Heat Energy Market
Energy Trading in District Heating Systems

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Delft University of Technology

MSc Thesis Complex Systems Engineering and Management

TUDelft Delft University of Technology

Challenge the future

Heat Energy Market

Energy Trading in District Heating Systems

By

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in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE
in **Complex Systems Engineering and Management**
Faculty of Technology, Policy and Management

at the Delft University of Technology,
to be defended publicly on Wednesday October 30, 2019 at 03:00 PM.

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Preface

Here in front of you lies the Master thesis I have been working on in the past six months. It concludes my six years as a student at the Faculty of Technology, Policy and Management. I was very fortunate to be able to combine my thesis with an Internship at AgroEnergy. I have always had an interest in Energy Systems and lately I specialised in District Heating during course projects and this thesis. In my time at AgroEnergy I have learned a lot and I was able to apply my background in System Engineering (Energy) in practice. I am grateful that AgroEnergy allowed me to start early on and help me scope my research. I would like to thank all people whom I have worked with and supported me throughout this period.

First and foremost, I would like to thank my thesis committee. I would like to thank Dr. ir. L. de Vries for being my first supervisor and providing critical feedback on my work. I liked the fact that deadlines were set early on and our meetings were few, but fruitful. Next, I want to thank Dr. ir. G. Bekebrede for her feedback on the simulation study. I am more familiar with computer simulation studies, rather than interactive ones. With her help I was able to take a company experiment to an academic level. I want to thank E. Valkenburg especially for being my external supervisor. When I applied we quickly discovered a match between their project and my thesis subject. I am glad I was a part of this project and I want to thank E. Valkenburg for answering all my questions and giving me an in-depth look in the world of energy supply.

Second, I want to thank my other colleagues at AgroEnergy. I want to thank R. Vellekoop for working on the WarmteDagMarkt project and introducing me to horticulture companies. I had a fun time gathering and predicting the results of the settlements each day. I also want to thank R. Versteeg for explaining most of the technical components of heat supply and R. Grootscholten for providing me with a lot of the data I used in this thesis.

Lastly, I want to express my gratitude to my family, friends and housemates for supporting me. I want to thank my parents for supporting me at home and in Delft. Finally, I would like to thank my friends and housemates for having the best years of my life as a student time in Delft.

L.J.A. van Gestel
Delft, October 2019

Summary

A transition is taking place in the Dutch horticulture sector, because the use of natural gas for heating must be reduced. To reach this goal, different parties have started the development of district heat networks and the development of carbon-neutral heat energy production. This has resulted in an increasing amount of district heating networks in the horticulture areas. However, the present system and market configuration have some downsides.

In short, the bilateral contracts result in a price that does not reflect the actual value of heat (due to risk hedges and link to the gas price) and it is impossible for producers and consumers to trade energy in the short run. This has resulted in the desire to implement a short term heat energy market, where energy can be traded (day-ahead) and where the price of heat energy is determined by supply and demand, similar to the gas and electricity market. Moreover, this type of District Heating System (DHS) is not bound by any regulation, so the stakeholders in the system are able to organise the way they trade energy themselves. According to AgroEnergy, an energy supplier for horticulture companies in a DHS in the region of Oostland, there is a willingness of producers and consumers to trade energy in the short run. This would give producers more flexibility to optimize their heat production financially, and consumers will be able to manage their energy demand better. Also, horticulture companies expect to get a fairer price for energy when competition is introduced among producers. However, if producers have considerable market power, such a short term market is still prone to market failures.

The characteristics of a DHS for horticulture companies make the implementation of a short term market promising, but the question is how it can be designed and if it will perform well, meaning prices will converge to marginal cost levels. Will a short term market still have dominant producers with considerable market power? After consulting the literature there still remained a knowledge gap on how a short term market can be designed and how this market will perform as a result of producer and consumer behaviour.

The aim of this research is to investigate how a short term market can be designed for a DHS in the Netherlands, how producers and large consumers behave on a short term market and how this affects the performance of the market. A DHS with only horticulture companies as consumers is selected as a case study for which we will design a short term market. The case that is selected is a DHS in the B3-Hoek (Lansingerland) in the province of Zuid-Holland. An analysis is done on the performance of a short term market that is based on the case. We simulated a short term market by inviting real producers and horticulture companies to take part in the simulation. With the participation of real stakeholders in this research, we are able to identify the characteristics of their behaviour based on their decisions and actions to make our conclusions more valid. To achieve our research objective, the following research question has been formulated:

How can a short term market be designed for large consumers in the DHS of the B3-Hoek?

To answer the main research question, the following research sub-questions are formulated:

SQ 1) What market design for the DHS in the B3-Hoek can be used to facilitate short term energy trade?
SQ 2) What is the behaviour of actors in the market and how does this affect the performance of the market?

First, the present market model of the DHS in the B3-Hoek is described so we can identify what institutional changes and corresponding technical changes have to be made to introduce a short term market. The present market model is shown in Figure 1 and Table 1:

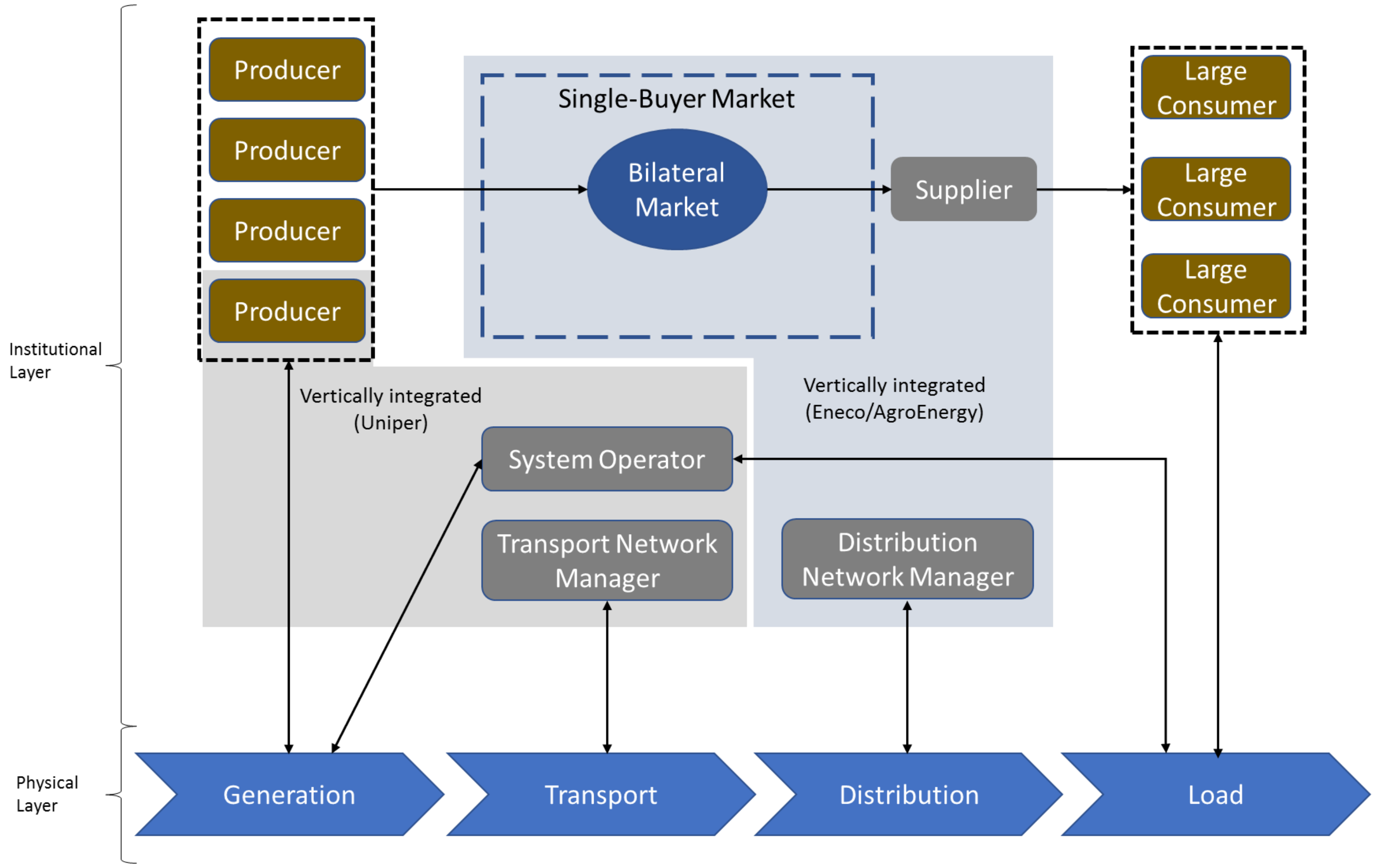

Figure 1 - Market model of the DHS in the B3-Hoek

The figure shows the conceptual model of how the heat market is currently organised. All producers and consumers sell/buy energy from AgroEnergy (Eneco). Eneco is also the supplier and distribution network manager. The system operator and transport network manager is Uniper, who is a producer of heat energy as well. The table shows the implementation of each design variable for energy market design, see Correljé & de Vries (2008).

Table 1 - Design variables currently used in the DHS of B3-Hoek

Design variable	Implementation
Public vs private ownership	Only distribution and supply are owned by a public company. The other parts of the system are privately owned.
Network unbundling	Part of production, system operation and transport are bundled (accounting). Distribution and supply are bundled (administratively).
Network access conditions	Access to the network: ex-ante negotiated. Access to capacity: timetabling. TPA wholesale level
Integrated vs decentralized	Decentralized, but some degree of integration.
Degree of market opening	Single-buyer market
Competition policy	Unregulated. Competition with the natural gas system
Congestion management	Not implemented
Arrangements with neighbouring networks	The waste incineration plant delivers heat via the Rotterdam network to the B3-Hoek and Uniper must allocate production capacity to the city DHS, before using it for the DHS in the B3-Hoek
Balancing mechanism	System operator with production assets
End user price regulation	No regulation. Contracts determine price (connected to gas).
Capacity mechanism	Not implemented

Design variable	Implementation
Position of regulator	No regulation for price or access. Province and municipalities give construction and production permits. Some production is subsidized by the Ministry of Economic Affairs.

For the new market design, every design variable was analysed and the alternatives that would best suit the short term market were chosen. The result of the analysis is a new market model and system configuration, shown below in Figure 2 and Table 2:

