trust in the system and in the participant's behaviour should be predictable. To make the behaviour predictable, institutional arrangements should be implemented that provide incentives to behave accordingly. For example fines if greenhouse growers do not supply the heat that was agreed upon.

The most important driver of the participants to participate in the system is economic gain. Since the system will operate in a competitive business environment. The institutional environment should therefore always take into account the economic gain of the different participants. The heat trading platform improves

profitability of participants, by combining the demand and supply of heat, electricity and CO_2, and thus creating an optimum in terms of efficiency (and economy)

Preliminary design

The design of a heat trading platform consists of two parts: dispatch and pricing. First the dispatch of the production facilities is described, and second then the heat price is determined.

Since economic gain for all participants is important, the social welfare of the system has to be maximized. However, the heat demand is presumed to be inelastic, therefore the maximization of the social welfare is equal to the minimization of the total cost. The dispatch of the production units therefore is based on the minimization of the total costs. Dispatch in this context is the determination which production unit produces at which time.

The dispatch consists of three different parts; the long-term objectives, the day-ahead dispatch and the intraday dispatch. The long-term objectives are not an actual dispatch, but are focused on achieving long-term objectives by influencing the day-ahead dispatch. Long-term objectives are for example continuity and sustainability of the thermal grid. This is needed, since the objective of the day-ahead dispatch is minimizing the total cost day-ahead and thereby ignoring the long-term.

The day-ahead dispatch, dispatches the production facilities in blocks of one hour in the most optimal way. In practice the day-ahead dispatch will consist of two optimizations. The first optimization is done before the electricity market settles and the second one is done after the electricity market settles. This is needed, since the dispatch of co-generation units cannot be done simultaneously for heat and electricity. Therefore one of the two has to be settled first. Since the electricity market is national and less flexible, electricity is settled first.

When the heat production facilities are dispatched, the supply and demand of heat are settled and fixed. However, on the day of the dispatch the demand and supply can differ. Therefore an intraday dispatch is created that matches the supply and the demand of heat and thereby keeping the network in balance.

The heat also has to be priced. Therefore a pricing system has to be developed. In this thesis it is proposed to do this by a single-buyers model, however no detailed analysis was done on the pricing topic so more research is needed.

Outcomes illustrative example

The outcomes of the simplified model of the heat trading platform are promising. The most important aspect of the smart thermal grid, economic gain, could be attained by both producers and consumers. The gap between the smart thermal grid and the alternative of having no grid is substantial enough; more than 8 million euros. However, the amount of economic gain per participant is hard to determine, since the economic gain depends on pricing.

Even big changes in the system, as for example an exit of a big producer, would not create a failure of the system. Even than the savings are greater than the fixed cost of the network. Moreover, variation in price and demand would cause a shift in the dispatching of production units, but will not endanger the continuity of the system. The preliminary design of the heat trading platform therefore shows huge potential for the smart thermal grid.

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ABBREVIATIONS

AVR	‘Afvalverwerking Rijnmond’: a waste processing company
B3-hoek	Area including the municipalities Bergschenhoek, Bleiswijk and ‘Berkel en Rodenrijs’, north of the city Rotterdam, now called Lansingerland
CHP	Combined Heat and Power
EFG	'Elektriciteitsfabriek Galileïstraat', one of the energy plants of E.ON
Eneco W&K	Eneco Warmte & Koude (Heating & Cooling), this is a department of Eneco
E.ON	A German energy company, owner of the RoCa and the EFG plants
OCAP	‘Organic Carbondioxide for Assimilation of Plants’, the company that sells pure CO_2
RoCa	Co-generation plant in Rotterdam and Cappelle
WAS	Heat delivery station
WLS	Heat supply station

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PART I: INTRODUCTION

1 INTRODUCTION

The research, described in this thesis, is done as a master graduation project in the framework of the Management of Technology Program, Faculty Technology, Policy and Management at the Delft University of Technology. This research is commissioned by Eneco W&K, Eneco AgroEnergy and by the section Energy & Industry of the Delft University of Technology.

The thesis concerns the thermal grid in the B3-hoek, a thermal grid partly owned and operated by Eneco W&K. The thermal grid 120 greenhouse growers receive heat from the E.ON energy plant in Rotterdam, called RoCa (E.ON, 2013). Due to changing market conditions, its commercial exploitation has become less interesting. To make the grid commercially more attractive, the transition to a smart thermal grid is investigated. In this smart thermal grid decentralized production units will supply heat to the thermal grid. Currently, the centralized production adjusts the supply to match the demand. However, with decentralized supply of multiple parties it will be hard to adjust the supply to the demand, due to the lack of information and cooperation between decentralized parties. Therefore, software has to be developed for matching the supply with the demand.

The research focuses on the formulation of the decision problems of a smart thermal grid. The definition of a decision problem is:

"The problem of finding a way to decide whether a formula or class of formulas is true or provable within a given system." (Oxford dictionaries, 2013)

In this project we will use a broader definition of the decision problem, not just looking how to find true/false answers, but how to organize a decision process with many stakeholders so that a decision can be made which aligns the interests of the relevant actors.

Eneco W&K, the department Eneco AgroEnergy and the TU-Delft are cooperating in a project to investigate the creation of this smart thermal grid. The project is divided into different parts:

Part 1 – The development of a 'dynamic netmodel'. A model that can simulate the physical thermal grid in the B3-hoek. This way different heat distribution scenarios can be modelled and tested before they are put into practice. This has to be done to guarantee network safety.

Part 2 – Enabling greenhouse growers, to supply and receive heat to/from the heat network.

Part 3 – The development of optimization software is done by AgroEnergy and the TU Delft. The software has to match supply and demand of heat in an 'optimal' way, while satisfying physical constraints, as well as transportation and production limitations. This software will perform the daily dispatch of all different production units.

This master thesis will do the prework for part three of the project. It is unknown, what the expectation of involved parties are; which factors influence the system; what the constraints of the system are; and what the optimal solution should be. Moreover, changing institutional context should be taken into account. Therefore a decision problem of this smart thermal grid has to be formulated. This formulation will be in the form of a preliminary design of a heat trading platform that takes into account the actors, constraints, the optimal solution and the institutional context. Based on this decision problem, the development of the optimization software can commence.

The main research question therefore is:

How can the decision problem regarding the smart thermal grid in the B3-hoek be formally described?

To answer this question and to give this research structure, four sub questions have been formulated. These sub questions combined, provide the basis for answering the main research question.

This report starts with the research problem and describing the objectives and the research questions. Next the background of this research is given in chapter 3, followed by the research approach in chapter 4. In chapter 5, 6, 7, 8 and 9 the analysis of the different parts of the system is described. These analyses provides more insight into the system and the dynamics of the system. Subsequently, chapter 10 will describe the preliminary design of the heat trading platform, split in the the economic dispatch and pricing of the smart thermal grid. To test the economic feasibility of the preliminary heat trading platform an illustrative example is given. This thesis will end with a conclusion, recommendations and a reflection.

The thesis is divided into 6 different parts, to create more structure. This schematically looks like:

Part I: Introduction

Chapter 1 : Introduction

Chapter 2 : Research problem

Part II: Research background

Chapter 3: Background information

Chapter 4: Research approach

Part III: Analyses

Chapter 5: System introduction

Chapter 6: Technical domain

Chapter 7: Actor domain

Chapter 8: Institutional domain

Chapter 9: Economic domain

Part IV: Preliminary design

Chapter 10: Economic dispatch & pricing

Part V: Economic feasibility preliminary design

Chapter11: Illustrative example

Part VI: Conclusions, recommendations and reflection

Chapter 12: Final conclusions & recommendations

Chapter 13: Reflection

2 RESEARCH PROBLEM

2.1 PROBLEM EXPLORATION AND PERSPECTIVE

Greenhouse growers use heat for the production of their crops. They can produce heat with boilers or CHP's, but the greenhouse growers in the B3-hoek can also purchase heat from the thermal grid. Since 1993 greenhouse growers purchase heat from this thermal grid. This heat is produced by 2 energy plants, owned by E.ON, in the city of Rotterdam. These energy plants, called the RoCa and EFG, produce heat for both greenhouse growers and for district heating system of the city of Rotterdam.

In the near future, E.ON expects to reduce the production of heat from the energy plant significantly, due to economic reasons. Therefore the greenhouse growers need to find other heat sources (Spronken, 2013). The current economic climate is characterized by low electricity prices and relatively high gas prices, reducing revenues from E.ON's energy plant significantly. Due to the reduction of electricity revenues, the commercial exploitation of heat is becoming less interesting. There are multiple underlying reasons why the E.ON is going to reduce the heat production and supply.

The first reason for the decline in heat from E.ON is the termination of the current heat supply contract, the so called 'must-run' for E.ON to supply heat to the greenhouse growers when demanded. Without this obligation, E.ON is not obligated to produce heat whenever the greenhouse growers ask for it. Secondly, from 2016 onwards E.ON is not producing the base load heating for the city of Rotterdam. In practice this means the plant will have less production hours, also reducing the hours they will produce for the greenhouse growers. The base load of heat production will be taken over by AVR.

This research is performed for Eneco W&K. Eneco W&K buys heat from E.ON and sells this through both the district heating system of Rotterdam city and the thermal grid in the B3-hoek. The base load production for district heating of the city of Rotterdam will be done by AVR. However, due to network constrains and heat demand in the city, the AVR has very limited possibilities to supply the B3-hoek. Due to the transport constraints, a decline of the E.ON production therefore automatically means that less heat can be sold in the B3-hoek.

Other reasons for this research are; the obligation to dismantle the physical network when the network is not used anymore, the removal will come with huge costs; moreover, the project can create possibilities for the development of sustainable heat production. The sustainable heat could be supplied through the network to the greenhouse growers.

Before the greenhouse growers can supply heat to the thermal grid, the grid has to be converted from a centralized to a decentralized grid. To decentralize the grid, software is needed to manage the supply of heat from different decentralized production units. This software will have to match supply and demand within the thermal grid, while being financially attractive for most of the participants(or being competitive with alternatives for heat production). The thermal grid has approximately 120 participating greenhouse growers, making the transformation of the thermal grid a complex assignment.

This research focuses on the problem formulation of the transformation of the thermal grid. The first step, the design of a preliminary heat trading platform, has to be done in order to create software that manages the decentralized thermal grid. And the first step in the creation of a smart thermal grid.

2.2 RESEARCH OBJECTIVES

The goal of this project is to create a problem definition concerning the decision problem of the smart thermal grid in the B3-Hoek. At the moment it is unclear how the decision process should be organized, therefore a preliminary design of a heat trading platform is developed, as definition of the decision problem. In order to develop this preliminary design, the system has to be analysed. With the problem definition, the preliminary design, the TU Delft can start with the development of the optimization algorithm.

2.3 RESEARCH QUESTIONS

As previously stated, the goal of this research is to provide the problem definition for the optimization regarding the smart thermal grid in the B3-hoek. This problem definition will enable the TU Delft to start with the development of the optimization. Therefore this research and the following research questions will all be about defining the problem definition. So based on the research objective, the main research question is:

MAIN RESEARCH QUESTION:

HOW CAN THE DECISION PROBLEM REGARDING THE SMART THERMAL GRID IN THE B3-HOEK BE FORMALLY DESCRIBED?

This research question is not specific and to answer this question multiple steps need to be taken. These steps are formulated in the sub-questions.

To describe the decision problem, it is important to first know what the system looks like. By "the system", the whole sociotechnical system part of the smart thermal grid is meant. The answer to this question describes the system, including the interaction between the physical network and the greenhouse growers. The first sub-question therefore is:

SUB-QUESTION 1: WHAT DOES THE SMART THERMAL GRID LOOK LIKE, BASED ON BASIC ANALYTICAL METHODS, AND HOW DOES IT CHANGE IN TIME?

It is very important to know what different stakeholders expect from this smart thermal grid project. This is important because a disagreement could potentially cause problems and these should be identified before the project has started. To analyse the stakeholders, a stakeholder analysis is done. This second sub-question is devoted to this stakeholder analysis:

SUB-QUESTION 2: WHO ARE THE INVOLVED ACTORS AND WHAT ARE THEIR EXPECTATIONS AND OBJECTIVES CONCERNING THE SMART THERMAL GRID IN THE B3-HOEK?

Things that are technically optimal, are not always economically viable. Both aspects should be taken into account to determine the system's viability. In a business environment an optimum is often found where the technical requirements can be met against the lowest possible investment and exploitation costs. However, also the institutional environment should be included, since the governance of the network is just as important as the economic and technical viability. All these aspects will also have to be investigated. This is captured in sub-question 3:

SUB-QUESTION 3: WHAT ARE THE ECONOMIC AND INSTITUTIONAL ASPECTS THAT INFLUENCE THE SYSTEM AND COULD CAUSE CONSTRAINTS ON THE SMART THERMAL GRID IN THE B3-HOEK?

After the stakeholder, technical, institutional and economical analyses have been executed, it is time to determine how the smart thermal grid should be created in practice. Developing the thermal grid smart, implies the creation of an IT-layer. Looking at all components combined, what are the constraints, degrees of freedom and the optimization criterion for such an IT-layer? In which way it has to be operated and what ambient factors/additional considerations should be taken into account? Sub-question 4 will answer this:

SUB-QUESTION 4: WHAT ARE THE CONSTRAINTS, DEGREES OF FREEDOM AND OPTIMIZATION CRITERION OF THE SMART THERMAL GRID IN THE B3-HOEK.

2.4 SOCIAL AND SCIENTIFIC RELEVANCE

2.4.1 SOCIAL RELEVANCE

Since the heat supply of the E.ON energy plant is expected to decrease in 2014, an alternative has to be found for the production of this heat. An alternatives for this decrease is the supply of heat by greenhouse growers. This would also clear the path for greenhouse growers to invest in sustainable energy production, like a geothermal power plant(or make current plants more profitable). The ability of selling their overcapacity to the network, makes it financially more interesting to invest in durable energy sources (van der Spek, 2013). The social relevance therefore is focused on stimulating greenhouse growers to operate and produce more sustainable energy.

2.4.2 SCIENTIFIC RELEVANCE

Due to for example technology innovations or economic transitions, a complex system sometimes has to undergo a transformation. The transition to a new system is complex, especially if this system involves different levels of actors, technology, economics and institutions. It is hard to define what has to be changed in order to come to a satisfactory result for the beneficiary. And therefore it is hard to define objectives and decision criteria for the transformation of such a complex system.

The system development life cycle model (Morris, 2013) is a model that describes how to develop, or transform a system. In the model multiple steps are distinguished (Rouse, 2013):

1) Evaluation of existing system
2) New system requirements definition
3) Proposed system design
4) New system development
5) The system is introduced and used
6) Maintenance and evaluation of the system

For the evaluation of the existing system and for the definition of the requirements for the new system, an analysis is needed. This analysis will be based on the framework of Groenewegen (Figure 3) combined with engineering economic techniques to assess the economic viability of the system (Groenewegen J. , 2005). The economic viability of the system will be tested in an example, that is based on economic engineering techniques. A preliminary system design will be proposed based on the analysis. Moreover, the system will be tested on economic feasibility, something that has not yet been done.

The combination of the framework of Groenewegen with engineering economic techniques has not yet been done before in the assessment of a smart thermal grid. The decision problem regarding the smart thermal grid will be described in the form of a preliminary system design. In which will be described how the decision process in the smart thermal grid should be organized. The proposed system design will therefore be an answer to the main research question.

PART II: RESEARCH BACKGROUND

3 BACKGROUND INFORMATION

In this chapter background information is given. This information is not researched and tested, but is needed to define some topics used.

3.1 SMART GRID

This research is about the creation of a smart thermal grid. More research has been done about smart grids. Electricity grids are facing a challenge of integrating decentralized sustainable electricity production, as for example solar and wind energy. So what makes a smart grid smart and what steps have to be made.

As mentioned above a smart grid has to integrate decentralized electricity production. However, it is more than that. It also means that grid operators, electricity producers and consumers have to balance their supply and demand to prevent the network from becoming imbalanced. This is also one of the things that has to be arranged in a smart thermal grid.

So what is the difference between the existing grid and a smart grid? In Table 1 the differences are shown. The most important differences are the change to a two-way communication and distributed generation. Other changes are the ways of monitoring; a smart grid does self-monitoring through a lot of sensors throughout the network. This is needed since decentralized production makes the network stability harder to control.

Existing Grid	Smart Grid
Electromechanical	Digital
One-Way Communication	Two-Way Communication
Centralized Generation	Distributed Generation
Hierarchical	Network
Few Sensors	Sensors Throughout
Blind	Self-Monitoring
Manual Restoration	Self-Healing
Failures and Blackouts	Adaptive and Islanding
Manual Check/Test	Remote Check/Test
Limited Control	Pervasive Control
Few Customer Choices	Many Customer Choices

Table 1: The smart grid compared with the existing grid (Farhangi, 2010).

These things also apply to a smart thermal grid. In the transition from the thermal grid in the B3-hoek to a smart thermal grid, these changes should be given some thought. As mentioned in the introduction, this research will focus on the heat trading platform. Making the grid intelligent through digital steering.

3.2 SMART THERMAL GRID

A thermal grid is used to transport heat from A to B. This is done by transporting heated water, that is cooled down at the consumers side by a heat exchanger. The sold heat is the amount of joules that is exchanged. This can be calculated by the following formula (Mills, 1999).

$$Q_{th} = V * \rho * C_w * \Delta T \tag{3.1}$$

$$Q_{th}: heat (J)$$

$$V: volume\ (m^3)$$

$$\rho: density (\frac{kg}{m^3})$$

$$C_w: specif\ heat (\frac{J}{kg * K})$$

$$\Delta T: Temperature\ difference (°C)$$

The existing thermal grids are mainly used for district heating. Heat, that is either a waste product or produced for heating, is transported to different districts. In these districts consumers can demand heat, without any communication with the supplier. For example, nobody will call the energy company before taking a shower. Most thermal grids only allow one way transportation. The consumers in the network cannot sell heat, they can only buy heat. With the creation of a smart thermal grid, the supply and demand have to be matched. A smart thermal grid should enable decentralized production sources, to supply heat to the network. In district heating, the big consumers could be able to supply heating to the network, if they have heat production facilities. In the B3-hoek where big greenhouse growers have their own heat production facilities, this is the case.

Making the network 'smart' is more than making it possible for other sources to supply heat. As shown in Table 1 a lot more has to be done to make the network 'smart'. Research has been done to the creation of a smart thermal grid, in which four steps are defined (Kerckhoffs, 2012).

1. Lower the temperature in the current networks. The temperature of the networks are often above 100 °C. Decentralized sources cannot supply such a temperature. A more efficient heat distribution and a lower distribution temperature is needed to achieve this goal (Werner, 2013).
2. The thermal grids have to be made flexible. The supply and demand have to be matched at any time. Two different aspects are necessary: activation of consumers and the storage of heat.
3. Creating bi-directional thermal grids. Due to this, decentralized sources are able to supply heat to the network.
4. Integration of all grids. Connecting supply and demand of electricity, heated and cooled water.

<u>Lowering grid temperature</u>

District heating, thermal grids, plays an very important role in many countries. However, the problem of district heating network is that the temperature supplied should be greater than the highest local heating network temperature, in the case of the B3-hoek this is the city of Rotterdam. Currently, Eneco W&K is investigation the possibility of lowering the temperature in the grid. Their goal is to lower the grid temperature to around 90 °C, making it possible for CHP to supply heat to the network.

Additionally, lowering the grid temperature decreases the losses, due to a lower ΔT between the pipeline and the surroundings. Another advantage is an decrease in mass flow rate, and thus lowering network cost, for example pumping cost. Moreover, a lower return temperature improves the efficiency of the central production plants (Curti, von Spakovsky, & Favrat, 2000).

<u>Increasing flexibility</u>

By actively controlling the heating load in a thermal grid the revenues from the electricity market can be maximized using CHP's. Since with active control it is possible to rearrange the heat demand, creating flexibility (Johansson, Wernstedt, & Davidsson, 2012).

Currently, Eneco W&K and E.ON are also investigating the possibilities to increase the flexibility of the thermal grid. Since, more flexibility will increase the economic performance of the thermal grid (Haga, Kortela, & Ahnger, 2012). This flexibility is increased with help of buffers. As the greenhouse growers' demand can be shifted by the buffers, the heat can be produced at economically favourable moments. Ideally, the demand of heat and the electricity price follow the same curve. However, as shown in Figure 2, the patterns are almost reversed. The supply and demand do not match at all. The matching between supply and demand can be facilitated by the buffers. As shown in Figure 1 the heat demand and heat purchase can be disconnected. With the use of buffers, heat can be bought at more favourable times (for example between 10:00 and 22:00) and be used for heating at night. The storage of heat in buffers creates flexibility in heat production and lowers the overall production cost (Haga, Kortela, & Ahnger, 2012).

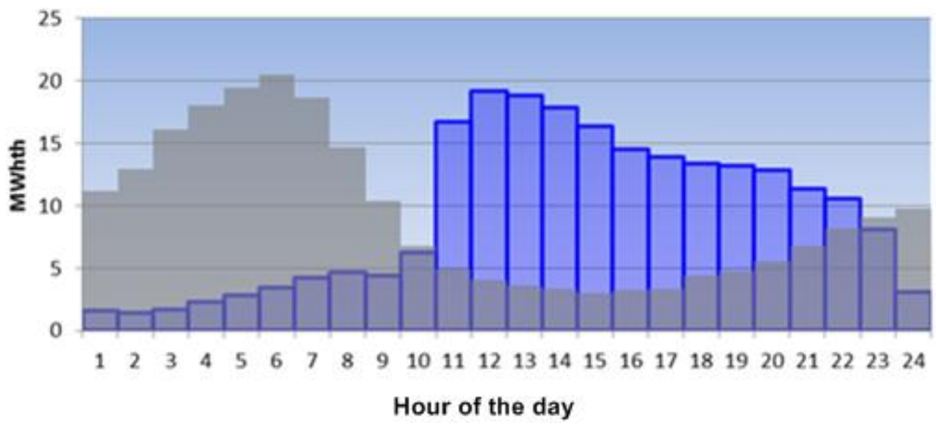

Figure 1: Heat demand pattern from greenhouse growers with buffers steered by Eneco(blue) vs demand from the same greenhouse growers without using their buffers(grey)

Not all the greenhouse growers have buffers, or want to let Eneco control their buffer. In Figure 2 the heat demand of all greenhouse growers in the B3-hoek is shown. In grey no buffers are used, this is the demand pattern as it was the past years. In black, Eneco uses 18 buffers to steer the demand of the greenhouse growers. It can be seen that at night the head demand decreases, while by day there is an increase in heat demand. This matching of demand and supply is a step towards the creation of a smart thermal grid (Johansson, Wernstedt, & Davidsson, 2012).

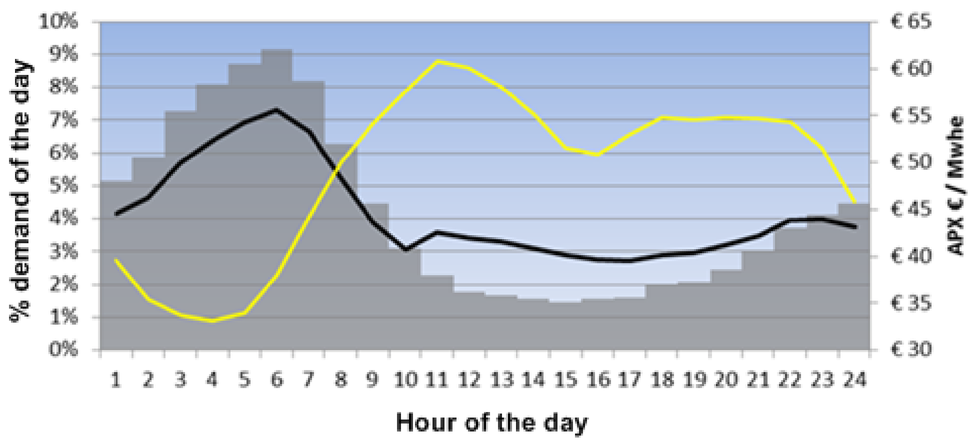

Figure 2: APX price (yellow) vs total B3-hoek heat demand with buffer(black) and total demand without buffers(grey)

Decentralized production

Besides the use of buffers, decentralized production has other advantages; improved reliability and efficiency of the energy supply; a swift response to changes in the heat demand; and the reduction of transmission losses. Moreover, multiple decentralized units with fast starts and ramp rates enable for more dynamic operations (Haga, Kortela, & Ahnger, 2012).

Due to the complexity of this mixed energy production engineers have trouble determining the optimal dispatch for the job. The operations of a thermal grid are heavily affected by the dynamics of the distribution network. This is due to the time delays in the thermal grid, which are large compared to production and consumption. Moreover this is due to the heat losses to the surrounding environment. For optimization of the operations of a thermal grid, it is therefore vital to have simulations models that simulate the demand. Currently these simulations are done by E.ON (Benonysson, Bohm, & Favn, 1995).

3.3 INDUSTRIAL DISTRICTS

The theory of industrial clusters applies to the area of investigation, the B3-hoek. In this area many greenhouse growers are clustered. This section elaborates on the theory of industrial districts, which explains why the greenhouse growers clustered and why the thermal grid was built.

Industrial districts is a concept from the beginning of the 20th century, in which firms, manufacturing a certain product, are geographically clustered (Marshall, Principles of Economics, 1920). There are various reasons for the geographical concentration of firms, mostly rested on production factors (e.g. capital, labor and natural resources) (Marshall, Industry and Trade, 1919) (Porter, 1988). The industrial districts defined by Marshall are characterized by a combination of cooperation and competition. The districts not only cause competition due to the presence of many firms but also, and moreover, cooperation between these firms (Belussi & Caldari, 2009).

Due to the globalization and changes in technology and competition, many of the traditional roles of locations have been diminished. It would therefore seem evident that the number of industrial districts, or clusters(as the districts are called by Porter) would diminish. Yet clusters are a striking feature of many regions and states, especially in the more developed countries (e.g. Silicon Valley). The prevalence of clusters therefore gives insights into the competition and the role of location in competitive advantage. The old reasoning from Marshall might be diminished, the new influences of the clusters on competition are growing in importance. These new influences are (Porter, 2000):

- *Access to specialized inputs and employees.* Clusters can provide superior or low costs access to specialized input, such as business services, components, machinery and personnel.
- *Access to information.* The information flow between companies in clusters is more developed. And the accumulation of information within firms and institutions can be accessed better or at lower costs, allowing firms to raise productivity.
- *Complementarities. A* cluster also enhances productivity though the facilitation of complementarities between the activities of the cluster participants.
- *Access to institutions and public goods:* The access to, for example, specialized infrastructure is often cheaper and more efficient. The private investments in cluster-specific goods and infrastructure are more common, due to the collective benefits perceived by cluster participants.
- *Incentives and performance measurements:* The local rivalry often is an incentive for improvements, due to constant performance measuring with firms with similar general circumstances, making it easier to compare firms.

These influences on the competition and cooperation between cluster participants increase the competiveness of the participants. A cluster is therefore a system of interconnected firms, whose whole is more than the sum of its parts. However, not only individual firms benefit from the clusters. Also the regional and state governments benefit from the existence of the clusters, due to the employment and economic prosperity cluster often provide. The clusters are therefore often an important component of governmental policies (Porter, 2000).

The B3-hoek is an example of such a cluster. Due to the existence of this cluster of greenhouse growers, it was possible to create a thermal grid. Currently supplying relatively cheap heat to approximately 120 greenhouse growers, creating a competitive advantage for those greenhouse growers.

The transformation to a smart thermal grid can profits from the already existing network and the cluster. Moreover, the cluster can profit from the smart thermal grid. This interaction can be explained by the fact that the transformation to a smart thermal grid, is made easier since the cluster is already developed. The cluster can profit from the smart thermal grid, since it utilizes the production units more efficient, reducing heat production cost.

3.4 DOMAINS WITHIN COMPLEX SYSTEMS

When regarding a smart thermal grid, it is noticed that the system involves different levels of technology, actors, economics and institutions. A system with these characteristics can be described as a multi-disciplinary, multi-level and multi-actor system. The four different domains are all interrelated, as shown in Figure 3. The domains consist of different levels. The distinction in different domains and levels is made to simplify and structure the analysis of the system.

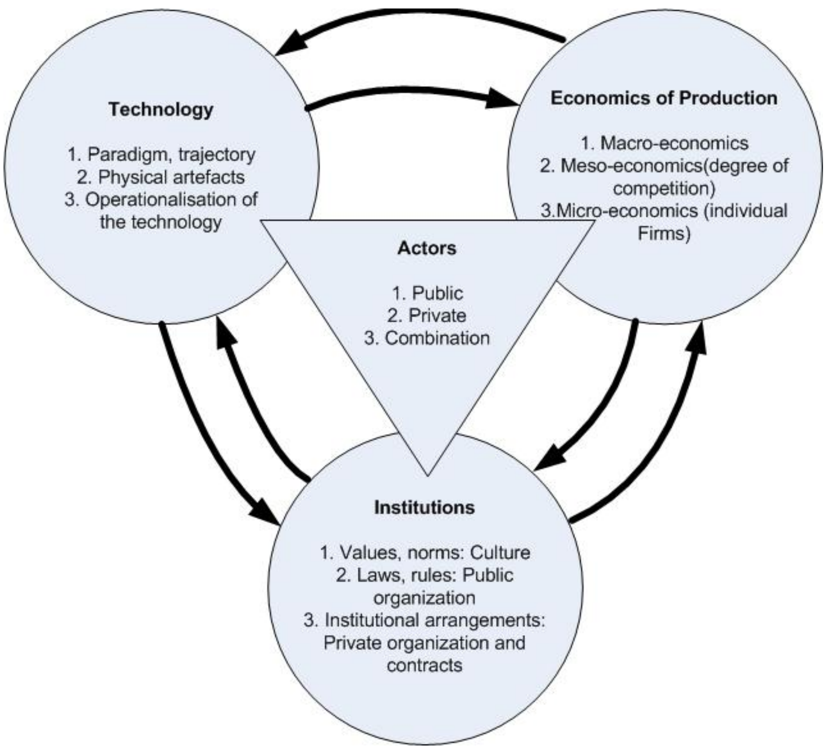

Figure 3: A multi-disciplinary, multi-level and multi-actor system (Groenewegen, 2005).

In this section the theory behind the framework presented by Groenewegen is discussed, this includes the relations between the different domains.

3.4.1 TECHNOLOGY

In the technology domain the first level consists of technological paradigms and trajectories. Technological paradigms are defined as patterns of solutions for technological problems. However, the technology in this thesis is already chosen, namely a thermal grid. There is a lock-in effect accompanying thermal grids, due to the high investments made. This makes it almost impossible to switch from technology (Dosi, 1982).

Technology does not develop in an isolated way, on the contrary, economic, institutional and social factors influence development of technology (Groenewegen, Spithoven, & van den Berg, 2010) (Dosi, 1982). Since the development of the smart thermal grid is influenced by economic, institutional and social factors, these have to be considered.

The second level is the level of the physical artefacts. In this case the physical artefacts are the pipelines, pumps, heat exchangers, valves and production units in the system. In short: the physical architecture of the network that already exists.

The third level of the technology domain is the operationalization of the technology. The operationalization of the smart thermal grid will determine how the technology will function. The transformation from a thermal grid into a smart thermal grid, is focused on how to operate the thermal grid in the most optimal way.

3.4.2 ACTORS

The first level of the actor domain are the public actors, governmental organizations. The public actors play a huge role in determining the formal institutions, rules and laws. The second level is the private actor level, which consists of companies and individuals. The actor domain is an important domain, since the public and private actors have a considerable influence on the different levels of the other domains (Groenewegen J. , 2005). Moreover, research shows that almost half of the failing projects fail, due to a lack of attendance from decisions makers to the key actors. It is therefore important to pay attention to the actors (Bryson, 2004).

3.4.3 ECONOMICS OF PRODUCTION

The economic domain consists of three different levels; macroeconomics, mesoeconomics and microeconomics. All three levels are discussed below.

Macroeconomics

In macroeconomics the emphasis is on the economy as a whole. Macroeconomics studies for example national income, employment and aggregated demand/supply. Macroeconomics will have an influence on the smart thermal grid. This influence will be in the form of the economic crisis for example, due to the economic crisis the demand for a lot of products is decreasing.

Meso-economics

Meso-economics consists of the production at region and industry level (Groenewegen J. , 2005). This level of economics studies the competiveness of whole regions, as for example the B3-hoek, compared to other regions.

Microeconomics

The third and last level is microeconomics. At this microeconomic level analysis is done of the behaviour of economic actors and production. The starting point of the analysis is based on the neoclassical theory: all economic actors make rational decisions in their own interest.

In a market all actors are presumed to pursue their goals in the most efficient way possible. This takes into account the influence of the environment. All choices of the actors combined creates the demand and supply. A market is in equilibrium if the demand equals the supply. However, since the demand and supply depend on price, a market can only be in equilibrium at certain price levels (often it is assumed that there is only one price equilibrium).

The outcome of this market can be regarded as efficient if no single actor can be better off without making someone else worse off (Pareto, 1971). This efficiency is also called the Pareto efficiency. The advantage of this efficiency is that it involves neither making judgment about an individual's real interest, nor assesses if the benefits of one outweigh the losses of another. The Pareto efficiency does not take into account the desirability of the distribution (Himmelweit, Simonetti, & Trigg, 2001).

Another efficient outcome of the market is called the Kaldor-Hicks efficiency. This efficiency is focused on wealth maximization. A market is efficient in terms of the Kaldor-Hicks efficiency if (Posner, 1980): "Resources are allocated efficiently in a system of wealth maximization when there is no reallocation that would increase the wealth of society." In this allocation of resources it means that some parties gain, while other parties lose, as long as the gains exceed the losses. It is important to notice that losers in this context do not need to be compensated for (Stringham, 2001). For wealth maximization within a system, the Kaldor-Hicks efficiency can be used.

Since resources are scarce relative to needs, the use of a resources in one way, prevents it from using it in another way. Therefore choices have to be made. These choices are made based on opportunity cost of an economic good or action and are measured in terms of the best alternative (Palmer & Raftery, 1999) (Himmelweit, Simonetti, & Trigg, 2001). Equilibriums in markets occur due to the opportunity cost of goods.

The standard microeconomic view of neoclassical economics is the basis for this economics of production domain. It is about an equilibrium in the market, based on efficient allocation of resources and about the minimization of the production costs (Groenewegen J. , 2005). As mentioned, in neoclassical theory all actors make rational decisions. However, economic actors make these decisions in an environment of institutions and other actors. Economic actors are influenced by their environment, and should also take this environment into account when making a decision (Himmelweit, Simonetti, & Trigg, 2001). This is discussed in the institutional domain.

3.4.4 INSTITUTIONS

There are multiple definitions of institutions in the English language. In this thesis an institution refers to:

"Durable set of agreements between parties that are part of a complex (technological) system, which have the form of formal and informal rules and organizational arrangements. Institutions take care of accountability, distribution and create common orientations and values, which constrain and shape the behaviour of parties involved. Thus improving the efficiency functioning of the system and its outcomes. " (March & Olsen, 1989) (Ostrom, 1990) (Koppenjan & Groenewegen, 2005)

Institutional economics

Closely related to institutions is Institutional Economics. Institutional economics is especially important, since the institutions have a large impact on how and whether or not economic transaction occur. Allocation mechanisms in the economy are part of a wider environment in which institutions (laws, rules, organizations) determine the outcomes of markets. Institutional economics concerns itself with explaining how actors coordinate their transactions (Groenewegen, Spithoven, & van den Berg, 2010). An opportune question is, how these transactions can be coordinated efficiently in order to reduce transaction costs. The transactions are done in an interdisciplinary environment, in a system with technology, actors and institutions. Institutional economics use the institutionalist model, shown in Figure 4, to describe a socioeconomic system. The domains of the model are comparable to that of Groenewegen's (Figure 3). However, Groenewegen describes the domain in more detail in order to describe the complexity of a multi-disciplinary, multi-level and multi-actor system. In this research Groenewegen's model is used, since the complexity of the smart thermal grid is described in more detail. Moreover, this model is not institutionally focused, contrary to the institutionalist model.

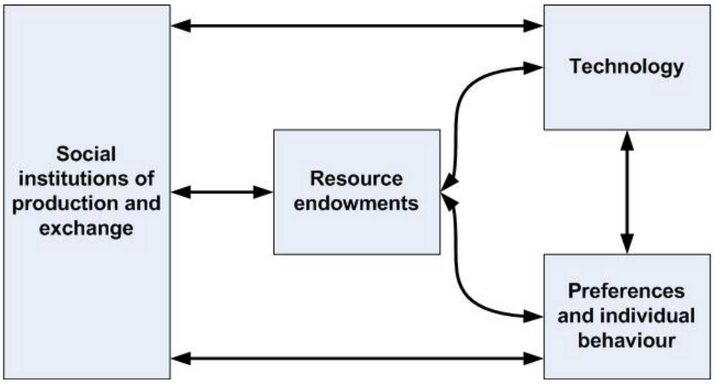

Figure 4: The institutionalist model of a socio-economic system (Himmelweit, Simonetti, & Trigg, 2001)

Four-layer institutional model

The institutional domain consists of three levels, as indicated in Figure 3. However, some institutional models consist of four levels, as for example the four layer model of Williamson. These four layers show the relevance of various economic perspectives on institutions (Williamson, 1998). Koppenjan and Groenewegen modified the model of Williamson, to analyse the functioning of complex systems from an institutional point of view. This adapted model is shown in Figure 5 (Koppenjan & Groenewegen, 2005).

The institutional domain in the framework of Figure 3 is based on the model of Figure 5, however they are different. This can be explained by the addition of a layer in the four-layer model, the actor layer. This is not a level in the Figure 3, since the actors are a different domain in the framework (Koppenjan & Groenewegen, 2005) (Groenewegen J. , 2005).

The first layer of the four-layer model is the actor and games layer. This level of analysis focuses on individual actors and their interaction in a complex system. In the institutional analysis the actors are analysed, however focused on the institutional environment and therefore elaborates on the behaviour of actors and their interaction aimed at creating and influencing provisions, services and outcomes. The behaviour of actors is characterized by trust, satisfaction, power, optimizing, interest and opportunistic behaviour (Groenewegen, Spithoven, & van den Berg, 2010).

The second layer consists of the (in)formal institutional arrangement. At this layer actors use mechanisms to coordinate the transactions between them. The institutional arrangement, also called governance structures, coordinates transactions amount(?) actors concerning labour, capital, goods and information. Examples are long-term contracts, sub-contracting, strategic alliances and joint ventures. In a network, actors can also create arrangements that facilitate the functioning of the network, called network governance (Koppenjan & Groenewegen, 2005).

The third layer, the formal institutional environment, is the layer that focuses on the formal rules, laws and regulations. The rules, laws and regulations determine the legal position of actors and the available means for transaction coordination. This layer is dominated by the legislator or the government, who designs and implements the formal institutions (Koppenjan & Groenewegen, 2005).

The last layer is the informal institutional environment. This environment is characterized by norms, values, orientations and culture. These informal institutions influence the mind-set of actors, analysed at the first layer. The informal institutions influence the perception of actors with respect to problems and solutions. This layer determines what kind of incentive structure is acceptable and effective (Koppenjan & Groenewegen, 2005).

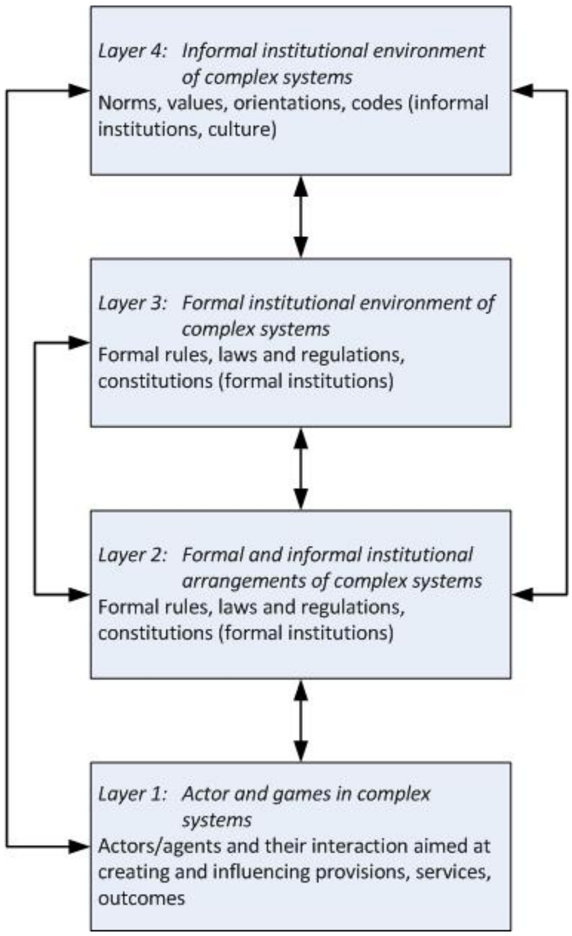

Figure 5: Four-layer institutional model, modified from Williamson (Koppenjan & Groenewegen, 2005)

3.5 FUNCTIONING OF GREENHOUSE

To give more insight in greenhouses, a short description of its workings is included. In greenhouses plants, flowers and vegetables are grown. At least 30% of the total cost of a greenhouse grower is energy (van den Ende, 2013). Therefore the whole energy household of a greenhouse is important. In Figure 6 the overview of the energy configuration of a greenhouse grower is shown. Not all greenhouse growers have this exact setup. Most greenhouse growers have boiler and some have a CHP and/or a buffer. However, this figure gives some insight in how the systems within a greenhouse are connected. In the next paragraph more information is given about the different systems.

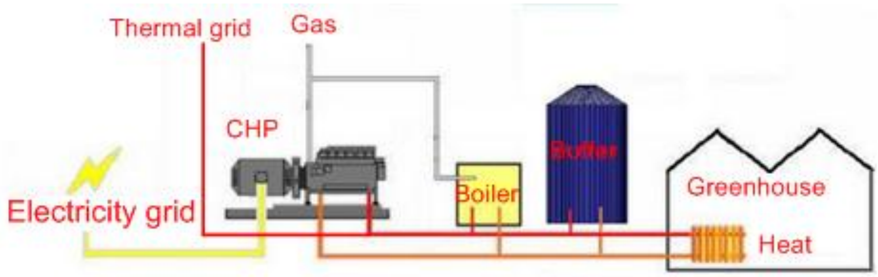

Figure 6: Overview energy configuration of a greenhouse

There is a declining trend in energy usage per m^2, while there is an increasing trend in physical production. Figure 7 shows the trend of energy usage and physical production per m^2 of greenhouse. The energy usage per m^2 is declining from 1990, with almost 40%. The declining trend in energy usage has come to a hold, however in the future the energy usage per m^2 will probably decline further. This can be explained by ongoing innovations in the area of energy usage within greenhouses. Moreover, the legislation from the local and national government will force greenhouse growers to become more sustainable, which in practice will mean less energy consumption and a reduction in CO_2 emissions (Gemeente Lansingerland afdeling Strategische Ontwikkeling, 2009).

The declining need for energy per m^2 will also have an effect on the thermal grid. Less heat will be demanded in the future. Moreover, the sustainability of the produced heat will have to increase, to be able to achieve the sustainability objectives. These two future trends of decline of energy usage and sustainability should be taken into account when developing the smart thermal grid. For example, it should be able to lower the distribution temperature, so geothermal production units can supply to the network.

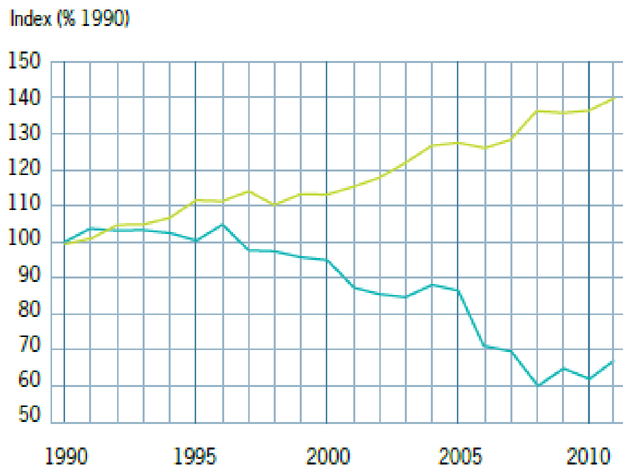

Figure 7: Physical production(yellow) vs energy usage per m2 (blue) from a greenhouse. (Van der Velden & Smit, 2011)

4 RESEARCH APPROACH

4.1 SCOPE

The end goal of the 'Warmteweb B3-hoek' is a fully functional smart thermal grid. To design this smart thermal grid, a lot of steps have to be taken. As part of the project, this research is making the definition of the decision problem in the B3-hoek. Since in this thesis a broader definition of the decision problem is used (see chapter 1), the decision problem will also describe the decision process. How can a decision be made, which aligns the interest of all relevant actors. Therefore the decision problem will include the drivers behind the system, the influences on and of the system, and a preliminary design of the system, called the heat trading platform, that makes the decisions in the smart thermal grid.

To develop or to transform a system as complex as mentioned above, the six steps mentioned in section 2.4 will have to be followed. This thesis will be restricted to the first three steps: evaluation of the old system; definition of the new system requirements; and a proposition of a system design.

The proposed method of analysis consists of dividing the system into 4 domains. This is done to generate an overview of all the different aspects of the system. Identification of problems, but also decision criteria is therefore more structured. This structure will ensure that the whole system is analysed, instead of just a part of the system. In Section 3.4 the method of analysis, based on the framework of Groenewegen, is presented.

Technology domain

The technology domain, consists of three levels. The technical paradigms and trajectories of the smart thermal grid are not discussed. Since a choice of technology, the thermal grid, has already been made. Due to the lock-in effect the physical network structure has to be used. Therefore, alternatives that work without the physical network are not considered and are left out of scope.

Since the already existing thermal network will be used in the smart thermal grid (due to the lock-in effect, see section 3.4.1), will the physical network be analysed in detail. Also the third level, the operationalization of the network, will be discussed. However, the heat trading platform is discussed in another chapter.

Actor domain

The focus in the actor domain will be on the private actors. As in most of the systems, the public actor have a huge influence by using laws and regulations. The public actors will be treated as static and no detailed analysis will be done on these actors. The static laws and regulations will be discussed in the institutional domain, with the formal institutions. This in contrast to the private actors, who are investigated in a stakeholder analysis.

Economic domain

The project of the B3-hoek, is focused on the thermal grid in the B3-hoek. The system therefore mainly operates on a firm level, working with demand and supply of goods. Therefore the micro-economics will play a significant role in the system and this research.

The macroeconomics influence the system as well, however this influence is taken as exogenous. Since the macroeconomics change and this change is hard to predict and to influence. The influence of the macro-economic level is only briefly discussed.

This thesis will not compare different regions (meso-level), or investigate the competiveness of the B3-hoek in comparison to other regions. This is left out of scope, due to the lack of relevance for the development of the smart thermal grid. The development of the smart thermal grid is more focused on an increase of revenue's within the cluster. However, when the smart thermal grid is operational it could be very interesting to investigate the increase of competiveness of the region, due to the smart thermal grid.

Institutional domain

The last domain is the institutions domain. Institutions play an important role in the transformation to the smart thermal grid, since the behaviour has to be structured in such a way that the system performs well. All the four levels indicated in Figure 5 are included in the scope, since all the institutions have an impact on the performance of the system.

4.2METHODS

4.2.1 METHOD OF SYSTEM ANALYSIS

For this research an analysis model, shown in Figure 8, is used. This model is based on the framework of Groenewegen (Figure 3). The goal of this model is to structure the overall analysis of the complex system in small sub-levels. These sub-levels are less complicated and therefore more easy to analyse. Due to the complexity of certain systems, this subdivision is needed to ensure that all aspects are covered.

Groenewegen splits the system in four different domains, the economic, technology, actor and institution domain. These domains are chosen because of the different scientific disciplines; economics, sociology, technology and legal. All domains are interrelated, as described in section 3.4. The domains are split into levels are, who in turn are split into sub-levels. The actual analysis is done on this sub-level. The sub-levels are not named in Figure 8, since the sub-levels are system dependent. For each of the different domains, different analysing methods are used. These methods are explained below.

After the analysis of the different sub-levels, all the different analyses per domain are combined to form a conclusion about the specific domain. The desired situation (the end goal of the transformation) is described from all the different perspectives. From these perspectives an aggregated view, or preliminary design of the heat trading platform, is developed. This heat trading platform consist of an economic-engineering optimization, since the optimal solution should be both technically and economically viable. With help of engineering economics methods the preliminary design is tested on economic feasibility.

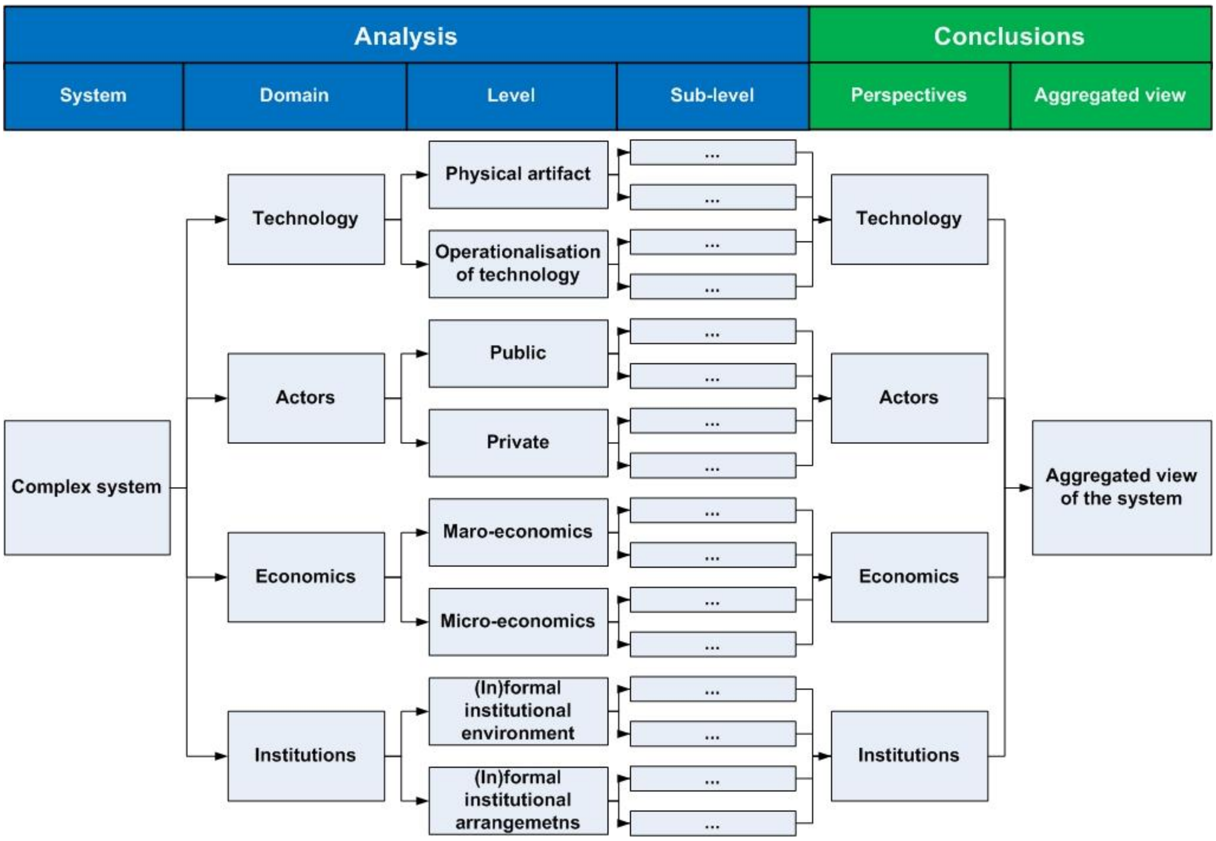

Figure 8: Multi-disciplinary, multi-level and multi-actor system analysis for transformation or development of such system

4.2.2 DATA COLLECTION

For this research data will be collected from multiple sources. Below will be discussed what sources are used and why.

Desk research

A lot of information about smart thermal grid, B3-hoek project, economic dispatch, pricing and optimization is already available. For the separated chapters information will be gathered from different sources. Information about the project and the network in the B3-hoek is information that is available on Eneco's sharepoint, where Eneco employees share their knowledge and information digitally. Some of this information is confidential, therefore this information will be handled very carefully. Information that does not concern the project directly, has to be found on the internet. Websites as scopus and google scholar will provide academic information for this research. Also sources from the TU library are used.

Interviews

The data that is collected from stakeholders is obtained by interviews. The goal of the interviews is to gain more knowledge and understanding about the needs, goals and expectations of the various stakeholders. An additional goal is to gain more knowledge and insights in the system. As a consequence, the interviews are done in a semi-structured way. The interviews are held with a script that contains some general questions and some stakeholder specific questions. Due to the open questions structure of the interview, stakeholders are encouraged to give additional information that might not directly be relevant to the questions, but can be relevant to the research. The semi-structured method gives room to ask questions to the context and the situation.

Due to this method, after each interview questions are reviewed. And if necessary the questions are revised to prevent certain misunderstandings and therefore receive better answers. The interview is summarized and send to the interviewee for approval and to validate the findings and correct errors.

The questions of the interview can be split in two. The first part is for the stakeholder analysis, these questions are designed to map the stakeholders and to analyse their goals, expectations and their priority. These questions should give better insight into the stakeholders' views and their relations with each other and the project. The second part is to get more understanding in the opinions, wishes and demands from stakeholders concerning the heat trade. This is particularly interesting for the optimization.

The population of this interview primarily exists of stakeholders involved in the B3-hoek project. The stakeholders are identified by the reputational approach. Sonja van Vooren (Eneco W&K) and Edwin Valkenburg (Eneco-AgroEnergy) served as key informants, to identify important actors for the stakeholder analyses. The identified stakeholders are not fixed, stakeholders can be added to the research in a later stage when a new insight comes to light.

The main stakeholders in this project are the producer of heat and the operator of the network (E.ON), greenhouse growers with a CHP (two will participate in the pilot for supplying heat to the thermal grid), the distributor (Eneco W&K), the heating platform/energy trade (AgroEnergy) and the consumers of heat (greenhouse growers). Most of these stakeholders exist of multiple actors, so it is actually a group of actors, with different opinions, power and expectations. As a consequence, for some groups, multiple actors will be interviewed. The most important actors will be identified by reputational approach, as mentioned above.

4.2.3 STAKEHOLDER ANALYSIS

When initiating a project considering the interests and information from the stakeholders is very important. Several studies report that about half of the decisions fail because decision makers failed to acknowledge the importance of the key stakeholders. For the success of a project it is therefore very important to attend to the interests and information held by the key stakeholders (Bryson, 2004). Moreover, in the optimization of the smart thermal grid the stakeholders play an important role. Eneco W&K need the input from the other stakeholders to improve the quality of the project and they need support to be successful.

Before the stakeholders are discussed, the term stakeholder has to be defined. In this thesis stakeholders are defined as :

"All parties who will be affected by or will affect [the organization's] strategy" (Nutt & Backoff, 1992)

To get more understanding about the stakeholders in this project, a stakeholder analysis is performed. The goal of this stakeholder analysis is to maximize cooperative potential and minimize obstructions for the project. All key stakeholders will be identified and be interviewed. As mentioned above the focus of the stakeholder analysis will be on the private actors. The public actors will be treated as static and are not described in detail.

The actor analysis is performed according to some basis steps which are defined by (Enserink, 2010):

1. *formulation of a problem as a point of departure;*
2. *inventory of the actors involved;*
3. *exhibiting the formal chart: the formal tasks, authorities, relations of actors and the current legislation;*
4. *determining the interests, objectives and problem perceptions of actors;*

5. *mapping out the interdependencies between actors by making inventories of resources and the subjective involvement of actors with the problem;*

6. *determining the consequences of these findings with regard to the problem formulation.*

4.2.4 INSTITUTIONAL ANALYSIS

As indicated in the model of Groenewegen (Figure 3) also the institutional domain is part of the complex system that is analysed. As shown in Figure 8 the institutional domain has to be analysed in order to gain a good aggregated view of the whole system. The institutions, defined in section 3.4.4, are important because they structure the behaviour in the system in such a way that the system performs well. In this part the manner of analysis of the institutional domain will be discussed.

For the analysis the by Koppenjan & Groenewegen adapted framework of Williamson will be used, shown in Figure 5. This framework is used in the institutional design for complex technological systems, as for example energy transport (Koppenjan & Groenewegen, 2005). The framework therefore fits the complex system of the smart thermal grid.

In the framework, shown in Figure 4, four different layers are defined; Actors(layer 1), (in)formal institutional arrangements (layer 2), formal institutional environment (layer 3) and the informal institutional environment(layer 4). The relation between the different layers is that the higher layers constrain and shapes the lower layers. Moreover, the lower layers have an influence on the development of the higher layers. For example the institutional arrangements set boundaries for the behaviour of individual actors (Koppenjan & Groenewegen, 2005). All the different layers will be analysed.

In this figure the actors are threated separately in the actor domain. In this thesis the individual actors are also threated separately from the institutional domain, since they are analysed in the actors analysis. However, in the institutional analysis the behaviour of different actors in the system and how these can be influence by institutions will be analysed. This is not done in the actor analysis.

4.2.5 ENGINEERING ECONOMIC METHODS

To determine the economic feasibility of an engineering project, engineering economic methods are used. Therefore in the illustrative example, where the economic feasibility of the heat trading platform is determined, engineering economic methods are used. This includes using the cash flow, time value of money, depreciation and interest rates, hereby are time and uncertainty defining aspects (Kemp, 2005). Additionally, the optimization is an engineering-economic optimization. Since both the heat trading platform needs to be economically but also technically feasible.

4.3 RESEARCH STEPS

To create the formal problem description, first the system has to be analysed. To structure the research, different steps have to be taken. An overview of the different steps is shown in Figure 9.

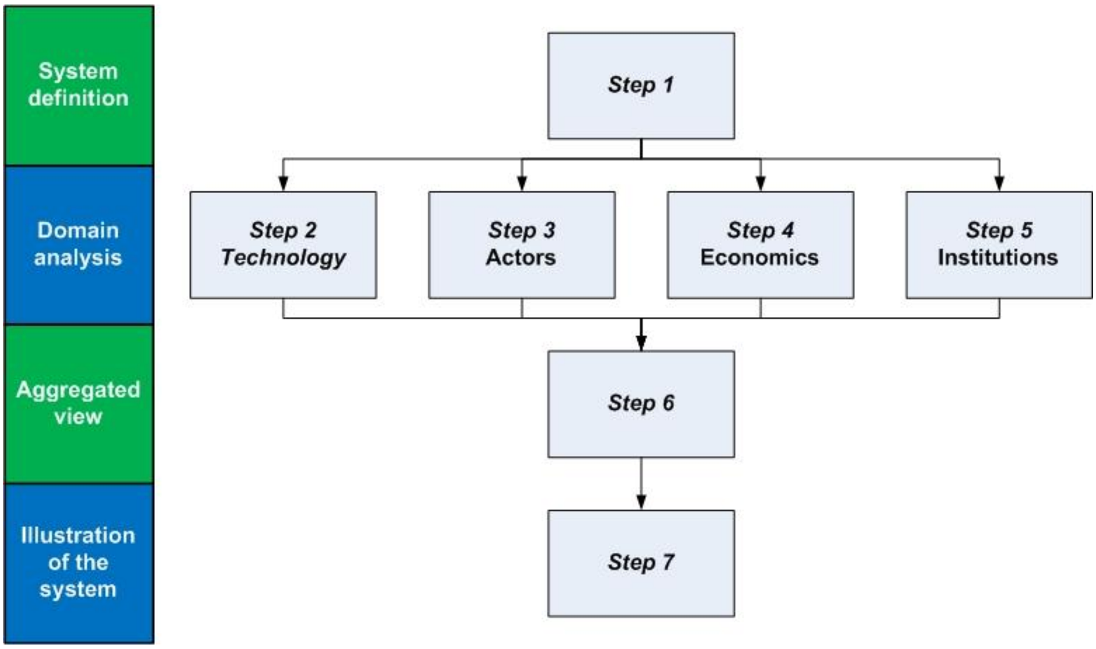

Figure 9: Overview of the research steps

Step 1: System definition

The system has to be introduced and defined. The system definition part will provide all the insight needed to get a general idea of the system.

Step 2: Technical domain analysis

In the B3-hoek a physical network already exists, and the smart thermal grid has to be created on the existing thermal grid. To create this smart thermal grid the physical network, technical installations and the thermal dynamic and fluid mechanic phenomena have to be analysed and known. Which all can give constraints to the optimization. For the technical analysis the whole system is split in three subsystems: production, transportation and switch from consumer to prosumer.

First a technical analysis is done for the production. There are multiple production sources and each has its production size and constraints. For the whole network all possible production facilities have to be taken into account to create an optimal allocation of production facilities. Production facilities as the RoCa, CHP, boiler and geothermal production will be discussed and analysed.

A big part of the system is the transportation through the network. Many kilometres of pipe are now connected with the RoCa and are used for the transportation of heat from the RoCa to the greenhouse growers. This network is engineered on one directional flow. In the new situation the supply of heat will be done by multiple suppliers, therefore other requirements for the physical network and the transportation of heat are necessary. In this part of the technical analysis, the transportation, the following topics will be analysed:

- Network layout: Since the network is not engineered for multiple suppliers, the network layout is not optimal for this purpose. What effect will this have on the transformation to a smart thermal grid, and what constraints will the current network layout give. What would an ideal network layout be for such a grid?
- Transportation losses: As in most physical networks there are transportation losses. What are these transportation losses and what is the cause of these losses?

- Pressure drop: The water flows through the network due to a pressure difference created by pumps. The pressure at a certain point in the network is influenced by multiple factors, what are these factors and how can these factors be combined to calculate the pressure drop.
- Water hammer: This is a phenomena that could occur by the transportation of fluids through the network. What is the effect of this water hammer and should it be taken into account?
- Temperature changes: Not all suppliers will deliver exactly the temperature they are required to deliver resulting in a fluctuating temperature. What will be the effect of these fluctuations and to what extent should they be taken into account.

The last part of the system that should be technically analysed is the consumer and prosumer part. A prosumer could be both a producer and a consumer (Tapscott & Williams, 2006). In this part will be discussed what should be done to change a consumer in a prosumer, or put differently; how to change a greenhouse grower from only consuming to a combination of consuming and producing. What is technically needed to make this change and what potential problems that could occur here.

Step 3: Actor domain analysis

In the stakeholder analysis the roles, responsibilities and opinions of the different actors are analysed. It has to be taken into account that the system is dynamic and will evolve from a normal thermal grid with one supplier, to a smart thermal grid with multiple suppliers. This will also change the role, responsibility and opinion of the stakeholders.

The opinion of the stakeholders will concern the transformation to a smart thermal grid. It is important to take the wishes and demands into account. This will create substantially more support compared to the situation in which not all wishes and demands of stakeholder are given serious thought.

Step 4: Economic domain analysis

Most of the decisions are based on economic grounds, due the fact that the primary goal of most private organizations is to earn money. This analysis is structured in the same way as the technical analysis. This means that the system is divided in the same three subsystems: production, transportation and switch from consumer to prosumer. In addition economic patterns in the system are analysed.

In the subsystem production, the cost of the different production sources will be analysed. These production sources are the same as discussed in the technical analysis. For the subsystem transportation the costs of transportation are analysed. The switch from consumer to prosumer is the last part that is economically analysed. In this analysis the costs of switching to prosumer are researched, in order to be able to calculate the potential benefits.

Step 5: Institutional domain analysis

The institutional domain analysis will be done as described in section 2.4.2.

Step 6: Development of preliminary design of a heat trading platform

After the analysis of the system is done, it is time to look at the system behind the smart thermal grid. Since creating multiple suppliers could create new problems that did not occur before, for example problems in coordination. The different production units have to be dispatched, preferably the production unit with the lowest cost will produce. This is called economic dispatching. The definition of economic dispatching is :

"The operation of generation facilities to produce energy at the lowest cost to reliably serve consumers, recognizing any operational limits of generation and transmission facilities." (USA, 2005)

To create economic dispatching, different optimization strategies can be followed. After the heat is distributed among the consumers (the greenhouse growers), also a price has to be determined. The price setting of the heat is an important part of the system, because this is one of the success factors of the system. Good price setting will create a system were greenhouse growers are more willing to participate in.

Step 7: Illustrate the preliminary design by example

In this step of the research an illustrative example is given, to test the economic feasibility of the system. The sample will be a simplified version of the B3-hoek, but should provide more information about the bottlenecks and behaviour of the system. In this example realistic data is used to simulate production facilities, greenhouse growers and network aspects. This should give more insights into the economic feasibility of the heat trading platform.

PART III: ANALYSES

5 SYSTEM INTRODUCTION

As mentioned in chapter 4, the system exists of four domains: technology, actor, economic and institution. The system is divided into these four domains, but what is the exact system that is being discussed? In this chapter the system is introduced and defined.

5.1 SYSTEM DEFINITION

“A system is defined as a part of reality that is being studied as a result of the existence of a problem or the suspicion thereof. An analyst will make a system model that clarifies the system (1) defining its boundaries and (2) defining it structure” (Enserink, 2010).

The part of the reality that is being studied is the thermal grid in the B3-hoek. As mentioned in section 4.1, the system involves four different domains, the technology-, economic-, institution- and actor-domain. To analyse this system all different domains have to be analysed.

5.2 SYSTEM DESCRIPTION

The thermal grid is used for transportation of heat. However, for making this grid smart the scope is broadened and all sources of energy will have to be included. For production, greenhouse growers require electricity, heating and CO_2. All these sources are interrelated, because a greenhouse grower can produce energy by themselves with CHPs and boilers. However, in the B3-hoek they can also choose to buy heat, CO_2, electricity and gas from the network. This creates a very complex system of prices and volumes that are all interrelated.

As the cost of energy is about 30% of the total costs of a greenhouse grower, energy management within the greenhouse is very important (van den Ende, 2013). Therefore the design of the smart thermal grid needs to include the whole energy household and not just the heat. In this part of the chapter, the different aspects of the energy usage in a greenhouse are discussed.

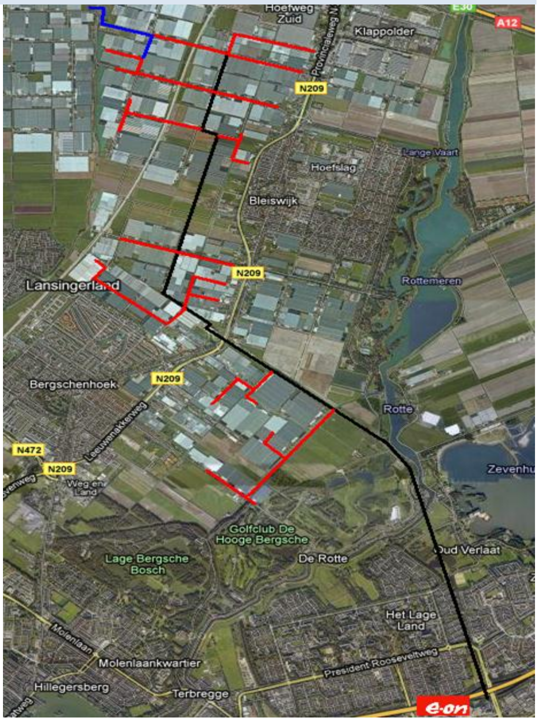

Figure 10: The area of the B3-hoek with the pipeline of E.ON(black) and the pipelines of Eneco(Red) (Arcadis, 2012).

5.2.1 HEATING

The system is as described above a thermal grid with 120 consumers. Figure 10 shows the area of the B3-hoek including the pipes that run through the B3-hoek. It also shows that the main pipeline(black), owned by E.ON, runs from the RoCa to the end of the B3-hoek. All the branches(red) are owned by Eneco. They are both partly owner.

The network is engineered to supply heat from the RoCa to the connected greenhouse growers. These greenhouse growers use this to heat their greenhouses. The amount of heat used per m^2 depends on many factors. For example, the weather, the crops or plants cultivated and the installations within the greenhouse.

The weather has the most dynamic influence on the heat demand. Changing outside temperatures, sunlight, clouds, rain and wind have a big impact on the temperature within the greenhouse and thus on the heat demand. For example the impact of rain can be seen in Figure 11. It can be seen that during the day much more heat is demanded when it rains. Another example is shown in Figure 12, where the supplied amount of heat on each day of the year is shown. The seasonal influence on the heat demand is very clearly visible. In summer the heat usage is on average three times as low as in winter. To increase the accuracy of the predicted heat demand, the weather prediction should be taken into account. However, since the weather is quite unpredictable, there will always be differences between the predicted heat demand and the actual heat demand.

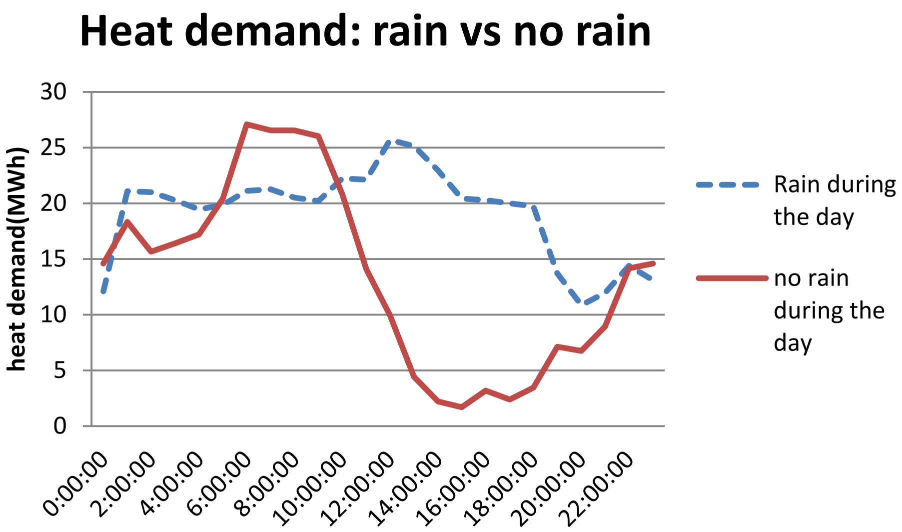

Figure 11: heat demand on the 11(rain) and 12(no rain) October 2013

Heating can be produced by boilers and by CHP, and in the B3-hoek greenhouse growers can also choose to consume heat from the thermal grid. Dependent on the electricity, heat and CO_2 price, a greenhouse grower has the decision to make or buy heat. If the thermal grid allows supply of decentralized production, the greenhouse grower has increased options, since he can also produce heat to sell it to the other thermal grid participants. This increased option gives the him more flexibility in the production of both electricity and CO_2.

The ability to sell excess heat, will change the business case for investing in a CHP or geo thermal plant, and this might lead to an increase in investments in production capacity (van der Spek, 2013). At the moment some greenhouse growers do not have a boiler (or a boiler that is out of production), this means that in times of extreme scarcity the heat price could rise above boiler production cost. If this happens too often, greenhouse growers without any production capacity will invest in boilers (Sintniklaas, 2013). Therefore the maximum heat price will have to be at least lower than the boiler production costs, since the heat will otherwise not be sold.

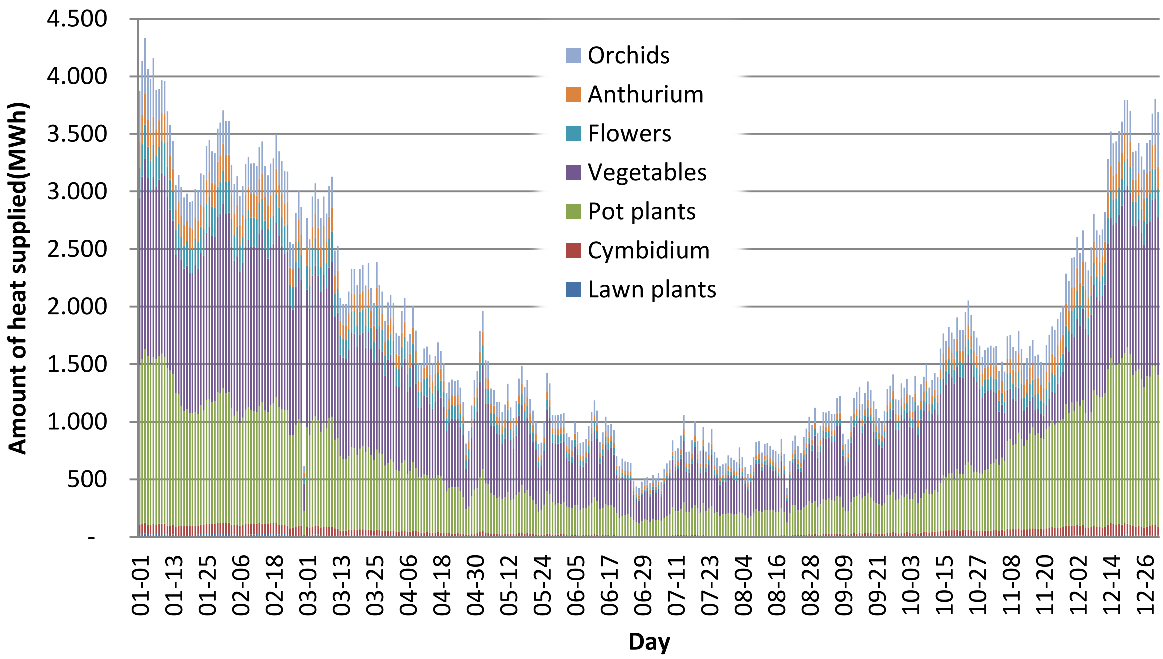

Figure 12:Amount of heat(MWh/day) used per culture(5 year average) (Arcadis, 2012)

5.2.2 ELECTRICITY

The demand for electricity is also different for each greenhouse grower. Some crops need a lot of light and therefore the electricity demand is higher. However, many greenhouse growers connected to the thermal grid have crops that do not need much lighting.

For greenhouse growers with a high electricity consumer (due to a high light demand), it is financially attractive growers to produce their own electricity. This saves them standing charge ('vastrecht' in Dutch), transportation cost, environmental fee('milieuheffing' in Dutch) and taxes (van den Ende, 2013). Since those greenhouse growers have substantial demand for both heat and lighting, the production is often done by a CHP. As the electricity production is leading, the heat produced is not always used. These greenhouse growers produce relatively more excess heat which could be sold on the thermal grid (van den Ende, 2013).

There are also greenhouse house growers with less demand for electricity. For them, heat production could be leading, and excess electricity is sold on the APX (power spot exchange). If the total costs of production are lower than the costs of buying heat, electricity and CO_2, it is more economical to use the CHP for production. In Appendix C the favourable production times are explained for a CHP. However, a CHP is financially more attractive when the electricity that is produced, is consumed by the greenhouse grower himself. In chapter 9 this will discussed.

5.2.3 CO_2

Most greenhouse growers use CO_2 to increase their production per m^2. The percentage of purity leads to an increase in harvest. The plants growth due to the photosynthesis process, where light energy and CO_2 are converted into carbohydrates. These carbohydrates are used in the growth of the plants. The photosynthesis process works when the temperature and light intensity are high enough, this is shown in figure 13. Consequently, greenhouse growers only need CO_2 by day, or during the time they actively use lighting.

Greenhouse growers can choose to produce CO_2 with either CHP or boiler, or sometimes can choose to buy pure CO_2 from a CO_2 grid. In the B3-hoek for example greenhouse growers can buy CO_2 from a CO_2 grid coming from OCAP (van Vooren, interview, 2013). Not all greenhouse growers that need CO_2 are connected to CO_2 grid, actually most greenhouse growers in the Netherlands are not connected to a CO_2 grid, and produce their own CO_2.

Since CO_2 is important for greenhouse growers, they are willing to produce CO_2 with their boiler or CHP at times they do not have heat demand (TNO Industrie , 2008). They could store this heat, or they could, if connected to a smart thermal grid, choose to sell this heat.

For the success of a smart thermal grid, a good functioning CO_2 production/grid is very important (van der Marel & Huizeling, 2013). If greenhouse growers produce their own CO_2, less heat will be bought from the grid. Greenhouse growers will start producing their own heat and CO_2 if that is cheaper than buying it. So the cost of buying heat+CO_2 should be lower than the cost of producing heat+CO_2.

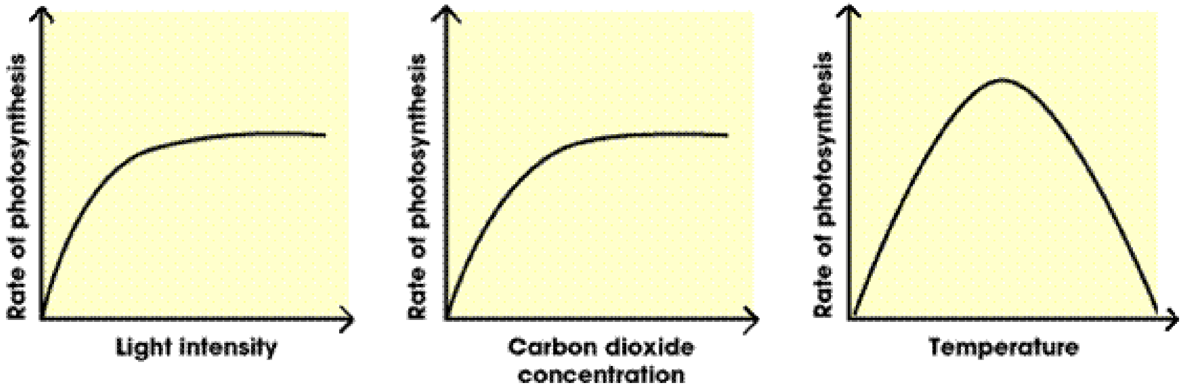

figure 13: Factors affecting photosynthesis (Vidani, 2013)

5.3 CONCLUSION

The system described consists of 120 greenhouse growers connected to a thermal grid in the B3-hoek. These greenhouse growers need three types of energy for their production: Heat, electricity and CO2. These three energy types are interrelated, since greenhouse growers can produce them with either a CHP or a boiler. Moreover, the greenhouse growers in the B3-hoek can also buy all three, through different networks. Therefore the greenhouse growers can chose to either buy the energy or produce himself. In the smart thermal grid greenhouse growers will also be able to sell heat, making them more flexible in the production of CO_2 and electricity.

The demand for each energy type differs per greenhouse growers. Different crops have different demand for CO2, heat and lighting. Moreover, the demand is dynamic due to the unpredictable weather conditions. It is therefore impossible to predict the demand on a day ahead bases 100% accurate.

6 TECHNICAL DOMAIN

The physical network in the B3-hoek is bound to different technical constraints and limitations. There will be technical constraints in production, transportation as well as in the switch to prosumer. All these three areas will create additional limitations to the operation of the smart thermal grid. In this chapter all three technical areas are discussed and analysed. This is done to create better insight into the system and its technical limitations.

6.1 TECHNICAL ANALYSIS

6.1.1 PRODUCTION

Normal thermal grids have one or several big commercial power plants supplying heat to the thermal grid. In the B3-hoek there is the unique situation of the availability of decentralized production facilities. However, at the moment these decentralized facilities are unable to supply heat to the thermal grid. And the big commercial plant, the RoCa, is the only supplier of heat to the grid. The next paragraphs will discuss all details of the different production sources.

Commercial energy plant

The commercial energy plant is defined as an energy plant that is primarily designed to produce and sell energy. Greenhouse growers do not have a commercial energy plant, because their production facilities are primarily used for self-production for their own greenhouses.

A few years ago most of the energy plants built in Western-Europe were combined cycle gas turbines (CCGT) energy plants (Eneco, 2013). The energy plant supplying heat to the B3-hoek is also such a CCGT energy plant (E.ON, 2013). The focus of this part will therefore be on CCGT energy plants. A CCGT energy plant has two different turbines; a gas turbine and a steam turbine. At the moment the efficiency of the new CCGT energy plant is up to 60%. However, this does not include the heat production. If that is taken into account the CCGT energy plants can reach higher yields, due to the combining efficiency of both electricity and heat. The RoCa for example has an electrical efficiency of X% and a thermal efficiency of X% (top caloric value).

As shown in Figure 14 the CCGT energy plants have an operational envelope in which they have to operate. There are three factors that influence this feasible region, namely the minimum fuel, maximum fuel and the maximum heat extraction. For the RoCa the maximum heat production for example is 200 MWth (van der Marel & Huizeling, 2013). As can be seen in Figure 14 a maximum heat production, means a decline in the maximum power production. Therefore the assumption that a lot of people have, that all the heat produced by CCGT energy plants is ‘waste heat’, is false. From point B to C it can be seen that the heat production has a negative impact on the power production. Only in the region from point A to B, the electricity production is not influenced by the heat production.

In order to solve imbalance in the thermal grid, the CCGT energy plant can move horizontally and vertically in the graph. In short imbalance is the mismatch between supply and demand in the network (explained in more detail in the next paragraph Transportation). Moving horizontally in the graph from Figure 14, means increasing or decreasing the production of heat. Moving vertically in the graph means increasing or decreasing the production of power. These movements cannot be done without consequences. However, moving horizontally is less of a problem for the energy producer, than moving vertically (van der Marel & Huizeling, 2013). As the power is sold one day ahead, they cannot produce more or less power without receiving huge penalties. This is an important driver for a CCGT, since they are not flexible in electricity production if the market is settled.

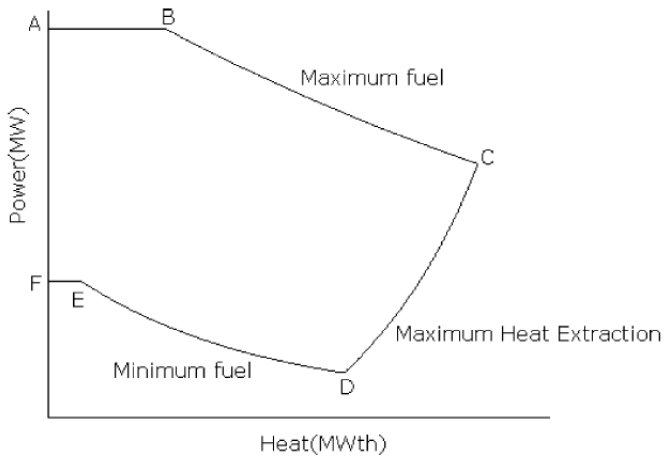

Figure 14: The heat-power feasible region for a co-generation unit (Ching-Tzong Su, 2004)

These big energy plants cannot shift in MW very easily. A (de-)increase in production goes in steps of several MW. If the energy plant has to adjust the production with less than such a step, this part of the production is done by boilers (van der Marel & Huizeling, 2013). The base load production is often done by the CCGT and the flexible load is done by boilers. Sometimes it is even more efficient to produce with boilers, due to low electricity prices or low heat demand. For example, during the summer time, the CCGT of E.ON does not produce at all, but all the heat production is done by boilers. In Figure 15 it can be seen that at peak moments and moments with little demand the boiler is turned on.

The Roca will from 2016 onwards stop with the production of the base load for the city of Rotterdam. This is taken over by the AVR. The new production scheme will therefore be different, but due to many factors it will be hard to predict what the new scheme will look like.

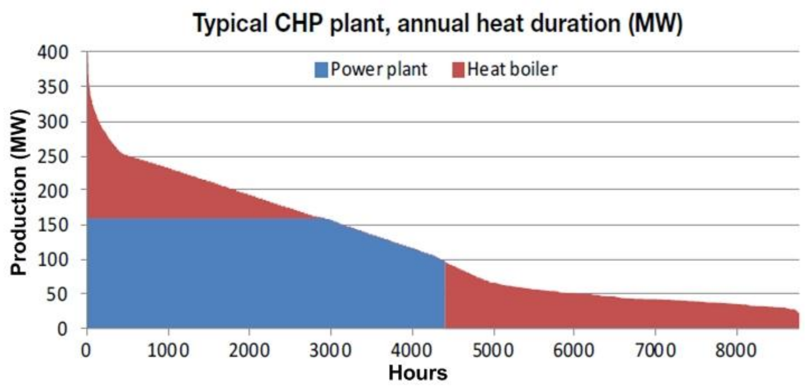

Figure 15: Typical CHP plant, annual heat duration (MW) (Haga, Kortela, & Ahnger, 2012)

The CCGT energy plant supplies heat in the B3-hoek with a temperature of 100 °C to 120 °C (Mes, interview, 2013). This temperature is higher than with other sources, since this temperature has to be supplied to the city of Rotterdam. No decentralized source, CHP or current geothermal can supply heat of that temperature, without using a heat pump. If different temperatures are supplied to the network, the temperature in the pipes can vary a lot, which could damage the pipes. So in order to be able to let other sources also supply to the network the feed temperature should be lowered (Kerckhoffs, 2012). At the moment the feed temperatures in the winter is 120 °C and in the summer it is around 100 °C, as shown in Figure 16.

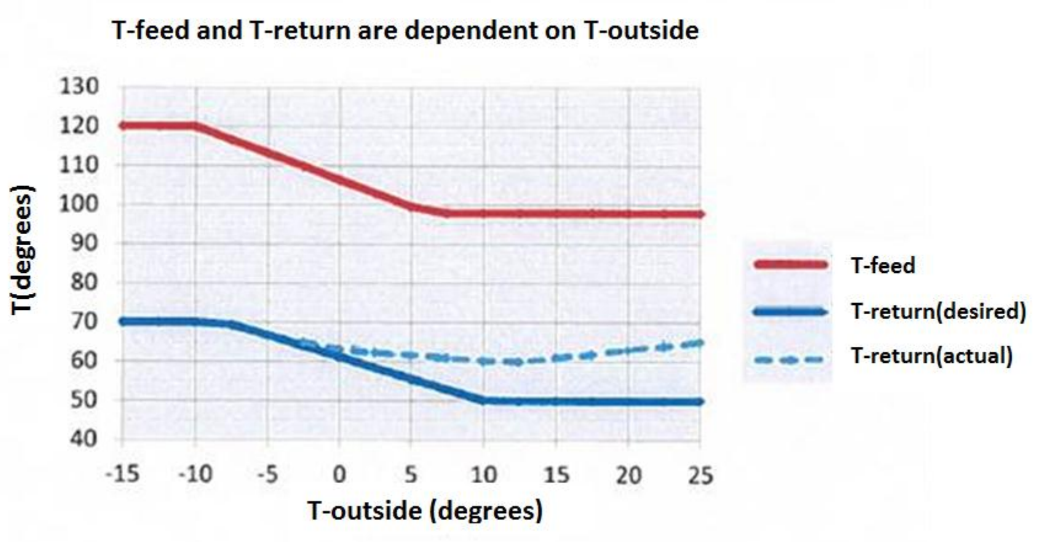

Figure 16 Distribution temperatures in the network depending on the outside temperature

Limitations:

- X

CHP

Above a big CHP is discussed, in this part we look at smaller CHPs, used in greenhouses. These CHPs are often used to produce heat, power and CO_2. The greenhouse growers primarily have a CHP to support their greenhouse. The average capacity of the CHP is approximately between 40 and 45 $W_{electric}$ per m^2 of greenhouse (Van der Velden & Smit, 2011). In 2011 CHPs from greenhouse growers produced 11,8 billion kWh, almost 10% of the total electricity production in the Netherlands (Van der Velden & Smit, 2011). In the future it could be a very good option for greenhouse growers, to sell their overcapacity of heat to the grid as well.

A common CHP has around 2 MWth of capacity, so that is substantially smaller than the RoCa. The yield of these smaller CHP is a bit more than the big plants and could reach up to 92%. This is a total efficiency consisting of 50% yield of heat and 42% yield of electricity, this is based on the lower heating value of gas (AEH Power Projects, 2006). The temperature of the heat produced by a CHP is maximum of 95 °C. In practice this means that the temperature supplied to the primary network will be around 85 °C.

In this thesis the focus is on two types of greenhouse growers, who both use their CHP differently. The first one are greenhouse growers with much CO_2 demand, these greenhouse growers primarily for the production of CO_2. The second group are greenhouse growers who need a lot of lighting. These greenhouse growers use a lot of electricity, which they produce with their CHP.

Limitations:

- A CHP can produce electricity, heat and CO_2 with gas as fuel.
- The start-up time is between 5 and 10 minutes, which is substantially lower than the start-up time of a big commercial energy plant (van der Spek, 2013). This makes these CHPs a lot more flexible than the big energy plant. However, the more cycles the CHP makes, the more maintenance the machine needs (COGEN Vlaanderen, 2006).
- The temperature supplied to the network is around 85 °C.
- The CHPs are engineered on the scale of the greenhouse, so most CHP's can primarily fill their own heat demand. This makes the available capacity for the grid much lower than the maximum CHP capacity.

- The cost of heat produced by a CHP fluctuates with the fuel price (gas), the electricity price and the CO_2 price.
- For a CHP to be able to supply heat to the network, a greenhouse grower needs a WLS (heat delivery system)
- The CHPs are operated by greenhouse growers, of whom most are not specialized in the energy market.

Boiler

The efficiency of different boilers is quite similar. The efficiency is defined as the percentage energy output compared to the energy input. The big boilers from E.ON have about the same efficiency as the boilers the greenhouse growers use; between 85% and 93% (Sintniklaas, 2013). At the moment greenhouse growers consume heat from the boilers of the RoCa. If losses are included, the heat of E.ON is more expensive. However, due to fixed discounts, given in the time that heat was very cheap, the boiler heat from the RoCa is cheaper for the greenhouse growers (van der Spek, 2013).