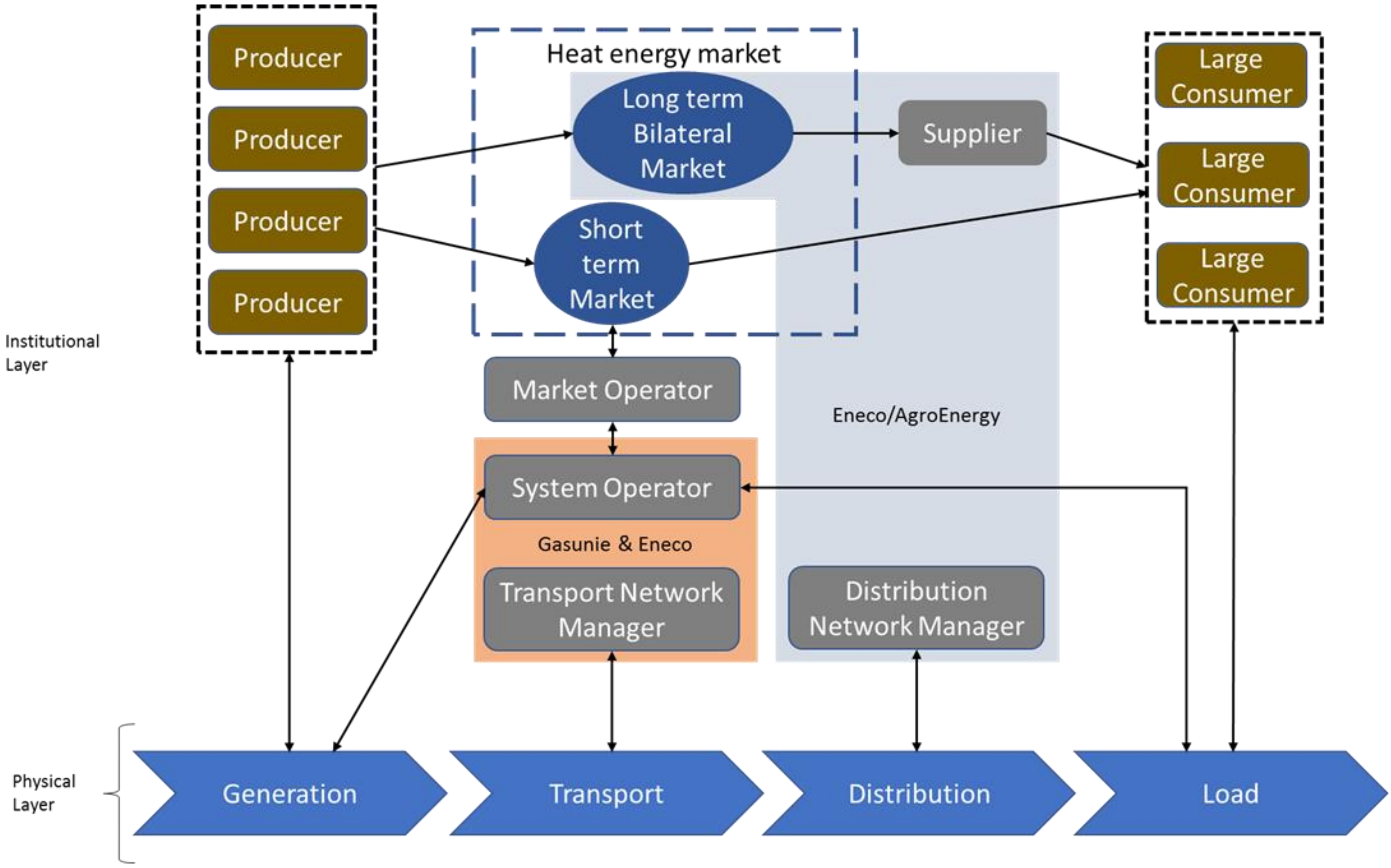

Figure 2 - Market design proposal for a short term market

Table 2 - Design variables for a short term market in the DHS of the B3-Hoek

Design variable	Implementation
Public vs private ownership	Private producers, public-private system operator and transport network manager, private distributor, private market operator.
Network unbundling	Production unbundled from network activities, system operation and transport management are bundled (ownership). Distribution and supply are bundled (administratively), Market clearing unbundled from system activities.
Network access conditions	Access to the network: ex-ante negotiated. Access to capacity: pooling. TPA wholesale level
Integrated vs decentralized	Decentralized, contracts between market operator for dispatch and system operator for balancing.
Degree of market opening	Wholesale market
Pace of market opening	By 2025, see paragraph 2.2
Competition policy	Unregulated. Competition with the natural gas system
Congestion management	Not implemented, see paragraph 2.2

Design variable	Implementation
Arrangements with neighbouring networks	The waste incineration plant delivers heat via the Rotterdam network to the B3-Hoek and Uniper most allocate production capacity to the city DHS, before using it for the DHS in the B3-Hoek
Balancing mechanism	System operator contracts Uniper for regulating capacity in the short term. In the long run demand-side management with distribution models combined with the buffers at horticulture companies
End-user price regulation	Regulatory control on transport costs. No regulation for market prices. Market clearing determines the market price.
Capacity mechanism	Not implemented, see paragraph 2.2
Position of regulator	Regulatory control on access and tariffs in the transport network. Province and municipalities give construction and production permits. Some production is subsidized by the Ministry of Economic Affairs. Public investment in the transport network is possible.

By comparing the proposed design with the present market model it can be concluded that three changes have to be made in the system. First of all, Uniper is currently the main producer in the DHS and is the owner of the transport line in the network. In the short term market, other producers should be allowed to enter the market. This means that non-discriminatory access conditions are required in the new market model. Therefore it is necessary to unbundle the production and network activities of Uniper. A private-public hybrid company of Gasunie & Eneco is suggested as the new owner of the transport network. Combined they have the necessary experience and tools to manage this part of the network. Non-discriminatory access condition and tariffs can be determined by Gasunie if they have a majority in shares.
Secondly, the short term market also introduces a new way of determining the dispatch of producers. This introduces a new role in the DHS, namely the role of the market operator. The short term market requires a market operator who will determine the dispatch, based on a uniform double-sided auction. An independent party should take care of this role to guarantee a level playing field for competition between producers and horticulture companies.
Lastly, the role of the system operator should be transferred to Gasunie & Eneco. However, due to the technical characteristics of the DHS they will have to contract Uniper in the short run to maintain balance in the system. In the long run, if horticulture companies invest in buffer capacity, demand-side management can be applied to balance supply and demand in the network throughout the day. Another option is to implement an intraday market as well, but this was not investigated in this research.

This concludes the first sub-research question: *"What market design for the DHS in the B3-Hoek can be used to facilitate short term energy trade?"*. However, the design is a conceptual model of the rules, operations and coordination deemed necessary for a short term market to function without the negative influence of undermining incentives, market power and opportunistic behaviour. It is also the question whether the short term market will perform well, given the (technical and economical) characteristics of the DHS in the B3-Hoek. This brings us to the second research sub-question: *"What is the behaviour of actors in the market and how does this affect the performance of the market?"*. In order to answer the second research sub-question, an interactive simulation was created. Horticulture companies and producers participated in a virtual short term heat market (day-ahead) with changing market conditions. The total demand during the simulation followed a trend from winter (where demand is high) to summer (where demand is lower). We monitored their behaviour and were able to quantify the market outcome. This helps us to evaluate performance indicators of the short term. In the simulation, only the trading activities were included because we are interested in the market performance and not in the physical performance of the DHS. Therefore the roles of the system operator and network manager were not present in the simulation. It is assumed that the physical flows are facilitated by both these actors in accordance with the results of the market settlement, without the need for balancing or congestion management.

By analysing the behaviour of the participants it was found that, when demand is high, producers are better able to increase their profits by strategically offering some of the capacity at higher prices. When demand decreases the room for this profit-seeking behaviour becomes less as it will yield a higher risk of not being settled. The behaviour of producers can be theoretically described as Cournot competition, where the output level of production is strategically used to increase profit. This behaviour of producers was identified in the simulation under tight market conditions. This means that, during winter the heat prices do not reflect the marginal costs of production in the DHS.
The growers collectively managed to put pressure on the producers to lower their offer price when market conditions became wide. The demand curve of the horticulture companies is very elastic, because of their own heat production asset (boiler). In tight market conditions, the demand curve is close to the level of producing heat with a boiler. When demand decreases and market prices become lower, the growers start neglecting their alternative costs as the bid price level. They take an expected level of the market price as the new bid price level. The result of this collective behaviour is that the demand curve not only becomes shorter (because of less need for heat energy) but also lowers. This puts pressure on the producers to offer at marginal cost levels. It means that during summer the heat prices do reflect marginal costs of production in the DHS.

For the analysis of the performance of the short term market, five performance indicators are used for evaluation. The results of the simulation show that a short term market can perform fairly well:
- Non-discriminatory access conditions to the system can be ensured by Gasunie
- The market prices will be lower than self-production
- When there are wide market conditions, competition on the production side increases and producers will offer their energy close to their marginal cost. However, in tight market conditions prices are above marginal costs and closer to the cost of self-production. This does allow the producers to make profits.
- Sufficient energy will be traded in a short term market, as long as the production costs of producers is lower than the cost of using a boiler.
- Stakeholders were positive about their experience in the simulation and the concept of including a short term market in this system.

Through this research, we were able to identify the reciprocity between behaviour and market performance. When the market conditions are tight, the dominant strategy for producers is to undercut their competitors and strategically use prices and production quantities to maintain market share and receive a price higher than marginal cost (Cournot competitive behaviour). As a consequence more profits can be made. The producers have a volunteer's dilemma who should use market power to drive up the market price so that all producers can benefit from this. However, this type of behaviour changes when market conditions become wider. In that case, producers start offering closer to their marginal costs.
The best strategy of growers would be to collaborate, but the individual has the incentive to deviate from this collaboration. This research has shown that the behaviour and choices made by horticulture companies could lead to implicit collaboration and to pressure the market price downwards.
The results of the short term market will not be those of a perfectly competitive market, meaning that the market price will always be at the marginal cost level of the price-setting producer. This is because producers will behave in a Cournot competitive way and strategically use prices and quantities to make more profits under tight market conditions. When supply exceeds the demand in wide market conditions, the market price will be closer the marginal cost level of the producers. Nevertheless, the market outcomes in both periods are considered desirable for both horticulture companies and producers. Horticulture companies benefit from lower costs of heat in a short term market compared to their alternative costs and producers are able to make profits.

Combining the answers of the research sub-questions concludes the main research question. A market design proposal was developed and the changes that need to be made in the DHS to include a short term market were presented. We have identified how producers and consumers behave and shown that the performance of the market scores well on the performance indicators. In this research, it was assumed that more producers enter the market in the near future and all horticulture companies will have buffers. Neither is currently the case and it is expected that with the current market share of Uniper and the system properties of the DHS in the B3-Hoek, market prices will be dominated by Uniper. A cost-benefit analysis was not performed to determine whether changing the system to facilitate a short term market is cost-efficient. Nevertheless, we showed how a short term market can be included in the system and that this can be a promising concept for short term trading. The following practical recommendations are identified for the implementation of the short term market.

Currently, the dominant position of Uniper in the DHS is a barrier for the implementation of a heat market. By 2024 the supply contracts between Uniper and Eneco come to an end. This is an opportunity to make the necessary changes in roles and ownership of system components. Therefore its recommended to already start drawing up a business case to check whether it is financially interesting for Gasunie and Eneco to obtain ownership. AgroEnergy should initiate this.

Furthermore, ArgoEnergy should do a technical analysis of the changes that have to be made to support a short term market. This technical analysis will also form the basis of the financial analysis about the costs that are involved for changing the system and its new operational structure. Are the transaction costs and investments worth it when changing the market structure?

The short term market requires a market operator, thus AgroEnergy should start looking for a company that is willing and capable of performing this role.

On top of that, AgroEnergy could start with an experiment where horticulture companies are allowed to trade their heat energy positions with each other. This could be a step towards short term trading when the new market model is not implemented yet.

Lastly, AgroEnergy should do a market consultation in the B3-Hoek to question more stakeholders about their opinion on the short term market implementation in the future.