Since most of the greenhouse growers have at least a boiler (as backup and for peak production), and the efficiency of these boilers is comparable, selling heat produced by the boiler will not happen that often. Only when greenhouse growers produce CO_2 with their boiler, and have excess heat from that process, the heat can be sold.

The inflow temperature of the boiler cannot be lower than 62 °C. Otherwise the flue gasses will condensate, which will damage the boiler heavily. The boiler will start heating automatically, to prevent the water from dropping beneath the 62 °C. So if heat is extracted from the thermal grid, this water has to be at least 62 °C, otherwise the boiler will start automatically (Sintniklaas, 2013).

Limitations:

- Boilers produce heat and CO_2.
- The efficiency of different boilers is comparable, even the big boilers from E.ON.
- Boilers need a steady inflow temperature of at least 62 °C. Therefore the temperature supplied to the greenhouse grower should be at least 62 °C.

Geothermal energy

Geothermal energy is a very interesting source of energy for greenhouse growers, because it is virtually independent of market fluctuations. Heat from a geothermal plant only has variable costs in form of electricity for the pump, but that is marginal compared to operating a CHP or boiler for heat production. The downside of geothermal energy is the heavy investments needed to build a geothermal plant and the risk involved building such a plant.

There are two main areas that geothermal energy can be divided in, shallow and deep geothermal sources. Shallow means up to 2.5 km and deep is beyond the 2.5 km. The temperature of each geothermal source depends on the depth of the sources. The temperature of the water at 2km depth is 60 °C on average. If you go even deeper to depths of around 3.5 km, temperatures up to 110 °C can be achieved. Yet, the investment, uncertainty and the current projected costs make deep geothermal energy not a realistic option in the B3-hoek (Arcadis, 2012).

In the B3-hoek two geothermal sources are already operational(one close to the thermal grid) and two more greenhouse growers are investigating the possibility of building other geothermal sources. This means that there is enough geothermal potential in the region. The operational source has a production capacity of 5 MW_{th} (Arcadis, 2012). However, the main problem in the case of geothermal energy is that the temperatures are too low(around 60 °C) to supply heat throughout the whole network, due to the high temperature in the network(between 95 and 110 °C). Local use of geothermal energy is an option (Arcadis, 2012). Consideration should be given to the idea of using geothermal energy only in branches of the whole network. These branches can be disconnected or cascaded from the network and the temperature in this branch can be lowered, depending on the season (van den Ende, 2013). With cascading the branch is not completely disconnected, but is still connected through a heat exchanger. Due to this, still heat can be exchanged between the branch and the rest of the network, while both have a different temperature.

Limitations:

- A geothermal plant built for greenhouse growers will only produce heat. Since many greenhouse growers need CO_2, alternative CO_2 sources need to be available.
- Fuel for the geothermal plant is electricity, to drive the pumps.
- Feed in temperature is around the 60 °C.
- Geothermal energy will not supply heat to the current, since the temperature of the grid is too high. It is only possible if branches are cascaded or completely disconnected.
- The investments in a geothermal plant are very high, compared to the other alternatives.

Buffer

The buffer is not a production source, however it can support production facilities to be more efficient or be used economically to buy and store cheaper heat. Peaks in the demand of heat, can be flattened by the use of buffers. The capacity of buffers varies, but in the B3-hoek they are between 100 and 2000 m^3 with a total of 30.000 m^3. It has to be noted that only the buffers with a size of more than 500 m^3 can be used to supply heat to the network (Arcadis, 2012). These buffers can serve as back up or to solve potential imbalance in the network. To give some idea of how much heat can be stored in a buffer, a buffer of 500 m^3 can provide around 2 MWth for approximately 11.6 hours(Appendix F).

In the optimization the use of buffers could be a good way to spread the demand and supply of heat over a longer period of time. Moreover, with the use of buffers, heat can be stored when the heat is cheap and when heat is more expensive this heat can be sold or used as shown in Figure 1.

Limitations:

- Buffers can be used to store heat
- Buffers can be used to balance the network
- Buffers bigger than 500 m^3 can be used to supply heat to the network.

6.1.2 TRANSPORTATION

Transporting water through pipelines can create effects that should be investigated, because some could impose limitations to the system. The software managing the smart thermal grid should always satisfy these limitations, in order to not damage the network. Below the limitations given by the network are analysed and some effects that could potentially cause limitations: pressure drop, water hammer, temperature changes, transport losses and imbalance.

Network

The physical network in the B3-hoek will give some limitations, since the network was designed for the supply from only one side(the RoCa). If a new network could be designed, some of these limitations could be taken into account. However, the current network will not be changed much, as this involves heavy investments (van Vooren, interview, 2013).

The current network layout can be approached by a tree form (as can be seen in Figure 10 in section 5.2). The main pipeline is big, but the branches are smaller, and the branches of a branch are even smaller. The pipe diameter ranges from 65 to 800 mm (Mes, SEON_warmteverlies, 2013). This can be explained by the fact that the maximum capacity needed is declining, due to the decreasing amount of demanded heat.

The first limitation that the network gives is the pipe diameter. Diameters of the pipes differ and are designed to supply heat to specific greenhouse growers. This means that the pipe diameters from the network to an individual greenhouse grower are different. This influences the capacity that an individual greenhouse grower can demand or supply to the network. Another restriction of the network is that it is built for a certain capacity, meaning that at the far end of the network, the pipe diameter is a lot smaller than in the beginning of the network. Also the maximum capacity of heat exchangers and pumps will be a constraint. The capacity throughout the network has to be mapped and taken into account as a limitation.

In the current setup the pipe diameter will be no problem, since all greenhouse growers in the network have a big enough connection to receive enough heat for peak demand. However, if the network is extended to connect new customers, it should be investigated what the limitations of the pipeline will be (Mes, interview, 2013).

The total amount of heat transported is calculated in formula 3.1 The debit, the amount of water per second [m^3/s], can be calculated by:

$$\dot{Q} = \frac{Volume}{time} = Area * velocity \tag{6.1}$$

The velocity in pipelines is dependent on the diameter. However, there is also a dependency between velocity and pressure drop. It is undesirable to have a high pressure drop in a pipeline. In the next paragraph this is discussed in more detail.

The location of the greenhouse grower in the network plays an important role. The estimated number of greenhouse growers that have a good location within the network and enough production capacity is 8 (Sintniklaas, 2013). These greenhouse growers who are at the end of the network. The pressure difference in the end of the network is lower, saving in pumping cost. So the number of greenhouse growers that is able to supply heat to the network is limited. In the ideal situation all greenhouse growers should be able to supply heat, however due to investment costs and location constraints, not all greenhouse growers will be able to.

Limitations:

- Pipelines in the B3-hoek have different diameters and therefore have different capacities.
- The network was designed for the transportation of heat from the RoCa to the greenhouse growers.
- In the network there is a maximum debit of water transport.
- When the network is extended to new customers, the capacity of the pipelines should be investigated. If the pipelines do not have enough capacity, this maximum capacity should be taken into account in the optimization. However, at the moment this is not an issue.

Pressure drop

The definition of pressure drop is the difference in pressure between two points in a fluid carrying network. This difference in pressure is created by friction between the fluid and the pipeline. The most important variables to calculate this pressure drop is the fluid velocity and the pipe dimensions.

In this investigation pressure drop is an important limitation in the network, because the entrance pressure should be high enough to overcome the overall pressure drop. However, the pipelines have pressure limitations, and the pumps that pump water in the network have limitations. This should be taken into account, in order to not damage any pipelines and to ensure the heat is transported through the network.

Looking at the formula below, assuming that the length of the pipe is constant, the factor influencing the Δp is $\frac{v^2}{D}$. So a decrease in diameter means a decrease in velocity, if you want to keep the Δp constant. In small pipelines therefore the maximum desirable velocity is much lower than in bigger pipes.

At the moment E.ON uses the pressure drop in the whole network to as a detection tool. E.ON measures the input pressure and the output pressure, the pressure of the return pipe, and the difference is the pressure drop in the whole network. If one of the greenhouse growers decides to consume heat, the pressure drop will increase. This is detected by E.ON and they take measures to ensure there is enough pressure in the network to supply heat to the greenhouse growers (van der Marel & Huizeling, 2013).

The pressure drop can be calculated from each individual pipeline by the following formula (Brown, 2002):

$$\Delta p = f * \rho * \frac{L}{D} * \frac{v^2}{2} \tag{6.2}$$

With:

$\Delta p = pressure\ drop\ [Pa]$

$f = Darcy\ friction\ factor$

$\rho = density\ [\frac{kg}{m^3}]$

$L = length\ of\ the\ pipeline [m]$

$D = diameter\ of\ the\ pipeline [m]$

$v = fluid\ velocity\ [\frac{m}{s}]$

In hydraulic engineering often flow rates are used instead of fluid velocity. It is therefore desirable to rewrite the formula to incorporate the flow rate $Q = v/A$ where A is the cross-sectional area, that can be written as $A = \frac{\pi * D^2}{4}$. This give a new formula from:

$$\Delta p = \frac{8 * f * \rho * l * Q^2}{D^5 * \pi^2} \tag{6.3}$$

With this formula the pressure drop in a straight pipeline can be calculated. However, the network exists of multiple pipes and besides that the network exist of a lot of valves, corners and T-components. Moreover, the influence of these parts should be investigated.

Limitations:

- Pressure drop is a phenomenon that should be kept to a minimum. With an increase in pressure drop, the overall pressure needed to pump water through the network increases. Which results in an increase in pumping cost. Also the investment costs for new pump will go up, since the pumps need to be dimensioned for a higher pressure.

Water hammer

Water hammer is a phenomenon that occurs when a fluid, in a closed pipeline, is suddenly stopped. This can happen because of the sudden closure of a valve or sudden stop of a pump. This will create a pressure wave through the pipe, that potentially could damage the system.

When designing a new heating network, water hammer is something you have to take into account because this can potentially damage the network. However, if you have taken counter measures, water hammer is a manageable phenomenon and not a factor that has to be taken into account in the software. For example water hammer shock absorbers could prevent water hammer.

Limitations:

- Water hammer is a phenomenon that should be dealt with, however, when adjustments are made this will not be a problem anymore. Therefore, it will not influence the daily dispatch, and causes not limitations on the optimization.

Imbalance

In the ideal situation the day after the demand and supply will perfectly match and no imbalance will be created. Since the demand for heat depends on many variables, predictions are hard to make. In practice imbalance will occur, due to these uncertainties. How significant this is, and how it has to be solved will be described below. This research will primarily focus on the day-ahead optimization, as it considers that imbalance a real-time problem. There are multiple forms of imbalance in the heat trading platform (Goudswaard P. , 2013):

1) Heat and pressure losses cause imbalance: Losses in heat and pressure will occur due to friction.
2) Small variations in heat transfer and transport within a certain bandwidth: For example, small variations in the production temperature.
3) Program imbalance: Someone does not produce or consume what he agreed on in the day-ahead settlement.

For this research, the day-ahead optimization, only the first form of imbalance is interesting. The other forms have to be fixed real-time. How the imbalance should be compensated can be read in section 8.1.2.

The solution for the imbalance caused by losses is to take part of them into account already a day ahead. For a big part the losses can be calculated one day ahead, and this should be incorporated in the optimization (Goudswaard P. , 2013). For the calculation of the losses, see next paragraph.

Limitations:

- Imbalance will occur in the network. However, it is a real time problem and not day-ahead problem. Which should be fixed with help of institutions.

Transportation losses

As hot water is transported through the network, heat transfer with the environment takes place. Most losses occur due to the temperature differences with the environment (ΔT). The environment is the soil where the pipes are in. These pipes are on a depth between 1 and 1.5 meter (Mes, SEON_warmteverlies, 2013). The temperatures on this depth is on average 10°C, with a bandwidth of 6 °C, depending on the outside temperature (Mattmüller, 2013). At Eneco the average ground temperature is also taken as 10°C (Mes, SEON_warmteverlies, 2013). Using the heat losses in the B3-hoek tool, developed by Eneco W&K, it is seen that the difference between the average and an extreme day (10 and 16 °C of ground temperature) is less than 10 %. This can be explained by the total ΔT, which is much higher, making that the 6 °C difference does not have a significant impact.

The losses in the network should be produced by one of the producers. So in addition to the heat demanded also heat losses should be produced in order to match supply and demand. The exact losses per hour can be calculated and should therefore be included. However, in this section, the heat losses are taken as a fixed amount per year.

At the moment these losses are around 28.000 MWh each year (Mes, warmteverlies B3-hoek, 2013). This is around 5% of the total delivered heat. These losses are independent of the amount of heat supplied. With a primary network temperature between 100-120 °C and a return temperature of approximately 52 °C, the yearly losses will stay more or less constant. If the feed and retour temperature in the whole network decreases, the losses in the network will decrease, due to a decrease in ΔT.

Limitations:

- Transport losses should be taken into account during production. The exact losses per hour can be calculated, these losses should be produced in addition to the normal demand.

Temperature fluctuations

In the network the temperature can fluctuate due to external factors. Mostly these are minor temperature fluctuations and which not a big problem. However, if heat from CHPs and the RoCa is mixed, big temperature fluctuations will occur.

Due to these fluctuations the diameter of the pipes will also vary, as a result of thermal expansion. In the long run this could cause metal fatigue in the pipelines. However, at the moment it is unknown what the effects will be and research is done at Eneco W&K to address this problem. If this turns out to be a non-issue then different temperatures could be allowed in the network. For example a higher temperature in the morning, when greenhouse growers need more heat, and a lower temperature in the afternoon, when there is less demand of heat (van den Ende, 2013).

Limitations:

- The limitations on temperature fluctuations are unknown, this is under investigation of Eneco W&K.

6.1.3 SWITCH TO PROSUMER

To make the switch from heat consumer to heat prosumer a WLS(heat supply station) has to be constructed. The system need a huge pump to be able to supply heated water to the primary grid. Since the pressure that should be overcome during peak hours is between 12 and 13 bar (Sintniklaas, 2013).

The greenhouse grower will be able to supply heat to the thermal grid, through a WLS. This station will deliver heat from the greenhouse grower to the network, by connecting the secondary line (in the greenhouse) with the primary line (the thermal grid). This is done by a heat exchanger, which will transfer heat from the secondary to the primary grid. This is exactly reversed from what the WAS does, the WAS transfers heat from the primary grid to the secondary grid. The functioning of a WAS is shown in Figure 17.

There are different steps to lower the temperature. The first step is to supply a lower temperature to the network from CHPs and mix this with heat from the RoCa. This will lower the temperature in the network till

105-115 °C, this will have almost no effect for the greenhouse growers. Within Eneco this is also called the smart thermal grid 0.5. This can be seen in Figure 18.

If the RoCa decides to stop delivery, the network temperature will decrease to around 85 °C. In this thermal grid only decentralized production will take place, with a much lower feed temperature than the RoCa. As a consequence the greenhouse growers will have to deal with a lower inlet temperature. This can be seen in Figure 19. This means greenhouse growers will have to cool down the heat further, to get the same amount of heat out of a m^3 water. However, to achieve this, the amount of heat exchanging area in the greenhouses has to be increased (Mes, interview, 2013).

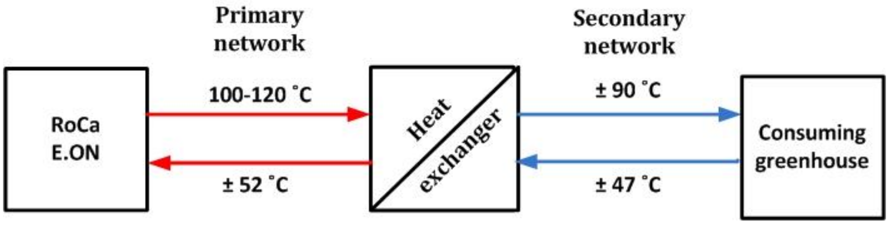

Figure 17: Current situation, only centralized production, no smart grid (van Vooren, update warmtewebB3hoek, 2012)

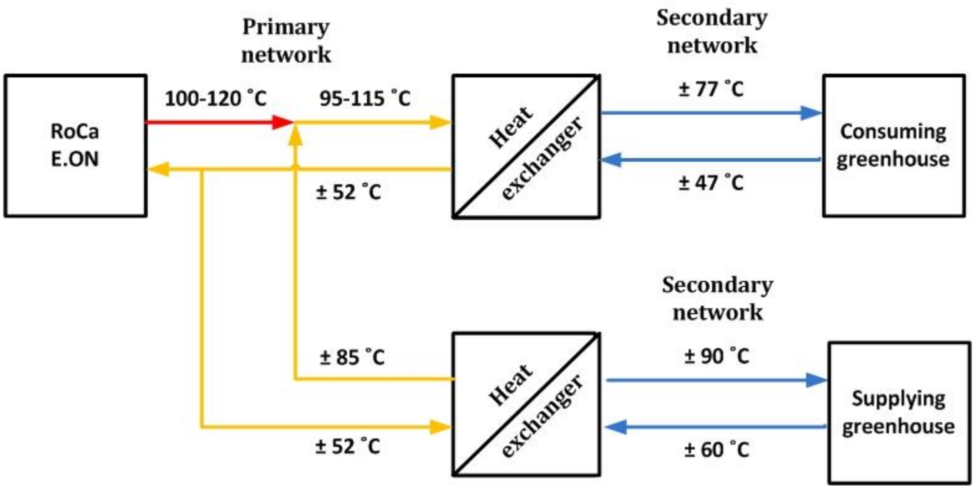

Figure 18 : Combination of decentralized and centralized production, smart grid 0.5 (van Vooren, update warmtewebB3hoek, 2012)

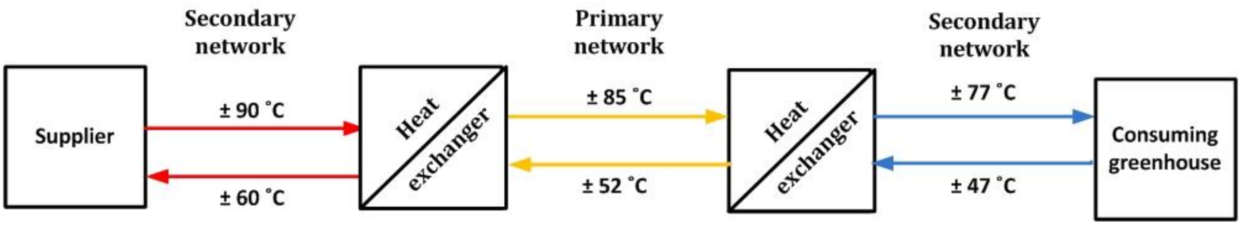

Figure 19: Decentralized production only, smart grid 1.0 (van Vooren, update warmtewebB3hoek, 2012)

Limitations:

- In the smart grid 0.5 it is possible for greenhouse growers to supply heat to the network. However, with reservation for the possibility of temperature fluctuations.
- To switch to prosumer a WLS has to be installed at the greenhouse.
- The overall temperature in the thermal grid will have to be lowered when the RoCa stops production.

6.2 CONCLUSION TECHNICAL ANALYSIS

Different production facilities have different characteristics. In Table 2 the different production facilities are compared. In the smart thermal grid in the B3-hoek a combination from these facilities has to be made. The main constraints of the sources is the feed temperature, start-up time, energy sources and size.

Options with different production sources						
	Feed temperature(°C)*	Heat production	Electricity production	CO_2 production	Startup time(min)	Size(MW thermal)
RoCa(CCGT)	100-120(lower is possible)	Yes	Yes	Yes**	x	200
CHP	85	Yes	Yes	Yes	10-15	1-5
Boiler	85	Yes	No	Yes	10-15	1-50
Geothermal	60-65	Yes	No	No	-	2-5
	*Into the primary network			**CO_2 is not sold		

Table 2: Options with different production sources

Technical constraints do not determine the dispatch of different production facilities. The technical constraints are the boundaries that the dispatch has to stay within. The dispatch of these facilities will probably be based on costs, which depend on different factors. This is discussed in the economic domain. In this domain the availability of different sources will also be discussed, because at the moment there is a limited amount of potential suppliers (Sintniklaas, 2013).

In Table 2 buffers are not included. Buffers do play an important role in production, they give the ability to disconnect production and demand. This give the greenhouse grower the ability to bridge a gap between the heat production and heat demand.

Other boundaries to the system are the network constraints. The network is not built for bi-directional flow, so it is possible that not all heat programmes are technically viable. Therefore the technical boundaries that should be taken into account:

- Network layout: The layout of the thermal grid can be compared to a tree, with decreasing pipe diameter in each following branch. This causes problems, but also opportunities. This characteristic gives the opportunity to split the grid in multiple smaller grids, making it possible for geothermal energy. The problem with the tree structure is that how further you get in each branch, the smaller the diameter of the pipes, which limits the flow. Which in turn, limits the greenhouse growers in their supply to the network.
- Pressure drop: a high pressure drop is undesirable, because the overall pressure will have to increase. This will increase the pump size and pump energy. Which is undesirable from an economic point of view.
- Temperature fluctuations: More investigation is done within Eneco on this topic at the moment. The outcomes of this research will provide insight in how much the temperature can fluctuate during a certain time interval.
- Heat losses: The losses per year are fixed if the ΔT if the feed and retour temperatures stay the same. A change in feed or retour temperature will have an effect on the losses in the network. Since the losses are predictable, these should be taken into account in the dispatch of production facilities.

It has to be said that almost everything is technically possible, however this comes at a cost. Many technical issues could be solved by investing into the network or into production facilities. The smart thermal grid will have to be both economically and technically viable.

The technical boundaries will create an inequality among the participants. For example location and available production facilities. This should be given serious thought, because this should not lead to the loss of support from participants. In the institutional analysis this will be discussed from the stakeholder point of view.

7 ACTOR DOMAIN

7.1 ACTOR ANALYSIS

In this chapter the actors are analysed, which is needed because in this system, as in most systems, actors are interrelated. They are partly depending on each other, or exert power over one and another. These relations have to be analysed to get full understanding of the system. This will give insight into the system and the system dynamics. The stakeholders are divided in different groups and companies, in each group at least one contact person is interviewed.

As mentioned in section 4.2.3. several steps will be taken to analyse the actors.

1. *formulation of a problem as a point of departure;*
2. *inventory of the actors involved;*
3. *exhibiting the formal chart: the formal tasks, authorities, and relations of actors and the current legislation;*
4. *determining the interests, objectives and problem perceptions of actors;*
5. *mapping out the interdependencies between actors by making inventories of resources and the subjective involvement of actors with the problem;*
6. *determining the consequences of these findings with regard to the problem formulation.*

To start with step 1, the formulation of a problem as a point of departure.

7.1.1 FORMAL RELATIONS OF ACTORS

The current situation will be described in this part of the chapter. For the sake of transparency a summary of this part can be found in Figure 20. This figure shows the relations between the different actors. The scheme starts with the roles that play a part in this network. The stakeholders and the responsibilities can change. However, in the smart thermal grid, the roles will stay the same. That’s why the roles are taken as a basis. The roles are connected to the different stakeholders. These stakeholders are mutually connected by contracts and by the link with the thermal grid in the B3-hoek.

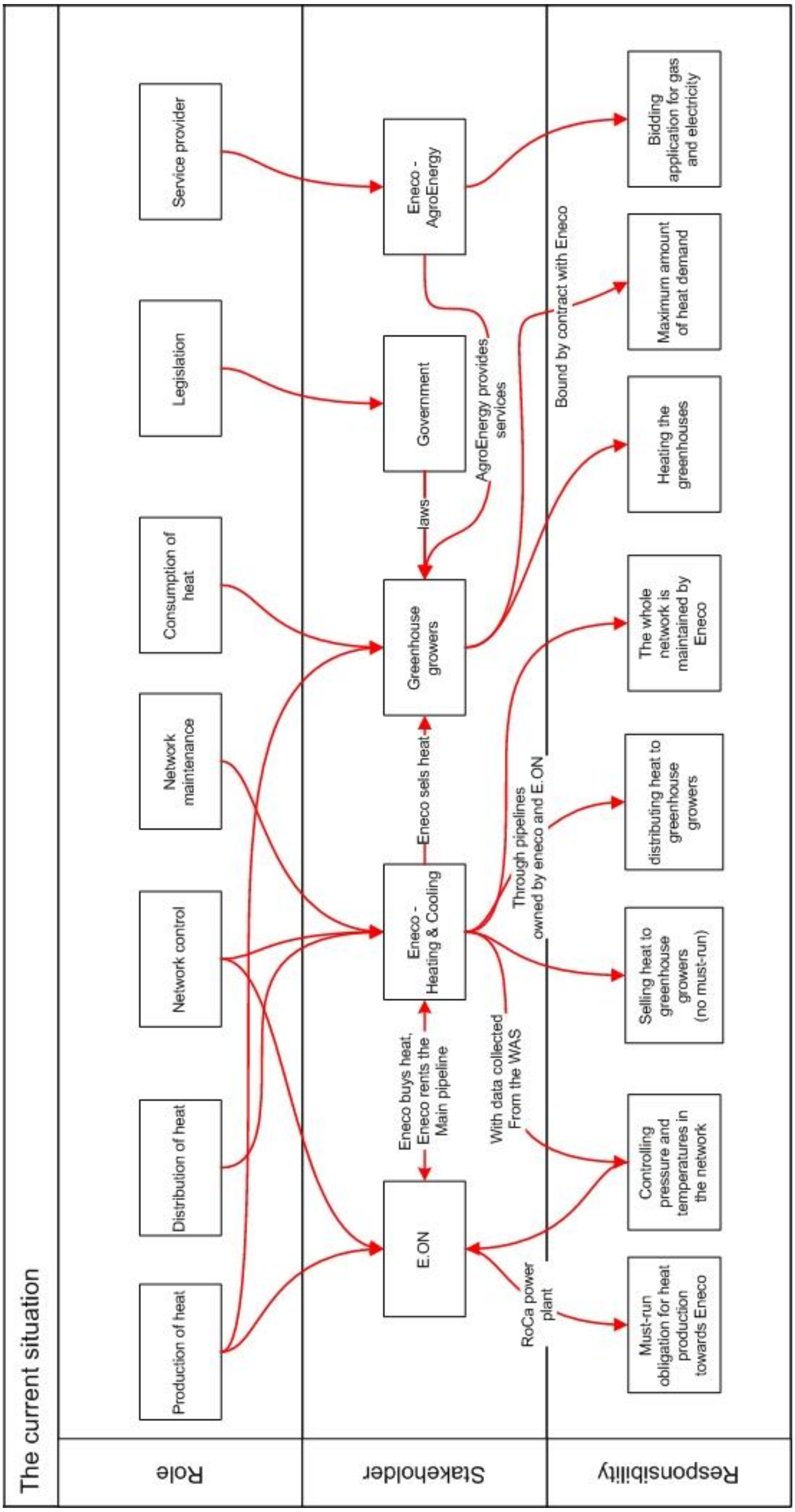

Figure 20: Stakeholder analysis - Heating network B3-hoek

Below the stakeholders are discussed separately. From every stakeholder the role and their responsibility is discussed.

E.ON

Role

The current situation can be distinguished by the fact that more than 90% of the heat used by the greenhouse growers connected to the heat network is produced by the RoCA (E.ON, 2013). Except for producing heat to the greenhouse growers in the B3-hoek, the RoCa also produces electricity for the grid and heat for the city of Rotterdam.

E.ON has another production facility in the city of Rotterdam, the EFG combined heat and power plant. This plant produces heat and power for the city of Rotterdam. This facility is going to be shut down in the near future, the RoCa and AVR will partly have to take over the heat production. This will lead to a decrease of heat supply for the greenhouse growers in the B3-hoek. Moreover, E.ON will increase the price of heat at unfavourable production times (Appendix C explains what the unfavourable times are), making it less interesting for greenhouse growers to buy heat (E.ON, 2013).

Responsibilities

E.ON not only owns the production facilities but also the main pipeline to the B3-hoek. They rent this pipeline to Eneco, who uses it to transport heat to the B3-hoek. E.ON is responsible for the stabilization of the whole physical network, making them partly the network controller. In practice this means keeping sufficient pressure, steady inflow temperature in the whole network and fixing imbalance in the network. This is a combined role with Eneco W&K, however the physical adjustment of the network is done by E.ON.

Eneco W&K

Role

Eneco W&K is a business unit from Eneco. Eneco W&K purchases, distributes and sells heat, so they play the middle man in the heat grid. In addition they own parts of physical heat networks. Eneco W&K mainly operates on the district heating market, for cities in the Netherlands. Apart from delivering heat to the districts, they also operate in the B3-hoek, selling heat to greenhouse growers.

Eneco W&K buys heat from E.ON, and distributes and sells this heat to the greenhouse growers in the B3-hoek. As consequence Eneco has contracts with E.ON for heat production and on the other hand they have contracts with the greenhouse growers for heat supply.

responsibilities

Eneco W&K is responsible for the maintenance of the whole heat network in the B3-hoek, this includes the main pipeline, owned by E.ON. The network also includes WAS (heat deliver station), valves and pumps.

Since Eneco W&K manages and maintains the whole network, they are also partly responsible for the network controlling. Eneco W&K have detailed knowledge of the network, because the WAS gives a lot of data about the pressure and temperature in the network. Together with E.ON they keep the network balanced.

Eneco W&K is also responsible for the quality of the heat they deliver. The water has to be on the right temperature and pressure. However, Eneco has a no guaranteed supply agreement, so they are not obliged to deliver heat to the greenhouse growers on demand.

AgroEnergy

Role

AgroEnergy is just as Eneco W&K a business unit from Eneco. The focus from AgroEnergy is greenhouse growers in the Netherlands. They supply natural gas and electricity to the growers and provides smart interfaces for energy trading to the growers.

One of the goals of AgroEnergy is to make greenhouse growers more durable by supporting with the development of geothermal energy. This competence is to facilitate and advise on trading electricity, gas and heat (Valkenburg, Interview, 2013). They have developed a bidding application for gas and electricity. The application estimates the best time to buy gas and buy or sell electricity to the market. This application does this by interpreting historical data, and uses this to forecast the prices of gas and electricity.

AgroEnergy is also developing an application that includes heat production. The application calculates the optimal time to sell electricity, produced by CHPs, to the grid. One day ahead the greenhouse grower has to indicate what his heat, CO_2 and electricity demand will be, the application then calculates what the optimal production hours. The responsibility of the production still lies with the greenhouse grower, and not with AgroEnergy, they only advise at what time to produce.

The goal of AgroEnergy is to extend this application from an individual level to a group of greenhouse growers connected in a network. However, this application will then look beyond the gas and electricity price, but also to the needs and demands of heat that the greenhouse growers in the network have. The cost of supply and value of demand of heat will generate a heat price, the determination of this price will be done on the virtual 'heat platform'. In the coming years AgroEnergy wants to exploit multiple heating clusters, also taken some of the long term risks of these clusters. In this thesis a preliminary design of the heating platform will be presented.

Responsibility

AgroEnergy is responsible for the delivery of the bidding application. Moreover, in the future AgroEnergy can be the service provider, which means they will be the party that might operate the dispatch of all the production units and pricing within the system. This will include taking all the risk of such a system.

Greenhouse growers

Role

As the users of the thermal grid in the B3-hoek, the greenhouse growers are important stakeholders. They must see the advantages of working together through a smart thermal gird. The biggest incentive for greenhouse growers to participate in the smart thermal grid is to reduce their energy cost. If the heat they buy from the thermal grid is more expensive then self-production, they will not use the thermal grid.

The self-production of the greenhouse growers exists of CHP and of boilers. At the moment these facilities mainly serve as back-up. This makes some of the greenhouse growers dependent on the thermal grid.

At the moment some greenhouse growers are working together with E.ON and Eneco in order to increase the value in the value chain. In the example mentioned in section 3.2, buffer optimization, the greenhouse growers have an financial incentive to fill their buffers at for E.ON favourable conditions.

Groups of greenhouse growers can be distinguished by production facilities and demand for energy:

- CHP + high electricity demand(due to lighting)
- CHP + high CO_2 demand (some plants need much CO_2)
- CHP (CHP produces primary for heat and the electricity is sold)

- Boiler
- Geothermal plant

All groups have a different utility for energy and therefore they are separated in different groups. The values of heat, electricity and CO_2 are combined. So if the value of electricity is higher, the value of heat can be lower in order to have the same overall value. The groups are therefore ranked on the basis of the demand for one of the three sources.

The first group, greenhouse growers with much electricity demand, will produce their own electricity because this saves them taxes and transportation costs. The value of their heat is lower, because the value of their electricity is higher. The same goes for the greenhouse growers with much CO_2 demand, except that the value of CO_2 is higher for them. Both groups could have excess heat, when they have a high electricity/CO_2 demand and a low heat demand.

The third group is a group with normal demand for both CO_2 and electricity. These greenhouse growers often sell electricity at the APX, in order to save on production cost for heat. However, they will mainly produce with their CHP when the electricity price is high, or when they have a high demand for heat. In the first case, they could supply heat to the network, in the latter case they will use the heat themselves. These greenhouse growers are left out of scope, since this type of greenhouse growers is not connected to the thermal grid. Since the heat price in the thermal grid is lower, greenhouse growers without a high demand for $CO_{2,}$ respectively electricity, do not benefit from having a CHP.

The boiler greenhouse growers often buy heat, electricity and CO_2 from the grid. They have a boiler for backup, or if they are not connected to the CO_2 grid, they use their boiler for CO_2 production. These greenhouse growers will not have much heat available, and will therefore not be connected as supplier.

The last group has a geothermal plant. They produce heat with their geothermal plant. Due to subsidies, it is very lucrative to produce as much heat as possible. However, the heat from geothermal plant is lower in temperature. Therefore this should be mixed or sold on a separated part of the network.

Responsibility

The greenhouse growers are responsible for their own production. None of the other stakeholders is responsible for anything that could go wrong in the greenhouse. Greenhouse growers should have 100% back-up facility for their own heat production, since Eneco has no must supply obligation. Moreover, with the bidding application all responsibility lies with the greenhouse growers. AgroEnergy merely gives advice with the help of the bidding application.

Municipality of Lansingerland

Role

The B3-hoek is an area within the municipality of Lansingerland, the area is important for the municipality and is included in the mission statement. This can be explained by the theory of industrial districts, section 3.3 elaborates on this theory. One of the mission statements of the municipality is that by 2025 the whole municipality, this includes the B3-hoek, should be CO_2 neutral (Bliksems BV, 2009). So the municipality benefits from sustainable developments with the greenhouse growers.

In practice, abandoning the heating network, could mean a huge setback in sustainability. Since all greenhouse growers will be forced to start producing their own heat, mostly with boilers. The production of this heat is less sustainable then when the RoCa produces it. A smart thermal grid will create the opportunity for sustainable sources to supply heat, as for example geothermal energy. The municipality will support initiatives that increase the sustainability of their city. The smart thermal grid has sustainable potential, making it interesting for the municipality.

7.1.2INTEREST AND OBJECTIVES OF ACTORS

E.ON

Greenhouse growers often need heat, when the electricity price is relatively low, for example in the night. The production of heat with the RoCa, on times when the electricity price is low, is expensive (explained in Appendix C). Due to the declining electricity price is the business model for E.ON not sustainable anymore, and they want to change this for example by optimizing the grid with buffers (van der Marel & Huizeling, 2013).

Several reasons prevent E.ON from abandoning the heat production for the B3-hoek. Firstly, E.ON has long term contracts with Eneco about the supply of heat with a must-run obligation. So if a greenhouse grower demands heat, and Eneco agrees (which is always the case), E.ON has the obligation to produce this heat. From 2016 onwards, E.ON has a new contract with Eneco without the must-run obligation for the greenhouse growers. From then on E.ON is not obligated to run on unprofitable times (van der Marel & Huizeling, 2013).

The must-run for the city of Rotterdam will stay in place, but for E.ON this is less of a problem. The usage of heat of the city is very predictable and peak demand is often when the electricity price is favourable (van der Marel & Huizeling, 2013). Abandoning the heat production for greenhouse growers will completely change the business case for the city of Rotterdam. The decline in heat demand will increase the fixed cost per MWh of heat. Consequently, increasing the heat price in the city of Rotterdam (van der Marel & Huizeling, 2013).

Secondly, E.ON has another obstacle to cease the heat production for the B3-hoek. As owner of the main pipeline to the B3-hoek, they are obligated by law to remove this pipeline when it is not used anymore. The removal of this pipeline will come with huge costs. Therefore E.ON will keep supplying heat to the B3-hoek after 2016, but then they will only produce heat when they get a good price (van der Marel & Huizeling, 2013).

Since E.ON will be part of the heating network, they support the development of the smart thermal grid. In that smart thermal grid, E.ON will be one of the suppliers, that can offer heat to the network. E.ON is advocate of a heat trading system, where the heat price is determined by the market. Since then they get the market value for their heat (something that is not the case now) (van der Marel & Huizeling, 2013).

Eneco W&K

Due to developments with the power plants of E.ON, E.ON has a business model that is under pressure. They want to make changes as is reflected in their new contract with Eneco valid from 2016. If E.ON stops or decreases the supply this will have a negative impact on the business case of Eneco W&K. It is in the interest of Eneco W&K to make sure the RoCa produces as enough heat at favourable prices. Therefore Eneco W&K is working together with E.ON to improve the profitability of the thermal grid.

However, Eneco tries to look into the future, because after 2023 there is a chance the RoCa plant will close. Therefore Eneco is investigating the possibility for a smart thermal grid. This ensures that Eneco makes optimal use of their existing assets. Besides the assets, Eneco want to keep the greenhouse growers as customer, and without the network there is a big chance the greenhouse growers will revalue their relation with Eneco.

AgroEnergy

AgroEnergy wants to use this application in the B3-hoek, but also in other projects. They expect that more thermal grids will emerge, due the increase in geothermal production, this will be a new market where

AgroEnergy wants to be in. The development of this application is one of the long term goals of AgroEnergy. And therefore they will develop their application, despite what happens with the B3-hoek project.

Greenhouse growers

Greenhouse growers become more competitive when they have lower energy costs. Therefore if it is profitable for greenhouse growers to make use of the smart thermal grid, they will (van den Ende, 2013) (van der Spek, 2013). However, the system should be built in such a way that it is not too complex and manageable (van der Spek, 2013). The system should also be fair, the situation cannot occur that some people think that others are better off (van den Ende, 2013). Therefore it could be an option to have an independent party arranging the trade of heat. This independent party has no stake in the thermal grid, other than facilitate the heat trade (van den Ende, 2013).

The system of trading and market clearing should be fair. However, it should be avoided that a false sense of inequality arises. In practice this cannot be prevented, due the network layout and the difference in production facilities. The communication between all parties should therefore be very transparent. As it cannot be the case that participants abandon the thermal grid, because of the inequality.

The objectives of the different greenhouse growers are different. However, all the current participants to the thermal grid have interest in the developments around the thermal grid. One of the options for the heat trade, is the creation of a market, just as electricity and gas. In this market heat should be traded, and a competitive heat price should be established. However, in this thermal grid there should always be the opportunity to buy, or sell, heat with long term contracts. This will fix the price for a certain amount of time, for example for a year. This way greenhouse growers can protect themselves from unstable prices and can expect a fixed price. This form of security should be included in the system, because some participants prefer to fix their energy costs (van den Ende, 2013).

7.1.3 INTERDEPENDENCIES BETWEEN ACTORS

In Figure 21 the power and interest of the different actors are mapped. For the project to be a success, a working smart thermal grid has to be created. All the actors should be positively involved in the project, because that is the only way the smart thermal grid will succeed. All the parties have to switch from centralized production, to decentralized production. This means that parties have to change their business model, role and contribution. Another vision on how to act in the thermal grid is required to make the step to a smart thermal grid.

The only actor that has a relatively low interest in the creation of a smart thermal grid is the municipality of Lansingerland. The municipality has a lot of different interests and this particular project therefore has a low priority. However, due to their power the municipality should be informed to prevent opposition. The municipality could for example delay permits or decline permits. There are more actors, for example on provincial level that could be added in Figure 21, however due to the nature of this research they are left out.

The relations between E.ON and Eneco W&K is complicated, since they are competitors and yet they have to work together to improve the thermal grid. Both parties have a high interest and power(influence) in the smart thermal grid. Eneco W&K as owner of a big part of the thermal grid has a lot of interest and power in the creation of a smart thermal grid in the B3-hoek, but they cannot do it alone. They need the other actors to be involved in the creation and operation of the smart thermal grid. Eneco W&K is one of the parties with the highest interest in the creation of this smart thermal grid, because they have to find an alternative option for the usage of the physical thermal grid.

The formal tasks of E.ON are the production of heat and physically managing the network. E.ON has quite some power on the whole process. Especially in the near future, E.ON will be important. There is not enough production capacity to supply heat to all greenhouse growers if E.ON decides to stop. Due to the lack in production capacity, E.ON is the most important production actor. Eneco W&K has alternatives for production, outside the greenhouse growers, but in the near future this will not be sufficient.

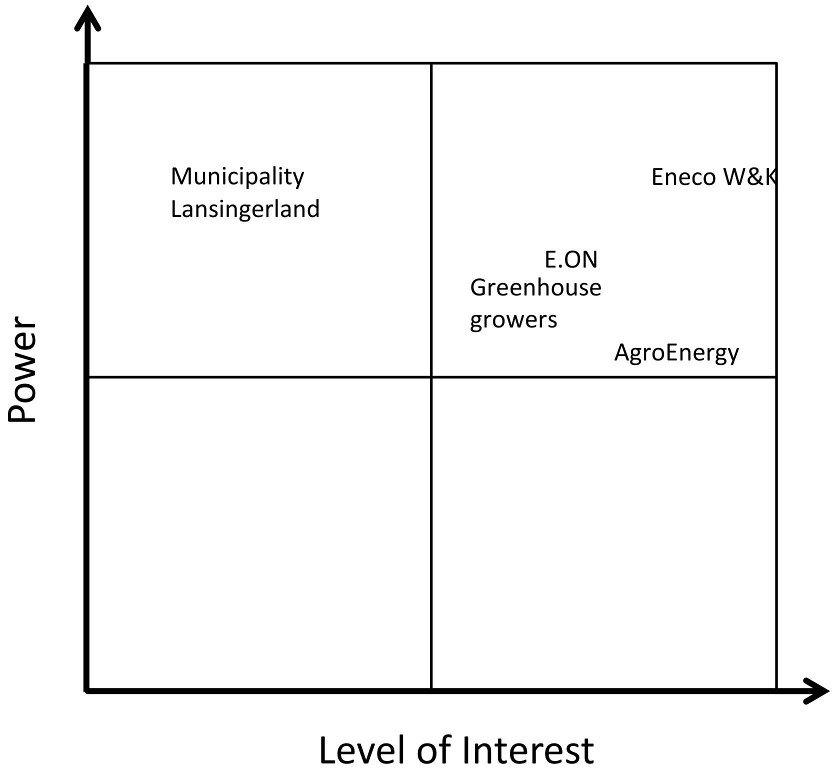

Figure 21: Power/Interest matrix for the project of the ‘warmteweb’ in the B3-hoek

AgroEnergy has a lot of interest with this project. One of their long term goals is to develop a system that optimizes the demand and supply from heat, gas, CO_2 and electricity within a network of greenhouse growers. They not only want to do this within the B3-hoek, but also in smaller clusters. According to AgroEnergy, a lot of money can be saved by greenhouse growers if they optimize their energy supply and work together. The power of AgroEnergy is medium, as they are supplier of the software. They have limited decision power, compared to Eneco W&K.

The greenhouse growers are the last actor in the matrix. They are the final consumer of the heat and user of the network. This makes them an important stakeholder. Some greenhouse growers are more actively involved in the Warmteweb project, but most of them do not bother in the project directly. They give priority to their greenhouses. However, changes in heat prices will have a direct impact on their businesses, therefore they have a high interest. The power of all the greenhouse growers is substantial, as consumers and potential suppliers of heat; due to the fact they are vital for the existence of the network. Enough greenhouse growers have to participate to reach the critical mass. Otherwise the Warmteweb will not work financially.

7.2 ACTORS IN THE SMART THERMAL GRID

The transformation from the current situation to a smart thermal grid means that some adjustments need to be made. This applies for the actors in the system. Making the system smart means a new way of looking at the whole system. Now it is a centralized system, where E.ON produces heat and the greenhouse growers consume this heat. Without giving much thought to demand and supply. In order to make this system smart, the mind set of all actors has to change. For example, the heat from the thermal grid will not be the 'cheap' heat from E.ON, but the heat will be given a realistic price. The change of the pricing system will therefore mean a change in the way actors look at their heat supply.