The following recommendations are given for future research; A future exploration study could be done to investigate how the gas prices and costs of alternative heat production methods change in the future. Will these alternative production methods be cheaper than using natural gas and when will this happen? The answer to these questions will inform heat network developers and policymakers on what can expect in the near future and give them the opportunity to take measures that make district heating cost competitive to gas.

The behavioural characteristics of the growers and producers found in this research can be used in a large scale computer simulation. The technical characteristics and constraints have often been neglected or simplified in the research of heating markets. The supply pattern of different heat production methods (CHP, geothermal, biomass, waste incineration and waste heat from industrial processes) and the demand patterns of horticulture companies throughout the year can be modelled to check whether there is enough capacity (production and transport) in the system and how much buffer capacity is needed for balancing purposes. Agent-based modelling could be used to develop such a model.

We have already mentioned that the liquidity of a heat market can be improved by adding an intraday market. Future research should explore the frequency by which an intraday settlement should take place. This can be discovered by analysing the production flexibility within the system and the operational time it takes to re-dispatch.

Lastly, it is recommended to perform more in-depth research into the market-clearing procedure by means of stakeholder consultation and process analysis. Most producers generate electricity and heat energy that need to be sold in different markets. The valuation of electricity and heat is co-dependent. Future research should investigate how producers should proceed in their valuation for energy production and how the settlement process of the heat market should be shaped to complement the settlement process of the electricity market.

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Introduction

1.1 Background

An energy transition is taking place in the Dutch horticulture sector (Ministerie van Landbouw Natuur en Voedselkwaliteit, 2014). After the Paris agreement (UNFCCC, 2015) and plans to decrease the natural gas production of the Groningen gas field from 2018 until 2022 (Ministerie van Economische Zaken, 2018), the Dutch horticulture sector made an agreement with the Dutch government to reduce CO_2 emissions to a total amount of 6.2 Mton by 2020. This agreement has been revisited in 2017 to a total amount of 4.6 Mton CO_2 emissions by 2020 (Ministerie van Landbouw Natuur en Voedselkwaliteit, 2017).

In order to achieve the goal in 2020, CO_2 emissions will need to decrease further by 1.3 Mton (from 5,9 Mton in 2017 to 4,6 Mton), but future predictions indicate this goal will not be accomplished (van der Velden & Smit, 2018). The main contributor to carbon emissions in the Dutch horticulture sector is the use of natural gas for heat energy. Natural gas is currently the dominant source of heat energy for the horticulture in the Netherlands (Centraal Bureau voor de Statistiek, 2014). In 2015, the Dutch cabinet proposed their future plans for heat energy in the Netherlands in the so-called "Warmtevisie" (Ministerie van Economische Zaken, 2015). This letter explains the need for new heat energy sources and new infrastructure to reduce the use of natural gas and thus the CO_2 in the Netherlands. One of these requirements is the development of district heating networks and the use of sustainable energy sources, like residual waste heat, biomass and geothermic energy. The transition from natural gas to sustainable sources is adopted in the "Van Gas Los" movement and the future vision of LTO Glaskracht to make the Dutch horticulture become carbon neutral by 2040 (LTO Glaskracht Nederland, 2018).

To reach these goals, different parties have started the development of district heat networks and the development of carbon-neutral heat energy production. This resulted in an increasing amount of district heating networks in the horticulture areas. District Heating Systems (DHS) can be classified in different categories depending on the type of consumer in the system: Industrial and Non-industrial (Ecorys, 2016; Oei, 2016b). Industrial DHS operate with high temperatures (100° Celsius or higher) and provide heat for industrial processes. Non-industrial DHS operate on lower temperatures (between 80° – 100° Celsius) and provide heat for city heating networks, block heating, heat cold storage networks and horticulture companies. A distinction can be made between small consumers and large consumers because of the Dutch regulation of DHS described in the Heat Act (Ministerie van Economische Zaken, 2019). The Heat act covers legislation for heat energy supply to small consumers, like households and small companies who have a connection capacity below 100kW. The Autoriteit Consument en Markt (ACM) checks if suppliers comply with the Heat Act. In summary, the Heat Act covers:

- Maximum tariff of heat
- Under which conditions a heat supplier may disconnect a consumer
- Financial compensation for consumers during outages
- Content of contracts between consumers and suppliers
- Handling disputes
- The obligation of the supplier to provide a smart meter

DHS with only large consumers, who have a connection capacity larger than 100kW, are outside the scope of the Heat Act. These are heat networks that connect producers with industrial companies and/or horticulture companies. In this research, the focus is on networks with only horticulture companies connected in a DHS (as consumers), because there is a desire to change the way these systems are configured.

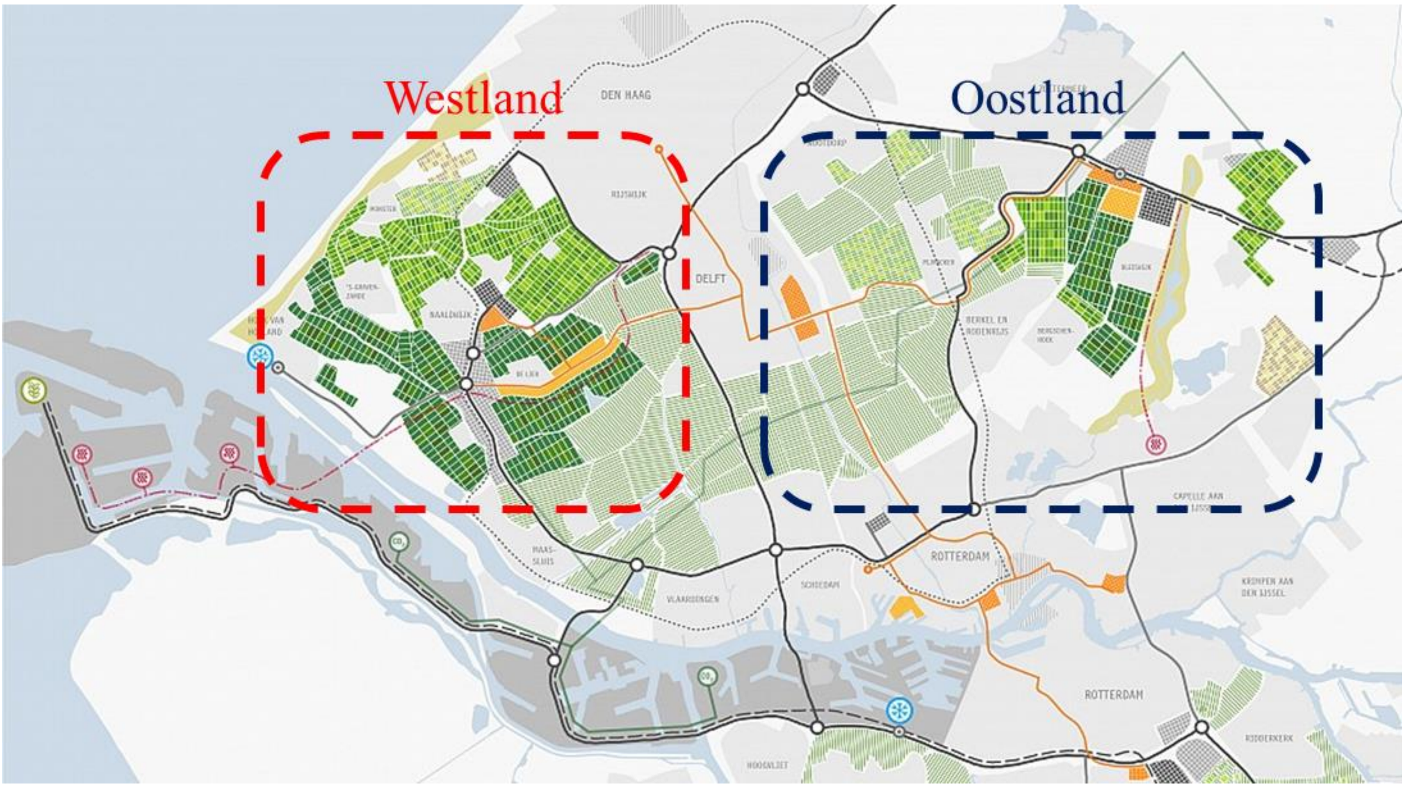


Figure 3 - Horticulture regions Zuid-Holland: Oostland and Westland (Source: van Bergen Kolpa Architecten http://www.vanbergenkolpa.nl/nl/604_greenport_westland_oostland.html)

In the province Zuid-Holland there is a high concentration of horticulture companies in two regions: Oostland and Westland. Here district heating networks have been developed to connect the horticulture companies to the residual waste heat from the port of Rotterdam or to local heat sources. The province Zuid-Holland wants to expand the network and connect the current heat networks. This project is called "WarmteRotonde". Their vision is to develop a transport network stretching from Rotterdam to the Hague, Leiden and municipalities in between and create an "open heat network", see Figure 4. This means that producers and consumers have non-discriminatory access to the heat network, are free to trade heat energy and where the price of heat energy will be determined by the market (CE Delft, 2015). The envisioned system is similar to the Dutch natural gas system and electricity system. However, DHS has certain characteristics that make the development of an "open system" or "free market system", like in the gas and electricity system difficult. There are high capital expenditures for infrastructure and assets, they are localized, have large transport losses, high entry barriers and limited availability of resources (Oei, 2016a; van Woerden, 2015). These characteristics are reasons why DHS today are mostly vertically integrated with one or few producers where transportation, distribution and delivery are organized by one company (CE Delft, 2015). Producers and single-suppliers have market power, because they have a natural monopoly in these systems. This causes potential market failures such as high prices and there is a lack of freedom of choice for consumers. Regulation is used to counter market failures,
but our system of interest is outside the scope of the Heat Act. This has resulted in the current market model of DHS for horticulture companies, where heat energy can be purchased through long term bilateral contracts with a single supplier. However, there are a few aspects to this market model that create an undesired situation for horticulture companies and producers.