Besides the view change, the actors will also have to deal with a change in roles, relations and responsibilities. Many details are not yet sorted out, therefore only a general set of statements can be formulated about the implications of the changes. For each role, the changes will be given below:

- *Production of heat:* Greenhouse growers and other third parties will be able to supply heat to the network. E.ON will lose their monopoly on the heat production. The producing parties will gain the responsibility of production. The disadvantage of supply from greenhouse growers is that they are not independent from changes in demand within a day. If the demand rises unexpectedly, more heat is demanded, but the supplying greenhouse grower has less heat available than he had planned for, since his greenhouse also needs more heat.
  Most likely it will mean that if a producer fails to meet his obligations, fines will be given. However, these are details that will have to be sorted out with all producers in a later stage of the development. As more parties are able to supply heat, E.ON will have to adapt to their preferences.
- *Transportation of heat:* The transportation of heat will have to be arranged by one party. At the moment this is Eneco W&K, because of their experience, this will also be the most likely actor to do this in the future. Due to the changes in suppliers, Eneco W&K will have to guarantee transportation and delivery. It cannot be the case that some of the heat that is bought, cannot be delivered. It is therefore important that all heat that is traded, can actually be produced and delivered.
- *Consumption of heat:* The heat will still be consumed by the greenhouse growers. The most important change is in the pricing system. If a market is created, prices will become variable, depending on the supply and demand. Greenhouse growers will try to buy heat when the price is low, and therefore have an incentive to match their demand with the supply. This means a radical change in their thinking and behaviour.
- *Network controller:* The shared responsibility between E.ON and Eneco W&K, will probably shift towards Eneco W&K. If E.ON does not supply heat to the network, it would be attractive to disconnect part of the main pipeline to E.ON, also making E.ON unable to control the network. Therefore Eneco W&K should control the network locally, to make them independent of E.ON.
- *Network maintenance:* The maintenance of the network is now done by Eneco W&K and this will most likely stay this way.
- *Service provider:* AgroEnergy and other parties are now providing energy serves to the greenhouse growers. In the smart thermal grid, they could expand their services from greenhouse growers to the whole system. AgroEnergy could manage the market and be the link between demand and supply.
- *Legislation:* The legislation part is assumed to remain the same.

Some important factors are still unknown, however the change to decentralized production is clear. It is therefore important that there is enough support locally for the creation of the smart thermal grid. A critical mass of both producers and consumers has to be available to make the grid financially attractive. In order to create as much as support as possible, the system should be transparent (van den Ende, 2013). This transparency will create trust with the participants, and trust is needed for actors to participate. Without trust in the system, they will most likely not participate.

7.3 CONCLUSION ACTOR ANALYSIS

Involving the actors in the development of a decentralized thermal grid, is very important. If the actors locally decide not to participate, the smart thermal grid will fail. The actors should have trust in the system and in other participants. Therefore the roles and responsibilities from all actors should be clear and transparent.

With all the changes that are made, the role of actors should always be taken into account. The reason for this is that the actors are dependent on each other. The greenhouse growers depend on the thermal grid for relatively cheap heat. While Eneco and E.ON are dependent of the greenhouse growers as consumers of heat. The three parties are committed to the continuation of the thermal grid, since disbanding the thermal grid would have financial consequences for them. For AgroEnergy disbanding the thermal grid has no direct financial consequences, however as part of Eneco they are indirectly committed to the continuation as well.

For all actors the most important thing is economic profitability, according to the interviews. The environment the system has to operate in, is a business environment. Therefore all actors should have economic gain, otherwise they will not participate. The system should create a win-win situation for everyone, or at least for Eneco, E.ON, AgroEnergy and enough greenhouse growers to sustain the system.

The different roles in the system will remain the same. However, who for fills these rolls will change with the introduction of the smart thermal grid. Actors will have to deal with changing responsibilities and roles. For example, producing greenhouse growers will responsible for the production of heat for others, this is a big change for them. It is important that this is taken into account very carefully, since greenhouse growers are in the first play greenhouse growers and no energy company. This is one of the changes that should be taken into account while developing the smart thermal grid. It cannot be that the responsibility and thereby the risks, are too high for greenhouse growers to produce.

In this analysis potential entrants in the heat market are not included, since it only focuses on the current actors. This is done because in the near future it is unlikely that other parties will enter the heat market, due to much economic uncertainty. However, it should be encouraged for additional parties to sell heat in the network. This increases the competition and the availability of heat, this would be good for the continuation of the smart thermal grid. This is seen from the point of view of both Eneco and the greenhouse growers. E.ON will probably be less content, however due to their size in the market they do not have to fear much.

In this analysis also not much attention is given to the behaviour, rules and regulations of the system. This will be analysed in the next chapter, the institutional domain.

8 INSTITUTIONAL DOMAIN

Since the complex system of interest, the smart thermal grid, includes multiple actors, coordination is necessary for the system to function. The smart thermal grid cannot operate fully automatically, since there will always have to be interaction with actors. These actors might want to override the outcomes of the system, for example producing more heat than was agreed upon. In this particular case the producer will create imbalance in the system, something that should be prevented. The system therefore needs rules that guide and coordinate the behaviour of the different parties (Koppenjan & Groenewegen, 2005).

These rules, or institutions (as defined in section 4.1), reduce the risk of opportunistic or strategic behaviour, reduce costs of interaction and limit uncertainty within the system. Clear institutions create more certainty about what is expected from actors and what can be expected from other actors. This certainty will increase efficient information sharing and negotiations within the system. Moreover, increasing the willingness to invest in the maintenance of a common facility or in the realization of a common facility (Koppenjan & Groenewegen, 2005).

The transformation of the system requires a revaluation of the already existing institutions. Given that the relation between some of the actors is changing significantly. It has to be determined what has to be adjusted to accommodate these changes. It is important that changes made within a layer fit with the other layers (see section 3.4, for the definition of the different layers). Since there cannot be contradictions between the layers (Koppenjan & Groenewegen, 2005). Therefore an institutional analysis is performed, according to the method described in section 4.2.1. This analysis will provide more insight into the different institutional layers of the system and the interaction between them.

8.1 INSTITUTIONAL ANALYSIS

The analysis is divided into four parts, as can be read in section 4.2.4. Each of the different layers will be analysed separatly.

8.1.1 LAYER 1: ACTORS

In the actor analysis the role, interest and objectives concerning the smart thermal grid of the different actors is described. However, the analysis does not elaborate on the behaviour of actors and their interaction aimed at creating and influencing provisions, services and outcomes. In layer 1 of the instructional domain, this is discussed.

Opportunistic behaviour

In this thesis it is assumed that all individual actors display optimizing behaviour, such as maximizing profits or minimizing costs. This behaviour can lead to opportunistic behaviour, such as deliberately providing false information to increase their own benefits at expenses of other system participants. Opportunistic behaviour is not always displayed. This is dependent on the circumstances. Therefore the system should safeguard against opportunistic behaviour, by creating an environment where it is in no one’s interest to show opportunistic behaviour. This can be done by creating institutions that have incentives to follow the optimization and not deviate from it (Groenewegen, Spithoven, & van den Berg, 2010).

Limitations of actor decisions (bounded rationality)

Actors do not take decisions in a vacuum, but among others, do this in an institutional environment. The institutional environment constrains and enables actors in their decision-making. The rationality of the decision-making process is influenced by a dynamic process of interaction with different elements of the societal system. This includes concepts such as trust, satisfaction, habits, and learning. However, the rationality of actors is bounded, meaning that the human capacity to solve and formulate complex problems is limited. Bounded rationality causes actors to still show optimizing behaviour, however constrained by a limited amount of information and limited capacity to process all the available information (Groenewegen, Spithoven, & van den Berg, 2010).

In the current situation, this bounded rationality is clearly shown. Greenhouse growers with a CHP try to minimize their energy costs. However, AgroEnergy shows with their bidding application that most greenhouse growers consistently minimize at a sub-optimal point. Since greenhouse growers have a limited amount of time and information, they act on their intuition and knowledge from the past to predict the energy markets. On the other hand, the bidding application processes up-to-date information. Based on these, rational data an optimization is done. And therefore they are able to make better predictions of the energy market. This allows AgroEnergy to minimize the energy cost of greenhouse growers in a more optimal way (Valkenburg, meeting productiekosten, 2013).

AgroEnergy does this optimization for an individual greenhouse grower. Even more savings can be achieved by the smart thermal grid, the optimization of a whole area of greenhouse growers. However, all participating greenhouse growers have to be convinced of the advantages the smart thermal grid provides for them. Greenhouse growers cannot question the outcomes of the system all the time, otherwise they might want to deviate from the dispatch (thereby influencing the outcomes of the optimization). With help of contracts, deviating from the dispatch can be discouraged (see section of layer 2). However, in the long run greenhouse growers have to trust that the outcome of the smart thermal grid is the best possible outcome. This can partly be achieved by transparency (van den Ende, 2013) (van der Spek, 2013). If greenhouse growers are able to understand the system and can understand the outcomes, they are less likely to oppose or question the system.

Inequality in the system

Since the optimization proposed is looking for the optimal solution for the whole system, the optimal solution for individual actors is not necessarily obtained. Since all individual actors in the system try to optimize their individual gain, they might not be willing to sub-optimize. However, the system will always provide a solution for an individual actor that is better than or equal compared to the situation without the smart thermal grid. The reference point should therefore always be a situation without participating in the smart thermal grid.

Moreover, the benefits per actor will be dependent on his situation, therefore the benefits per actor can differ. Consequently, inequality between actors can occur in the system. This inequality can be explained by the investments made by actors and the risks that accompany them. Actually this inequality might be unavoidable, since these investments and risks should be rewarded, otherwise actors will be reluctant to make investments that benefit the system. This inequality in benefit distribution can also be an incentive for actors to invest in for example production capacity, buffers or energy saving measures, since they are rewarded for their investments.

The distribution of benefits in the system should be transparent. Not every euro in the system has to be explained, but some insights have to be provided into what the general benefits of the different investments are. This is a tool to increase the understanding of the outcomes of the system and could also be a way to promote investments.

Cooperation in the system

The smart thermal grid gives greenhouse growers new opportunities to cooperate. In the smart thermal grid it is easier to share production facilities and buffers, since these facilities can be connected to the thermal grid, something previously impossible. An example is mentioned by the greenhouse grower Hans Bunnik, he stated that the cost per m^3 of buffer decline when the buffer gets bigger. Therefore he claimed that it would be much cheaper to invest with multiple greenhouse growers in one big buffer, then all invest in smaller separated buffers (Bunnik, 2013).Therefore the business case of co-investing is improved, due to the smart thermal grid.

This also raises the question if some groups of cooperating greenhouse growers would not be better off, not to participate in the optimization. Since the optimization optimizes the whole system, the solution could be suboptimal for a sub-group of cooperating greenhouse growers. This is something that should be investigated when the optimization is developed and therefore is something for future research.

8.1.2 LAYER 2: THE (IN)FORMAL INSTITUTIONAL ARRANGEMENTS

There are different ways of making network institutional arrangements, or network governance(link to chapter 3.4); shared governance, network administrative organization, and lead organization. In shared governance the network is governed by the network members themselves, without a separate governance entity. Network participants are responsible for managing the internal and external network relations and operations themselves. Therefore all the decisions are made collectively. The disadvantage of shared governance is that it becomes highly inefficient when the network consist of more than 10 participants (Provan & Kenis, 2007). Moreover, this form of governance requires a high amount of trust between the network participants. Trust in this case is defined as: 'the willingness to accept vulnerability based on positive expectations about another's intentions and behaviours' (McEvily, Perrone, & Zaheer, 2003). Consequently, shared governance is rejected as an institutional arrangement, since the network consists of around 120 participants that do not all trust each other.

The network administrative organization is a separated entity that is set up specifically to govern the network. This organization exclusive purpose is to govern the network. This could be a non-profit organization or a government entity. The advantage over the shared governance, is that this form of governance is very efficient in network with a high number of participants. The network participants collectively monitor the network administrative organization, therefore some trust between the network participant is necessary (Provan & Kenis, 2007).

The lead organization governance structure is characterized by one centralized leading organization. This form of governance is also more efficient than shared governance, when dealing with a high amount of network participants. The lead organization coordinates all key decisions and major network activities. Moreover, the lead organization facilitates the activities of network members in their efforts to achieve network goals and could provide administration for the network. Trust between network participants is not required, as long as all the network participants trust the lead organization to act in the best interests of the network (Provan & Kenis, 2007).

Therefore lead organization governance is the best option for network governance of the smart thermal grid. Taken into consideration that Eneco W&K together with AgroEnergy took the initiative to develop the smart thermal grid and therefore already act as a lead organization. AgroEnergy in its role as service provider, wants to execute the daily operation and the administration of the smart thermal grid.

Institutional arrangements coordinate transactions among different actors in a network. Three moments of transaction can be distinguished: long-term, day-ahead and intraday. The moments are distinguished due to a difference in risk, uncertainty and complexity (Koppenjan & Groenewegen, 2005).

Long-term

In the network investments have to be made, to facilitate participants to supply and/or demand heat from the grid. Before these investments are made, at the moment done by Eneco W&K, long term guarantees are needed. Otherwise there is too much uncertainty about return on investment (ROI).

In the network guarantees to the participants should be given. This in order to improve their business case for investments in for example production, by reducing the long term risks and uncertainty. These long-term guarantees, could be a fixed amount of heat per year, or a fixed price. However, these long-term contracts will have to be made on an individual basis.

Day-ahead

The optimization will give a dispatch for the heat production for the day-ahead. The demand and supply of all the participants in the network is then fixed. A deviation from this heating program will cause imbalance in the thermal grid, since the supply and demand of heat will not match anymore. Therefore agreements have to be made, to ensure that everyone follows the heating program. For producers this means they deliver the amount of heat and for the consumers this means they demand the amount of heat they agreed upon.

Besides the physical heat trade, a financial transaction will have to take place. This transaction, coordinated by the leading organization, should be part of the delivery agreement. The consumer and producer do not have a direct contract with each other, but both have contracts with the leading organization.

Intraday

Since the heating program given by the optimization, is based on prediction, the actual demand of heat will always deviate from the heating program. Imbalance between demand and supply in the network is therefore unavoidable. See the different forms of imbalance in the network in section 6.2.

The different measures to match supply and demand are (Goudswaard, Interview in naam van AgroEnergy, 2013):

- Price incentives: With price incentives the demand or supply can be decrease or increased. By lowering the heat price for example, it will be more attractive for consumers to buy heat.
- Central buffer: A buffer that is only used for balancing the grid. The buffer can absorb excess heat, and if filled can also increase the supply.
- Contracts: With some parties in the network 'afschakel' contracts can be used. The heat supply to these consumers can be terminated in case of a shortage of heat.
- Big producer: A big producer, for example the E.ON, can increase or decrease their heat supply (van der Marel & Huizeling, 2013).

In the agreements it should be stimulated that both the consumer and producer use their buffers to absorb their own small deviations from the heating program. However, if there is a substantial amount of heat not supplied or demanded from the network, there will be an imbalance in the network, called program imbalance (someone deviates from the program). When a producer produces less heat than agreed upon, another participant will have to produce this heat. The producers will receive a fine that at least covers the costs of the replacing heat production costs. In the other situation, where a consumer demands less heat than agreed upon, the consumer will pay for the heat that was agreed upon. These rules are developed by Peter Goudszwaard, energy consultant for AgroEnergy (Goudswaard P. , 2013). Both agreements will have to be made in a self-regulating way, the incentives should be high enough for parties to do everything in their power to do as agreed upon (Groenewegen, Spithoven, & van den Berg, 2010).

8.1.3 LAYER 3: FORMAL INSTITUTIONAL ENVIRONMENT

Next to the arrangement between actors, also formal rules and regulations exist that apply to all actors. The most important rules and regulations related to the production and transportation of heat are discussed below.

Heat law

In the Netherlands the heat law will be applied as from 1-1-2014. This law regulates the delivery of heat to consumers (First Chamber, 2013). This law does not apply to delivery to greenhouse growers, but only to small consumers(small businesses and households). So it does not directly apply to the smart thermal grid in the B3-hoek and the producing greenhouse growers. However, if in the future the smart thermal grid is connected to residential areas, the heat law will apply to the producing greenhouse growers. This means that the greenhouse growers will need a license for their heat production and they can only ask a predetermined maximum price for his heat.

Energy tax

Energy taxes have to be paid for the consumption of gas and electricity. However, there are some exceptions (Blom, Schroten, & Geurts, 2011):

- No energy tax has to be paid if the gas or electricity is used for the production of electricity, when the production unit has an electrical efficiency of at least 30% and a minimum power of 60kW. This is the case for all the CHPs used in the B3-hoek.
- All greenhouse growers pay less taxes over their consumed gas.

If greenhouse growers buy heat from the thermal grid, they pay taxes equal to the gas equivalent of the produced heat. So three distinctions are made here :

Greenhouse growers' production with CHP: Pay no taxes over the consumed gas. Moreover they do not pay taxes over the self-produced electricity and heat.

Greenhouse growers production with boiler: Pay a reduced tax rate over the consumed gas. Moreover, they do not pay taxes over the self-produced heat.

Greenhouse growers buy from the grid: Both taxes need to be paid over the bought electricity and heat.

CO_2 emission trading scheme (ETS)

The goal of the ETS is to reduce industrial greenhouse gas emission. The trading system is based on the 'cap and trade' principle. The cap is the total amount of greenhouse gas that can be emitted by the heavy industry in Europe. This cap is reduced over time, so that the total amount of greenhouse gas emissions will diminish. In 2020 a reduction of 21% has to be achieved compared to 2005. Companies receive or buy greenhouse gas emission allowances, which they can trade. Due to the limited amount of allowances available, these allowances will have a value, indirectly giving a value to greenhouse gas emission (Europan Commission, 2013).

The greenhouse growers in the Netherlands also have to deal with the ETS. However, the greenhouse growers have their own system within the ETS. Furthermore they have made a deal with the Dutch government to combine all CO_2 emissions of the whole sector (along with energy tax reduction for the sector). If the sector cap is exceeded, a fine will have to be paid by the whole sector (split by the energy consumption). This should give the sector an incentive to reduce the CO_2 emissions, by using waste heat and geothermal energy. An exception is made if CO_2 is bought for fertilization (the producer already paid for this CO_2 emission) and electricity produced by CHPs that is sold (Productschap Tuinbouw, 2013).

In both systems the CO_2 emission is paid by the heat producer and therefore the consuming greenhouse growers do not have to take into account this CO_2 emission. The consumer will indirectly pay for the CO_2 emission in the heat price. In an estimation made by Productschap Tuinbouw, greenhouse growers will have to pay a bit over €100 per hectare in 2014 (Productschap Tuinbouw, 2013).

At the moment the costs of CO_2 emission are relatively low, also due to the low price of the emission allowances (due to the economic crisis). However, an increase in the price of CO_2 emission allowance, will increase the business case for the development of heat production units with less or no CO_2 emission, as for example geothermal energy (de Haas, 2012). Given that an increase in the cost of CO_2 emission, will also increase the heat price.

Subsidy

The Dutch government provides subsidy to stimulate the development of sustainable energy production. This subsidy is called SDE+ (Stimulering van Duurzame Energie). This subsidy is a compensation per unit of production, due to the unprofitability of these production units. Production units that can apply for this subsidy are for example:

- Energy production fuelled by biomass
- Geothermal energy
- Solar thermal energy

In principle a subsidy with a cap of €23,40 is given to every geothermal energy plant per produced MWh of heat (Platform Geothermie, 2013).

8.1.4 LAYER 4: INFORMAL INSTITUTIONAL ENVIRONMENT

Informal institutions have a great influence on the mindset of the actors (layer 1) in a network. This layer has an influence on the perception of actors with respect to the identification of problems and considered solutions. The informal institutional environment determines what incentives are acceptable and efficient (Denzau & North, 1994). Actors use their norms and values to influence and developed the institutions, therefore it is relevant to have an insight in them. Individual actors might have different norms and values, however they can be generalized over a group of comparable actors. In this part three different groups are considered: the government, greenhouse growers and energy companies. All actors analysed in the actor analysis are represented in one of these groups. In the actor analysis the governmental organizations were addressed shortly, since these actors are taken as static and not directly involved in the transformation of the smart thermal grid. However, the formal rules in the formal instructional environment are designed and implemented by the Dutch government. Therefore the government is discussed in here in the institutional domain.

Values and norms of the Dutch government

The Dutch government is focused on sustainability and energy savings, in order to reduce the effects on climate change. This is reflected in the Energieakkoord (energy agreement) the Dutch government made with over 40 parties(from the industry, consumers, employers, NGO's) to invest in sustainable growth. In the agreements parties commit themselves to investing in energy savings and sustainable production. This agreement should not only benefit the environment, but also the Dutch economy (Social-Economische Raad, 2013). The relevant parts of the agreement are:

- In 2023 16% of all energy production should be sustainable.
- In 2050 an energy reduction of 80-95%, compared to 1990, should be achieved.
- Improvement of the ETS, cause of its current inadequateness.

Values and norms greenhouse growers

There is growing awareness among greenhouse growers that their sustainability should be improved. However, greenhouse growers still have to run a business. In the interviews conducted for this research, the greenhouse energy consultants and the greenhouse grower indicated four important values for the smart thermal grid (Bunnik, 2013) (van den Ende, 2013) (van der Spek, 2013):

- Economic gain
- Sustainability
- Flexibility
- Stability (continuity)

Firstly, since greenhouse growers operate in a competitive market, they have to have economic gain. There is a economic driver behind the thermal grid. The moment the economic gain decreases the greenhouse growers will consider alternatives heat sources. As indicated by Hans Bunnik: 'if the heat price rises, I will consider investing in alternatives'. In this investment decision, he takes in consideration that he will be able to sell heat through the thermal grid (Bunnik, 2013). Meaning that a price increase, could be an incentive for the investments in additional heat production.

Secondly, greenhouse growers are becoming more aware of their impact on the environment. Some greenhouse growers already have developed a geothermal production plant, and others also consider investing in sustainable heat production. This is also reflected in the Energieakkoord, where greenhouse growers are committed to (Social-Economische Raad, 2013):

- reducing the total amount energy use, as a sector, with 11 PJ until 2020.
- Improve the innovation program for energy savings and CO_2 emission.

The smart thermal grid improves the business case for investing in sustainable energy production, since an excess of heat can be sold through the network. The network also makes it easier to have a group of greenhouse growers jointly invest in facilities, since they can use the thermal grid to exchange heat.

Thirdly, the network provides more flexibility, since there is more than one heat production facility. By switching between different heat production facilities, the optimal heat production program can be developed. This also makes the greenhouse growers less dependent on one production facility.

The last value that the greenhouse growers indicated is stability and continuity. The thermal grid should provide a long term solution, since investments are made for a long period of time. This also includes price stability, since not all greenhouse growers like to have 30% of their total cost fluctuate a lot.

Values and norms of energy companies

Energy companies are also gaining more awareness of sustainability. Eneco is one of the more progressive energy companies, and is promoting sustainability actively and providing all their customers with 100% sustainable power. However, energy companies are commercial parties, and therefore operate in a competitive environment. Investments in sustainable energy production, should therefore be profitable.

The energy sector also made a commitment to the Energieakkoord (Social-Economische Raad, 2013):

- Invest in smart grids.
- Improve decentralized energy production, facilitated by companies and civilians, by reducing cost and increase accessibility.

The smart thermal grid inherently improves companies, mainly greenhouse growers, by reducing the costs of decentralized energy production and increasing the accessibility to decentralized production, since conditions of co-investing in production facilities are improved. The development of the smart thermal grid therefore perfectly fits into the commitments Eneco made to the Dutch government.

8.2 CONCLUSION INSTITUTIONAL ANALYSIS

It is presumed that all actors display optimizing behaviour, this optimizing behaviour is constrained rationality. This is also the case with greenhouse growers, where the bidding application showed that the greenhouse growers are consistently sub optimizing. It is therefore interesting for greenhouse growers to use the bidding application, and the smart thermal grid in future, since this will offer them more benefits. The system of benefits distribution (transactions), but also the system of the coordination of the dispatch, key decisions and major network activities, should be created and governed. The governance of the smart thermal grid should be done by one lead organization. This lead organization will most likely be Eneco (W&K and AgroEnergy), since there is too little trust among participants to create a network administrative organization and Eneco already has taken the lead in the development of the smart thermal grid.

There are three time periods of transactions that need to be governed with institutional arrangements: long-term (1-10 years), day-ahead and intraday.

The long-term should provide long term guarantees, to reduce uncertainty in the system. The institutional arrangements created for the long term, could also give room to steer on long term objectives, for example the continuation of the smart thermal grid.

The day-ahead is focused on the heating programme or dispatch of the different production units and the inherent responsibilities and obligations. Actors have to follow the heating programme otherwise imbalance between supply and demand will occur.

The intraday should fix the imbalance between demand and supply in the system that is created for example by the dynamics of the weather. Agreements should be made that stimulate actors to accommodate the small deviations from the heating programme, by for example using their buffers. However, in the case of substantial imbalance, institutions should be created that focus on balancing the network.

The formal institutions have a static influence on the smart thermal grid. However, they should be monitored. Formal institutions concerned with the smart thermal grid are: Energy taxes, CO_2 emission trading scheme and subsidies.

The informal institutional environment has an influence on the perception of actors with respect to the identification of problems and considered solutions. It is therefore important to take this layer into account. The most important value of greenhouse growers is economic gain. Therefore their perception with respect to the smart thermal grid, will primarily be financially driven. The creation of institutions should always take into account the economic gain of the greenhouse growers, but also of the other participants, since all actors, in this business environment have economic gain as primary objective. Other important values of greenhouse growers are: sustainability, flexibility and stability (or continuity). Since the growing awareness of climate change , sustainability is increasingly becoming an important value for the energy companies.

In this thesis and this chapter the institutional arrangements are not discussed in detail. In the development of the smart thermal grid, the institutional arrangements should be developed by the lead organization in close cooperation with the participants since the institutional arrangements will be applicable to the participants, making it important to involve the participants in the formulation of the institutional arrangements. These arrangements should include clear daily management of the system, as much as possible self-regulating.

Participants should be encouraged to keep the system balanced. These arrangements should be clear and transparent to reduce uncertainty among participants.

Additional research has to be done to benefit the distribution system. A benchmark (reference point) has to be created for all participants, to judge how much gain they have. Moreover, it has to be determined what desirable behaviour is and how this can be steered. For example the use of buffers to compensate for small deviations from the heating program is desirable. In addition, the objectives of the long-term objectives should be determined in cooperation with the participants. Since the long-term objectives could decrease the economic gain on the short term, which might not be acceptable for all participants.

9 ECONOMIC DOMAIN

The focus of the economic domain is on the finances within the system and on the demand and supply patterns of different parties and facilities.

The goal of this chapter is to gain more understanding in the economics of a smart thermal grid. A lot is technically possible, however, it is the economic gain of the smart thermal grid that is the first priority of all parties involved. Firstly, the cost of different aspects of the system will be analysed. Secondly, the economic patterns in the system will be investigated.

9.1 ECONOMIC ANALYSIS

This analysis is focused on the cost of heat production. This includes economic patterns that influence the production costs.

9.1.1 COSTS OF THE SYSTEM

Production costs

The production costs of the different production source are different, and there is even a difference within the different production sources (size, efficiency, manufacturer). In this chapter the heat costs are described generally per production source. A comparison between the different sources gives more insight into the dispatching of different production sources. Generally the cost of a MWh of heat can be divided into 3 different categories, the fixed, the variable costs and earnings. Per production sources the heat production cost differ, as can be seen in :

Heat production cost	RoCa	CHP(CO_2)	CHP(lighting)	boiler	Geothermal plant
Fixed costs[€/year]					
Depreciation(+interest over the loan)	•	•	•	•	•
Yearly maintenance	•	•	•	•	•
Costs for the use of the gas network	•	•	•	•	
Variable costs[€/MWh]					
Costs for fuel	Gas	Gas	Gas	Gas	Electricity
Variable maintenance cost per MWh	•	•	•		
Heat transportation costs	•	•	•		
Energy taxes				•	
Earnings[€/MWh]					
Earnings of selling electricity	•	•	•		
'avoided costs' electricity		•(low)	•		
'avoided costs' CO_2		•	•(low)	•	
Subsidy					•

Table 3: Heat production cost per production source

$$Heat\ cost\ [\frac{€}{MWh}] = \frac{fixed\ costs}{MWh\ produced\ per\ year} + Variable\ costs - Earnings \qquad (8.1)$$

The price per MWh of heat can vary. The main reason is that the electricity price changes during the day. Moreover, the fuel and CO_2 prices can vary, but most greenhouse growers have contracts to fix these prices for a certain period. Due to the variation in electricity price, the earnings of selling and the avoided costs of using electricity also changes with the hour. The avoided costs are the costs that are saved by self-production, or put differently, the savings for not having to buy electricity or CO_2 on the market.

For dispatching of production units, often the marginal costs are compared. The marginal costs are the costs of the production of one additional unit (Sullivan & Sheffrin, 2003). However, in the case of a CHP it is a bit more complicated due to the joint cost of the production of electricity and heat can be split in numerous ways. In this thesis electricity and CO_2 are both considered by-products in the calculation of the marginal cost. The heat costs are calculated as the plant's production cost, less the value of electricity (and CO_2 if used) or less the value of the subsidies (which are also earnings in this thesis). Depending on the cost and the revenue's the marginal cost can therefore even be negative (Difs & Trygg, 2009). The marginal cost of heat production are defined in this thesis as:

$$Marginal\ cost\ of\ heat\ production\ \left[\frac{€}{GJ}\right] = Variable\ cost - earnings \tag{8.2}$$

In Table 4 the marginal production costs of the different production units is shown. These costs are estimated marginal costs of all production units, with an electricity price of €45 per MWh and a gas price of €26 per MWh. At the moment these prices are the long term prices for gas and electricity and are therefore representative for the current situation. The details of the calculation of the heat costs per production unit and the underlying assumptions can be found in Appendix D.

In Table 4 two different CHPs are included; a CHP with a primary goal of CO_2 production (the CHP(CO_2)) and a CHP with as primary goal electricity production for lighting (CHP(lighting)). The difference in the costs of heat production can be explained by the difference in the electricity value for different CHPs. For greenhouse growers with much lighting, the value of electricity is higher, than for greenhouse growers with much CO_2 demand. The value of this electricity is higher, because of the so called avoided costs. The greenhouse grower avoids buying electricity at the market, which included transportation costs and taxes. These avoided costs have to be added to the value of the electricity produced.

For a greenhouse grower with much CO_2 demand, the value of the produced CO_2 is higher. Moreover, due to the same principle of avoided costs. The costs for buying CO_2 and the transportation do not have to be paid and count as avoided costs. The total costs of production have to be recovered by the total value of heat, electricity and CO_2 combined. So an increased value of electricity, respectively CO_2, lowers the costs of heat. The heat from a CHP(lighting) is cheaper than the CHP(CO_2) because the market value of electricity is much higher than the market value of CO_2.

In Table 4 it can be seen that the marginal costs of the Geothermal plant are negative. This can be explained by the subsidy provided by the Dutch government of maximum of €23,40 per MWh of heat (Platform Geothermie, 2013). For this example a subsidy of €15,60 (about 2/3 of the maximum amount) per MWh of heat is taken. Further observations are that a CHP (lighting) and CHP(CO_2), are cheaper than the RoCa. This can be explained by the avoided cost. These marginal cost are calculated based on the average electricity and gas price of 2013, €51,88 per MWh respectively €27,06 per MWh. These marginal cost only serve as example, since the marginal cost change with a change in electricity and gas prices.

As already mentioned in this paper, currently the most expensive production unit is the boiler. Since most of the greenhouse growers have boilers, the maximum heat price will have to be below the boiler price. Otherwise, they will produce the heat themselves.

Marginal cost of production (€/MWh)		
Geothermal plant	€	-10,21
CHP(lighting)	€	14,22
CCGT(RoCa)	€	x
CHP(CO_2)	€	14,22
Boiler	€	36,12
AVR	€	18,00

Table 4:Estimation of marginal cost of production units for current situation

Figure 22 clearly shows that the marginal production costs of a boiler, €36,12 per MWh, is independent of the electricity price. All the costs of all other production sources are dependent on the electricity price. If the electricity price becomes too low, some production units will become more expensive than the boiler. In that case no heat will be sold. The marginal production costs change every hour because of the electricity price, therefore the dispatch of production units can change every hour. The electricity price is very volatile and can easily differ more than €30 per MWh in price within a day. This difference in electricity price has a huge effect on the marginal production costs of the CHP and the RoCa, as can be seen in Figure 22. The marginal production costs will also be very volatile due to the volatility of the electricity price. The volatility of the electricity price will be discussed in chapter 9.1.2.

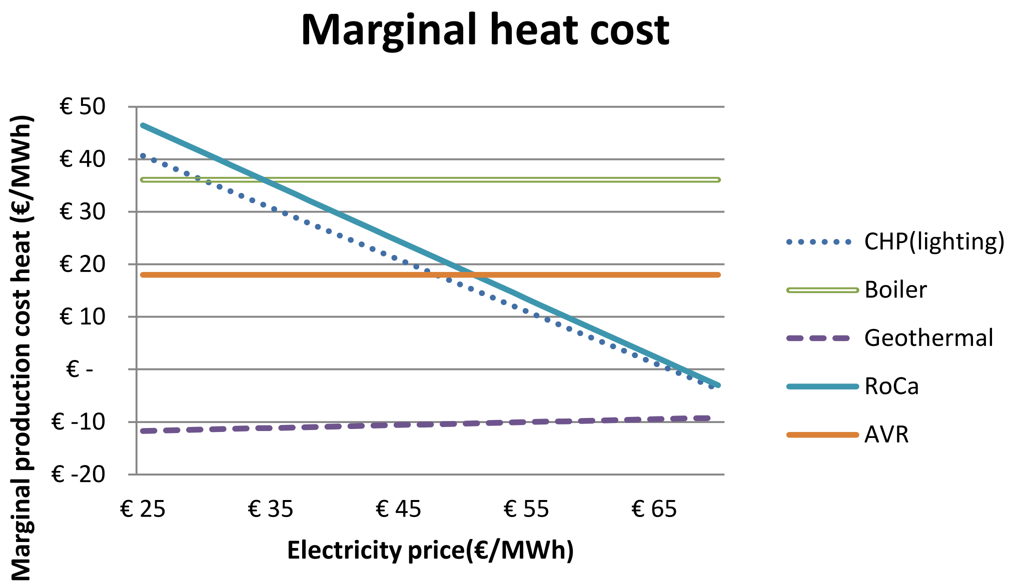

Figure 22: Marginal production cost with electricity prices(gas price=€27.06 per MWh)

The variable production costs also depend on the fuel costs, in this case only gas (with geothermal as an exception). In Figure 23 the marginal heat production costs with a changing gas price and a fixed electricity price are shown. The marginal heat cost of all the gas-fuelled production units, increases linearly with the gas price. The CHPs and the RoCa have a slope that is comparable; the geothermal plant and the boiler have a different slope.

The slope of the geothermal plant is 0, because there is no connection between the marginal heat production costs and the gas price. The slope of the boiler is less steep than from the other three gas-fired plants. These three plants use more gas for the production of the same unit of heat than a boiler. However, they also produce electricity together with that heat. Since the electricity price is fixed, the revenues from electricity production do not increase, but their gas costs increase proportionally harder than from the boiler. Therefore, the slope of the CHPs and the RoCa are steeper than is the case with a boiler.

In practice the gas price is fixed per day. Per day the gas price can differ quite a lot. In 2013 for example the lowest gas price was €24,71 per MWh and the highest price was €39,39 per MWh, almost a 60% difference. This means that the fuel costs will vary per day instead of per hour.

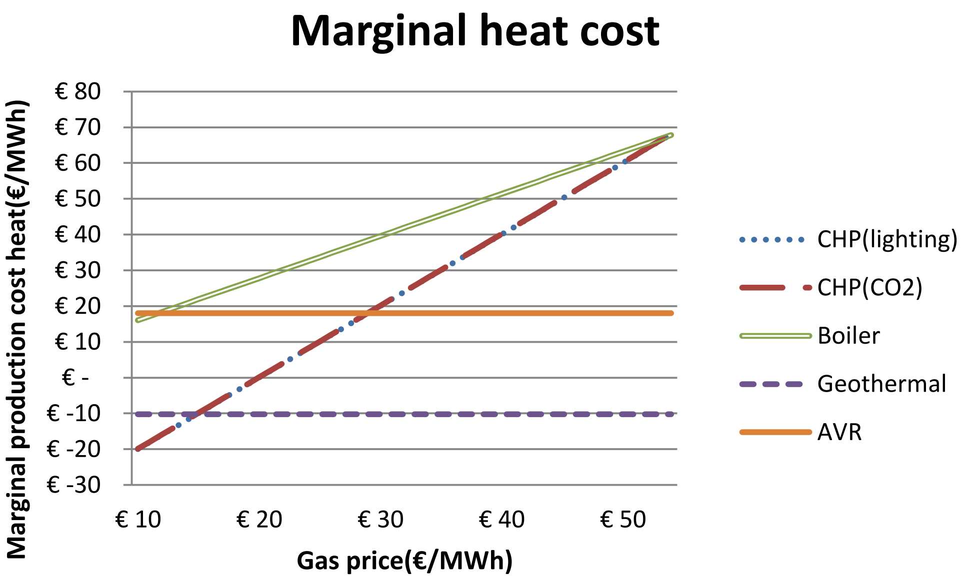

Figure 23: Marginal heat cost with changing gas price (Electricity price = €51.88 per MWh)

Transportation costs

Since the thermal grid is all about the transportation of heat, the cost of transportation is important. The transportation cost can be divided in two; fixed and variable costs.

- Fixed cost(per year):
  - Depreciation (+interest over loan)
  - Maintenance
  - losses
- Variable cost (per MWh)
  - Pump costs

$$Transportation\ cost = depreciation + maintenance\ cost + cost\ of\ losses + pumping\ cost \qquad (8.3)$$

There are three fixed cost; the depreciation, the maintenance cost and cost of heat losses. The depreciation cost of the thermal grid is left out of scope, since these costs are confidential and are too complex to estimate. At the moment the maintenance is done by the owner of the network; Eneco W&K. To estimate the maintenance cost of the network, Eneco W&K developed a tool. From this tool the estimated maintenance costs are €180.000 per year (Eneco H&C, 2013). The interest rate over the investment should be included in the transportation cost. Due to a lack of information this is not taken into account here.

The heat losses are not 'fixed', but they depend on the temperature difference(ΔT) between the heated water and the surrounding. Therefore, the losses are not related to the amount of MWh that is transported through the network. Generally, it can be said that the average yearly ground temperature around the pipe is 10 °C (Mattmüller, 2013). The losses calculated with this average yearly ground temperature, are labelled as fixed costs.

As mentioned in the technical analysis, at the moment the losses are around 28.000 MWh each year. With an estimated price of €28.8 MWh of heat this loss costs around 0.8 million euro each year.

The pumping costs are the variable transportation costs. These include operating a pump, which is needed for the transportation of water. The pumps have to keep the pressure in the whole network high enough, so that the heated water can be transported throughout the network. From multiple locations heat can be pumped into the grid, however from some locations this is done more easy, due to a low pressure difference between the feed and return pipelines. These locations can be found in the end of the network, where the pressure is the lowest.

It could be the case that a producer that is actually more expensive in production, can compensate this with lower pumping costs. The average pressure difference is estimated by Stephan Mes, system engineer of Eneco W&K, at 7 bar. The pumping costs for a pressure difference of 7 bar are €0,57 per MWh. With an estimated heat volume of more than 0.55 million MWh per year (Koornneef, Arcadis warmtevraag per teelt 2011, 2013), the pumping cost are at least €320.000. The total pumping cost are a very rough estimation, but it gives an indication of the cost. More details about the calculation can be found in Appendix E.

Pressure difference(bar)	Pumping cost (per MWh)
4(low value)	€0.33
7(average value)	€0.57
10	€0.81
13(maximum value)	€1.06

Table 5: Pumping cost (per MWh)

A lot of the transportation costs are fixed. All these fixed costs, should be shared among the participants or among the amount of transported MWh of heat. With a lower amount of transported heat, the costs for the remaining MWh has to increase, due to the fixed costs. This will reduce profitability and/or attractiveness of the grid. To make the grid profitable for everyone, the amount of participants and the amount of MWh should be high enough. The total estimated transportation costs are:

$$Transporation\ cost = depreciation + maintenance\ cost + cost\ of\ losses + pumping\ cost \quad (8.3)$$

$$Transporation\ costs = depreciation + 180.000 + 800.000 + 320.000$$
$$= depreciation + \ 1.300.000\ euros$$

To economically justify these costs they should be at least €2,34 per MWh (transportation cost /amount of MWh transported) The influence of these costs on the final heat price will be significant.

Cost of switching to prosumer

To switch from consumer to prosumer a WLS has to be built next to the WAS. This only works for greenhouse growers already connected to the grid. If this is not the case, additional investments are needed to connect the greenhouse grower to the grid. These investments differ for each individual case, because the length of the pipe needed to connect a greenhouse is the main factor and this is different for each greenhouse grower.

The investment cost for a greenhouse grower to build a WLS station are approximately €80.000 on average, depending on capacity (Mes, interview, 2013). This includes all costs, also the pump, to turn a consumer into a prosumer. If a depreciation term of 10 years is taken with 6% interest on investments, each year the fixed costs will be €10.870 per installed WLS.

9.1.2 ECONOMIC PATTERNS WITHIN THE SYSTEM

The demand and supply of heat follow a certain pattern. The demand and supply depends a lot on external factors, like weather and electricity prices. These patterns should be observed, recorded and analysed over a longer period of time before they can be considered statistically meaningful. From these patterns also the influence on the heat price are discussed.

Seasonal patterns

For the demand of heat three seasons are defined; winter, summer and flank months (spring and autumn). Due to demand differences, the dispatch of production units per season differ.

In Figure 24 the heat supply of E.ON is shown. From data collected from Eneco W&K the production units used by E.ON per period are indicated in Figure 24. In the summer and in part of spring and autumn the demand for heat is low, too low for the CCGT. During these periods heat is produced with boilers. In winter the heat demand is sometimes too high for the CCGT and additional heat is produced with boilers. During the winter season the CCGT plant produces the base load heat and the peaks are produced by boilers (Hooijman, 2013). In chapter 6.1.1 and Figure 15 this is explained.

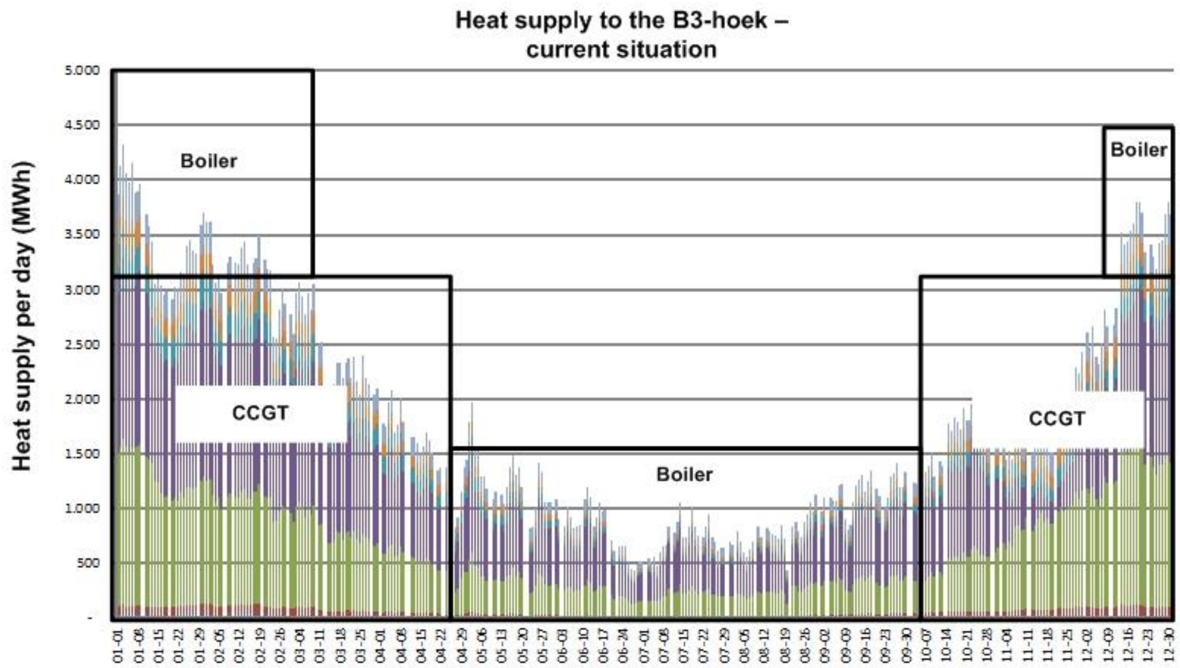

Figure 24: Heat supply to the B3-hoek in the current situation

When greenhouse growers are able to supply heat to the network, it is interesting to investigate at what moments they should supply heat. Most of the time CHPs can produce cheaper heat than boilers, this also includes the big boilers of E.ON. Looking at Figure 24, it can be seen that E.ON often produces heat with boilers. This heat can potentially be produced cheaper by greenhouse growers. This is shown in Figure 25.