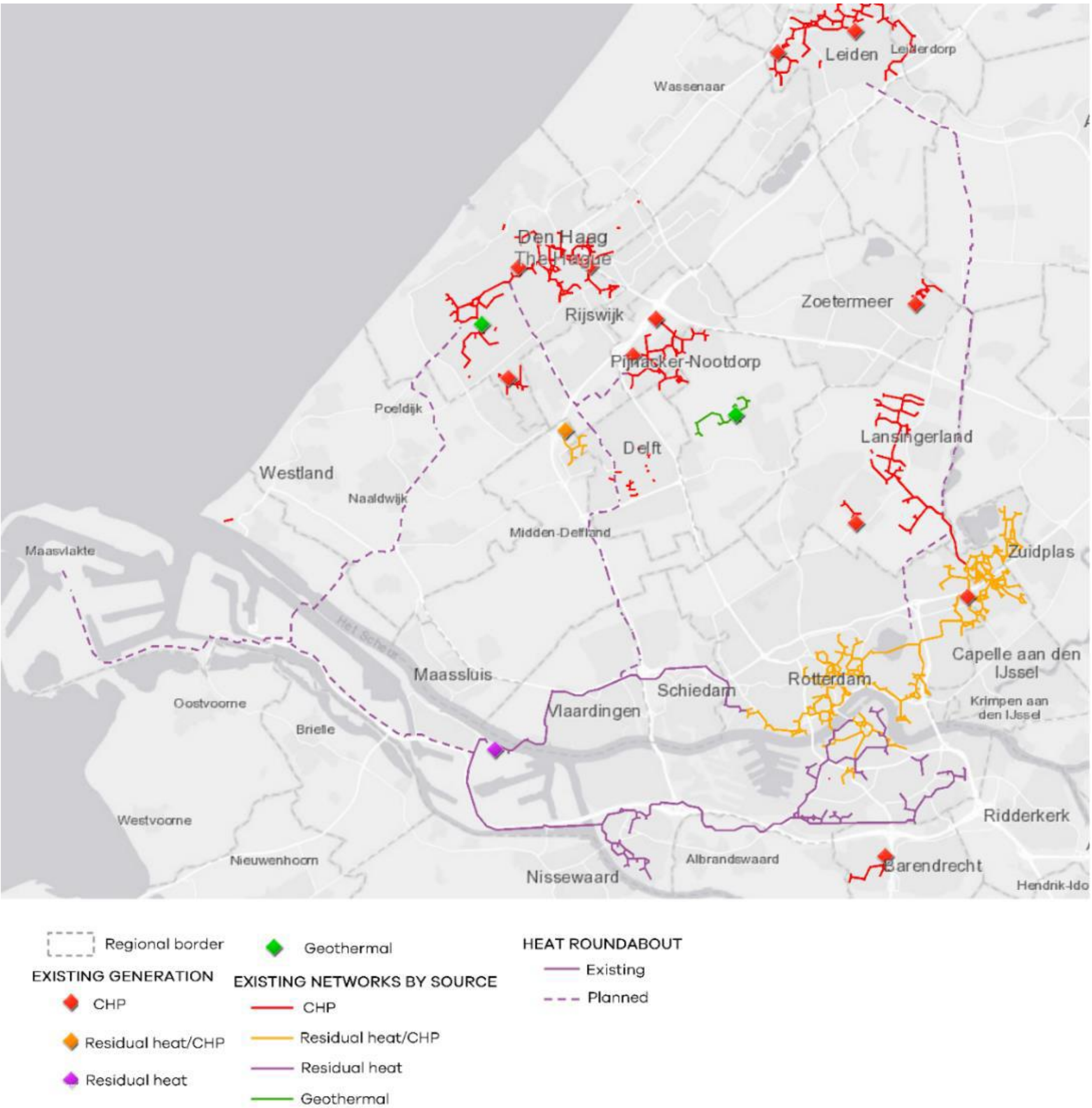


Figure 4 - Heat network vision Zuid-Holland (CE Delft, 2015)

1.2 Problem Statement

The first undesirable aspect of these bilateral contracts is the way the price is formed. One supplier negotiates a price for long term energy supply with consumers and producers. They contract a position to consume or produce heat energy over a specified period (year or quarters). The heat energy price rises due to a combination of market power of the supplier and the risks of the long term positions. Suppliers hedge the risk in their contracts with the consumer who then pay a price which is higher than the true value of supply. The supplier runs the risk that consumers do not use and/or pay the amount of energy they have contracted. This happens when too much energy is contracted or the consumer does not require the contracted amount of energy in the case of a warm winter or crop failure. This gives the incentive to suppliers to negotiate higher prices for consumers by including a risk premium. Producers also run a risk when they commit themselves to future production of heat energy. Prices that are set in the past might not cover future costs of changing fuel costs or market conditions. This incentivises producers to inflate their costs and negotiate for higher prices.

Also, the way heat energy is currently priced in the contracts is undesirable. As electricity and gas, heat energy can be considered a commodity, since the quality is not dependent on how it is produced. It is an interchangeable good. Nevertheless, it does not have its own commodity price. Currently, the price of gas is the dominant indicator of the price of heat. The reason for this is that a lot of heat production systems for horticulture in the Netherlands use natural gas as fuel and it is, therefore, the main component of the marginal cost of production. Therefore it is used as a reference price. Other heat energy sources used in biomass, residual waste heat and geothermal plants have different marginal costs that do not relate to the costs of gas. However, the price for heat energy from these sources is still indexed to the price of natural gas in contracts. This price-setting method must change in the future where gas will not be the dominant energy source for heat.

The last undesirable aspect of bilateral contracts is that the consumers and producers take a risk when selecting a contract volume position. They contract a specific amount of energy that they will likely consume/produce in a certain period. Horticulture companies need heat energy for the growth of their crops. The amount of energy they need is very dependent on the weather. Especially during the winter, a cold or warm winter influences energy usage significantly. Long term weather predictions are very difficult to make correctly, thus there is a risk of not contracting enough or too much energy. Currently, AgroEnergy (the single-supplier in the DHS) offers heat energy in the short term for a variable price calculated by costs of supplying this additional amount (cost-plus pricing method). If horticulture companies bought too much energy, they still pay for the total contracted amount even though some volume has not been used. This is referred to as “Take-or-Pay” contracts.
Producers are tied to contracts that determine their production output. However, the gas and electricity markets determine a large part of the costs to run the plant. The price of gas changes daily and the price of electricity even changes per hour. Therefore most producers want to produce at times when the electricity and gas market conditions are favourable. Today there are occasionally unprofitable “must run” situations. Producers do not have the flexibility to determine when and how much heat energy they want to produce, due to the contracts and bilateral market structure.