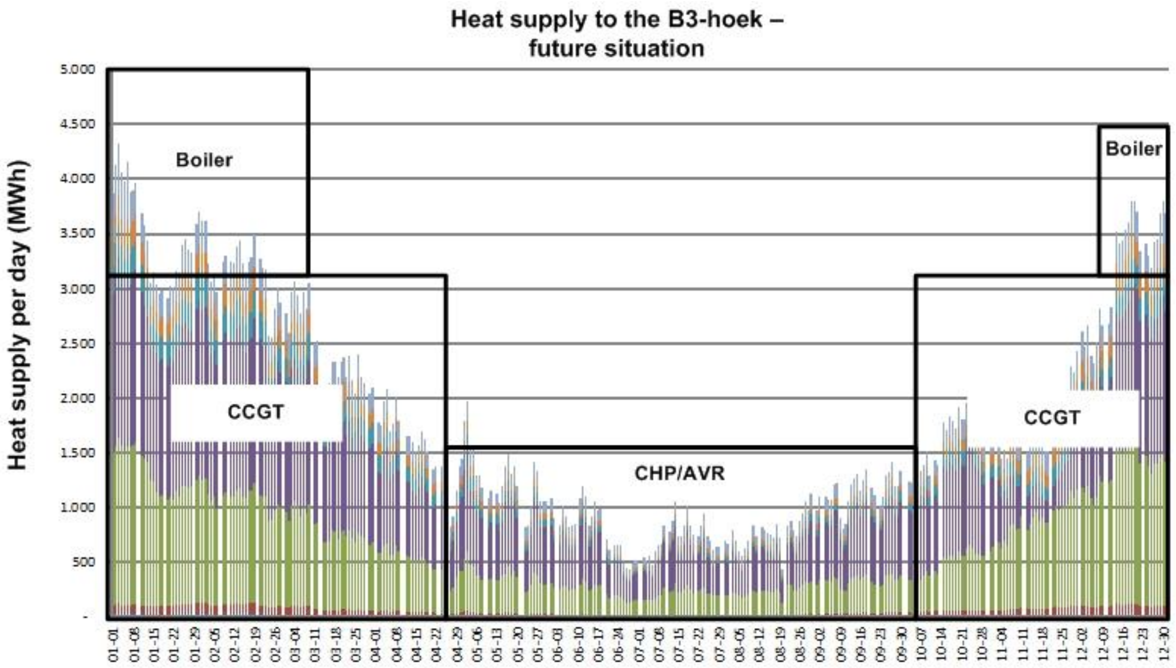

Figure 25: Heat supply to the B3-hoek in the future situation

The price of boiler heat from E.ON is higher than the heat greenhouse growers can produce with their own boilers, so they will not buy it from E.ON. Therefore both during the peak demand in the winter and the low demand in the summer, the boilers from E.ON will not produce any heat for the B3-hoek thermal grid.

In winter the boiler production from E.ON is not taken over by CHPs. This can be explained by the size of the CHP. The CHPs are designed to cover part of the heat demand of the greenhouse. The CHPs are not designed to cover the peak load of the greenhouse, because this will only happen a few weeks per year. During these winter days the CHP will only produce for their own demand. Therefore the winter time heat supply from CHPs to the thermal grid will practically be zero and the heat has to be supplied by alternative production facilities.

In summer, as shown in Figure 25, the greenhouse growers' CHPs are able to supply heat. In summer the demand for heat is low, and so the CHPs have an overcapacity. This overcapacity can be sold to other greenhouse growers. Also the AVR is able to supply heat during the summer, when the city of Rotterdam has little heat demand. However, in the winter the AVR will not supply heat, since the heat demand in the city is too high.

Daily patterns

Several patterns can be discerned that are important in relation to the day to day operations of the system. The first pattern is the daily heat demand pattern; this pattern shows the demand of heat on an hour to hour basis. Since this pattern is very dependent on the weather, the demand pattern covering the three seasons is discussed. Following that, the patterns of the important cost factors for heat are discussed. Since in this system mainly CHPs are used, these factors are the most important. The cost of heat depends on the electricity price, and on the related spark spread. Both patterns are discussed below. The daily gas price is not discussed, because this price is determined once a day, so there is no daily gas pattern.

Heat demand

A daily heat demand pattern of a typical greenhouse grower in the B3-hoek is shown in Figure 26. This figure is based on actual data from Eneco W&K. This is the demand of heat the greenhouse growers extract from the thermal grid. The demand of heat is also the supply of heat in the network in the B3-hoek, because in this thermal grid demand and supply always match. E.ON always supplies what the greenhouse growers demand.

The demand pattern of individual greenhouse growers could be different than shown, because the figure shows the total demand. In Figure 26 the demand of heat on three different days is shown. These days are selected in three different seasons to show the difference in demand between the seasons. These days are representative for each of the seasons. Autumn is not shown, because this season is comparable to spring as far as temperature is concerned. Some observations can be made if we look at Figure 26. The overall demand in winter is high and declines towards summer. This is an observation also made on the basis of Figure 12. This can be explained by the differences in weather. Towards summer the outside temperature is rising, so less heating is needed.

There is also a difference visible in demand/supply depending on the time of day. At night heat demand rises due to the absence of sunlight and falling outside temperatures. During the day the demand decreases, and depending on the season, the demand can almost disappear.

The demand pattern of individual greenhouse growers can differ significantly from these patterns. This can be explained by differences in crops and plants, differences in energy management and the availability of a boiler or CHP.

As shown in chapter 3, the demand pattern can be changed with the use of buffers. Buffers are used to store heat for a short amount of time, for example to store heat during the day. And the heat can also be stored for the next day. However, with these buffers the heat cannot be stored across different seasons. There is technology available with which it is possible to store heat for longer periods of time. However, these will not be discussed in this research, because these techniques are still in a research phase and therefore not likely to be commercially available the coming decade (Vermeulen & van Wijmeren, 2013).

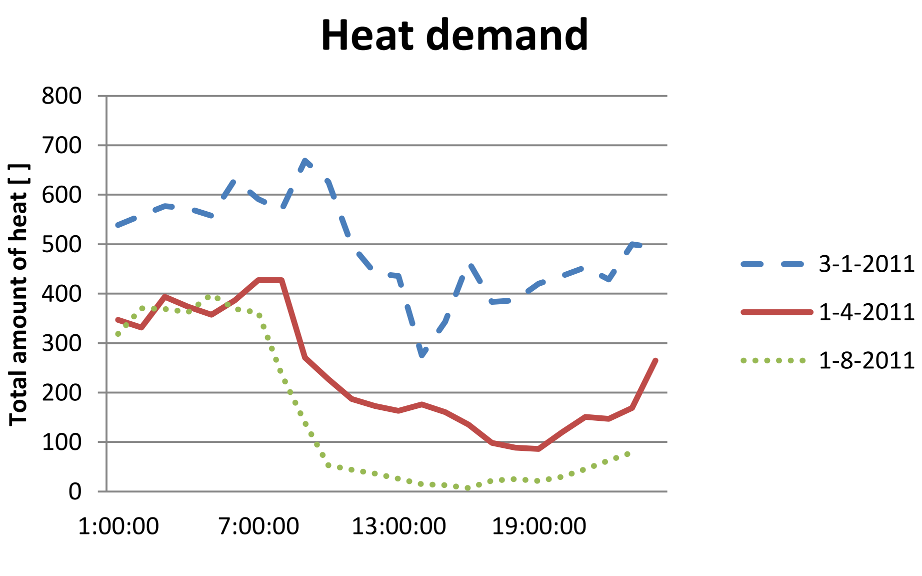

Figure 26 Heat supply in three different seasons (Koornneef, Arcadis warmtevraag per teelt 2011, 2013)

Electricity market

The heat price and electricity price are connected, due to the use of CHPs. It is therefore interesting to look at the APX prices and the average pattern of the APX. In Appendix C, the favourable moments of production are discussed. In short, for a CHP the favourable moments of production are when the electricity price is high.

In Figure 27 the development of the electricity price in the Netherlands per hour per season is shown. This average is taken to show the general daily trend per season. It has to be said that the electricity market can be volatile and the daily patterns can be quite different. However, Figure 27 shows the average prices hour, per season. From Figure 27 can be concluded that in 2013, it was more favourable to produce electricity during the spring, than during the other two seasons. The same goes for the time of production; two peaks can be distinguished in winter and spring, one during the day and one during the evening. In the summer the peak during the evenings is smaller. If we look at favourable times for an CHP to produce, this will be when the electricity price is high, so during the peaks of the day.

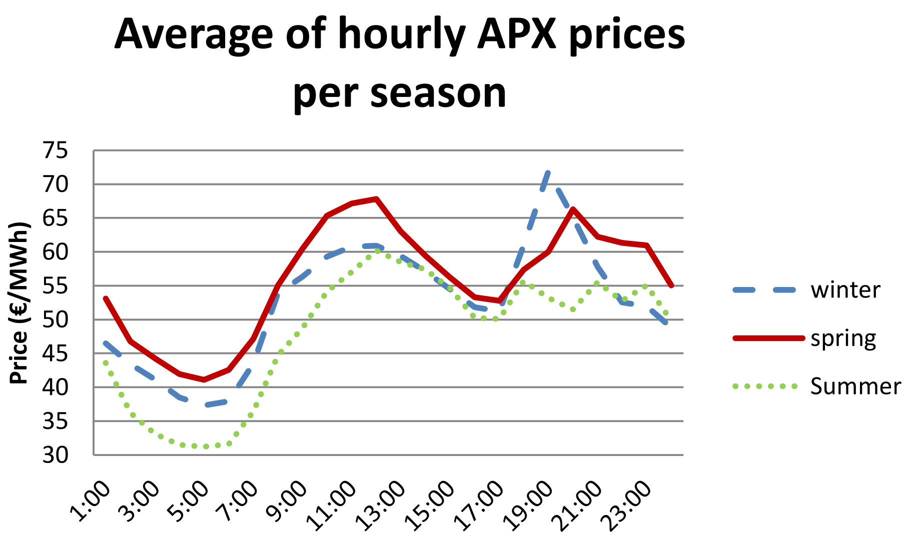

Figure 27:Price of electricity on average each hour, per season (Koornneef, 2013 APX data, 2013)

9.2 CONCLUSION ECONOMIC ANALYSIS

In this chapter the different aspects of the economic domain are discussed. The main aspects of the economic domain are the costs and the economic patterns of the system. There is a correlation between both, because the variable costs often change with the electricity price, heat demand and the heat production.

Currently, one of the most important factors in relation to the production costs of heat is the electricity price. Most of the cheap heat production is done by CHPs and the RoCa. And at unfavourable production moments for both CHP and the RoCa the production is done by boilers. At the moment the electricity price is volatile, consequently, the variable production costs are also volatile. This can be seen in Figure 22. The production cost and electricity revenues of the CHPs and the RoCa decrease linearly with an increasing electricity price.

Another very important factor in the production cost of heat is the gas price. Almost all the heat is produced with gas as fuel. So a change in gas price, directly changes the production costs of heat. However, the gas price is not as volatile as the electricity price. The gas price is only determined once a day, and fluctuates during the year. So the daily impact of the gas price is minimal. Over a longer period of time, however, changes in gas prices can have a big impact on the cost of heat.

The costs related to the transportation should not be left out of the cost calculation. The estimated yearly cost is 1.3 million euros, or at least €2,34 per MWh. These costs are significant and should be incorporated in the heat price, or a yearly fee.

PART IV: PRELIMINARY DESIGN

10 ECONOMIC DISPATCH & PRICING

The focus of the chapter will be on the formulation of a preliminary design. This is split in dispatching the different production units and the price of heat production. Since the dispatch is almost disconnected from the pricing in the heat trading platform design. Only for a price estimation is needed in the dispatch, to be able to include the external parties. The economic dispatch investigates the division of the heat production among different production units. The definition of economic dispatch :

"The operation of generation facilities to produce energy at the lowest cost to reliably serve consumers, recognizing any operational limits of generation and transmission facilities." (USA, 2005)

The dispatching of heat production occurs on the bases of production costs, but the margin on the heat is important as well (margin is difference between cost and revenue). However, it is still unknown how the heat will be priced, so the margin cannot be determined. Therefore, also the pricing of the heat is discussed in this chapter. These two topics are intertwined, due to the connection between production and prices. First the production will be determined, than the pricing of heat will be done. First the dispatch of different production units will be analysed in section 10.1. Then different manners of creating a market and pricing will be discussed in section 10.2.

10.1 DECISION PROBLEM – ECONOMIC DISPATCH

The three following components in economic dispatch are discussed;

1) Long-term objectives: The long-term objectives take into account investments decisions, market predictions and objectives for the thermal grid set by the participants. This way the dispatch is not only based on short term variables, but also on long term variables. The long-term objectives give constraints to day-ahead dispatch.
2) Tay-ahead dispatch: Planning the dispatch for tomorrow is done based on load forecast for the next day. The load forecast is dependent on the weather, the gas and power prices. The quality of these forecasts determines how accurate the predictions are and how good supply and demand match the next day. In this dispatch restrictions given by the long-term dispatch are taken into account.
3) Intraday dispatch: Often additional dispatching is needed to match supply and demand during the day. The dispatch of production facilities during the day is done to keep the whole grid in balance.

Both long-term and intraday dispatch are discussed, but mainly in connection to day-ahead dispatch. Day-ahead dispatch is discussed in more detail, since the focus of this research is on day-ahead dispatch. This is done since the heat trading platform will primarily operate on a day-ahead bases.

10.2 VARIANTS OF ECONOMIC DISPATCH

In this thesis the focus is on the welfare of all participants. Therefore the objective of the dispatch is focused on the economic gain of as much participants of the thermal grid as possible. Other objectives are possible; for example the profit maximization of Eneco W&K in the smart thermal grid or maximizing the profit of the heat consuming greenhouse growers. However, these objectives are left out of scope since this thesis is looking into a solution that best fits the interest of all actors, the creation of a win-win situation.

10.2.1 SOCIAL WELFARE MAXIMIZATION

In section 3.4.3 in the microeconomics, there are two ways described of efficient market outcomes: the Pareto efficiency and the Kaldor-Hicks efficiency. Both efficiencies try to optimize the whole market. However, the difference is that in the Pareto efficiency the market is efficient as no single actor can be better off, without making someone worse (Pareto, 1971). While in the Kaldor-Hicks efficiency the wealth of the market is maximized. This means that single actors can be worse off, as long as the total gains exceeds the losses (Posner, 1980). Since the market is relatively small in the smart thermal grid example, losses of individual actors could be compensated. This guarantees maximum wealth for the whole system. This compensation should be based on the reference point, the situation without an actor participating in the smart thermal grid.

The social welfare refers to the well-being of or benefit for all participants, both consumers and producers (Liu & Shen, 2008). In order to get the highest possible well-being or benefits for all participants, the social welfare has to be maximized. The benefits are measured as the revenues minus the costs, also called the surplus.

In the paper of (Liu & Shen, 2008) the social welfare is expressed as follows:

$$Social\ Welfare = Generators'surplus + Wholesalers'surplus + Customers'surplus \quad (9.1)$$

In this expression the wholesaler is also included. The wholesaler is included explicitly for the network management. This way the cost for transport and maintenance of the network are also included. Turning the expression into a formula, the formula becomes (Liu & Shen, 2008):

$$SW(P_G, P_D) = \sum_{j=1}^{m} U_j\left(P_{Dj}\right) - \sum_{i=1}^{n}\left(C_i(H_{Gi}) + C_{Ti}\right) + C_{Tfixed} \quad (9.2)$$

Where $U_j\left(P_{Dj}\right)$ is the utility in [€/h] of consumer 'j' in terms of heat consumed, P_{Dj}, in [MWh/hour]; $C_i(H_{Gi})$ are the generating costs in [€/h] of unit 'i' in terms of heat produced, H_{Gi}, in [MWh/hour]; C_{Ti} is the cost of transportation, P_{Gi}, in [€/h]; C_{Tfixed} are the fixed costs for the transportation in [€], here primarily the maintenance of the network and the heat losses. The social welfare also accounts for the investments costs, these are incorporated in the generating costs (Sauma & Oren, 2005).

So in order to maximize the total benefits for all participants in the system, the social welfare should be maximized (Liu & Shen, 2008). When maximizing the social welfare, the constants, as for example the fixed transportation cost, do not influence the final result of dispatching different production units. Therefore these constants can be left out.

In the interviews held, the rigidity of heat demand is put forward (van den Ende, 2013) (Goudswaard, Interview in name of AgroEnergy, 2013) (Valkenburg, Interview, 2013). This rigidity can be explained by the fact that greenhouses need to be heated and greenhouse growers will not make concessions on that. Their heat demand is therefore presumed to be inelastic, consequently the heat demand is fixed (up to the point where self-production is cheaper). In optimizing the social welfare the greenhouse growers the utility, with the heat demand as input variable, therefore becomes constant. Since the utility of the greenhouse growers is constant, the maximization of the social welfare is equal to the total cost minimization (Sauma & Oren, 2005).

10.2.2 COST MINIMIZATION

To ensure the most economic gain, the cost of production should be as low as possible. Therefore the first objective is total heat cost minimization. This objective aims to reduce the total cost of heat within the system to a minimum (while meeting the constraints of power and heat demand). Due to this objective, the cheapest production units will have an advantage in the amount of heat production. How cheap a production unit is, is determined by the operating costs (Frangopoulos & Dimopoulos, 2004). Operating costs are expenses associated with administering a business on a day to day basis. This includes both fixed and variable costs.

According to normative principles decision makers should let their choices solely be affected by the prospective of future consequences of different options (Tan & Yates, 1995). The costs already made, as for example investments and fixed costs, are done in the past and cannot be recovered. These costs are called sunk costs. So the decision to sell heat should be made purely on the additional costs of producing one additional MWh of heat. These costs are also called the marginal production costs.

For the social welfare of the smart thermal grid, it would be better to take the operating costs. Since including the investment costs in the heat costs gives the actual costs of the heat. However, in practice the investment costs will be ignored in the decision to sell heat, due to omitting the sunk costs.

Besides the costs for heat production, the transportation costs are included in the heat price as well. A part of these costs are fixed and cannot be optimized. However, the variable transportation costs, the pumping costs, depend on the location of the supplier (described in chapter 9.1.1). The pumping costs range between €0,33 and €1,06 per MWh of heat (section 9.1.1: Table 5). Therefore the heat cost per MWh can differ per location.

10.3 LONG TERM OBJECTIVES

The dispatch of production is done a day-ahead and as proposed in the next section, will be done by minimizing the marginal production costs. However, minimizing day-ahead marginal production costs, does not necessarily mean minimizing the costs of the production on the long term. A long term objective in this case could be, ensuring that future heat production capacity is sufficient. This means that incentives will have to be created to invest in heat production capacity, for example giving guarantees for a minimum amount of heat supply.

The day-ahead dispatch has to take into account long term objectives, therefore the long term objectives should be incorporated in the day-ahead dispatch. The long term objectives should be formulated as constrains for the day-ahead dispatch. These long term objectives should be determined by the participating parties. Some examples could be:

1. <u>Availability of cheap heat production capacity:</u> As already mentioned above, the closing of the RoCa could reduce the capacity of cheap heat significantly. Anticipating on the closing, by improving the business cases for other production facilities should be done to ensure availability of cheap heat.
2. <u>Stability of the heat price on the long-term:</u> This means that the heat price, and therefore the heat production costs are less dependent from future development in for example the gas and electricity price. This objective was also indicated as important in the interviews (van der Spek, 2013). Facilities that give this system stability, could be given a premium or guaranteed amount of heat supply. This could improve the business case for the development of such production facilities, for example a geothermal plant (assumed geothermal plants can supply heat to the network).
3. <u>Sustainability:</u> This could be a long term objective, that supports the development of sustainable heat production. As indicated in the interviews, sustainability is becoming increasingly important (Bunnik, 2013).

An additional advantage of the long-term objectives is the possibility to close long-term deals. Since 30% of the total costs of a greenhouse grower is energy, some greenhouse growers like to fix the price of their energy (van den Ende, 2013). In these long term objectives a market can be created for long-term heat trade. This way producers can fix their supply, while consumers can fix their demand.

10.4 DAY-AHEAD DISPATCH

For the day-ahead dispatch the heat demand is estimated. This estimation is done by the greenhouse grower himself, or by advanced IT-systems. The combined estimated demand of all the greenhouse growers will be used to dispatch the different production units for the next day. The demand will be matched with the supply of heat, and afterwards a heat price is determined.

In Appendix G a model for the settlement of the demand and supply of heat is given. For the settlement of heat, the settlement of electricity is also needed. This is due to the co-generation units in the system that both produce electricity and heat. The model in Appendix G explains that in order to fix the supply of heat, first the electricity production has to be settled on the APX market. More details are discussed in Appendix G.

The system consist of co-generation units (CHPs and the RoCa) and of heat generation units (boilers and geothermal plants). The goal of the dispatch is to match demand and supply of heat in the most optimal way. To create as much understanding of the system as possible, first a very simplified cost minimization is discussed. Sequentially, the complexity is increased, ending with a description of the optimization problem which will be used in the preliminary design of the heat trading platform.

The underlying limits and characteristics of production are not discussed in this chapter. The general limits and characteristics of production are discussed in Appendix H. However, in beginning of the coming section the general cost function for gas-fueld production units is discussed. Only gas-fueld production units are incoorperated since other forms of fuel are not used much in the B3-hoek. However, in the future, if these other fueled production units are introduced, the should be included. The following decision problems are discussed:

1) General production cost function for gas-fueled production units
2) Optimization of individual greenhouse grower with CHP
3) Optimization of a network of greenhouse growers (CHP and boiler)
4) Optimization of the network, including external parties
5) Optimization of the network, including external parties and buffers with unlimited capacity
6) Cost minimization of a network, including external parties and actual buffers
7) Two step optimization
8) Optimization for the preliminary design

10.4.1 GENERAL MARGINAL PRODUCTION COST FUNCTION FOR GAS-FUELED PRODUCTION UNITS

The production cost of heat for one production unit is described in section 9.1.1. The costs can be divided in the following categories; fixed costs, variable costs and earnings. As mentioned above, for the objective of cost minimization this will be based on the marginal production costs. Therefore formula 9.2 from section 9.1.1 will be used. However, instead of the marginal cost of heat per MWh, the marginal cost of heat will be taken per hour. The marginal heat production costs per production unit of greenhouse grower 'j' on time 'i' are:

$$C\left(H_{Gij}, P_{Gij}, CO_{Gij}\right) \; = Variable\ cost - earnings \tag{9.3}$$

$$Variable\ cost = Generation\ cost + heat\ transport\ cost$$

$$Earnings = CO2\ earnings + electricity\ earnings + subsidies$$

Generation cost: The generation cost are dependent on the amount of fuel used. The amount of fuel (gas) used is dependent on the heat and electricity generation. In section 6.1.1 Figure 14 the envelope of the feasible region of a co-generation plant is shown, it can be seen that both heat and electricity generation influence the fuel usage. The envelope of the feasible region differs per production unit, and therefore the fuel usage per production unit is different. CHPs from a greenhouse growers have a fixed ratio between the electricity and heat generated and often only production at maximum capacity (in order to reduce maintenance cost).

There are also many greenhouse growers with a boiler which should be taken into account in the optimization. This is done in the general function by $P_{Gij}, = 0$. Unlike CHP's, can boilers can very switch between different amounts of heat and CO_2 production. However, the ratio between heat and CO_2 in a boiler is fixed. The production is therefore determined by the energy source with, relatively, the highest demand(for both CHP and boiler). If a geothermal plant is connected to the grid, both power and CO_2 production will be 0. And for fuel, electricity is taken instead of gas.

The amount of fuel used per production unit can be written as:

$$f_{ij}(H_{Gij}, P_{Gij}, CO_{Gij})$$

Where:

$f_{ij}(H_{Gij}, P_{Gij}, CO_{Gij})$ is the amount of fuel (gas or electricity) used for production on time 'i' of greenhouse grower 'j' in $[m^3 \text{ } or \text{ } MWh]$

With decision variables:

H_{Gij} is the heat generated by greenhouse grower 'j' at time 'i' in [MWh]

P_{Gij} is the electricity generated by greenhouse grower 'j' at time 'i' in [MWh]

CO_{Gij} is the CO_2 produced by greenhouse grower 'j' at time 'i' in [kg]

The generation cost per hour is the amount of fuel used multiplied with the fuel price:

$$C_{gij} = f_{ij}(H_{Gij}, P_{Gij}, CO_{Gij}) \ * F_{price}$$

Where:

C_{gij} is the generation cost on time 'i' by greenhouse grower 'j' in [€]

With input variables:

F_{price} is the fuel price in (for boilers this includes taxes) $[€/m^3]$

Heat transportation cost: The cost of heat transportation is a cost that occurs if heat is transported. A greenhouse grower will buy heat from the network if he produces less than his own demand. And over the heat bought, he will pay transportation cost. Taxes are included in the transportation cost, since energy tax has to be paid if heat is bought from the network. The heat transportation cost can therefore be written as:

$$C_{Tij}(H_{Gij}) = \begin{cases} (H_{Dij} - H_{Gij}) * T_{cost}, & H_{Gij} \leq H_{Dij} \\ 0, & otherwise \end{cases}$$

Where:

C_{Ti} is the transportation cost of heat on time 'i' in [€]

With input variables:

H_{Di} is the heat demanded by a greenhouse grower time 'i' in [MWh]

T_{cost} is the transport cost of heat in (including energy taxes) [€/MWh]

CO_2 earnings: The production units produce next to heat and electricity also CO_2. The amount of CO_2 produced is 1,78 kg/m^3 of gas (Moran & Shaprio, 2006). The amount of generated CO_2 can be written as:

$$CO2_{Gij} = f_{ij}(H_{Gij}, P_{Gij}, CO_{Gij}) * 1.78$$

Where:

$CO2_{Gij}$ is the CO_2 generated by greenhouse grower 'j' at time 'i' in [kg]

If a greenhouse grower generates his own CO_2 he has avoided cost (section 9.1.1) , which can be written as:

$$AC_{CO2ij}(H_{Gij}, P_{Gij}, CO_{Gij}) = \begin{cases} CO2_{price} * f_{ij}(H_{Gij}, P_{Gij}, CO_{Gij}) * 1.78, & CO2_{Gij} < CO2_{Dij} \\ CO2_{price} * CO2_{Dij}, & CO2_{Gij} \geq CO2_{Dij} \end{cases}$$

Where:

AC_{CO2ij} are the avoided cost of own CO_2 production at time 'i' in [€]

With input variables:

$CO2_{Dij}$ is the CO_2 demand by greenhouse grower 'j' at time 'i' in [kg]

$CO2_{price}$ is the price of CO_2 if bought (these cost are fixed) [€/kg]

Electricity earnings: Since electricity can be used as well as be sold to the grid, the earnings of electricity are split in two. The first earnings are the avoided cost of using own produced electricity(section 9.1.1). The avoided cost of electricity can be written as:

$$AC_{Pij}(P_{Gij}) = \begin{cases} P_{(price-buy)} * P_{Gij}, & P_{Gi} < P_{Di} \\ P_{(price-buy)} * P_{Dij}, & P_{Gi} \geq P_{Di} \end{cases}$$

Where:

$\mathrm{AC_{Pij}}$ are the avoided cost of own electricity production at time 'i' in [€]

With input variables:

$\mathrm{P_{(price-buy)}}$ is the price of electricity if bought [€/MWh]

$\mathrm{P_{Dij}}$ is the power demanded by greenhouse grower 'j' at time 'i' in [MWh/h]

There are also direct earnings from selling electricity. The price of selling electricity is different from the price at which a greenhouse grower can buy electricity. Moreover the selling price is variable and is different every hour. The electricity earnings can be written as:

$$E_{Pij}(P_{Gij}) = \begin{cases} 0, & P_{Gij} < P_{Dij} \\ P_{(price-sell)i} * (P_{Gij} - P_{Dij}), & P_{Gij} \geq P_{Dij} \end{cases}$$

Where:

E_{Pij} are the earnings from selling electricity on time 'i' in [€]

With input variables:

$P_{(price-sell)i}$ is the price of selling electricity at time 'i' in [€/MWh]

Total heat production cost function of greenhouse grower 'j' at time 'i':

$$C(H_{Gij}, P_{Gij}, CO_{Gij}) = f_{ij}(H_{Gij}, P_{Gij}, CO_{Gij}) * F_{price} + C_{Tij}(H_{Gij}) - AC_{CO2ij}(H_{Gij}, P_{Gij}) - AC_{Pij}(P_{Gij}) - E_{Pij}(P_{Gij})$$

10.4.2 OPTIMIZATION OF INDIVIDUAL GREENHOUSE GROWER WITH CHP

The objective here is to minimize the total cost of heat. However, with co-generating units the costs have to be split between the electricity, CO_2 and heat production. So in the total cost of heat the production costs of both electricity and CO_2 should be included, as can be read in the last section. Therefore the minimization will be done over the total cost of energy, instead of the total cost of heat.

Since the bid on the electricity market are collected on a day ahead basis, the optimization function will have to calculate the production cost one day-ahead. This is done, so greenhouse growers can sell their produced electricity on the electricity market. A bid on the electricity market consist of 24 blocks of one hour. For each block the electricity price and capacity has to be given. Each block is indicated with i. For heat production the same blocks of one hour are taken. For production units that do not produce electricity for the electricity market, it is also an option to dispatch them on another time window, for example 15 minutes. However, in this thesis only block of 1 hour are used. Other time windows has to be investigated in future research.

For the total production cost per day for a CHP the following assumptions are made:

Heat: The greenhouse grower makes an estimation of his heat demand (H_D) in MWh for the next day. The heat demand is not flexible, however due to the use of buffers, the heat supply is flexible. So the heat can be produced at the most favourable moments. The optimization will find the most favourable moments to generate heat, divided in 24 blocks per day. The assumption hereby made is that the buffers have unlimited capacity. However, by the end of the day the buffer is on the same level as at the beginning of the day. The combined generated heat in all blocks has to match the total demand of heat each day, so $\sum_{i=1}^{24} H_{Gi} = H_D$.

CO_2: An individual greenhouse grower estimates CO_2 demand($CO2_{Di}$) in kg for the next day per block. The CO_2 demand has to be fulfilled without delay, because CO_2 cannot be stored. Additional production of CO_2 is no problem and can be discharged. If the greenhouse grower is connected to the CO_2 grid he is able to buy CO_2 as well.

Electricity: The greenhouse grower estimates his own electricity demand (P_{Di}) in MWh for the next day per block. The electricity also demand has to be fulfilled instantly, because the assumption is made that electricity cannot be stored. Additional production of electricity is sold on the electricity market. A shortage of electricity is bought on the electricity market.

Trade: Only electricity can be sold and electricity and sometimes CO_2(depending on the connection to the CO_2 grid) can be bought. So everything is produced by the greenhouse grower.

Expanding formula 9.3, the minimization of the marginal production cost of heat per day for an individual greenhouse grower can be given as:

$$min \sum_{i=1}^{24} (\, C(H_{Gi}, P_{Gi}, CO_{Gi})) \tag{9.4}$$

With:

$$\sum_{i=1}^{24} H_{Gi} \geq H_D$$

$$CO_{Gi} \geq CO_{Di}$$

Where:

P_g is the electricity generated per day [MWh/day].

H_g is the heat generated per day [MWh/day].

10.4.3 OPTIMIZATION OF A NETWORK OF GREENHOUSE GROWERS (CHP AND BOILER)

In this part the energy cost minimization of a group of greenhouse growers connected by a thermal grid, will be discussed. For the total minimization of the total marginal production cost of heat per day of all participants the following assumptions are made:

Network: External parties with demand or supply for heat are also left out of scope, but within the network of greenhouse growers heat can be traded. External parties for the supply of CO_2, or the supply and demand for electricity are in scope. The transportation costs are included here.

Heat: The demand of heat per hour is equal to the supply of heat per hour, so H_{Di}=H_{Gi}. Buffers are left out of scope, so heat cannot be stored. For every individual greenhouse grower, 'j', an estimation of heat demand per hour is made (H_{Dij}). The total demand for heat per hour is $H_{Di} = \sum_{j=1}^{n} H_{Dij}$. The total supply per hour is equal to the supply per hour of all individual greenhouse growers $H_{Gi} = \sum_{j=1}^{n} H_{Gij}$.

CO_2: CO_2 cannot be sold among greenhouse growers, so it has to be produced by themselves or bought from the OCAP.

Electricity: Electricity will not be sold directly among the greenhouse growers, but the electricity will be sold to the Dutch electricity market.

Production cost: The marginal production cost of heat from greenhouse growers with a CHP are the same as described in problem variant 1, so including variable costs and earnings.

The total heat production cost minimization for 'n' greenhouse growers can be given as:

$$min \sum_{i=1}^{24} \sum_{j=1}^{n} (C(H_{Gij}, P_{Gij}, CO_{Gij})) \tag{9.5}$$

With :

$$H_{Gi} = \sum_{j=1}^{n} H_{Gij} \ \ for\ all\ 1 \leq i \leq 24$$

$$H_{Di} = \sum_{j=1}^{n} H_{Dij} \ \ for\ all\ 1 \leq i \leq 24$$

$$H_{Gi} = H_{Di} \ \ for\ all\ 1 \leq i \leq 24$$

So the total energy costs are minimized per hour. The heat can only be bought from other greenhouse growers. From these calculations it follows that the production of heat is equal to the demand of heat.

10.4.4 OPTIMIZATION OF THE NETWORK, INCLUDING EXTERNAL PARTIES

In the network described above only participating greenhouse growers can exchange heat. All participating greenhouse growers need to give information on their demand for CO_2, electricity and heat and about their production cost. With this information the optimization function will calculate an optimum. The decision to buy or sell energy is therefore not in the hands of the greenhouse growers, but is done by the optimization function.

In practice however, there will be greenhouse growers who like to manage their own energy household. These greenhouse growers just want to sell and buy heat at a certain time for a certain price. And they do not want to participate in the optimization. It should therefore be possible for external parties to participate in the heat trade. Besides greenhouse growers, also E.ON will be one of those external parties, who just want to sell heat on the network (van der Marel & Huizeling, 2013) (van der Spek, 2013).

The assumptions are the same as described in problem variant 2, with the only addition of the demand and supply of heat from external parties. The demand, respectively the supply, of heat will therefore be expanded with the demand and supply from external parties 'k'. The prices that the external parties provide, will be taken into account in the optimization. For selling heat, the parties have to provide their minimum price they want to sell heat for, ideally these are the marginal production costs, so they can compete with the participants of the system. If an external party wants to buy heat, he has to indicate his maximum price per MWh, $H_{price-buy(ik)}$. If the maximum price is lower than the estimated heat price, $H_{price-estimated}$, the heat demand of the external party will be 0. Since the external party is not willing to pay more for a MWh of heat. The heat price is estimated based on all the data that is available for the optimization.

The minimization of the total marginal production cost of heat per day, including external parties, for all participants can be given as:

$$min \sum_{i=1}^{24} \left(\sum_{k=1}^{m} \left(H_{Gik} * H_{price-sell(ik)} \right) + \sum_{j=1}^{n} C\left(H_{Gij}, P_{Gij}, CO_{Gij} \right) \right) \tag{9.6}$$

With :

$$H_{Gi} = \sum_{j=1}^{n} H_{Gij} + \sum_{k=1}^{m} H_{Gik} \ \ for\ all\ 1 \leq i \leq 24$$

$$H_{Di} = \sum_{j=1}^{n} H_{Dij} + \sum_{k=1}^{m} H_{Dik} \ \ for\ all\ 1 \leq i \leq 24$$

$$H_{Gi} = H_{Di}\ for\ all\ 1 \leq i \leq 24$$

$$H_{Gik} \leq H_{Gik_{indicated}}\ for\ all\ 1 \leq i \leq 24$$

$$H_{Dik} = \begin{cases} H_{Dik}, & H_{price-buy(ik)} < H_{price-estimated(i)} \\ 0, & otherwise \end{cases}$$

With decision variables:

H_{Gik} is the heat generated by external party 'k' at time 'i' in [MWh/h].

With input variables:

$H_{Gik\_indicated}$ is the maximum amount of heat that external party 'k' wants to produce at time 'i' in [MWh]

$H_{price-sell(ik)}$ is the minimum price an external party 'k' wants for the heat at time 'i' in [€/MWh]

$H_{price-buy(ik)}$ is the maximum price an external party 'k' wants for the buy at time 'i' in [€/MWh]

$H_{price-estimated(i)}$ is the estimated heat price before the optimization starts at time 'i' in [€/MWh]

H_{Dik} is the heat demanded by external party 'k' at time 'i' in [MWh/h].

10.4.5 OPTIMIZATION OF THE NETWORK, INCLUDING EXTERNAL PARTIES AND BUFFERS WITH UNLIMITED CAPACITY

Including buffers in the minimization has a big impact on the outcome. The heat production will become more flexible, and thus cheaper. The assumptions described in problem variant 3 are still used. The only change is the implementation of the buffers.

Due to the implementation of the buffers the supply and demand per hour, as in the previous objectives($H_{Gi} = H_{Di}$), do not have to be matched. Now the total supply and demand per day has to match $H_G = H_D$. This means that during the day the buffers can be filled if there is more supply, and be emptied if there is more demand. All the buffers from individual greenhouse growers are presumed to be one big buffer that has unlimited capacity.

10.4.6 COST MINIMIZATION OF A NETWORK, INCLUDING EXTERNAL PARTIES AND ACTUAL BUFFERS

In the previous example the buffers capacity is taken as unlimited and all the buffers are presumed to be one. However, in practice the buffers do have a capacity and cannot be taken as one. Greenhouse growers have different sizes of buffers, all using the buffers for their own gain. Since they all use the buffer for their own, the buffer becomes a new option, next to generating and buying. So to fill his heat demand the greenhouse growers has to following options: Generation, buy on the market, extract from buffer. With generation and buying on the market, the greenhouse grower takes into account the buffer usage. So he can buy more or less on the market than his demand, depending on the usage of his buffer.

The buffer usage can be both positive, filling up the buffer, and negative, extracting heat from the buffer. The heat losses in the buffer are not included in these limitations.

The introduction of the buffer come with additional limitations for the objective:

$$H_G = H_D + (BS_{i=24} - BS_{i=0})$$

$$0 \leq BS_{ij} + Bu_{ij} \leq BC_j$$

$$BS_{ij} = BS_{(i-1)j} + Bu_{(i-1)j}$$

$$H_{Di} \leq H_{Gi} + Bu_i$$

With decision variable:

BU_{ij} is the buffer usage from greenhouse grower 'j' at time 'i' in [MWh]

With input variables:

BS_{ij} is the buffer state from greenhouse grower 'j' at time 'i' in [MWh]

BC_j is the buffer capacity of greenhouse grower 'j' in [MWh]

10.4.7 TWO STEP OPTIMIZATION

In reality there will be two steps in the optimization, both optimization are similar but the inputs are different. The first optimization is done as described above and will be done before any settlement is done. Then first the electricity market will be settled. Fixing the H_{Gij} en P_{Gij} of all the CHPs(the production units that both produce electricity and heat). The fixed H_{Gij} en P_{Gij} of the greenhouse growers with a CHP will be used as input variables for the second optimization. In this second optimization the distribution of heat will determined. A more detailed description of these two steps is given in Appendix G. In the first optimization it is proposed to work in blocks of 1 hour, since this matches with the APX market. However, in the second optimization the timeframe of the blocks can be adjusted. This will not be further researched in this thesis, but can be interesting for future research. Since a smaller timeframe will increase the accuracy of the optimization, positively influencing the outcomes.

10.4.8 OPTIMIZATION FOR THE PRELIMINARY DESIGN

The previous 7 problem variants were building up to an optimization that is done in the heat trading platform. This optimization includes buffers, external parties and different production facilities:

$$min \sum_{i=1}^{24} (\sum_{k=1}^{m} \left(H_{Gik} * H_{price-sell(ik)}\right) + \sum_{j=1}^{n} C\left(H_{Gij}, P_{Gij}, CO_{Gij}\right)) \tag{9.6}$$

With :

Demand and supply limitations:

$$H_{Gi} = \sum_{j=1}^{n} H_{Gij} + \sum_{k=1}^{m} H_{Gik} \;\; for\ all\ 1 \leq i \leq 24$$

$$H_{Di} = \sum_{j=1}^{n} H_{Dij} + \sum_{k=1}^{m} H_{Dik} \;\; for\ all\ 1 \leq i \leq 24$$

$$H_{Gi} = H_{Di}\ for\ all\ 1 \leq i \leq 24$$

External party limitations:

$$H_{Gik} \leq H_{Gik_{indicated}}\ for\ all\ 1 \leq i \leq 24$$

$$H_{Dik} = \begin{cases} H_{Dik}, & H_{price-buy(ik)} < H_{price-estimated(i)} \\ 0, & otherwise \end{cases}$$

Buffer limitations:

$$H_G = H_D + (BS_{i=24} - BS_{i=0})$$

$$0 \leq BS_{ij} + Bu_{ij} \leq BC_j$$

$$BS_{ij} = BS_{(i-1)j} + Bu_{(i-1)j}$$

$$H_{Di} \leq H_{Gi} + Bu_i$$

10.5 INTRADAY DISPATCH

Often changes in the dispatch are needed to match supply and demand during the day. The dispatch of production facilities during the day is done to keep the whole grid in balance. In section 6.1.2 there is a brief description of the different sorts of imbalance and in section 8.2 a short description of the measures is given. Imbalance has different degrees, and different measures can be taken, depending on the degree of imbalance. The intraday dispatch is therefore not based on an optimization as described above, but the different stages of the measures. First will be tried to fix the imbalance by using the participants and then a big central buffer could be used. The last stage is combined, either participants are disconnected or a big producers changes his energy supply.

10.6 REFLECTION ON PRICING

The heat price is one of the core elements in a smart thermal grid. Heat can be bought and sold, and transported through the grid. Before this transport can take place, a deal has to be closed between two parties, determining the amount and the price of the heat. At the moment the heat is bought by Eneco W&K from E.ON, and then sold to the greenhouse growers. These greenhouse growers have a contract with Eneco W&K for a certain amount of heat against a fixed price. At the moment E.ON and Eneco have a monopoly on producing, respectively selling heat to the network.

With the creation of the smart thermal grid a new dimension is introduced in the heat market. The product on the market, heat, will still be homogeneous, but other suppliers will enter the market. In economic terms this market can be called a homogeneous oligopoly. A market with a homogeneous product, with only a few suppliers. This market form has consequences for the trading of heat.

Many of the interviewees indicated that heat should be traded just as gas and electricity. However, between the gas/electricity and the heat market are some differences. The main difference is found in the size of the networks. Both gas and electricity have nationwide grids, while thermal grids are a purely regional phenomenon. This has implications for the amount of producers and consumers, which is much less than in nationwide networks. Although in the nationwide networks there are a small number of intermediaries, big companies who sell the energy to the consumers.

Looking at the B3-hoek, there are 120 greenhouse growers with heat demand. Some of those greenhouse growers got a CHP and should be able to supply heat in the future. It should be noted that the greenhouse growers' core business is not related to the energy business. They need cheap energy, because it accounts for 30% of their costs, but their main business is producing crops and plants in the greenhouses. This is a big difference with the current energy producers, as for example E.ON, whose core business is the production and trade of energy.

At the moment the prices of heat are connected to the gas price (van Vooren, Mid-term meeting, 2013). This is due to the heat production facilities being fuelled by gas. If heat is produced with a CHP, electricity is also produced. So instead of the heat price depending only on the gas price, the heat price also depends on the electricity price. The electricity price is very volatile, while the gas price is stable. Therefore only connecting the heat price to the gas price would make the revenues from a CHP very volatile.

With the creation of the heat market in the B3-hoek, there are considerations to be made. The fact that the market will be a homogeneous oligopoly, will probably impact the pricing of heat. There are also some limits the heat price should stay within. The lower limit is that the revenues should cover the cost of heat production, if this is not the case no production will take place. Although there are different production options, most of the production power is the CCGT (RoCa), CHPs and boilers. The price of heat should be above the lowest production costs plus transportation costs. The upper limit is the marginal boiler production cost. Almost every greenhouse grower has his own boiler, so if the heat price on the network is above the boiler price he will produce it himself.

The RoCa is the biggest heat production by far (200 MWth). However, due to the size, there is a minimum amount of production. This minimum amount of heat is more than the total available production capacity with greenhouse growers. Although, the RoCa also have to supply heat to the city, but this shows that the RoCa is the biggest production facility in the B3-hoek by far. So when matching the supply and demand, the RoCa will play an important role in the price determination. Since E.ON is dominant in the market, they have price leadership, meaning that all smaller parties (the greenhouse growers) will follow their price (D'Aspremeont, Jacquemin, Jaskold, & Szewicz, 1983). In the near future E.ON will have market dominance, but if E.ON does not produce heat, Eneco can supply heat from AVR to the greenhouse growers. Eneco could also become a dominant supplier due to the volumes they supply.

This reasoning could also work if one big greenhouse grower supplies to the network. If this is not the case and all producers are comparable in power, the heat price will be determined in the network. However, it is unknown whether these prices will differ much. This is something that will have to be tested in practice.

Despite all this, the current model might still be viable. At the moment there is a single-buyers model, that means there is one company selling heat to consumers and this company is also the single-buyer of heat. This model can take local conditions into account. Another advantage is that the suppliers do not sell directly to the consumers, which would imply additional costs in form of administrative obligations. Moreover, the core business of potential suppliers, the greenhouse growers, is not selling heat (Söderholm & Warell, 2011).

This single-buyers model has to advantage of the implementation of long-term objectives. For example the single-buyer can give long term guarantees, but the other way around, can also demand long-term guarantees of customers. Moreover, price differentiation can be introduced. For example two different prices could be set, a peak and low price. The peak price is during the night, when the production of heat is relatively expensive, while during the day the prices could be lower. This would keep the system relatively easy to understand. This system applies to external parties, that want to control over the time they buy heat.

It has to be mentioned that participants of the optimization cannot chose when to buy their heat. This is decided upon by the system. The price of the heat for these participants therefore should be equal, since the most optimal time for the whole system, does not automatically mean that all participants can buy heat at the economically best time. It might be more optimal that there is a stable demand of heat during the day.

Another manner of a pricing system is a bit more complicated. This manner combines highly expressive human negotiation with the advantages of an electronic reverse auction. The supply and demand are cleared at an electronic auction with help of algorithms. Hereby the Kaldor-Hicks efficiency can be obtained, only with a win-win for buyers and sellers. However, the market-clearing will be highly complex and the outcomes will be hard to verify by participants. A lot of trust is needed to apply this sort of pricing system (Sandholm, 2007). It is very questionable if the greenhouse growers are prepared to trust the system in such a way that this is possible (van den Ende, 2013).

10.7 CONCLUSION ECONOMIC DISPATCH & PRICING

If the system is based on the Kaldor-Hicks efficiency, the optimization will optimize on the maximum wealth, or social welfare, of the system. Yet, some actors will have to be compensated, since optimizing on the maximum social welfare means that some individual actors can be worse off. Since the heat demand of the greenhouse growers is presumed to be inelastic, the maximization of the social welfare is equal to the total cost minimization (Sauma & Oren, 2005). The optimization of the economic dispatch is therefore based on the minimization of the cost.

The dispatch consists of three separated parts; the long-term objectives, the day-ahead dispatch and the intraday dispatch. The dispatch of production is done a day-ahead. The long-term objectives of the operation of the smart thermal grid, could be different than the objectives of the day-ahead dispatch. Therefore long-term objectives are introduced that constraint the day-ahead dispatch. Examples of these long-term objectives are continuity and sustainability.

The day-ahead dispatch dispatches all the production facilities in blocks of one hour. This is the core of the smart thermal grid. When and how much do the production facilities have to produce. This dispatch is based on the minimization of the marginal production cost. Therefore first a general marginal production cost function is given :

$$C(H_{Gij}, P_{Gij}, CO_{Gij}) = f_{ij}(H_{Gij}, P_{Gij}, CO_{Gij}) * F_{price} + C_{Tij}(H_{Gij}) - AC_{CO2ij}(H_{Gij}, P_{Gij}) - AC_{Pij}(P_{Gij}) - E_{Pij}(P_{Gij})$$

With help of the general marginal production cost function the day-ahead dispatch optimization can be given:

$$min \sum_{i=1}^{24} (\sum_{k=1}^{m} (H_{Gik} * H_{price-sell(ik)}) + \sum_{j=1}^{n} C(H_{Gij}, P_{Gij}, CO_{Gij})) \quad (9.6)$$

With :

Demand and supply limitations:

$$H_{Gi} = \sum_{j=1}^{n} H_{Gij} + \sum_{k=1}^{m} H_{Gik} \; for\ all\ 1 \leq i \leq 24$$

$$H_{Di} = \sum_{j=1}^{n} H_{Dij} + \sum_{k=1}^{m} H_{Dik} \; for\ all\ 1 \leq i \leq 24$$

$$H_{Gi} = H_{Di} \; for\ all\ 1 \leq i \leq 24$$

External party limitations:

$$H_{Gik} \leq H_{Gik_{indicated}} \; for\ all\ 1 \leq i \leq 24$$

$$H_{Dik} = \begin{cases} H_{Dik}, & H_{price-buy(ik)} < H_{price-estimated(i)} \\ 0, & otherwise \end{cases}$$

Buffer limitations:

$$H_G = H_D + (BS_{i=24} - BS_{i=0})$$

$$0 \leq BS_{ij} + Bu_{ij} \leq BC_j$$

$$BS_{ij} = BS_{(i-1)j} + Bu_{(i-1)j}$$

$$H_{Di} \leq H_{Gi} + Bu_i$$

In practice the day-ahead dispatch will do this optimization twice. The first optimization will be done before the electricity market settles. The second optimization will be done after the settlement of the electricity market. This optimization will use the settlement from the electricity market as input to calculate the actual dispatch of the heat production facilities.

When the day-ahead dispatch is settled the demand and supply of heat are fixed. However, this is based on prediction of the heat demand. The actual demand will always be bit different, creating an imbalance between demand and supply of heat. This imbalance has to be fixed with an intraday dispatch. Fixing the imbalance can be done in multiple ways; price incentives, central buffer, 'afschakel' contracts or contract with a big producer. In all four ways the demand or the supply is influenced to match the demand with the supply.

Besides matching demand and supply of heat, there should also be a pricing system that settles the heat price. Most of the interviewee indicated that they want an open heat market, where heat can be traded. However, the number of suppliers is limited, moreover one of the suppliers (E.ON) produces more than 50% of the heat. This is not an ideal situation for an open market, therefore it could be interesting to apply the single-buyers model. In which one party that buys all the heat, and subsequently sells this heat to consumers. This model would allow the steering on long term objectives. However, in this thesis the pricing system is not worked out in detail. Further research is needed to determine a good pricing system.

PART V: ECONOMIC FEASIBILITY OF PRELIMINARY DESIGN

11 ILLUSTRATIVE EXAMPLE

In this chapter an illustrative example of the preliminary design of the heating platform will be discussed. In the previous chapters all different domains are analysed separately. This example will combine the economic, actor and institution domain into one model. This example is done to test the economic feasibility. In the model engineering economic techniques, as for example time value of money. The technical domain is not included, the technical feasibility of the dispatch will therefore not be part of this example. This is done to reduce complexity.

The model is created to give some insights into the functioning of the smart thermal grid. It is a simplified and generalized model, therefore the model will not be used to produce hard conclusions. The model will merely be used to give some general statements about the system and to give points of attention.

The model consist of the five different production units; RoCa, AVR, CHP(CO_2), CHP(lighting), boiler. The AVR has a maximum capacity of 55MW(due to pipeline and station limitations). The model is based on data from 2012. In the model the availability of other sources is also included. Also buffers are not included in the model, the model matches the heat demand and supply per hour.

In this model the buffers are not taken into account. The same goes for the geothermal plants, it is assumed that they will not supply to the network, due to low temperatures. In the future this might be possible, but this is not included in this model. The assumptions made for this model are described in Appendix J.

11.1 ECOCNOMIC FEASIBILTY HEAT TRADING PLATFORM

In this example the investments are left out of scope. This is done because the merit order and the division of production capacity will be based on the marginal costs (see section 10.4). This section will only look at the current available production units and their marginal cost. Investments in new production is not included.

Production

The price of heat includes transportation cost, taxes and 10% revenues. This way the production units price can be compared to the price of boiler heat. If production units get more expensive than boilers the heat will be produced by boilers. Moreover when the supply of heat through the network is lower than the demand. The boiler group shown in Figure 28 exists of greenhouse growers producing heat with their own boiler. This heat is not sold, but only produced for own usage.

The cost of heat produced by a boiler is dependent on three factors: the gas price, the CO_2 price and the CO_2 demand of the greenhouse grower. A greenhouse grower only has CO_2 demand when the sun is shining, because of the photosynthesis of the plants. In the model this is taken into account by using the average light intensity per day, to estimate the additional CO_2 demand of the greenhouse grower. The heat production cost, for a boiler and CHP(CO_2), are therefore dependent on the availability of light.

The total heat production done by boilers is 185.222 MWh. This is 27% of the total heat production. As mentioned, boiler heat will not be transported through the network, so the decline in heat transportation, compared to 2012, will be 27%.

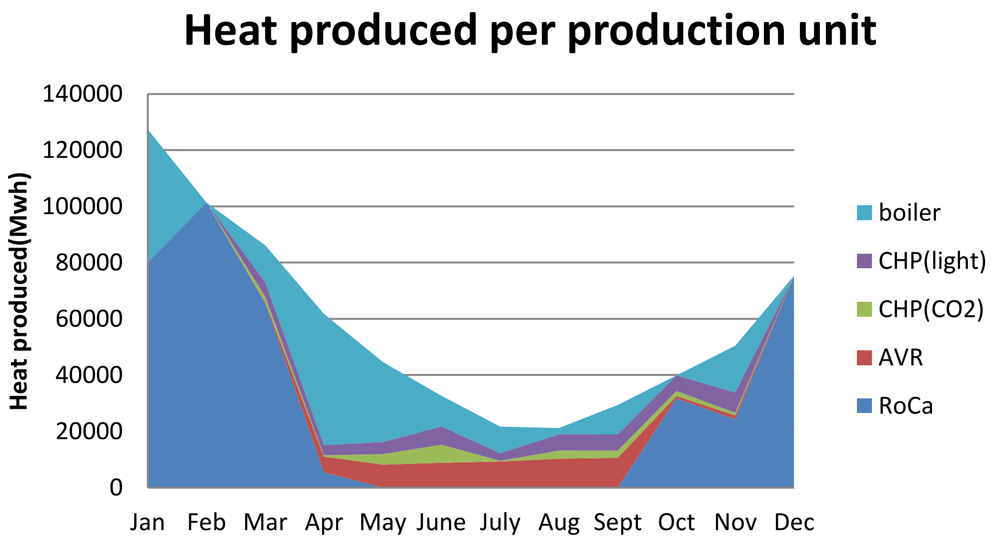

Figure 28: Heat production per production unit, extrapolated from 1 day in the month(based on data from 2012)

In Table 6 the amount of heat production per year per production unit is shown. The RoCa and the boilers are the big producers in this network. Together they produce 83% of all the heat.

As mentioned above, the demand for CO_2 is highest when the sun is shining. In Table 6 the average marginal cost per production unit are shown. The average production costs of a CHP(CO_2) are €-0,71. These negative cost can be explained by the high price of CO_2. From the model it is calculated that with the production of 1 MWh of heat 404 kg of CO_2 is produced. This CO_2 has an overall value of €22,27 (€0,055 per kg).

The CHP(CO_2) produces the lowest total amount of heat. This can be explained by the availability of CHP(CO_2) capacity, but also by the demand for heat when the CHP(CO_2) is cheap. The CHP(CO_2) is relatively cheap when the sun is shining, however at these moments there is less demand for heat. For example during a hot summer day, a CHP(CO_2) can produce very cheap heat. Whereas the heat demand is very low on such a day. In the B3-hoek the CHP(CO_2) capacity is maximum 18 MW. So besides demand, there is also limited supply.

With the use of buffers, heat produced during the day could be consumed at night. In this way the overcapacity of relatively cheap heat during the day, can be used to supply heat at night. This is also explained in section 3.2. However, as mentioned, buffers are left out of scope.

The average marginal cost from Table 6 are different from the average marginal costs from Table 4. This can be explained by the calculation of two different models. The model used in chapter 9 calculates all the costs on a yearly basis. Estimations of production hours are made and the gas and electricity prices are fixed throughout the whole year. In the model used in this section, the number of production hours is dependent on the merit order of marginal costs per hour. The marginal costs of, for example a CHP(CO_2) can therefore be much lower, because the CHP(CO_2) produces only at the most profitable hours of the day. In the marginal cost the transportation cost are also included.

The model of chapter 9 is used to show the differences between the costs of the different production units, with changing electricity and gas prices (taken as a yearly average). The model in this section is used to analyse the total production of the different production units per hour and the marginal costs during that hour.

Production unit	Total production (MWh)	Percentage of production(%)	Total marginal cost (€)	Average marginal cost (€/MWh)
RoCa	383.552	55	x	x
AVR	55.387	8	€ 980.100	€18.00
CHP(CO_2)	21.011	3	€ -14.688	€-0.71
CHP(lighting)	46.663	7	€ 206.504	€4.50
Boilers	185.222	27	€ 4.291.433	€23.58
Total	**2.548.983**	**100**	**€ 8.070.798**	

Table 6: Heat produced in the B3-hoek per year

Transportation

The transported heat does not include the self-produced heat by boilers, since this heat is used by the greenhouse growers themselves and will therefore not be transported. For this reason the boilers are left out of Figure 29. The RoCa produces by far the most heat, 76% of total heat transported. This can be explained by the absence of production capacity of the other production units in the winter and the high production capacity of the RoCa. In the winter, both AVR and CHPs cannot supply heat. The heat coming from the AVR is needed in the city of Rotterdam and the greenhouse growers need their own heat.

The total amount of heat transported is 691.835 MWh of heat. The total transportation cost are estimated to be 1.3 million euros (section 9.1.1). So the transport cost per MWh are €1,88. In section 9.1.1 it was mentioned that there is a minimum requirement on the amount of heat transported, otherwise the transportation cost are too high. However, this critical mass is hard to calculate, because it is also dependent on the electricity and gas prices. If the price of heat of a CHP and a boiler is differ significantly, the transportation cost can be higher than when the price difference is very small.

In this model the transportation cost are included in the heat price. It could also be possible to pay a fixed fee each year. Taking the 120 greenhouse growers in the B3-hoek this fixed fee will be on average around €9200 per year. The fixed fee can differ per greenhouse grower, since the fee will be linked to the heat capacity of the greenhouse grower.

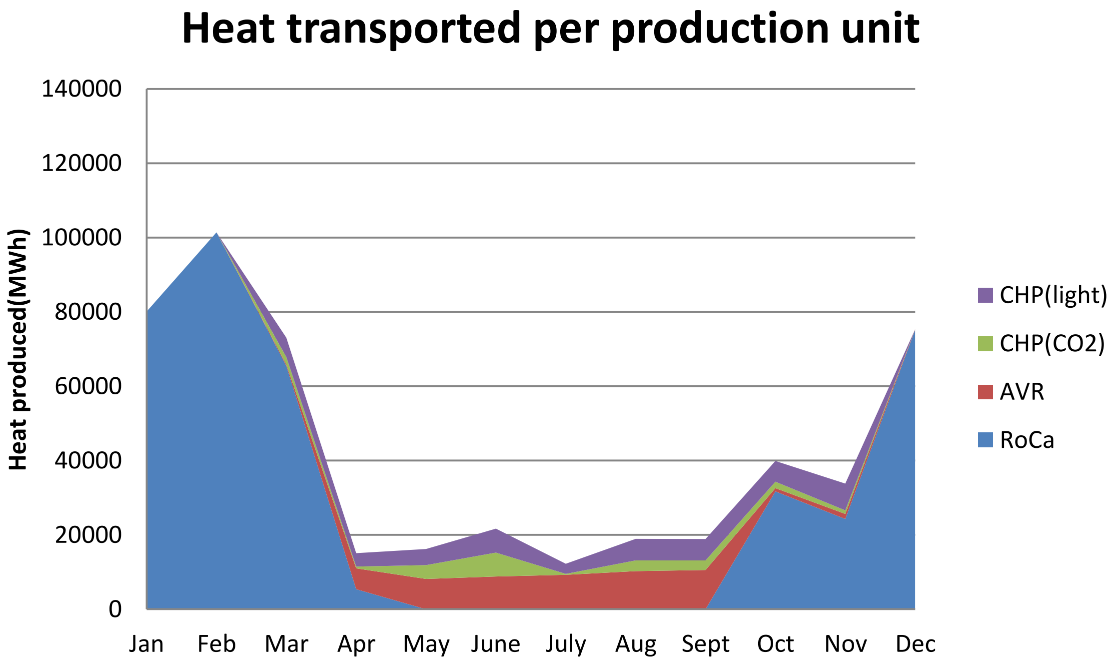

Figure 29: Heat transported through the B3-hoek network per production unit, extrapolated from 1 day in the month (based on data from 2012)

Finance overall network

The total marginal costs of the system with 5 available production units is €8.070.798 (Table 6), this compared to €16.248.839(data from the model) when all this heat was produced with boilers. So the savings, calculated on the basis of the marginal costs only, are €x. This does not include revenues for the suppliers and the network controller. However, if both the suppliers and network controller take €3,60 of profit per MWh, there is still €x of savings left.

There is enough financial space to make the whole network work, at least in the conditions assumed. The conditions are simplified, but based on real data from 2012. However, in the model investments are not taken into account.

Finances individual suppliers

In Table 6 the marginal costs of production of the different production units is shown. These are the marginal costs of the heat produced. In the case of the CHP(CO_2) the marginal production costs are negative, this means that when the CHP(CO_2) is producing heat, each additional unit of heat saves costs. This can be explained by the revenues and 'avoided costs' of both CO_2 and electricity. If both are high enough, the revenues and the avoided costs cover the production costs, therefore even without taking heat into account, the production unit already earns back its marginal costs.

Table 7 shows the revenues of all the different production units, and also the revenues per production facility. Since the revenues can vary due to a change in pricing system, two assumptions about the pricing are made: 1)Heat is sold with a minimum price is €7,20 per MWh; 2)The heat price is equal to the marginal cost of the most expensive producing production unit, +10% revenues.

Production unit	Total revenues (€)	Number of facilities	Revenues (€/facility)
RoCa	x	1	x
AVR	€144.827	1	€144.827
CHP(CO_2)	€199.072	12	€16.589
CHP(lighting)	€535.771	12	€44.647
Boilers	€5.455.606	100	€54.556

Table 7: Revenues of the different production units

The greenhouse grower with a CHP, needs to invest in a WLS to be able to supply heat. Per year a WLS costs €10.870 (section 9.1.1). Both CHP(CO_2) and the CHP(lighting) can pay those costs and still have revenues on their sold heat. The number of facilities is a safe estimate. It is assumed that the CHP's have a size of 2 MW, while in practice there are some greenhouse growers with CHP's of 3 MW. If a greenhouse grower has a CHP of 3 MW, the fixed costs of a WLS would stay equal, but the revenues would increase by 50%.

The revenues of the boilers is based on the 'avoided costs' of heat production. On average a greenhouse grower saves more than 50.000 euros by buying heat, instead of producing it himself with a boiler. It has to be stipulated that this is only valid on the basis of the current assumptions. A change in pricing system for example, will have an effect on the cost of heat, and therefore on the 'avoided heat costs'. It would seem evident that the revenues of greenhouse growers with a boiler has to be lower, since most of the risk are with the supplying parties.

All these revenues are based on the difference between the earnings and the marginal costs.

11.2 DYNAMICS OF SYSTEM

The thermal grid in the B3-hoek is not a static system. There are different factors that make the smart thermal grid a dynamic system; price, demand and supply fluctuations. These three factors make the system change in time. For example the demand can change every second, due to changing weather conditions. And the supply can change due to bankruptcies and equipment reliability .

In this section some of these influences will be discussed. To begin with, a big change in suppliers, namely the disappearance of the RoCa, the biggest supplier in the network. Then the effect of a change in gas price, electricity price and in demand in the model will be analysed. This is done in sensitivity analysis. This analysis studies the uncertainty in the output, if the inputs of the system change.

Closing of the Roca

If the RoCa stops supplying heat to the B3-hoek, a big supplier of heat will disappear. Consequently, the supply of heat will decrease significantly. The transported heat through the network goes from 506.613 MWh to 137.777 MWh, a decrease of 73%. Moreover the cost of transportation triples, from €2,54 per MWh to €7,64 per MWh. This increase makes the other production units more expensive, and therefore they lose competiveness.

However, even with the increase in transportation costs, still 137.777 MWh heat is transported. Even without the RoCa the network will be interesting for both heat consumers and suppliers. Moreover, investments in heat production facilities other than boiler will become more interesting. What could increase the heat production in the network.

Due to the increase of heat production with boilers, the sustainability of the heat, and thereby of the greenhouse growers will decrease. This should be taken into account, especially since the greenhouse growers committed to a decrease in CO_2 emission (see section 8.1.3).

Sensitivity analysis

In the sensitivity analysis, three different input factors, electricity price, gas price and demand, are fluctuated with + or -10%. This way the impact of the different factors on the system is investigated. The exact results from the sensitivity analysis can be found in Appendix I . In this section the most important results are presented and discussed.

Electricity price:

The marginal costs of the RoCa and the CHP are very dependent on the electricity price. A change of 10% in electricity price caused a change of more than 40% in marginal costs. The marginal costs changed between €0,57 and €0,98. While in the meantime the marginal cost price of the AVR and the boiler stayed equal (section 9.1.2 : Figure 22).

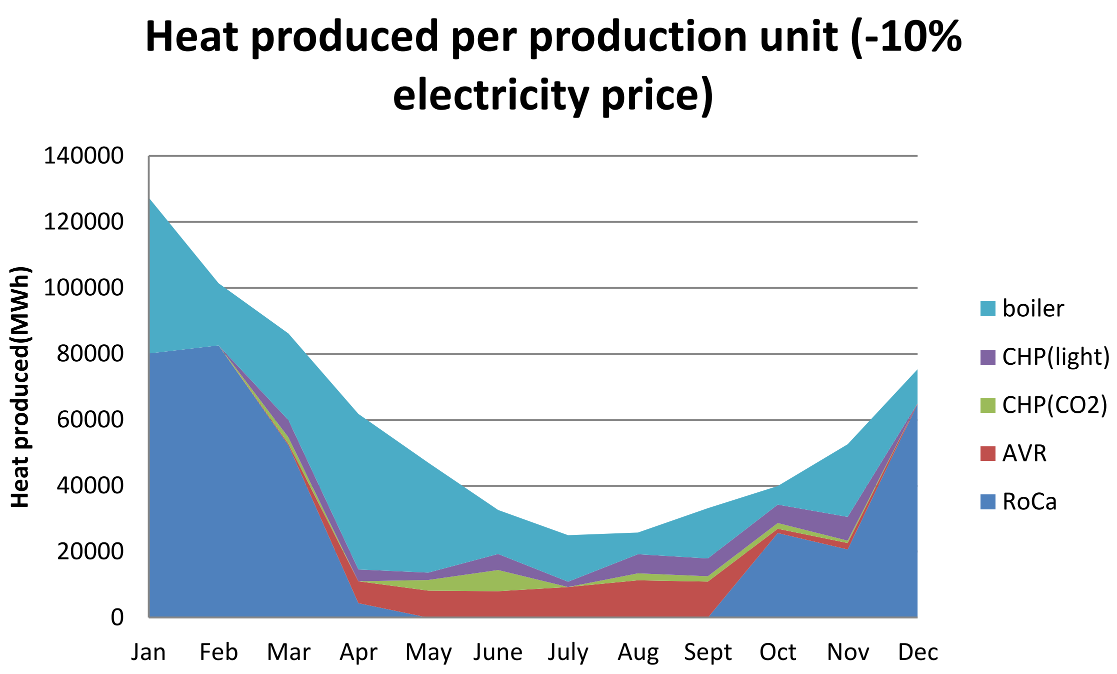

Figure 30: Heat production per production unit, extrapolated from 1 day in the month (-10% electricity price)

In Figure 30 a dispatch can be seen, in case the electricity prices decline with 10% on average (Figure 28 is reference situation). Since the marginal cost of CHP and Roca change with 40%, they lose competiveness. Therefore there is more production with boilers. The boiler production rises from 27% of the total production to 37% of the total production, a rise of almost 70.000 MWh. The AVR supplies more or less the same amount of heat. This can be explained by the fact that the AVR was already supplying near maximum capacity.

The increase in marginal heat production cost of the CHP does not have a big impact on the amount of produced heat. This can be explained by the fact that when the CHP's supplied heat, they had avoided cost. Their marginal cost were already low, so an increase of 40% still kept their marginal cost relatively low.

The impact on the amount of transported heat with an increase in electricity price of 10% is far less than a decrease of 10%. The heat produced becomes cheaper, however often the heat was already cheaper. Therefore the total amount of heat produced by CHPs and RoCa is increasing only a little.

Gas price:

Gas is the main fuel for the heat production. Only the AVR does not use gas for heat production and is therefore independent of the gas price. However, the other generation units, using gas for fuel, are heavily dependent on the gas price. For the boiler a change in gas price, means a proportional change in the marginal costs of production (section 9.1.2: Figure 23). However, for the co-generation units a change in gas price has a comparable effect to a change in electricity price. The marginal heat production cost changes with more than 40%, compared to a change in gas price of 10%.

Relatively the boiler is becoming more expensive compared to the co-generation units. Therefore there is a change in total production of the RoCa with 4% to 59% of the total heat production. Also the CHP produce a bit more heat, but that is marginal compared to the RoCa.

Demand:

A change in demand does not have an effect on the marginal cost of production. However, a change in demand, automatically means a change in supply. Since there is a limited supply of both CHPs and AVR, an increase in demand means not much extra supply of heat from CHP and AVR. Most of the additional demand is covered by the RoCa and boilers. Since the increase in demand is mostly in the winter (in absolute terms).

Following the trend described in section 3.5, the heat demand will decrease over time. With a decrease of 10% in demand, most of the loss of production is with the boiler and RoCa. Relatively, there is less production with boilers, increasing the sustainability of the greenhouse growers.

11.3 CONCLUSION ILLUSTRATIVE EXAMPLE

Enough heat will be traded in the heat trading platform to overcome the fixed transportation costs. As can be seen in Figure 28, there are enough possibilities to produce for the different facilities. Financially, it is attractive for both consumers and producers, the degree of attractiveness depends on the production cost and amount of production. However, every participant in the system can have economic gain. The amount of economic gain, not only depends on costs, but also on the price of the heat. Since the pricing structure is unknown, a good estimate of the individual economic gain is hard to make. However, with some assumptions for pricing, Table 7 shows the economic gain per individual participant. In this pricing scheme suppliers get at least €7.20 per MWh of heat. And more depending on the highest marginal cost of production.

The pricing system used for Table 7 will most likely not work in practice. Since the greenhouse growers with a boilers, baring the least risk, have the most gain. Therefore the rewarding system should be different, in order to increase the gain of risk baring parties. This could for example be an increase in the minimum heat price, or an increase in of the revenues on top of the marginal cost.

In Figure 28 it can be seen that the RoCa has a huge share in the production of heat. But even with an exit of the RoCa from the system, there will be enough heat transportation left to cover the expenses. However, the transportation cost of heat will triple, decreasing the competiveness of the heat suppliers.

From the sensitivity analysis it can be concluded that at the moment the heat price is very dependent on the electricity and gas prices. A change structural change of 10% in one of them, has a huge impact on the production cost of heat. However, the continuity of the system is not endangered by these structural changes. Only the dispatch of the different production units will differ.

Still future price stability it is advisable, since this is also one of the wishes of the greenhouse growers. Therefore production facilities that are less dependent on the gas and electricity prices or have a reversed relation with either the gas or electricity price could be an interesting option to explore. An example of these are boilers fueled by electricity, or a geothermal source with a heat pump, that can produce cheap heat when the electricity price is low, this in contrast with the co-generation facilities.

PART VI: CONCLUSIONS, RECOMMENDATIONS AND REFLECTION

12 FINAL CONCLUSIONS & RECOMMENDATIONS

12.1 CONCLUSIONS

The system, i.e. the thermal grid in the B3-hoek, is an existing thermal grid, with one central heat production facility. In this thesis the options for turning this thermal grid into a smart thermal grid are analysed. In this thesis the options for turning this thermal grid into a smart thermal grid are analysed. In this smart thermal grid all consumers, the greenhouse growers, have decentralized production facilities (boilers, geothermal plants or CHPs). These facilities have enough capacity to cover all the heat demand, but are currently unable to share and supply heat through the thermal grid. In the smart thermal grid different production facilities would be able to supply heat to the network. The different production facilities have to be dispatched in order to match the heat supply and demand. This also gives the opportunity to do the dispatch efficiently, to save costs and increase competiveness of network participants.

The focus of this thesis is the decision problem of the smart thermal grid, as indicated by the main research question :

HOW CAN THE DECISION PROBLEM REGARDING THE SMART THERMAL GRID IN THE B3-HOEK BE FORMALLY DESCRIBED?

Since a broader definition of the decision problem is used, the decision problem encompasses the organization of the decision process as well. In this thesis therefore a first step is made in the design of a heat trading platform. The heat trading platform should coordinate the transactions between the system participants, in alignment with the interests of the relevant actors. It consists of an economic dispatch of all production facilities and institutions to govern the network. Furthermore the designers of the heat trading platform have to deal with the technical limitations of the physical system.

These aspects should all be in accordance with the expectations of the participants and actors of the system. An important aspect of the transformation into a smart thermal grid, is gaining support of all relevant actors. At the moment the actors are the existing multiple greenhouse growers, Eneco W&K, Eneco AgroEnergy and E.ON. The primary objective of all actors in the system is economic gain.

The economic gain is dependent on the costs of heat and the eventual price of heat. Currently, one of the most important factors in relation to the production costs of heat are the prices of electricity and gas, since almost all production facilities are gas-fuelled and most of the low cost heat production is done by CHPs and the RoCa.

The most economic gain is achieved if the total welfare in the system is maximized. In the Kaldor-Hicks efficiency the wealth in a system is maximized. In practice this means that actors could be worse off, as long as the total gains in the system exceeds the losses (Posner, 1980). Since the market is relatively small the losses of individual actors can and should be compensated for. However, the point when actors are worse off, the reference point, should be carefully determined. This could be, for example, the current situation without smart thermal grid. More research should be done to determine this reference point.

The complexity of the transformation to the smart thermal grid can be marked by the cooperation of actors that are also competitors. This is the case between Eneco and E.ON, as well as between the greenhouse growers. Network governance is therefore harder, since they are reluctant to share information and work together. Especially the benefit distribution among the participants is complicated, since all individual actors are assumed to strive for a maximization of their own benefits. In order to reduce uncertainty and gain trust of the participants, the institutions that manage the network and distribute the benefits, should be clear and transparent. This will decrease reluctance towards the system and increase the number of transactions.

This institutional environment has to manage the whole system by setting clear system rules. It will manages the benefit distribution, coordinates the dispatch, key decisions and major network activities should be governed by one lead organization (for example Eneco).

As mentioned above, the most economic gain is achieved by the Kaldor-Hicks efficiency which optimizes the social welfare in the system. Since heat demand of greenhouse growers is inelastic(thus the utility is constant), the maximization of the welfare is equal to the costs minimization (Sauma & Oren, 2005). The proposed dispatch for the heat trading platform is therefore a minimization of the costs. The dispatch of the production facilities has to be done on day-ahead, therefore this dispatch is also called the day-ahead dispatch. This dispatch can be described as:

$$min \sum_{i=1}^{24} (\sum_{k=1}^{m} \left(H_{Gik} * H_{price-sell(ik)}\right) + \sum_{j=1}^{n} C\left(H_{Gij}, P_{Gij}, CO_{Gij}\right)) \tag{9.6}$$

With :

Demand and supply limitations:

$$H_{Gi} = \sum_{j=1}^{n} H_{Gij} + \sum_{k=1}^{m} H_{Gik} \ for\ all\ 1 \leq i \leq 24$$

$$H_{Di} = \sum_{j=1}^{n} H_{Dij} + \sum_{k=1}^{m} H_{Dik} \ for\ all\ 1 \leq i \leq 24$$

$$H_{Gi} = H_{Di}\ for\ all\ 1 \leq i \leq 24$$

External party limitations:

$$H_{Gik} \leq H_{Gik_{indicated}}\ for\ all\ 1 \leq i \leq 24$$

$$H_{Dik} = \begin{cases} H_{Dik}, & H_{price-buy(ik)} < H_{price-estimated(i)} \\ 0, & otherwise \end{cases}$$

Buffer limitations:

$$H_G = H_D + (BS_{i=24} - BS_{i=0})$$

$$0 \leq BS_{ij} + Bu_{ij} \leq BC_j$$

$$BS_{ij} = BS_{(i-1)j} + Bu_{(i-1)j}$$

$$H_{Di} \leq H_{Gi} + Bu_i$$

This day-ahead dispatch, dispatched all available production facilities in the most optimal way, by minimizing the marginal production cost of heat. In this optimization external parties, that just want to trade heat, are also included. The optimization is limited by demand and supply, external party and buffer limitations.

In this dispatch the technical limitations are left out. However, these technical limitations should be incorporated in the dispatch of the different production facilities. It is undesirable that the optimal dispatch of production facilities is technically not feasible. The economic optimization therefore has to be constrained by the technical limitations in order to create a dispatch that is both economically and technically feasible. In chapter 6, the technical domain, the technical limitations of production, transportation and prosumers are discussed.

Besides the day-ahead dispatch there are two additional transaction times; the long-term and the intraday. The long-term has to provide long-term guarantees to participants, in order to reduce uncertainty. This way objectives, that are not achieved by minimizing the total costs, can be included in the system. The intraday time is focused on fixing the imbalance in the system. Due to the accuracy of day-ahead predictions, there will always be imbalance in the system. This imbalance between demand and supply has to be corrected.

The results from the illustrative example are promising. The simplified model shows that enough heat will be traded to cover the fix cost of the thermal grid. The overall improvement is substantial, making it possible to let all participants have financial advantages from the smart thermal grid. Since the pricing system is not fully developed, it is hard to determine the exact financial benefits per participant. However, The current heat trading platform design gives useful insights in the operations of the system and its' limitations.

The proposed system design has its shortcomings. The heat trading platform should include more than one day. This way the buffers can be used more optimally, since the different daily circumstances are taken into account. Moreover, the institutional environment should be developed further, for example the design of the benefit distribution system. Additionally, the behavior of coalitions between actors should be mapped. Forming coalitions in the smart thermal grid could have a positive effect (might reduce complexity), but could also have a negative effect (increase total cost in the system).

12.2 RECOMMENDATIONS FOR THE DEVELOPMENT OF THE HEAT TRADING PLATFORM

This research provided a formal description of a smart thermal grid. However, the real development of the smart thermal grid in the B3-hoek has yet to begin. In this chapter recommendations are given about the development of the smart thermal grid, this is called the daily business since this are recommendations for work that needs to be done in the near future. Since the development of the smart thermal grid is done by Eneco and the TU Delft, for both recommendations are given.

12.2.1ENECO

Pricing & institutions

The system investigated in this thesis should be viewed as a decentralized system, which operates under a different set of rules compared to a centralized system. In a centralized system everything is done by a central supplier, with limited responsibilities for the other participants. However, in a decentralized system the responsibilities will also be more decentralized. To ensure stability, rules and regulations should be established. These rules, together with a pricing system, will form the basis of trading heat in the smart thermal grid. This institutional environment should be created in an early stage of the development of the optimization. The institutional environment can have an influence on the optimization and this has to be taken into account during the development of the optimization.

Additional research has to be done to the benefit distribution system. A benchmark (reference point) has to be created for all participants, to judge when they are worse off. And if they are worse off, how much they should be compensated for. Moreover, it has to be determined what desirable behaviour is and how this can be steered (game theory). During this research almost all actors indicated that they would like to trade heat, just like electricity and gas. However, as can be read in section 10.6 an open heat market has its disadvantages. The number of suppliers is low for an open heat market. Therefore, other possibilities of heat trading should be investigated, for example the single-buyers model discussed in section 10.6. A heat price that fluctuates per hour is not desirable, however a peak and low price could be a good option to create an incentive for consumers to consume at certain times.

This implies that the greenhouse growers have still freedom to decide when to buy heat. This is the case for the external parties. However, for the participants in the system, this is already decided. They buy heat when its most optimal for the whole system. Therefore the heat bought by the participants should be equal of price.

The institutional arrangements should be developed by one leading organization in cooperation with participants. The most likely organization to do this is Eneco. Eneco should therefore take the lead in the development of the institutional arrangements.

Long-term objectives

The day-ahead dispatch focuses on economic gain. The production facility with the lowest marginal production costs can produce. However, in the long-term the minimization of the costs might not ensure the highest economic gain. Also other objectives, as for example, more durable production facilities, or heat price stability, are not covered in the day-ahead dispatch.

Therefore Long-term objectives need to be established by Eneco and the other participants in the system. All parties need to work together to establish these long-term objectives. Due to this long-term objectives, initiatives can be implemented that are important for the continuity of the system. These long-term objectives will give guidance to the day-ahead dispatch.

These long-term objectives might not be optimal on the short-term, however they are important for the continuation of the network. Eneco, as potential leading organization, should propose these long-term objectives that steer the network. Eneco might also be the better party, since the focus of many participants is on short them survival (due to the economic crisis).

Involving external parties

Up till now, it is assumed that all involved parties will join the smart thermal grid. However, for operating the smart thermal grid, greenhouse growers need to give up some of their independency. Since the optimization is going to determine when they are going to produce heat, and when they are going to buy it.

Not all participants want to give away their independency. As already mentioned in section 10.4.4, E.ON will supply heat, but want to manage this themselves. The system should also be open to these external parties, that operate independently. Eneco and AgroEnergy will have to investigate what the size of this external group is and what the best way is to incorporate them into the system.

In the decision problem presented in section 10.4.8 they are included in the optimization. However, it is not discussed how they are going to fit in the rules and pricing system. The institutional environment concerning these external parties should be established.

Sustainability

The continued existence of the thermal grid in the B3-hoek should not have only a financial motivation. Almost all interviewees indicated that the creation of a smart thermal grid should also improve the sustainability. In the early years of the smart thermal grid, still a lot of the production will be done by boilers. Boilers produce a lot of CO_2 and are not very sustainable. Therefore the goal should be to lower the grid temperature to a temperature that also geothermal sources are able to supply heat. Greenhouse growers will have to invest in new systems, that can use that lower temperature.

Eneco should support these greenhouse growers in the transition to a sustainable greenhouse. This will help not only the greenhouse growers but also the involved municipalities and the Rijnmond area to reach their climate goals. Another advantage of lowering the grid temperature is that this lowers the heat losses in the network. For this improvement of sustainability their might be subsidies available to further improve the network.

12.2.2 TU DELFT

KISS principle

In this case KISS stands for Keep It Simple and Straightforward. The greenhouse growers want a transparent system. They do not have to understand the whole optimization, but they have to understand the outcomes. Since the participating greenhouse growers need to give away their independency, it is logical and predictable that they want to know what they can expect in return. If they do not understand the outcomes they are likely to be opponents rather than participants. The TU Delft should therefore develop an optimization with unambiguous and understandable outcomes. Greenhouse growers, and other participants of the system, should therefore be involved and asked for feedback during the development phase.

Technical limitations

In this research the technical limitations, especially those of the physical network are not discussed in great detail. The 'netmodel' that is currently under development, could provide much insight into these technical limitations. From the 'netmodel' the importance of the technical limitations can be investigated, and also the manner of implementation into the optimization can be investigated. There is an option of implementing simplified technical limitations into the optimization. By doing so the optimization will be fast enough to be run every day. In the 'netmodel' extreme scenarios can be tested. This gives good insight in the technical limitations, and if these have to be included in the optimization.

There is also the option of leaving the technical limitations out of the optimization. If the 'netmodel' demonstrates that the technical limitations in practice never form actual limitations, they would only overcomplicate the optimization. The outcome of the optimization should be tested for technical feasibility. However, in the case that the limitations are hardly met, this this will only be a formality.

In the design of the heating platform, the technical limitations are not yet implemented. In the formal description of the decision problem the technical limitations are left out. However, in chapter 6 the technical limitations are clearly described. Moreover, there are engineers at Eneco that have a lot of knowledge about the network and its limitations.

Fragmentation of the network

In this research the thermal grid is considered as a whole. However, fragmentation of the thermal grid is also an option, since the network is built up from different branches. In the optimization the ability to operate the different branches independently should be considered. This could be done in the long-term optimization, where the benefits of separating part of the network could be included. This fragmentation should be steered, so that branches can be connected and separated each season.

The advantage of the separating the branches would be:

- Less transportation losses, since parts of the network that are not used are disconnected.
- Different feed temperatures in each branch possible. This would create the possibility for geothermal facilities to deliver low quality heat to part of the network.

However, since most greenhouse growers need their own heat production in winter, and centralized production needs to reach all greenhouse growers, the network should be connected in winter. The TU Delft should take this fragmentation of the network into consideration in the long-term optimization.

Also cascading(see section 6.1.1: geothermal energy) part of the network should be considered. In doing so, parts of the network will have different temperatures, but are connected through a heat exchanger. This way branches are not disconnected, but are separated from the grid by a heat exchanger.

Social welfare

If the system is based on the Kaldor-Hicks efficiency, the optimization will optimize on the maximum wealth, or social welfare, of the system. Yet, some actors will have to be compensated, since optimizing on the maximum social welfare means that some individual actors can be worse off. A benchmark (reference point) has to be created for all participants, to judge whether they are worse off. And if they are worse off, how much they should be compensated for.

Moreover, this thesis looks at the social welfare of the whole network. However, it could be that some groups in the network are better off if they maximized the welfare with the group, instead of the whole network. It has to be investigated if this can occur and if these groups are disadvantage by the whole network optimization.

The other way around, it might be the case that some participants undermine the performance of the whole network, for example by not cooling down their water enough. These participants should be identified and measures should be taken to improve their performance. In the previous example this could be to increase the heat exchanging surface.

Pricing system

Since the pricing system still has to be developed this is not discussed in this thesis. However, it could be interesting to look at the game theory. This helps with the understanding how decision-makers interact. Since the participants all want to maximize their own utility, it might be interesting to look at the game theory for noncooperative games. More especially to the nash equilibrium. The nash equilibrium is a strategically stable situation, since no actors benefits from deviating from the equilibrium (Vega-Rendono & F., 2003). Game theory could help in the development of the pricing system and the optimization. Since this was not discussed in this thesis, therefore further research should find out if and how the game theory could help in the development of the system.

There is also a lot of knowledge about the pricing system at AgroEnergy. They already have a vision on the pricing system, which is an open heat market. If another pricing system is proposed, AgroEnergy has be convinced. They will operate the software of the heat trading platform, therefore they have to agree with all components of the optimization. Their vision at the moment is that the pricing system should not be overcomplicated, which in their opinion means an open heat market (Valkenburg, Interview, 2013).

Coalitions

This thesis looks to the actors as individual actors that interact, but that all want to achieve maximum benefits. However, it could also be the case that actors will work together to increase their combined benefits. This is not discussed in much detail in this thesis. However, the forming of coalitions should be taken into account. This could influence the outcomes of the optimization, and thereby should be considered. To investigate this, first research should be done if coalitions would increase the benefits of the actors. Since if this is not the case, there is a low chance that coalitions will be formed.

However, if it turns out coalitions could provide substantially more benefits to the participants of the coalition it has to be taken into account in the heat trading platform. This does not necessarily have to be negative, since these coalitions could lower the amount of individual participants, which could decrease the calculation time of the optimization. Therefore it might even be better to form coalitions in the thermal grid, for example the greenhouse growers from one branch. This could reduce the complexity of the optimization.

12.3 RECOMMENDATIONS FOR FUTURE SCIENTIFIC RESEARCH

In this section recommendations for future scientific research are presented. This are fields of research which are not yet explored, but would be interesting to do so.

Adding electricity intraday market to the optimization

CHP's can be turned on and off relatively fast. Therefore they are ideal to balance the electricity grid. However, at the moment the electricity intraday market is not included in the optimization. Greenhouse growers have to do that individually. It might be rewarding to collectively act on both day-ahead and intraday market. This could be a very interesting topic to investigate, since the intraday market is getting more volatile. Therefore there is an increasing need for fast and flexible power production, like CHP's. Moreover, the complexity of connecting both day-ahead and intraday markets of both heat and electricity will be very complex.

Design of an optimal physical network for a smart thermal grid

The physical network of the B3-hoek is already in place. However, for the future it could be interesting to design a smart thermal grid from the start, including the physical network. What will financially and technically be the best smart thermal grid.

13 REFLECTION

This thesis is the result of almost four months of research into the smart thermal grid of the B3-hoek. This chapter discusses what lessons are learned during this research. This chapter is divided into different paragraphs. In these paragraphs the reflection is presented on the scope, developed models, outcomes of study and my personal experience of the research.

13.1 SCOPE

The scope was the development of the smart thermal grid in the B3-hoek. The scope involved the whole smart thermal grid, which meant that all different domains had to be analysed. Beside the institution domain, all domains were analysed. However, all separated domains are broad enough to service as topic of independent research's. Therefore it was chosen to analyse the different domains up to a certain detail level as well as not analysing the institution domain.

It was hard to establish the boundary of what to analyse within the domains and what not. In the end, I think all domains are analysed enough to create a good understanding of the system. Some very specific topics are not analysed, however this was not needed to create the decision problem.

The illustrative example was not needed for the formulation of the decision problem. However, I think the example gives good insight into the operation of the system. Although it is simplified, it still is a good illustration of the potential operation of the system. Especially, the positive outcome gives enough reason to continue the development of the smart thermal. The outcomes are positive, since it is estimated that the surplus large enough, even when the RoCa stops.

In the search for the decision problem, the focus turned to the day-ahead dispatch. So how can we divide the production in a so economic manner as possible. In the end of the research, I realized that marginal production cost minimization in the long run could not be optimal. Therefore the long-term dispatch was introduced, to give steering to the day-ahead dispatch. I think the combination of both dispatched, creates the most optimal economic optimization. Especially for long-term investments, the long-term dispatch can improve the final business case.

The hourly dispatch, the dispatch that has to match the final demand and supply is not analysed in detail. This dispatch, or repair, should be investigated further. It is not analysed in detail, since fixing the imbalance is not seen as the biggest obstacle. There are numerous manners of fixing the imbalance, and in consultation of all participants the best options should be chosen.

A final aspect that is left out of scope, and therefore is not analysed, is the time delay between supply and demand. Since the transportation of heated water from point A to B takes time, there is a considerable time delay between supply and demand. This effect is not analysed in this research, since it was initially not identified. However, the effect of the time delay should be investigated. It can potentially have an effect on the decision problem presented in the conclusion.

13.2 RESEARCH APPROACH AND USED METHODS

The method of analysis used was based on Groenewegen and existed of four different domains. Analyzing the four different domains and there sub-levels gave a good and clear structure in the overall analysis and the thesis. This helped me to get a good overview of the different aspects of the system and also made it more easy to analyze. However, by splitting the analysis in the domains the domains got analyzed separately. This led to one of the comments of the committee that the chapters were not glued together.

Moreover, I could have focused more on the interrelations between the different domains. This would have glued the thesis more together, and made it a more complete. I found it hard to combine the different domains together. Looking back at the method of analysis I am positive that the method provided me with structure, what was very useful for me.

The separated analyzing methods proved to be very useful. These additional methods of performing a stakeholder analysis and an institutional analysis provided me with a framework. This framework improved the structure in my thinking and in my thesis. However, relating these methods to the level of detail proved to be somewhat of a challenge. The scope of my thesis is very broad, and due to time constraints, does not allow to go into much detail on the different topic. On each of the different domains it would be possible to write a complete thesis, therefore setting clear boundaries was hard. It could therefore be that some topics are discussed in too much detail, while others lack some details. I tried to be a thorough without getting into much detail.

13.3MODELS

In this thesis two models are developed. The first model (chapter 9) was built to easily calculate the marginal cost of heat production, so that the different production units could be compared against changing market conditions. The second model (chapter 11) was built to model the heat trading platform. Both models are simplification of the reality, since the reality is too complex to model in the limited amount of time given for this research. The first model was developed to answer get more insight in the actual and the marginal cost of heat the different production units, in chapter 9. To calculate the actual cost a model was that could calculate the total cost of heat production per year. With a few assumptions the actual and the marginal heat cost could be calculated. But all based on a fixed prices per year and on an estimated amount of production hours.

The data from the first model was enough to compare all the production units by cost. However, for the illustrative example a model was needed with less assumptions, that was closer to reality of the smart thermal grid. Therefore an additional model was needed that would be more fit to illustrate the smart thermal grid.

The assumption of fixed prices and the fixed amount of production hours per year, were changed. Since in reality the prices and the amount of production hours vary. For the gas, electricity and CO_2 price, 2012 was taken as reference year. All prices were known per hour, and based on that a merit order per hour based on cost could be developed.

The outcomes of the second model, gave more insight in the actual working of the system. As shown in chapter 10, the actual amount of production per day was constructed. However, the first day of the month, of each month was analysed. The best would be to analyse each day separately, however due to constraints of the model and the available time this is not possible. In both models the buffers are left out of scope, this is done to simplify the model. Including the buffers was not possible in this timeframe.

13.4 OUTCOMES

The outcomes of the illustrative example were positive. Due to the simplification of the model, it cannot be concluded that the actual system of the smart grid will have the same outcome. However, it gives an indication of the possibilities, that should be investigated further. The expectations of the result of the model were more moderate, the huge surplus that is shown now was not expected. I expect that in reality the surplus will be lower than what the model indicated. However, this is extremely difficult to predict, since many inputs for the model vary a lot. In the investigation of the profitability of the smart thermal grid multiple future scenarios should be tested.

The final decision problem is a general optimization for a smart thermal grid. Each system is different, and therefore each system will have other underlying formulas and assumptions. However, the proposed decision problem gives a good objective function of the smart thermal grid.

13.5 PERSONAL EXPERIENCE

Finally I want to give a short reflection on the graduation process from my point of view. In the beginning I had problems defining the project and the scope of the project. I started out with the idea, I would create already a big part of the optimization. However, this was a bit too optimistic. With support of my supervisors, I managed to define a good scope, that was also achievable within the set time for the master thesis.

Looking back on the chosen scope, I might have found it interesting to go into more detail in economic modeling of the smart thermal grid. A good economic model would be able to give an accurate prediction of the behavior of the smart thermal grid. However, the development of such a model would take time, and the additional contribution to the main research question, compared to the current model is questionable.

Working on my master thesis was something I had to get used to. I'm used to work in groups, and also prefer to work in groups. However, it was a good experience to work individually for 5 months. I especially learned to work in a structured way, and that this structure should be determined before, and not halfway of the project.

Writing my master thesis at Eneco was a very good decision. I enjoyed working at Eneco and this motivated me to go to Eneco and work at my thesis every day. I think I would not have come this far, by working at home or at the TU Delft.

When I compare my thesis project to what I have learned the past 7 years at the Technical University of Delft, I noticed that the skills I learned were useful. My background in mechanical engineering, gave me the knowledge needed to understand the thermal grid. While my master Management of Technology, provided me with the multidisciplinary view, that was needed in this project. Overall the master thesis corresponded with my previous education.

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APPENDICES

A. DEVELOPMENTS IN THE MARKET OF GAS-FIRED POWER PLANTS

Nowadays the energy consumption and market climate are different than what was forecasted in 2000. Today, the average power price has declined, while the gas en coal prices stay relatively high. Further the electricity demand has weakened due the bad economic climate in the Netherlands. And the increased share of renewable sources, for example wind and solar energy, from the domestic and the German market created an declining average power price. (Price Waterhouse Coopers, 2013)

This climate is increasingly bad for the big conventional power plants(gas- and coal-fired). However, the coal-fired power plants are outperforming the gas-fired power plants due the declining trend of the coal price relative to the gas price, causing the dark spread to increase, and the spark spread to decline. In Figure 31 and Figure 32 an example of the development of the dark- and spark spread are shown in the UK.

Figure 31: Clean dark spread(coal) **(Franke, 2013)**

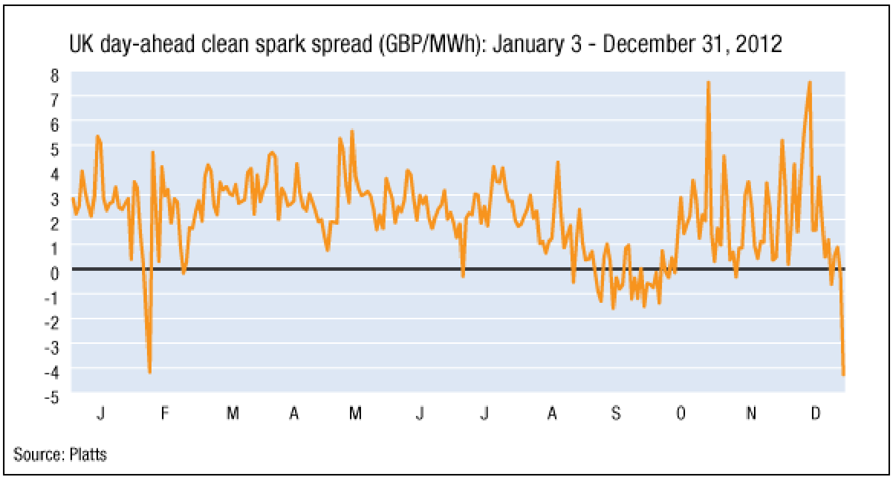

Figure 32: Clean spark spread (gas) (Franke, 2013)

Due to this trend the gas-fired power plants are having less and less operating hours. So the declining average electricity price combined with less operating hours, causes the gas-fired power plants to be unprofitable. The sustainable advantage that these gas-fired power plants should have is neutralized by the low CO_2 prices. (Bouma, 2012). Therefore, unsustainable coal-fired power plants produce energy cheaper. Would the CO_2 price be higher, the gas-fired power plants would gain advantage, since they produce less CO_2 per unit of energy.

B. B3-HOEK PROJECT DESCRIPTION

The project is divided in different parts:

Part 1 – The development of a model, called the 'netmodel', that can simulate the physical thermal grid in the B3-hoek. This way different heat distribution scenarios can be modelled and tested before they are put into practice. This has to be done to guarantee the safety of the network. This is done by Eneco W&K.

Part 2 – Enabling greenhouse growers, to both supply and receive heat. This part of the project is also done by Eneco (H&C).

Part 3 – The development of optimization software done by AgroEnergy and the TU Delft. The optimization software has to match supply and demand of heat in the most 'optimal' way, while satisfying physical constraints, as well as transportation and production limitations. This software will perform the daily dispatch of all different production units.

Some of the greenhouse growers already have a small combined heat and power (CHP) plant, which could, combined with other sources, fill the gap that the E.ON energy plant will leave. Currently, the idea is that the greenhouse growers will produce their own heat with the possibility of selling this heat to other greenhouse growers in a 'smart thermal grid'. Eneco Heat&Cold(department of Eneco), AgroEnergy and the TU-Delft are cooperating to create this smart thermal grid. This research will cover a part of this work, focusing on the problem definition for the optimization of this smart thermal grid.

AgroEnergy is already developing a bidding application, for individual greenhouse growers, that calculates the optimal time to sell electricity to the grid. The plan is to extend this bidding application from an individual greenhouse grower to a group of greenhouse growers. However, this application will not only look at producing electricity but also to the needs and demands of heat that these greenhouse growers have. The heat produced against the lowest cost, will then be distributed among the each other. The cost of supply and value of demand of heat will generate a heat price, the determination of this price will be done on the virtual 'heat platform'. Yet this heat distribution has a lot of constraints, for example the diameter of the pipes, flow direction and network architecture. The optimization of the bidding application therefore has to be adjusted so that it will also be technically feasible. The output of this optimization will also serve as input for the 'heat platform'. This 'heat platform' will determine, on the bases of the input from the bidding application, price(s) for the distributed heat.

At the moment Eneco Heat&Cold (H&C) is working on a model that describes the possibilities of the heating network and can simulated different scenario's. This model, called the 'netmodel' will give the technical constraints of the heating network and can calculate scenario's for heat distribution. However, this model cannot be run next to the bidding application, because then the optimizations will bounce from the application to the 'netmodel' and back. The challenge is to integrate the constraints of physical network, given in the 'netmodel', in the optimization of the bidding application.

The task of the TU Delft is the development of an optimization function that also includes a technical feasibility. This research, described in this project proposal, will be focusing on a part of this work. Before any optimization can be developed the problem definition or the criterion, the constraints and the °C of freedom have to be known. This research will focus precisely on that.

C. FAVOURABLE PRODUCTION TIMES

In this paper *favourable production times* is mentioned quite often. This has to do with the matching of demand and supply. Due to the flexibility of demand, and because of the use of buffers, the supply can also be flexible. This flexibility can be used to shift production to moments with low production costs.

In this thesis the focus is on the heat price, so it is important to know at what times a production unit can produce the cheapest heat. Or, in other words ; what are the favourable production times.

In this appendix some background information is given about this favourable production times, per production unit.

CHP

For the production of heat and power a CHP plant uses gas as fuel. The profitability therefore depends on the heat, electricity and gas prices. CHP plants often use the spark spread for the indication of profitability. For example, Appendix A shows the trends of the big power plants explained in terms of spark- and dark spread (darkspread is for coal-fired power plants). These spreads are defined as the difference between revenue (from selling electricity and heat) and the fuel costs (gas). In Figure 33 the spark spread of 2-1-2013 is shown. This figure is made to give some indication of the general trends of the spark spread on a random day.

To make this picture some assumptions were made concerning the CHP and heat price. For the CHP the electrical efficiency was taken as 42% and the thermal efficiency is taken as 50%, as described in the technical analysis. The reference heat price is taken as the price it would cost to produce heat with a boiler, which is €36,12 per MWh_{th} (this includes the actual gas price). The heat price (boiler produced) depends on the efficiency of the boiler and the gas price. The heat price can also depend on the CO_2 price. In this graph this is not taken into account, however.

Since the gas price is locked per day, the heat price, produced by boiler, stays constant the whole day. The electricity price in contrast is determined anew each hour. This can also be seen in the graph. The spark spread has the same curve as the electricity price, because the electricity price is the only variable factor if we look at one day.

Profitability is defined as the difference between revenues and costs. The variations in the revenues and costs occur because of varying fuel costs and revenues for production units. The fixed costs are independent of the variations in time and from different prices. So in the determination of a favourable production moment, the fixed costs do not play a role. In the spark spread therefore the fixed costs are excluded and the variations are included.

In the determination of favourable production times for a gas-fired plant, we look at the spark spread in Figure 33. The most favourable times are during the day and in the beginning of the evening. This can be explained by a high electricity price. In general, for a gas-fired power plant it can be said that the most favourable time of the day to produce is the time when the electricity price is high. The most favourable time, in terms of spark spread does not automatically mean high profits. As the spark spread does not include fixed costs.

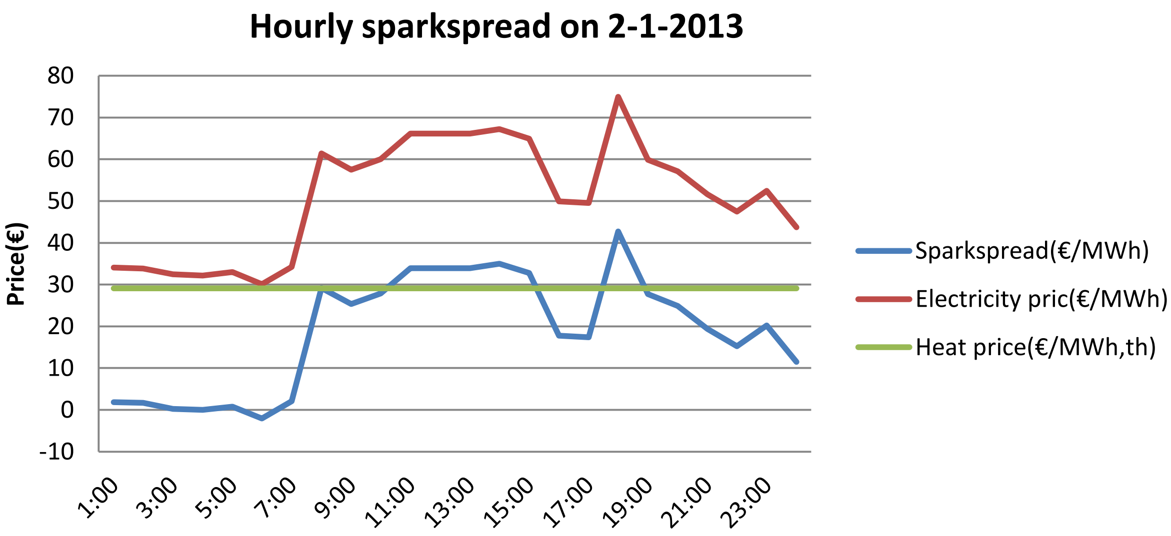

Figure 33: Sparkspread vs electricity and heat price(cost of boiler production) 2-1-2013 (Koornneef, 2013 APX data, 2013) (Koornneef, Gasprijzen 2013, 2013)

The spark spread is used for both the RoCa and the CHPs of the greenhouse growers. Since the drivers are the same, the production units can profit from the same favourable moments.

boiler

The fuel used for boilers is gas. However, the difference between a boiler and a CHP is the electricity production. A boiler does not produce any electricity and is therefore independent of that driver. In Figure 33 the heat price is the heat price produced by a boiler. It can be seen that the price is fixed throughout the day. Since the boiler heat price is only dependent on the gas price, the price of boiler production is stable. The favourable production moments are therefore defined in comparison to other production sources. If the cost of heat from a CHP is higher than the cost of heat from a boiler, the boiler becomes interesting.

Geothermal production

Geothermal production in the Netherlands is an economically attractive undertaking. . This can be explained by the subsidies given for geothermal units. For a time period of 15 years, these units get €14.76 per MWh of heat subsidy (Platform Geothermie, 2013). Since the estimated marginal production costs are €4.18, this results in a marginal heat cost of €-10.58 per MWh. This does not include risk and investment costs.

Despite of the subsidies, building a Geothermal plant is expensive. Its successful its exploitation is prone to a number of uncertainties. Bottom line here is that there is no such thing as free heat.

D. PRODUCTION COST

For the calculation of the marginal production costs $HC_{marginal}$ the following formula is used:

$$HC_{marginal} = C_{fuel} + C_{operating} - E_{electricity} - AC_{electricity} - AC_{CO2}$$

With:

$$HC_{marginal} = marginal\ heat\ costs\ (\frac{€}{kWh})$$

$$C_{fuel} = fuel\ costs = \frac{fuel\ price}{heat\ efficiency}\ (\frac{€}{GJ_{heat}})$$

$$C_{maintenance} = mainantance\ costs(\frac{€}{GJ_{heat}J})$$

$$C_{interest} = cost\ of\ interest\ over\ the\ investment$$

$$E_{electricity} = Electricty\ earnings\left(\frac{€}{GJ_{heat}}\right) = \frac{kWh\ electricity\ produced}{GJ_{heat}\ produced} * electricty\ price(sell\ price)$$

$$AC_{electricity} = Avoided\ costs\ for\ electricity\ \left(\frac{€}{GJ_{heat}}\right) = \frac{kWh\ electricity\ produced\ and\ used}{GJ_{heat}\ produced} * electricity\ price\ (buy\ price)$$

$$AC_{CO2} = Avoided\ costs\ for\ CO2\left(\frac{€}{GJ_{heat}}\right) = \frac{kg\ of\ CO2}{GJ_{heat}\ produced} * CO2\ price$$

There is a difference in the avoided costs for electricity and its earnings The earnings of electricity are determined by the selling price of electricity. The avoided costs for electricity are determined by the purchase price. The difference between the two are the transportation costs and taxes. These are included in the purchase price of electricity. It is for greenhouse growers financially very attractive to produce their own electricity, because they save on transportation costs and taxes.

There is a difference in the avoided costs for electricity and the earnings of electricity. The earnings of electricity are determined by the selling price of electricity. The avoided costs for electricity are determined by the purchase price. The difference between the two are the transportation costs and taxes. These are included in the purchase price of electricity. It is for greenhouse growers financially very attractive to produce their own electricity, because they save on transportation costs and taxes. The $HC_{marginal}$ will be lower when a greenhouse grower uses his own produced electricity instead of selling the produced electricity.

Before the calculations for the marginal production costs are made, research is done to produce the numerical data needed. To get these data many generalizations and assumptions had to be made. This can be explained by the fact that the whole system of 120 greenhouse growers is too complex to analyse within a short time frame. Therefore the individual production units are not analysed but a generalization of every production unit is made. In Table 8 the assumptions are shown together with the explanation and reasoning behind very assumption.

Assumptions made in economic analysis

Unit	***Assumption***	***Explanation***
Electricity price	Current: €51,88 per MWh Future: €	Current: Average of electricity prices in2013
Gas price	Current: €27.06 per MWh Future:	Current: Average of gas prices in 2013
Thermal efficiency	RoCa: x%	source: x
	CHP: 50%	source : (Smit & van der Velden, 2008)
	Boiler: 90%	source : (Sintniklaas, 2013)
Electrical efficiency	RoCa: x%	source: x
	CHP: 42%	source: (Smit & van der Velden, 2008)
Caloric value of gas (top value)	35.17 MJ/m^3	Source: (energieleveranciers, 2013)
Heat capacity	RoCa:200 MWth	source: (van der Marel & Huizeling, 2013)
	CHP: 2 MWth (on average)	source: (Koornneef, interview, 2013)
	Boiler: 2 MWth	this value is taken to make a good comparison with the CHP
	Geothermal: 5 MWth (1 unit)	source: (Arcadis, 2012)
Production hours	RoCa: 3300 h	The RoCa is turned off 5 months per year (due to low heat demand). Rest of the months they produce 2/3 of the hours. Makes approximately 3300 h per year.
	CHP(CO_2): 3000 h	Producing during the 60 favourable hours of a week, with 2 weeks down time.
	CHP(lighting): 4300 h	Same production hours as a CHP(CO_2) + 4 additional hours(on average each day of the year) in the night for electricity production.
	Boiler: 3000 h	On average 9 production hours per day, with 1 month down time.
	Geothermal: 6500	Maximum production, about 2/3 of the time. Mostly dependent on the demand for heat. Estimation is 6500 hours of production time.
Profile effect(electricity revenue per hour /average electricity price)	RoCa: x%	During 35% of the time (60 hours / 168 hours) they produce at peak times. This creating an average profile effect of around 120%.
	CHP: 130%	The greenhouse growers produce at the favourable times, with an average of 130%. (based on average prices during the day)
Avoided CO_2 cost	€9 per MWh	A kg of CO_2 costs €0,05. Converted to MWh, makes this €9.
Electricity capacity cost	€15 per MWh	Source: (Valkenburg, meeting productiekosten, 2013)
Gas capacity cost	€6,8 per MWh	Source: (Valkenburg, meeting productiekosten, 2013)
Energy taxes	6%	Source: (Valkenburg, meeting productiekosten, 2013)
Electricity taxes	€15 per MWh	Source: (Valkenburg, meeting productiekosten, 2013)
Maintenance cost	RoCa: €xper MWHth	Source: (COGEN Vlaanderen, 2006)

	CHP: €11 per MWh	Source: (Hooijman, 2013) rough estimation
	Boiler: -	Source: (Valkenburg, meeting productiekosten, 2013) reason: the maintenance cost are extremely low
Investment costs	RoCa: unknown	Cost are unknown
	CHP: €500.000 per MWh	Source: (Valkenburg, meeting productiekosten, 2013): estimation
	Boiler: €100.000 per MWh	Source: (Valkenburg, meeting productiekosten, 2013): estimation
	Geothermal: €1.100.000 per MWh	Source: (Platform geothermie, 2013), the investment cost are estimated between 0,8 and 1.4 million euro. The average of that is used.
Interest on investment	6%	Within Eneco the interest on investments in set on 6%
Depreciation time	CHP: 10 years Boiler: 10 years Geothermal: 10 years	Within Eneco the depreciation time is set on 10 years, for such an investments.

Table 8: Assumptions made in the economic analysis

In Excel a model is created that can calculate the heat price, both marginal and in total for all different production units. For all different sources such a model is created. In Figure 34 the model if the CHP(lighting) is shown.

	A	B	C	D	E	F	G	H	I
1									
2		**Calculation greenhouse grower with lighting**							
3									
4		**General input**					**Marginal cost calculation**		
5		Electricty price	51,88	[€/MWh]			*cost per MWh thermal*		
6		gas price	27,06	[€/MWh]					
7		thermal efficiency	0,5				**Fuel cost(per year)**		
8		electrical efficiency	0,42				Total production time	4300	hours
9		CO2 emmision	1,78	[kg/m3 of gas]			theoretical production	61920	[GJ]
10		CO2 emmision cost	0,005	[€/kg]			theoretical production	17200	[MWh]
11		Caloric value of gas(top value)	35,17	[MJ/m³]			gas used	1760591,413	[m3]
12							CO2 produced	3133852,715	[kg]
13		**specific input**							
14		thermal capacity of CHP	2	[MWth]			CO2 emission cost	€ 15.669,26	
15		electrical capcity of CHP	1,68	[Mwe]			Gas cost	€ 465.432,00	
16		Total capacity of CHP(theoretical)	4	[MW]			Yearly fuel cost	***€ 481.101,26***	
17		Production hours(without lighting)	2500	full capacity hours					
18		Profile effect for production hours without lighting	130%	Electricty revenu per hour/base load electricity price					
19		Production hours(lighting)	1800	full capacity hours			**Operating cost(per year)**		
20							maintenance cost	€ 79.464,00	
21		avoided CO2 cost	2,5	[€/GJ] thermal			Gascapacity cost	€ 49.123,20	
22							interest	€ 60.000,00	
23		**Production(per year)**						***€ 188.587,20***	
24		Thermal production	8600	[MWh] thermal					
25		electrical production	7224	[MWh] electrical			**Earnings**		
26							electrical earnings	€ 283.264,80	
27		**Network costs**					Avoided CO2 cost	€ 77.400,00	
28		Electricitycapacity cost	15	[€/Mwe]			Avoided electrical cost	€ 247.605,12	
29		Gascapacity cost	6,8	[€/Mwe]				***€ 608.269,92***	
30									
31		**taxes**					**Investments**		
32		gas	0	[€/m3]			investment cost per year	***€ 0,00***	
33		electricity	15	[€/MWh]					
34							**Heat**		
35		**Cost per Mwe**					cost of heat	€ 61.418,54	
36		maintenance cost	11	[€/Mwe]			price of heat	**€ 1,98**	[€/GJ]
37									
38		**Investment cost**							
39		CAPEX	500.000	[€/Mwth]					
40		Interest on investment	6%						
41		depreciation time	10	years					

Figure 34: Model for heat cost calculations, in this case for a greenhouse grower with much demand for lighting

E. PUMPING COST

The pump cost can be calculated as follows:

$$C_{pump\ per\ hour} = Power_{pump} * P_{electricity}$$

$$C_{pump\ per\ second} = pump\ cost\ (\frac{€}{h})$$

$$Power_{pump} = Pumping\ power(kW)$$

$$P_{electricity} = electricity\ price\ (\frac{€}{kWh})$$

These are the pumping costs at a certain $Power_{pump}$. The $Power_{pump}$ can be calculated as follows (ADT dieseltechniek B.V., 2013):

$$Power_{pump} = Q_v * \Delta P * \frac{1}{\eta}$$

$$Q_v = debit\ (\frac{m^3}{s})$$

$$\eta = efficiency\ of\ the\ pump$$

$\Delta P = pressure\ difference\ between\ the\ feed\ and\ retour\ pipe\ at\ the\ greenhouse\ grower$(Pascal)

$$\sum C_{pump} * Q_{th}$$

The ΔP is different at each location, and can even differ due to a change in producers. A big difference in the ΔP can lead to significant pumping cost differences. The pump cost are the only variable transportation costs.

Since it is still unknown how the transportation cost are billed, it could be done per MWh of heat. The two formulas above combined are the pumping cost per second. Since all costs and revenues are in MWh, it is more convenient to also have the pumping costs in MWh. This can be done by multiplying the pumping costs per second with the operation time, and divide that by the total amount of MWh pumped. The pumping costs per MWh of heat can be calculated as follows:

$$C_{pump} = \frac{Q_v * \Delta P * \frac{1}{\eta} * \frac{P_{electricity}}{3600} * t_{operation}}{Q_{th}}$$

$$t_{operation} = operation\ time\ (h)$$

F. CALCULATION BUFFER PRODUCTION CAPACITY

In Table 9 buffer capacity is calculated for a of 500 m^3 buffer. This buffer has a feed temperature of 90 °C and a retour temperature of 50 °C, creating a delta T of 40 °C. This calculation is done with the following formula:

$Q_{th} = V * \rho * C_w * \Delta T$ (Mills, 1999)

The Q_{th} for this buffer is 23.26 MWh. To give an indication of the amount of heat, the heat demand is defined as 2 MW. A greenhouse with an average heat demand of 2 MW, can extract heat from the buffer for almost 12 hours.

Buffer Capacity		
volume	500	(m^3)
density	1000	Kg/m^3
specific heat	4,187	kJ/(Kg*K)
Delta T	40	Degrees celsius
Qheat	83740000	kJ
Heat demand	2	MW
total production time	11,6305556	h

Table 9: Buffer Capacity calculation

G. SYSTEM OF SETTLEMENT AND DISPATCH

In this appendix clarification is given about the proposed system of settlement and dispatch for heat and electricity. Co-generation units can produce both electricity and heat. However, the marginal cost of heat depends on the revenues of selling electricity. And the marginal costs of electricity depends on the revenues from selling heat. This is a circle of two variables that depend on each other. The whole settlement is shown in Figure 35 and is explained below.

So one of the two variables has to be settled first, in order to create an overall settlement of both (van der Spek, 2013). It is determined to settle the electricity production first, due to the higher value of electricity and the nationwide trading system. The nationwide trading system is not flexible compared to the heat trading system in the B3-hoek. The heat settlement is more easily adjusted to the electricity settlement, than the other way around. To determine the amount and bid price of the electricity, the following steps are taken (based on information from Edwin Valkenburg):

1) Estimation of individual and total heat demand is made, based on data from greenhouse growers and weather forecasts.
2) Estimation of the electricity price on all the hours of the day is made, based on historical data and forecast from energy prices.
3) For different production units, the production costs are estimated.
4) A proposal for dispatch of different production units is made. Including all limits and production characteristics. Here the optimization is done according to the objective function.
5) Making a bid on the APX market for a certain price, amount and time (electricity has 24 blocks per day).

After the bid is made the APX market will settle an electricity price and production amount for all separated hours. Now all parties know how much electricity they will have to produce and what price they will get for it. This can deviate from their initial bid, meaning they will not produce on all hours they made bids for.

After the APX settlement the amount and price of heat will have to be determined. This will go as follows

1) Determine the actual supply of heat (known due to the electricity production)
2) Refresh the estimation of the demand of heat (due to the APX settlement the demand for heat can change)
3) Dispatch production units (according to one of the dispatch objectives)
4) Settle a heat price

Now the different production units are dispatched and the cost and revenues are known.

In these steps external parties are left out. Only parties that participate in the whole process are able to sell or buy heat. However, in practice their will be independent parties wanting to sell or buy heat on the network. Therefore these independent parties have to be included in the estimation of the heat demand and supply. They will be asked to give an estimation of their demand/supply of heat before the settlement of the APX.

After the APX settles, they can give their actual supply or demand for heat on different hours. In the dispatch of sources, these data is taken into account. This whole settlement process is shown in Figure 35.

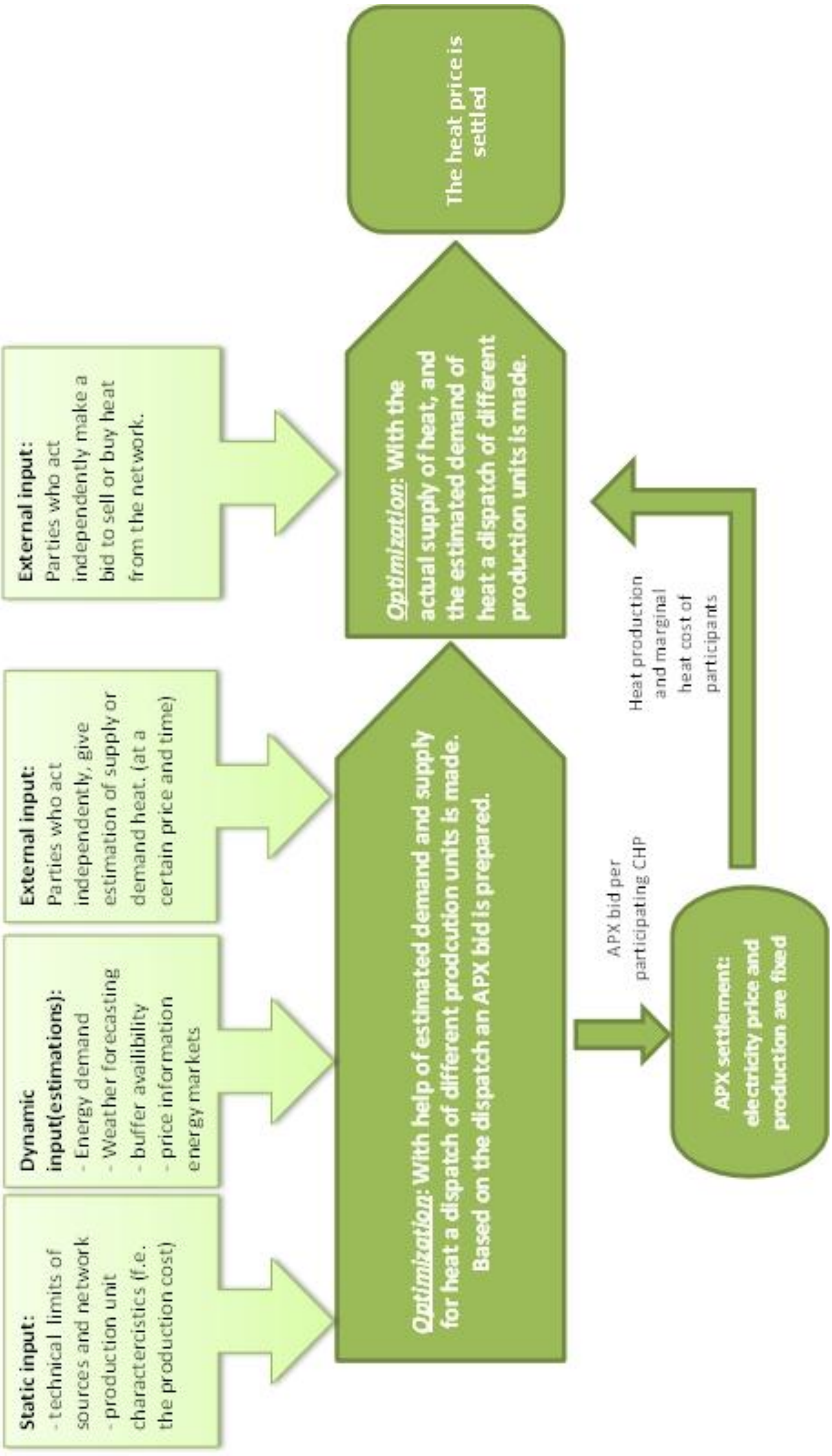

Figure 35: The system of settling heat/electricity price and demand, together with dispatching different production units(this figure is based on a figure from Edwin Valkenburg (AgroEnergy))

H. DISPATCHING LIMITS AND UNIT CHARACTERISTICS

With day-ahead-economic-dispatching, generating units are selected to produce heat the next day. This dispatch takes into account operating limits and production unit characteristics (FERC Staff, 2005):

Operating limits:

- Ramp rate: How fast can the output of a production facility be changed
- Maximum and minimum production capacity
- Minimum amount of run time
- Minimum amount of down time (the time the facilities have to be turned off)

Technical limits:

- Pump capacity
- Maximum debit through the pipelines
- Temperature fluctuations
- Pressure drop

Production unit characteristics:

- Cost of generation:
    - Variable operation costs (both fuel and none fuel costs)
    - Earning of generation (selling of electricity)
    - Avoided costs due to generation (using own electricity)
    - Efficiency of the production facility
- Start-up costs
- Location (pump costs)

These are a lot of different factors to take into consideration for the dispatch of the different production facilities. For the dispatch the operating and technical limits and the production unit characteristics are important. The limits are boundaries, maximums and minimums, where the dispatch has to stay within.

The production unit characteristics are different for each production unit. Based on these characteristics the different production units are dispatched.

The dispatch of thermal production units in a smart thermal grid is dependent on economic and none-economic factors. Economic factors are the prices on different markets as gas-, electricity-, and CO_2 prices. These prices determine the costs and earnings of the different production facilities. These factors play a substantial role in the determination of the production cost of heat. Due to the hourly fluctuation of the electricity price, the total production costs also fluctuate each hour. The dispatch therefore is made per hour. However, the dispatch also looks across hours, to gain maximum benefits from, for example, the start-up costs. Therefore, the dispatch is made per hour, but this is done by looking at the demand and supply of the whole day.

None-economic factors also influence the dispatch. The available volume that can be supplied and the water temperature to be supplied (quality of the heat) are factors that should be taken into account. The quality of the heat is a subject for discussion among experts. The same goes for the maximum debits and pressures through the pipes.

I. SENSITIVITY ANALYSIS

The model for heat cost calculations has to be tested for robustness. Therefore the sensitivity analysis is performed. This analysis identifies to what extent variables or constants have an influence on the model. In addition the sensitivity analysis is used to investigate to what extent certain input variable have an effect on the function of the smart thermal grid.

Therefore a minor change of 10% is given to different variables and constants, to test how much the outcome changes. In this way variables and constants with a high impact on the outcome can be identified. For the changing input variable the electricity price, the gas price and the demand are taken. The output variables that are investigated are:

- Heat produced per production unit
- Total transported heat
- Average marginal cost per production unit when producing.

So what is the impact of for example a change in electricity price in the average marginal cost per production unit.

Sensitivity analysis

Change in input variable	*Changes in output variables*	*Explanation*
Electricity price -10%	Heat produced: RoCa: -13,9% AVR:+5,1% CHP(CO_2):-15,2% CHP(lighting): -11,1% Boiler: +29,2% Total heat transported: -211.831 GJ: -11,6% Average marginal: RoCa: +51% (+€0,96) AVR: - (stays equal) CHP(CO_2):+390% (+€0,77) CHP(lighting): +46% (+€0,57) Boiler: - (stays equal)	The production units who also produce electricity are getting more expensive. Making boilers and AVR relatively cheap. Most of the production is taken over by boilers, because they have 'unlimited' capacity, also in the winter. To total amount of heat transported is reduced by -11,6%, due to the increase of boiler production. Heat from boilers is not transported, since boiler own produce the demand heat that is not transported. The marginal cost of the CHP(CO_2) increase by 390% from €-0,20 to €0,57(an increase of €0,77), this relatively a big increase.
Electricity price +10%	Heat produced: RoCa: +9,5% AVR:-6,8% CHP(CO_2):+6,4% CHP(lighting): +3,6% Boiler: -16,3 % Total heat transported: +128.135 GJ : +7% Average marginal: RoCa: x AVR: - (stays equal) CHP(CO_2):-496 % (-€0,98) CHP(lighting): -62% (-€0,78) Boiler: - (stays equal)	With an increasing electricity price, the increase in heat produced for transportation is less than the decrease from the previous example. Especially the CHPs, who a relatively small increase in production. This can be explained by the lack of production capacity. The average marginal cost decrease, is comparable with the increase in the previous example. The is therefore very dependent on the electricity price, a change of 10% in electricity price, means a change of around 50% in heat price.
Gas price +10 %	Heat produced: RoCa: -4% AVR: +31 % CHP(CO_2):-9 % CHP(lighting): -7% Boiler: +1%	With an increase in the fuel price of both the co-generation and the boiler, the AVR becomes very attractive. With an increase of fuel price of 10%, the AVR sells 31% more heat. The amount of transported heat stays about

	Total heat transported: -6.390 GJ : -0.4% Average marginal cost: RoCa: x AVR: - (stays equal) CHP(CO_2):+415 % (+€0.82) CHP(lighting): +80% (+€1.00) Boiler: +12%(€0.80)	the same. Since the boiler produces 1% more, a small decrease in transported heat occurs. However, this decrease, compared to the increase in gas price, relatively small. The cost of all gas-fired plants increase, the cost of the co-generation plants increase more than 60%. However, the boiler cost increase just a bit more than the gas price.
Gas price -10 %	Heat produced: RoCa: +7% AVR: -6 % CHP(CO_2):+10 % CHP(lighting): +9% Boiler: -16% Total heat transported: +105.091 GJ : +6% Average marginal cost: RoCa: x AVR: - (stays equal) CHP(CO_2):-414% (-€0.82) CHP(lighting): -75% (-€0.94) Boiler: -11%(-€0.70)	The heat production cost of all gas-fired plants decrease, as to be expected. Since the cost of the co-generating units decrease more than the boiler, the boiler loses 16% of heat production. This is also seen in the amount of transported heat, that increases with 6%.
demand +10 %	Heat produced: RoCa: +9% AVR: +2 % CHP(CO_2):-1 % CHP(lighting): +3% Boiler: +15% Total heat transported: +132.141 GJ : +7% Average marginal cost: RoCa: x AVR: - (stays equal) CHP(CO_2):-20% (-€0.04)) CHP(lighting): +4% (+€0.05) Boiler: -11%(-€0.03)	An increase in demand is mainly absorbed by the RoCa (9% increase) and boilers (15% increase). This can be explained by the limited capacity of the other production units. An increase in demand, has almost no effect on the average marginal cost.
Demand -10%	Heat produced: RoCa: -11% AVR: -4% CHP(CO_2):-5 % CHP(lighting): -2% Boiler: -14% Total heat transported: -173.268 GJ : -10% Average marginal cost: RoCa: x AVR: - (stays equal) CHP(CO_2): -54% (-€0.11) CHP(lighting): +4% (-€0.09) Boiler: -1%(-€0.00)	With a decrease in demand mainly the big producers, the RoCa and boilers, reduce the production. With a decrease in the demand the prices stay relatively stable.

J. ASSUMPTIONS CHAPTER 10

Most of the assumptions are the same as in the economic domain model. Below the changes are shown:

Assumptions made in illustrative example		
Unit	***Assumption***	***Explanation***
Electricity price	Data from 2012 is used	The prices from this year are complete, in contrary to 2013
Gas price	Data from 2012 is use	
Heat capacity	RoCa:200 MWth	source: (van der Marel & Huizeling, 2013)
	CHP(lighting): 24 MWth	source: (Arcadis, 2012) in total 48 MWth. However, CO_2 and lighting are split. In the summer 18 MWth available (75% of capacity) and in the spring 12 MWth (50% of capacity)
	CHP(CO_2): 24 MWth	source: (Arcadis, 2012) in total 48 MWth. However, CO_2 and lighting are split. In the summer 18 MWth available (75% of capacity) and in the spring 8 MWth (33% of capacity)
	Boiler: unlimited	Almost all greenhouse growers have a boiler as back up.
	AVR: 55 MWth	Maximum capacity through the pipeline. Per month different capacities available. (source: (Hooijman, 2013))
Light intensity	Different each hour, but based on actual values.	This information is based on the data from KNMI. (KNMI, 1989)
Lighting	The plants need at least 200W/m2 of light intensity. However, no lighting between 20:00-24:00	Rough estimate
CO_2	CO_2 is needed when there is atleast 100 W/m2 of light intensity	Rough estimate
Demand	The demand is based on actual data from 2012.	Source: (Koornneef, Arcadis warmtevraag per teelt 2011, 2013)

K. INTERVIEWS

INTERVIEW ARJAN VAN DER SPEK (ENOVA)

2.a) Wat is op dit moment u rol in de warmte business?

Vroeger paprika tuinder. Nu adviseur voor het energiemanagement van de glastuinbouw. Voorbeeld cluster Bergschenhoek, waar bij 6 tuinbouwbedrijven de gezamenlijke energievoorziening wordt gemanaged. Hiervoor is software ontwikkeld om de energievoorziening te optimaliseren. Bijvoorbeeld WKK's sturen op onbalans en inzicht geven in de kosten en opbrengsten.

Naast energieadviseur ook voorzitter van de klantencommissie van de RoCa en bestuurder van LTO glaskracht.

2.b) Wat is u rol in het ontwikkelen van het smart thermal grid, ook wel 'warmteweb B3-hoek'?

Pilot klant bij Eneco en E.ON, on bijvoorbeeld buffer optimalisatie en terug levering op het net te testen.

3.a) Wat is u doel van het project?

Vanuit LTO: Om het netwerk beschikbaar te houden, moet je omwille van de continuïteit mee veranderen en dus zulke projecten steunen. Zelf als energieadviseur zijn dit soort project ook heel leerzaam.

3.c) Heeft u bedenkingen of zorgen over het project ?

- *Op dit moment proberen de tuinders koste wat het kost warmte uit de RoCa te krijgen, zelfs als daar de ketel aan gaat. Dat kan niet zo doorgaan.*
- *Er wordt misschien te weinig WKK capaciteit bijgebouwd om de RoCa te vervangen. Als tuinders met WKK omschakelen naar geo, kunnen die wel leveren op het netwerk.*
- *In de toekomst zullen tuinders steeds minder warmte nodig hebben. Voorbeeld: Vroeger gebruikte een tuinders met tomaten 60 m^3gas (of een equivalent hiervan) per m^2, tegenwoordig gebruikt dezelfde tuinder tussen de 35- 40 m^3gas. En er zijn zelfs al proeven waarbij slechts 25 m^3gas wordt gebruikt per m^2.*
- *Nu moet er al aangegeven worden wanneer de RoCa gaat stoppen, zodat tuinders hier rekening mee kunnen houden.*
- *Bij een overschot aan warmte, kan deze warmte bijna niks waard zijn. En bij een tekort zal de warmte bijna tegen ketelprijzen worden verkocht. Er kunnen dus hele erge schommelingen in prijzen ontstaan. En hier kunnen mensen misschien strategisch op in spelen.*
- *Iedereen wil op de gunstige momenten warmte afnemen, bijvoorbeeld door de sparkspread. Hierdoor kunnen technische beperkingen de handels mogelijkheden in de weg gaan zitten.*

4.a) Hoe ziet een smart thermal grid eruit voor u?

Een kopie van het elektriciteitsnet, alleen dan een stuk kleiner. Doordat het net zo klein is, moet er wel gekeken worden naar optimaliseren van vraag en aanbod omdat anders de prijzen teveel zullen schommelen(zie hierboven).

Het hele systeem moet langzaam ontwikkeld gaan worden. Dus steeds een stukje uitgebouwd worden.

4.b) Uitgaande van meerdere leveranciers en afnemers, wat is er dan nodig om het systeem draaiende te houden en hoe ga je dit aansturen?

1. *geef tuinders veilige voorraad in de buffers. Daarbuiten kan de netbeheerder de buffers gebruiken om het netwerk te regelen. Prijsbepaling van warmte moet dan door een onafhankelijke partij gedaan worden.*
2. *Vooraf een warmteprijs bepalen, zodat tuinders hierop in kunnen spelen.*

Het probleem is dat er niet te werken is met 2 variabelen (warmteprijs en elektriciteitsprijs) die afhankelijk van elkaar zijn, zonder er eerst 1 vast te stellen. Er moet dus uiteindelijk eerst een warmteprijs bepaald worden.

5.a) Wat is u concrete doel van het project? (CO_2 reductie, kosten besparing, winst, mogelijkheid voor duurzame bronnen, alternatieven voor de RoCa, nuttig afvalwarmte gebruiken, prijsgevoeligheid reduceren, marktwerking, minder afhankelijkheid van 1 productiemiddel)

1. *economisch rendement*
2. *duurzame bronnen, doordat overtollige WKK's hun warmte kunnen verkopen is de business case voor een geothermie bron een stuk beter.*
3. *Flexibiliteit en minder afhankelijk van 1 partij.*

6) Hoe belangrijk vind u het project, in vergelijking tot u normale werk en andere projecten? (hoog/gemiddeld/lage prioriteit)

Hoge prioriteit, doordat het gaat over de toekomst van de warmte voorziening.

7) Heeft u alternatieve voor het ontwikkelen van het smart thermal grid, zoja, wat dan?

Losse clusters met gezamelijke CO_2, warmte en elektriciteits vraag en voorzieningen. Door dit systeem kunnen de tuinders laagwaardige warmte(geothermie) zelf gebruiken en hoogwaardige warmte (WKK) verkopen.

8) Welke aspecten mogen flexibel blijven in het warmteweb?

De warmtelevering is flexibel door het gebruik van buffers. Doordat de meeste bedrijven zonder buffer behoorlijk verouderd zijn, is maar de vraag in hoeverre die tuinders er nog zijn als het systeem moet gaan werken. Daarnaast zou het aantrekkelijker gemaakt kunnen worden om buffers te bouwen, nu wordt dit namelijk een beetje afgehouden.

Scenario's

1) **De warmtehandel is mogelijk, ook Eneco kan namens E.ON en AVR warmte biedingen op doen**
2) **De warmtehandel is mogelijk, maar de RoCa stop met produceren (scenario voor over meer dan 10 jaar)**

9.a) Wat denkt u dat de rol van u (of bedrijf), in het smart thermal grid, zal zijn in beide gevallen en waarom?

1) produceren en consumeren van warmte.

2) produceren en consumeren van warmte. Er moet in dit geval wel een kritieke massa zijn om het systeem in de lucht te houden. Sommige tuinders zullen misschien moeten herinvesteren. In dit scenario is de vraag maar of de kritieke massa wordt gehaald, zeker als de omstandigheden zijn zoals nu. (Weinig investeringsbereidheid en slechte sparkspread)

9.b) Wat denkt u dat de rol van andere partijen binnen het smart thermal grid zal zijn in beide gevallen en waarom?(wie doet de productie, handel, onderhoud, services, transport, sturen van netwerk (bv onbalans))

- *Eneco of Stedin netbeheerder. (liever Eneco want Stedin is heel inflexibel)*
- *Voor de rest lastig te bepalen hoe het systeem zich ontwikkeld, maar de prijsbepaling wordt lastig en moet gedaan worden door een onafhankelijke partij. Met namelijk onafhankelijk van de grote energiemaatschappijen.*

9.d) Ziet u ook potentiele nadelen voor u of andere in deze twee situaties?

Om het systeem in de lucht te houden moet er voldoende volume door het systeem gaan. Anders zijn de kosten van het netbeheer te hoog.

10.a) Hoe wordt de onbalans opgelost?

De onbalans moet in ieder geval niet geregeld worden als op de elektriciteitsmarkt. Hierdoor kunnen er overshoots ontstaan (op de elektriciteitsmarkt bijvoorbeeld 1 uur prijs +€400 en het uur daarna prijs -€300). Onbalans oplossen doormiddel van buffering door de netbeheerder.

10.b) Hoe gaat het verdienmodel in de 2 scenario's eruit zien?

In beide gevallen moet het werkbaar zijn voor de tuinders.

10.c) Zijn jullie bereid in het warmteweb te investeren?

Ja als er geld mee te verdienen valt.

11.a) Spelen er nog beperkingen een rol bij het functioneren van het warmteweb, en indien ja welke?

- *Betrouwbare en betaalbare CO_2 levering is absoluut een voorwaarde. Dus als in 2016 de afspraak tussen E.ON en OCAP verloopt, mag de CO_2 prijs niet omhoog schieten.*
- *CO_2 en warmte mag samen nooit duurder zijn dan de ketelprijs.*

11.b) Heeft u nog opmerkingen of vragen over het interview?

- *WKK's gaan ook wel eens niet aan. In de ervaring van Arjan is er ongeveer 1x per week storing, maar dit is makkelijk op te vangen met buffers en eventueel met ketels. Hierdoor zijn WKK's net zo betrouwbaar als bijvoorbeeld de RoCa.*
- *WKK heeft een opstarttijd van ± 5 a 10 minuten*
- *De warmteprijs zal een omgekeerde APX grafiek laten zien. Als de elektriciteitsprijs hoog is, zal warmte goedkoop zijn. Als de elektriciteitsprijs laag is, zal de prijs van warmte stijgen.*

INTERVIEW HERMAN VAN DEN ENDE (AMT INTERNATIONAL)

2.a) Wat is op dit moment uw rol in de warmtebusiness?

Energieconsultant op tuinbouwgebied

2.b) Wat is uw rol in het ontwikkelen van het smart thermalgrid, ook wel 'warmteweb B3-hoek'?

Projectleider aardwarmtebron bij Hollandplant(klant van Eneco en gebruiker warmteweb). Hierbij zijn er besprekingen gaande met Eneco, om de mogelijkheden van warmtelevering aan de buren te bekijken.

3.a) Wat is volgens u de aanleiding van het project?

Gascentrales zijn op dit moment te duur door veranderende tijden. Kolencentrales, wind- en zonne-energie zijn veel goedkoper en dus economisch veel aantrekkelijker.

3.b) Wat is volgens u het doel van het project?

- *het economisch rendabel maken van de gehele keten. Voor de tuinders is het doel om overtollig warmte te verkopen, of juist te kopen tegen een goede prijs.*

3.c) Heeft u bedenkingen of zorgen over het project ?

Niet direct, waarschijnlijk zijn er op deze manier grote voordelen te behalen.

4.a) Hoe ziet de ideale smart thermalgrid eruit voor u?

- *De invoertemperatuur verlagen naar ± 90 graden celcius, zodat warmte van WKK's ingevoegd kan worden.*
- *Iedereen moet aan iedereen kunnen leveren.*

4.b) Wat verwacht u van de warmtehandel, gefaciliteerd door AgroEnergy in het warmteplatform?

Ik verwacht dat de warmteprijs gebaseerd gaat worden op bied- en laadprijzen, dus zoals AgroEnergy het voorstelt is een goede manier. Gewoon warmte net als gas, elektriciteit en CO_2 verhandelen. Hierbij moet dus ook de mogelijkheid bestaan voor maand-, seizoens- en eventueel jaarprijzen. Sommige tuinders willen namelijk hun energiekosten voor langere tijd vast leggen (30% van de kosten van een tuinder is energie). Dus niet elke tuinder zal op de daghandel warmte willen kopen

5.a) Wat is uw concrete doel van het project? (CO_2- reductie, kostenbesparing, winst, mogelijkheid voor duurzame bronnen, alternatieven voor de RoCa, nuttig afvalwarmte gebruiken, prijsgevoeligheid reduceren, marktwerking, minder afhankelijkheid van 1 productiemiddel)

- *Economisch rendement; er moet geld te verdienen zijn anders gaat niemand mee*
- *prijsgevoeligheid reduceren; het mag niet zo zijn dat door dit project de warmte heel prijsgevoelig wordt. Sommige tuinders willen niet dat 30% van hun kosten, heel erg kunnen fluctueren.*

7) Heeft u alternatieven voor het ontwikkelen van het smart thermalgrid. Zo ja,welke dan?

De temperatuur van het totale netwerk omlaag zou veel economisch rendement opleveren. Daarnaast kan nu de temperatuur in de zomer al omlaag, er is dan toch een stuk minder warmtevraag.

8) Welke aspecten mogen flexibel blijven in het warmteweb?

- Moment van start van levering
  Niet flexibel, alleen flexibiliteit doormiddel van buffers.
- Hoeveelheid gevraagde warmte
  Kan flexibel blijven, doordat tuinders zelf nog warmte kunnen bij produceren.
- Hoeveelheid geleverde warmte
  Als hier geld mee te verdienen valt, zeker.
- heeft u nog andere aspecten die flexibel mogen blijven?

De temperatuur in het primaire net zou per uur moeten kunnen verschillen. Bijvoorbeeld in de ochtend, als de tuinders hun kas opwarmen, een hoge temperatuur en later op de dag een lagere primaire temperatuur.

Scenario's

1) **De warmtehandel is mogelijk, ook Eneco kan namens E.ON en AVR warmtebiedingen doen**
2) **De warmtehandel is mogelijk, maar de RoCa stopt met produceren (scenario voor over meer dan 10 jaar)**

9.a) Wat denkt u dat de rol van u (of uw bedrijf), in het smart thermalgrid, zal zijn in beide gevallen en waarom?

In beide gevallen is mijn rol die van leverancier van warmte. Maar doordat de aardwarmtebron een lagere temperatuur geeft moeten er strengen in het netwerk worden afgesloten met kleppen, om daar de temperatuur te verlagen. Als de aardwarmtebron niet levert, kan de klep open en maakt de streng weer deel uit van het netwerk.

9.b) Wat denkt u dat de rol van andere partijen binnen het smart thermalgrid zal zijn in beide gevallen en waarom?(wie doet de productie, handel, onderhoud, services, transport, sturen van netwerk (bv onbalans))

De eigenaar van het netwerk en van de warmtehandel moet onpartijdig zijn t.o.v. alle klanten. Agro Energy zou daarin een hele goede rol kunnen spelen, als betrouwbare en niet-belanghebbende partner.

10)

a) **Bent u bereid om warmte te leveren, zo ja heeft u hier nog voorwaarden of specifieke wensen voor ?**
Ja zolang er geld mee te verdienen valt.
b) **Bent u bereid warmte af te nemen van andere tuinders, zo ja heeft u hier nog voorwaarde voor of specifieke wensen?**
Ja zolang er geld mee te verdienen valt.
c) **Bent u bereid te investeren in productmiddelen en/of buffers, zo ja wanneer zou u dat overwegen?**
Als dit economisch gunstig is, is investeren in een buffer zeker een optie.
d) **Bent u bereid om u buffers in het warmteweb te gebruiken?**
Ja en dit kan eventueel ook door Eneco gedaan worden. Maar hiervoor is heel veel vertrouwen nodig. Daarnaast moet dit ook economisch gunstig zijn.

11.a) Spelen er nog beperkingen een rol bij het functioneren van het warmteweb, en indien ja welke?

- *Heel belangrijk is het psychologisch aspect; er moet onderling vertrouwen zijn in het systeem. Maak daarom het systeem zo transparant mogelijk.*
- *Daarnaast zijn er tuinders die extra voor zekerheid betalen, dus het moet ook mogelijk zijn om een prijs voor langer termijn vast te leggen.*

11.b) Heeft u nog opmerkingen of vragen over het interview?

- *Voor een goed werkende smart grid moeten er genoeg buffers zijn. Tuinders zijn misschien wel bereid te investeren in buffers, maar degene die de warmtehandel faciliteert, moet wel betalen voor het gebruik van buffers (huurprijs).*
- *Tuinders met belichting (bv rozenkwekers) hebben relatief vaak warmte over. Het is namelijk financieel aantrekkelijk om zelf elektriciteit te produceren, zelfs met een lage elektriciteitsprijs. Met zelf produceren besparen de tuinders namelijk vastrecht, transportkosten, milieuheffing en belasting.*
- *Daarnaast zijn er tuinders die zelf CO_2 moeten produceren, hierdoor hebben ze soms warmte over.*

INTERVIEW EDWIN VALKENBURG (AGROENERGY)

2.a) **Wat is op dit moment u rol in de warmte business?**

Senior projectleider AgroEnergy

2.b) **Wat is u rol in het ontwikkelen van het smart thermal grid, ook wel 'warmteweb B3-hoek'?**

Deel projectleider 'warmteplatform', de B3-hoek wordt in dat geval gezien als potentiele klant.

3.a) **Wat is volgens u de aanleiding van het project?**

B3-hoek tuinbouw gebied, waar warmteplatform toegepast kan worden. Ook bij een veranderde rol van E.ON.

3.b) **Wat is volgens u het doel van het project?**

Idee en concept van het warmteplatform combineren met de technische beperkingen.

3.c) **Heeft u bedenkingen of zorgen over het project ?**

- *Dat de B3-hoek te groot en te complex is.*
- *Het is een uitdaging om alle verschillende disciplines bij elkaar te brengen.*

4.a) **Hoe ziet een ideaal smart thermal grid eruit voor u?**

Van ieder punt in het netwerk warmte leveren en afnemen en zorgen dat dit technisch mogelijk is. Belangrijkste uitdaging hiervoor is hoe je het financieel allemaal met elkaar gaat regelen.

4.b) **Wat verwacht u van de warmtehandel, gefaciliteerd door AgroEnergy in het warmteplatform?**

Warmte moet hetzelfde worden verhandeld als gas en elektriciteit.

5.a) **Wat is u concrete doel van het project? (CO_2 reductie, kosten besparing, winst, mogelijkheid voor duurzame bronnen, alternatieven voor de RoCa, nuttig afvalwarmte gebruiken, prijsgevoeligheid reduceren, marktwerking, minder afhankelijkheid van 1 productiemiddel)**

1. *Economisch rendement*
2. *Verduurzaming*
3. *marktwerking*

6) **Hoe belangrijk vind u het project, in vergelijking tot u normale werk en andere projecten? (hoog/gemiddeld/lage prioriteit)**

Hoge prioriteit, omdat het faciliteren van dit soort netwerken een pijler is van AgroEnergy.

7) **Heeft u alternatieve voor het ontwikkelen van het smart thermal grid, zoja, wat dan?**

nee

8) **Welke aspecten mogen flexibel blijven in het warmteweb?**

- ***Moment van start van levering*** → *Ja flexibel*
- ***Moment van einde van de levering*** → *ja flexibel*
- ***Hoeveelheid gevraagde warmte*** → *niet flexibel, maar buffers*

- ***Hoeveelheid geleverde warmte gaan.*** *→ afhankelijk van buffer*
- ***heeft u nog andere aspecten die flexibel mogen blijven?***

Scenario's

3) **De warmtehandel is mogelijk, ook Eneco kan namens E.ON en AVR warmte biedingen op doen**
4) **De warmtehandel is mogelijk, maar de RoCa stop met produceren (scenario voor over meer dan 10 jaar)**

9.a) Wat denkt u dat de rol van u (of bedrijf), in het smart thermal grid, zal zijn in beide gevallen en waarom?

1) Agro wil marktwerking gaan introduceren. E.ON kan hierdoor warmte tegen een marktprijs aanbieden.

2) Agro wordt exploitant, wie, wat en wanneer gaat leveren.

9.b) Wat denkt u dat de rol van andere partijen binnen het smart thermal grid zal zijn in beide gevallen en waarom?(wie doet de productie, handel, onderhoud, services, transport, sturen van netwerk (bv onbalans))

Eneco W&K: net en systeem beheer.

9.d) Ziet u ook potentiele nadelen voor u of andere in deze twee situaties?

2) Dat er te weinig productie capaciteit is.

10.a) Hoe wordt de onbalans opgelost?

1. *Buffering tuinders*
2. *Buffer in het net*
3. *Grote producent*

b) Hoe ziet u de energieprijs ontwikkeling ? (warmte, gas, el)
Het is heel moeilijk in de toekomst kijken, daarom moet het warmteweb flexibel zijn en met veranderde prijzen nog steeds competitief zijn.

c) Zijn jullie bereid in het warmteweb te investeren?
AgroEnergy is hiervoor geen logische partij.

INTERVIEW PETER GOUDSWAARD (ENERGY MATTERS)

2.a) Wat is op dit moment u rol in de warmte business?

Werknemer bij Energy Matters, via Energy Matters verhuurd aan AgroEnergy. Als extra man voor productontwikkeling warmte.

2.b) Wat is u rol in het ontwikkelen van het smart thermal grid, ook wel 'warmteweb B3-hoek'?

Technische problemen oplossen, zoals:

- *Hoe ga je om met onbalans in een klein netwerk?*
- *Wat voor aspecten spelen er een rol in warmtenetten?*
- *Hoe gaan we om met netcongestie?*

3.a) Wat is volgens u de aanleiding van het project?

E.ON blijft niet op langere termijn op deze manier warmte leveren.

3.b) Wat is volgens u het doel van het project?

Voor AgroEnergy is dit een kans om de markt te vergroten, door warmte als extra product toe te voegen in de B3-hoek. Daarnaast het volledig regelen van kleinere project, bijvoorbeeld aardwarmte bronnen.

3.c) Heeft u bedenkingen of zorgen over het project ?

WKK vermogen is te klein, hierdoor is er niet echt een alternatieve warmte leverancier voor de RoCa.

4.a) Hoe ziet een ideaal smart thermal grid eruit voor u?

Hangt van de situatie af, het belangrijkste is altijd de economisch overwegingen. Investeringen moeten altijd terug verdient kunnen worden.

4.b) Wat verwacht u van de warmtehandel, gefaciliteerd door AgroEnergy in het warmteplatform?

Dat de biedapplicatie warmte moet alles doet. Dus al het werk van de tuinders moet uithanden genomen worden. De vraag is alleen of de tuinders hierop zitten te wachten.

Misschien moeten tuinders zelf prijzen voor hun warmte opgeven, maar de werkelijke warmteprijs wordt dan lastig te bepalen.

5.a) Wat is u concrete doel van het project? (CO_2 reductie, kosten besparing, winst, mogelijkheid voor duurzame bronnen, alternatieven voor de RoCa, nuttig afvalwarmte gebruiken, prijsgevoeligheid reduceren, marktwerking, minder afhankelijkheid van 1 productiemiddel)

- *Economisch rendement*
- *Mee helpen aan verduurzaming glastuinbouw, in combinatie met geothermie.*

6) Hoe belangrijk vind u het project, in vergelijking tot u normale werk en andere projecten?

Hoge prioriteit. Smart heat grids zijn een belangrijke ontwikkeling voor de energievoorziening in de glastuinbouw. De ontwikkeling van een smart heat grid in de B3-hoek kan er ook op andere plaatsen voor zorgen dat warmte betaalbaar blijft en warmte verduurzaamd wordt.

7) **Heeft u alternatieve voor het ontwikkelen van het smart thermal grid, zoja, wat dan?**

- *Geen economisch andere opties*
- *Wel warmte vanuit de Rotterdamse haven halen*
- *Diepere geothermie*
- *Meer WKK vermogen, als dit weer rendabel is.*

8) **Welke aspecten mogen flexibel blijven in het warmteweb?**

- **Moment van start van levering**
  Tuinders willen warmte wanneer ze vragen, dit kan alleen ondervangen worden door buffer capaciteit.
- **Hoeveelheid gevraagde warmte**
  Dit is afhankelijk van hun eigen productiecapaciteit. Mocht dit niet aanwezig zijn, zijn ze niet flexibel in hun gevraagde warmte.
- **Hoeveelheid geleverde warmte**
  Geleverde warmte hangt van de buffer capaciteit af, in het net kan weinig gebufferd worden.
- **heeft u nog andere aspecten die flexibel mogen blijven?**
  - *Aanvoer temperatuur, hierdoor kunnen andere bronnen aangesloten worden.*
  - *Retour temperatuur, meer uitkoelen. Dit scheelt transport energie.*
  - *Productdifferentiatie binnen warmte(zelfde als 'groene stroom')*

Scenario's

9.a) **Wat denkt u dat de rol van u (of bedrijf), in het smart thermal grid, zal zijn in beide gevallen en waarom?**

AgroEnergy exploitant: Biedapplicatie + facturatie

10) **Specifieke vragen per stakeholder**

d) *Hoe wordt de onbalans opgelost?*
- *Prijs incentives (lokale buffering)*
- *Centrale buffer door netbeheerder aangelegd (voor het net moet iig een expansie voorziening komen)*
- *Grote producent onbalans laten oplossen*

e) **Hoe gaat het verdienmodel in de 2 scenario's eruit zien?**
Exploitant → Marge op de handel + eventueel winst uit bronnen waar in geïnvesteerd is.
Netbeheerder → Vast bedrag per maand

f) **Hoe ziet u de energieprijs ontwikkeling ? (warmte, gas, el)**
Midden lange termijn → weinig verandering in de prijzen
Lange termijn (heel onzeker)→ Maar nu is er veel overcapaciteit, mede door zon/wind energie. Deze 2 bronnen zullen voor veel prijsfluctuaties blijven zorgen. Het warmteweb moet dus heel flexibel zijn, om goed met de prijsfluctuaties om te gaan.
Doordat handelsplatform dagprijzen geeft, zou het flexibel genoeg moeten zijn voor prijsfluctuaties.

g) **Zijn jullie bereid in het warmteweb te investeren?**
Als Energy Matters niet

INTERVIEW ROBERT KOORNNEEF (ENECO W&K)

2.a) Wat is op dit moment u rol in de warmte business?

Contract manager van Eneco W&K, verantwoordelijk voor de contracten tussen Eneco en E.ON en tuinders

2.b) Wat is u rol in het ontwikkelen van het smart thermal grid, ook wel 'warmteweb B3-hoek'?

Op dit moment probeert Robert de retour temperatuur te verlagen, dit is indirect belangrijk voor het smart thermal grid. Omdat tuinders een lagere temperatuur leveren dan E.ON, moeten de ontvangende tuinders het wate naar een lagere temperatuur koelen om genoeg warmte te krijgen. Daarnaast zal Robert als contract manager, en contactpersoon van de tuinders, een rol gaan spelen als tuinders daadwerkelijk gaan leveren aan het warmteweb.

3.a) Wat is volgens u de aanleiding van het project?

Toekomst bestendigheid, onafhankelijkheid van E.ON, betere totstandkoming warmteprijs.

3.b) Wat is volgens u het doel van het project?

Leveren en invoeden van warmte voor tuinders mogelijk maken

3.c) Heeft u bedenkingen of zorgen over het project ?

- Techniek van de tuinders is onzeker. Klanten hebben verschillende installaties(tussen 1 en 30 jaar oud), die niet allemaal een lage aanvoer en retour temperatuur aan kunnen(die nodig zijn om tuinders te laten leveren). Deze tuinders moeten dus af gestoten worden of moeten investeren. De vraag is alleen of het de investering voor een tuinder waard is.

- Het tuinders af stoten is wel een van de zorgen van Robert, er moeten er namelijk genoeg overblijven om het warmteweb in de lucht te houden. De vraag is of dat gaat gebeuren.

- Leveringszekerheid is nu extreem goed, E.ON levert bijna altijd. Straks wordt het netwerk veel afhankelijker van meer partijen en installaties, dit geeft waarschijnlijk een stuk lagere leveringszekerheid. Dit is wel heel belangrijk voor de tuinders, kan dus een probleem worden.

- WKK kan goed leveren als de aanvoer temperatuur iets verlaagd wordt (90 graden), maar het leveren van aardwarmtebronnen word op korter termijn heel ingewikkeld. De temperatuur van aardwarmte is namelijk rond de 65 graden, en veel tuinders kunnen niet met deze temperatuur overweg.

- Met ketels op het netwerk leveren is zinloos, doordat de kosten van ketels redelijk vergelijkbaar zijn. Hierdoor bestaat de leveringsmogelijkheden uit WWK en aardwarmte(die voorlopig te lage temp voor netwerk heeft). Hierdoor is productie redelijk beperkt.

4.a) Hoe ziet een ideaal smart thermal grid eruit voor u?

Een grid met een lage temperatuur (65 graden), waar veel klanten in mee kunnen met leveren en afnemen. Waardoor er voldoende aanbieders zijn, en marktwerking ontstaat.

4.b) Wat verwacht u van de warmtehandel, gefaciliteerd door AgroEnergy in het warmteplatform?

Hoop: 100% marktconforme prijs

Realistisch: Geen 100% marktconforme prijs door gebrek aan aanbieders. En contracten met E.ON, waardoor E.ON voorlopig nog veel wil blijven leveren. Het is namelijk de vraag of andere partijen net zo'n goedkope warmte als E.ON kunnen leveren. Dus marktwerking wordt heel lastig.Wel komt er prijsvariatie, waardoor het voor tuinders met buffers interessant wordt om op gunstige tijden af te nemen en dit in de buffer op te slaan.

5.a) Wat is u concrete doel van het project? (CO_2 reductie, kosten besparing, winst, mogelijkheid voor duurzame bronnen, alternatieven voor de RoCa, nuttig afvalwarmte gebruiken, prijsgevoeligheid reduceren, marktwerking, minder afhankelijkheid van 1 productiemiddel)

- *kosten beparen/winst*
- *mogelijkheid duurzamere alternatieven (WWK is efficiënter dan RoCa, dus duurzamer)*
- *prijsgevoeligheid (niet alleen afhankelijk van elektriciteit en gas prijs, maar ook aardwarmte)*

6) Hoe belangrijk vind u het project, in vergelijking tot u normale werk en andere projecten? (hoog/gemiddeld/lage prioriteit)

Voor Robert is dit het belangrijkste project. Maar Eneco als bedrijf is dit niet belangrijk, doordat het een hele kleine invloed op het bedrijfsresultaat heeft. (kleine volumes en kleine marges)

Verlaging van de warmtenet temperatuur is bijvoorbeeld veel belangrijker voor Eneco, omdat dit ook geld oplevert bij stadsverwarming

7) Heeft u alternatieve voor het ontwikkelen van het smart thermal grid, zoja, wat dan?

In plaats van een groot grid, een aantal kleinere grids (10 bv).

8) Welke aspecten mogen flexibel blijven in het warmteweb?

- **Moment van start van levering**
- **Moment van einde van de levering**
  De tuinder wil warmte wanneer hij dat vraagt(gebeurd automatisch). Maar start en einde van levering kan door buffers opgevangen worden. Dit is dus de bandbreedte.
- **Hoeveelheid gevraagde warmte**
  De hoeveel warmte die een tuinder gebruikt is niet flexibel. Maar door zelf bij te stoken, kan er wel minder dan de gevraagde hoeveelheid geleverd worden. De hoeveelheid gevraagde warmte aan het net is dus flexibel met een maximum van de gevraagde hoeveelheid.(+buffering)
- **Hoeveelheid geleverde warmte**
  Dit moet een dag van te voren al in het platform worden geboden. Hierdoor nog wel flexibel een dag van te voren.
  Maar als de tuinder zelf meer warmte nodig heeft, zal hij zijn eigen kas altijd voor laten gaan, zelfs als hij warmte voor iemand anders hoort te produceren.
- **heeft u nog andere aspecten die flexibel mogen blijven?**
  Gas is ook redelijk flexibel, dit is namelijk gekoppeld aan de warmte vraag. Door de backup installatie goedkoper te maken (collectief afspraken maken met netbeheerder) zou het houden van backup interessanter worden. Deze zou dan meegenomen kunnen worden in de optimalisatie.

Scenario's

5) **De warmtehandel is mogelijk, ook Eneco kan namens E.ON en AVR warmte biedingen op doen**
6) **De warmtehandel is mogelijk, maar de RoCa stop met produceren (scenario voor over meer dan 10 jaar)**

9.a) Wat denkt u dat de rol van u (of bedrijf), in het smart thermal grid, zal zijn in beide gevallen en waarom?

1) Rol Eneco veranderd weinig. Eneco zal dan misschien nog extra warmte van de tuinders kopen en een marge op elke Gj pakken.

2) Er is waarschijnlijk te weinig productievermogen in deze situatie. Daarnaast kan niet iedereen produceren er moet ook afgenomen worden. Rol Eneco hierin is lastig te voorspellen, misschien hetzelfde als in situatie 1.

9.d) Ziet u ook potentiele nadelen voor u of andere in deze twee situaties?

2) Als RoCa stopt en er zijn te weinig leveranciers wordt het warmteweb financieel *onhoudbaar.*

10) Specifieke vragen per stakeholder

h) Hoe wordt de onbalans opgelost?
Betaald door de veroorzaker

i) Hoe gaat het verdienmodel in de 2 scenario's eruit zien?
Vastrecht zou ideaal zijn, gewoon vaste maandelijkse inkomsten. Maar marge op de Gj prijs kan ook. Deze marge is dan wel afhankelijk van de 'meerwaarde' die Eneco kan toevoegen.

j) Hoe ziet u de energieprijs ontwikkeling ? (warmte, gas, el)
Warmteprijs is afhankelijk van warmte en gas prijs. De sparkspread zal slecht blijven, doordat gas duurder wordt en elektriciteit goedkoper. Het verdienmodel van Eneco moet dus sparkspread onafhankelijk worden.

k) Zijn jullie bereid in het warmteweb te investeren?
Waarschijnlijk niet. Marges te laag.

11.a) Spelen er nog beperkingen een rol bij het functioneren van het warmteweb, en indien ja welke?

- *Werkbaarheid van het warmteweb is heel belangrijk, de klanten moeten het kunnen snappen. De energiehandel moet niet te ingewikkeld worden.*
- *Tijd die ze moeten investeren voor de warmtehandel*
- *Risico's die tuinders extra moeten dragen mocht er iets fout gaat, bijvoorbeeld onbalans die verrekend gaat worden.*
- *Nu is de warmtevraag heel eenvoudig, ze kunnen afnemen wanneer ze willen en hoeven het niet een dag van te voren te voorspellen.*
- *Het alternatief, geen warmteweb, is misschien iets duurder, maar wel betrouwbaarder en overzichtelijker.*

INTERVIEW SONJA VAN VOOREN (ENECO W&K)

2.a) Wat is op dit moment u rol in de warmte business?

Manager speciale projecten binnen Eneco W&K

2.b) Wat is u rol in het ontwikkelen van het smart thermal grid, ook wel 'warmteweb B3-hoek'?

Als manager speciale projecten, verantwoordelijk voor het gehele 'warmteweb B3-hoek' project.

3.a) Wat is volgens u de aanleiding van het project?

Behoud netwerk en klanten.

Door de elektriciteitsprijs ontwikkeling, daling van subsidies en de koppeling van elektriciteitsprijs en warmteprijs. Is het voor E.ON steeds minder voordelig om warmte te produceren. De daling in productie is slecht voor de business case van Eneco, daardoor moet er wat veranderen.

3.b) Wat is volgens u het doel van het project?

Op een economisch acceptabele manier, voor Eneco en ook voor de tuinders. Als het voor de tuinders niet economisch acceptabel is, zullen ze niet aan het project meedoen.

3.c) Heeft u bedenkingen of zorgen over het project ?

- *Of de business case wel positief zal uitvallen voor Eneco. Technisch kan het hoogstwaarschijnlijk wel, maar tegen welke prijs en hoe het terugverdiend moet worden is onbekend.*
- *Willen de klanten het?*
- *WKK is ook stroomprijs (sparkspread) afhankelijk. Hierdoor hebben de WKK's dezelfde goede draaitijden als de RoCa. Mochten tuinders veel belichting nodig hebben 's nachts, zou het nog wel eens interessant kunnen zijn om in te voeden.*

4.a) Hoe ziet een ideaal smart thermal grid eruit voor u?

- *Lage temperatuur(65 graden, zodat ook geothermie toegepast kan worden)*
- *Autonoom netwerk*
- *Eventueel een biomassa installatie in plaats van de RoCa voor piekvraag*

4.b) Wat verwacht u van de warmtehandel, gefaciliteerd door AgroEnergy in het warmteplatform?

Tuinder handelt al op CO_2/elektriciteit/gas op het handelsplatform. Het handelsplatform moet hierbij ook nog warmte gaan verhandelen. Zodat je beter kan arbitreren op alle 4.

5.a) Wat is u concrete doel van het project? (CO_2 reductie, kosten besparing, winst, mogelijkheid voor duurzame bronnen, alternatieven voor de RoCa, nuttig afvalwarmte *gebruiken, prijsgevoeligheid reduceren, marktwerking, minder afhankelijkheid van 1 productiemiddel)*

Warmteketen optimaliseren, door kosten te besparen

1. *Economisch rendement*
2. *Duurzaamheid*
3. *CO_2(via OCAP geleverd), bij minder warmtelevering ook minder CO_2 vraag aan het net*

6) **Hoe belangrijk vind u het project, in vergelijking tot u normale werk en andere projecten? (hoog/gemiddeld/lage prioriteit)**

Het project is voor Eneco W&K heel belangrijk. In de B3-hoek zelf zijn de marges niet heel hoog, maar door de B3-hoek blijven andere projecten rendabeler. De verdeling van warmtevraag:

- *1/3 Rotterdam consumenten*
- *1/3 Rotterdam zakelijk*
- *1/3 tuinders B3-hoek → hier zijn betere stooklijnen en uitkoeling. Hierdoor wordt de warmte veel efficiënter gebruikt.*

7) **Heeft u alternatieve voor het ontwikkelen van het smart thermal grid, zoja, wat dan?**

Minder smart, wel invoeden, maar geen handelsplatform

8) **Welke aspecten mogen flexibel blijven in het warmteweb?**

- *Stooklijn flexibel, door inmengen, hierdoor kunnen meer bronnen worden toegestaan.*
- *Flexibiliteit per uur is het doel (dus elk uur andere warmteprogramma)*
- *WKK veel flexibeler dan de RoCa*

Scenario's

1) **De warmtehandel is mogelijk, ook Eneco kan namens E.ON en AVR warmte biedingen op doen**
2) **De warmtehandel is mogelijk, maar de RoCa stop met produceren (scenario voor over meer dan 10 jaar)**

9.a) **Wat denkt u dat de rol van u (of bedrijf), in het smart thermal grid, zal zijn in beide gevallen en waarom?**

1) grootste deel van de warmte zal door de RoCa geleverd worden. E.ON zal als grote producent dus wel sturend blijven in het netwerk. De rol van Eneco zou eventueel kunnen zijn, om voor E.ON op het handelsplatform te gaan handelen, en dus nog steeds warmte te kopen en te verkopen. Maar dit hangt vaan alle actoren af. Als er heel veel tuinders gaan invoeden, is het business model van Eneco onlogischer, dus dan is het beter om dit allemaal bij AgroEnergy te plaatsen.

2) Agro handelt en Eneco doet het netbeheer

9.b) **Wat denkt u dat de rol van andere partijen binnen het smart thermal grid zal zijn in beide gevallen en waarom?(wie doet de productie, handel, onderhoud, services, transport, sturen van netwerk (bv onbalans))**

2) de rol van E.ON hangt van de situatie af. Geothermie kan er bijvoorbeeld bijkomen. Productiemiddelen die economisch rendabeler zijn, zullen hoger in de merit order komen.

9.c) **Wat zijn de voordelen voor u in deze twee situatie?**

Flexibiliteit word een groot voordeel, verschillende productiemiddelen.

9.d) **Ziet u ook potentiele nadelen voor u of andere in deze twee situaties?**

Als de electriciteitsprijs blijft dalen, wordt warmte duurder (door dalende sparkspread). Hierdoor zal de productie van E.ON maar ook van WKK's een stuk duurder worden.

10) Specifieke vragen per stakeholder

a) **Hoe wordt de onbalans opgelost?**
E.ON blijft het doen zolang de RoCa een grote speler op het netwerk blijft. Daarna is het moeilijk te zeggen, eventueel wordt dat een trader die WKK's aanstuurd.

b) **Hoe gaat het verdienmodel in de 2 scenario's eruit zien?**
AgroEnergy krijgt een handelsrol en Eneco W&K wordt netbeheerder

c) **Hoe ziet u de energieprijs ontwikkeling ? (warmte, gas, el)**
- *Flexibiliteit zorgt voor toekomstbestendigheid.*
- *Duurzame bronnen zijn niet meer vraag gestuurd, maar pushen elektriciteit op de markt. Hierdoor blijft elektriciteitsprijs wispelturig.*

11.a) Spelen er nog beperkingen een rol bij het functioneren van het warmteweb, en indien ja welke?

Technische beperkingen, die door het bestaande netwerk opgelegd worden.

INTERVIEW STEPHAN MES (ENECO W&K)

2.a) Wat is op dit moment u rol in de warmte business?

System engineer bij Eneco W&K. In deze rol technisch adviseur van verschillende projecten, waaronder de B3-hoek.

2.b) Wat is u rol in het ontwikkelen van het smart thermal grid, ook wel 'warmteweb B3-hoek'?

Vanaf het begin betrokken geweest in zijn rol als technisch adviseur.

3.a) Wat is volgens u de aanleiding van het project?

Doordat de E.ON RoCa centrale "must-run" voor de warmte lijden zij veel financieel verlies. Daarnaast is de verwachting dat de RoCa meer aan de stad moet leveren door het sluiten van de EFG centrale. Hierdoor minder vermogen voor de tuinders beschikbaar.

3.b) Wat is volgens u het doel van het project?

Het warmtenet is nog niet afgeschreven, dus het geïnvesteerde geld is nog niet terugverdiend. Mocht het net niet meer gebruikt worden, moet het ook nog verwijderd worden, de kosten hiervoor zullen veel te hoog zijn.

3.c) Heeft u bedenkingen of zorgen over het project ?

- Technisch is het hoogstwaarschijnlijk haalbaar.

- Maar er kunnen problemen ontstaan met veel warmte leveranciers. Hierdoor kan de temperatuur in het net veel gaan schommelen. Wat tot vermoeiing in de buis kan leiden.

- Er zit ook nog een uitdaging in het software matig aansturen van de Warmte Levering Stations (WLS-en). Eneco moet deze WLS-en centraal gaan aansturen.

- Er moet een extra temperatuur ventiel in het systeem van de tuinder geïnstalleerd worden, om de het leveren aan het net mogelijk te maken. Eneco zou dit misschien moeten doen inclusief de aansturing hiervan, de vraag is of de tuinders dit zullen willen (baas in eigen bedrijf).

- De verliezen in het warmteweb van de B3-hoek zijn gemiddeld ongeveer 5%. Dit is ongeacht het aantal afnemers, hierdoor zullen de verlieskosten hoger zijn bij minder afnemers. Nu compenseert E.ON het verlies, betaald door Eneco. Maar bij een zelfstandig draaiend netwerk moet ook iemand deze verliezen gaan produceren.

4.a) Hoe ziet een ideaal smart thermal grid eruit voor u?

- Het net in een ring maken, hierdoor minder druk nodig bij willekeurige invoeding.

- Hooguit een back-up centrale, voor het geval dat een van de grotere leveranciers uitvalt.

4.b) Wat verwacht u van de warmtehandel, gefaciliteerd door AgroEnergy in het warmteplatform?

- Zij moeten een goede afstemming van vraag en aanbod verzorgen. Er moet dus genoeg vraag voor het aanbod zijn.

5.a) Wat is u concrete doel van het project? (CO_2 reductie, kosten besparing, winst, mogelijkheid voor duurzame bronnen, alternatieven voor de RoCa, nuttig afvalwarmte gebruiken, prijsgevoeligheid reduceren, marktwerking, minder afhankelijkheid van 1 leverancier)

- Het project is puur financieel gedreven, doordat het huidige verdienmodel inzakt.

Volgorde:

- Kosten besparen/winst

- Minder afhankelijk van 1 leverancier (E.ON)

- mogelijkheid van invoeden duurzame bronnen.

6) Hoe belangrijk vind u het project, in vergelijking tot u normale werk en andere projecten? (hoog/gemiddeld/lage prioriteit)

Essentieel voor Eneco W&K, als de opbrengsten hiervan wegvallen, ziet het er slecht uit. De afdeling W&K verdiende een paar jaar geleden een groot deel van het geld binnen Eneco. Stephan weet niet of dit nog steeds zo is.

7) Heeft u alternatieve voor het ontwikkelen van het smart thermal grid, zoja, wat dan?

- Hooguit warmtepompen gebruiken, maar dit is hoogstwaarschijnlijk geen optie.

8) Welke aspecten mogen flexibel blijven in het warmteweb?

- **heeft u nog andere aspecten die flexibel mogen blijven?**
  De WLS moet ontworpen worden op flexibiliteit, maar het optimaliseren van de WLS moet nog gebeuren.

10) Specifieke vragen per stakeholder

l) Hoe ziet u de energieprijs ontwikkeling ? (warmte, gas, el)
Op het moment is de elektriciteitsprijs laag door een overschot aan elektriciteit. Op langer termijn zal dit overschot verdwijnen en zullen de prijzen stijgen.

m) Zijn jullie bereid in het warmteweb te investeren?3
Nee waarschijnlijk niet, gedeeltelijk komt dit ook door duurzame imago van Eneco. Investeren in decentrale fossiele productie is niet heel duurzaam.

2) Wat is op dit moment u rol in de warmte business?

Hans Bunnik is algemeen directeur Bunniks Plants. Bunnik Plants is op dit moment consument van de warmte van het warmteweb.

3) Heeft u bedenkingen of zorgen over het project ?

- Op dit moment niet, Bunnik Plants is een hele blije klant. Op dit moment is het warmteweb een win-win situatie.

- Leveringszekerheid/betrouwbaarheid van het netwerk is essentieel, dit moet in de toekomst ook goed blijven.

- Eneco bepaald de prijs, hierdoor kunnen ze indirect de investeringen(in bijvoorbeeld een buffer) van de tuinders beïnvloeden.

4) Wat is u concrete doel van het project? (CO_2 reductie, kosten besparing, winst, mogelijkheid voor duurzame bronnen, alternatieven voor de RoCa, nuttig afvalwarmte gebruiken, prijsgevoeligheid reduceren, marktwerking, minder afhankelijkheid van 1 productiemiddel)

1) MVO (maatschappelijk verantwoord ondernemen)
2) Economisch rendement

5) Heeft u ideeën voor het ontwikkelen van het smart thermal grid, zoja, wat dan?

Een grote buffer bouwen in het gebied. Dit zou eventueel door een groep tuinders gedaan kunnen worden(als dit financieel aantrekkelijk is). Dit is een stuk goedkoper dan allemaal los een kleine buffer bouwen. Dit doordat de kosten per m^3 afnemen als de buffer groter wordt.

6) Welke aspecten mogen flexibel blijven in het warmteweb?

In principe kunnen de tijden van warmte levering flexibel zijn door het gebruik van buffers. Wel moet de warmte beschikbaar zijn als het in de kas nodig is.

7) Specifieke vragen

n) **Bent u bereid warmte te leveren?**
Er zijn nu geen plannen om warmte te gaan leveren, doordat Bunnik Plants alleen een ketel heeft staan. Mocht er in de toekomst door Bunnik Plants warmteproductie gebouwd worden, vindt meneer Bunnik het een interessante optie om zijn overtollige warmte te verkopen via het netwerk(daar zijn nu geen plannen voor).

o) **Bent u bereid warmte af te nemen?**
Ja gebeurd nu al. Het maakt niet uit van wie de warmte komt, zolang het maar betrouwbaar en betaalbaar is.

p) **Bent u bereid te investeren in productiemiddelen en/of buffers, zo ja wanneer?**
Op het moment wordt er niet nagedacht over investeringen. Bij veranderingen in de warmteprijs of leveringszekerheid wordt dat een ander verhaal. Op dit moment zit de warmteprijs tegen het plafond, mocht de prijs omhoog gaan worden alternatieven interessant. Zoals bijvoorbeeld bio gas, hout gestookte ketels of geothermie.

11.a) Spelen er nog beperkingen een rol bij het functioneren van het warmteweb, en indien ja welke?

Zoals boven al genoemd zijn er twee aspecten essentieel voor het warmteweb:

1) *Continuïteit*
2) *Prijs*

   Een negatieve verandering in een van beide, maakt het voor Bunnik Plants interessant om over investeringen in alternatieve productiemiddelen na te denken.

Opmerkingen:

- *De warmte van E.ON is restwarmte, maar doordat ze onhandig gebruik maken van de productie maken ze hierop verlies. Meneer Bunnik betwijfeld of E.ON echt veel verlies maakt.*
- *Het warmteweb maakt producent en consument afhankelijk van elkaar, daardoor moeten ze met elkaar door ontwikkelen om de continuïteit te waarborgen.*