In summary, in the current market structure the price does not reflect the actual value of heat (due to risk hedges and link to the gas price) and there is no way for producers and consumers to trade heat energy short term. This has resulted in the desire to implement a short term heat energy market, where energy can be traded in the short-run (besides the long term bilateral market) and where the price of heat energy is determined by supply and demand, similar to the gas and electricity market. However, such a short term market is still prone to market failures if producers have considerable market power. Their dominant position could allow them to abuse their market power by setting the price for heat higher than the marginal costs. For instance, Åberg, Fälting, & Forssell (2016) have found that in Sweden, where the heat market is deregulated, district heating companies have considerable market power and are able to set high prices. Under perfect market conditions, price and volume should converge to the marginal cost levels of the price-setting power plant as a result of competition (Weintraub, 2007). This begs the question why a short term heat market in an unregulated DHS for horticulture companies would not fail because of market power abuse by producers? The answer to this question lies in a unique technical characteristic of horticulture companies in such DHS.

Horticulture companies have their own heat production assets, even though they are connected to a heat network. Insurance companies demand that each horticulture company connected to a heat network also has an additional heat source, in the case of outages or failure in the DHS. Also, the supplier (AgroEnergy) does not guarantee the supply of heat energy. Therefore all horticulture companies have a gasfired boiler and some also have a combined heat and power unit. Combined these assets have enough capacity to produce their heat demand, even in cold periods when a lot of heat energy is needed. This alternative source of heat makes a

horticulture company less reliant on a producer, thus the market power of the producer is limited. When the producer asks a high price, a horticulture company will decide to produce heat himself if that option is cheaper. Moreover, since this type of DHS is not bound by any regulation, the stakeholders in the system are free to organise the way they trade energy themselves. According to AgroEnergy, there is a willingness among producers and consumers to trade energy short term. For producers, it would give them more flexibility to optimize their heat production financially and consumers are able to manage their energy demand better. Also, horticulture companies expect a fairer price for energy when competition is introduced among producers.
These characteristics make the implementation of a short term market promising, but the question is how it can be designed and if it will function well. Will a short term market still have dominant producers with considerable market power? Do agents behave strategically to influence the market price? A literature study was done to see if these questions can be answered by the current literature or there remains a knowledge gap.

Literature

To conduct the review of the literature on DHS, the search engines Google Scholar and Scopus have been used. Keywords such as "district heating systems", "competition in district heating", "district heating market", "heat energy wholesale market" and "district heating network" have been used to find relevant literature. By a process of snowballing and going back and forwards between papers, more were found. Papers were selected if they discussed competition in heat energy systems, short term/wholesale trading, district heating markets, DHS market design or economic behaviour related to energy markets. The results of the literature search is discussed below.

The literature on DHS is growing in recent years. There is a lot of research being done into the development of district heating, but they are either technical studies of networks and production assets or talk about/evaluate the market design of DHS in other countries. It is found that most heat energy sectors are still regulated, while Denmark and Sweden have deregulated the market. For further reading, see (Åberg et al., 2016; Brange, Englund, & Lauenburg, 2016; Grohnheit & Mortensen, 2003; Klein, 1996; Li, Sun, Zhang, & Wallin, 2015; Lund et al., 2018, 2014; Magnusson, 2016; Mazhar, Liu, & Shukla, 2018; Paiho & Reda, 2016; Pirouti, Bagdanavicius, Ekanayake, Wu, & Jenkins, 2013; Rolfsman, 2004; Sayegh et al., 2017; Söderholm & Wårell, 2011; Song, Wallin, & Li, 2017; Syri, Mäkelä, Rinne, & Wirgentius, 2015; Werner, 2017; Wissner, 2014; Zhang, Ge, & Xu, 2013).
To the best of our knowledge, there are currently no examples of DHS where are short term market for producers and consumers is implemented. To scope the literature review on the design of this market model in a DHS, it was chosen to only include research that was done in the context of the Netherlands. Five studies were identified when looking for literature on DHS market design in the Netherlands and consumer/producer behaviour[1] in a short term market.

A study done by Bijvoet (2017) looked into the competitive behaviour of producers and consumers in an open district heating network. She developed a conceptual model of a wholesale market with a spot market for short term heat energy trade between producers and large consumers. Here, horticulture companies were considered as large consumers in the DHS as well. She found that unbundling ownership of the network and production activities was necessary to allow new producers to connect to the network and stimulate competition. The owner of the network should not be allowed to dictate unfavourable and/or discriminatory terms for new producers that ask for access to the network. A limitation of the suggested market model is that the focus was only on the economic institutions. There was no analysis done on the technical characteristics of a DHS. These can impose constraints for the institutional design in DHS, such as network ownership and access conditions. Also, an agent-based model was used to investigate the behaviour of producers and horticulture companies in a spot market. Her findings show that that strategic behaviour of greenhouse owners prevents producers from

[1] In this research we classify behaviour as the valuation of heat energy by a consumer or producer. This means that we look into what price points are chosen for an amount of heat energy volume in the bids/offers from consumers/producers in a heat energy market.

exercising their market power and the ability to drive market prices up. However, the limitation of this conclusion is that the bidding strategies were developed by the researcher. It would be interesting to find out in practice how actual producers and horticulture companies would develop a strategy if they did the bidding themselves. This would be a more valid way to investigate their behaviour and the outcome of a short term market. Also, the model was based on a DHS that still needs to be developed. It would be interesting to use an existing and matured[2] DHS as case, so that market conditions in a model correspond better to reality.

More research into market design for DHS was done by Oei (2016) and van Woerden (2015). Their research focused on the identifying design variables for a market model for the district heating sector in the Netherlands. Policy instruments and design choices were proposed for the design of a market model. The scope of Oei was for the whole district heating sector rather than a specific DHS. Oei suggested policymakers can draw lessons from the Danish and Swedish market model for the Dutch heating sector. Van Woerden focused on a case in the municipality of The Hague and suggests a single-buyer model where multiple producers are able to gain access to the system. Both studies have a different scope and were not aimed at designing a short term market. Nevertheless, lessons can be learned about their design approach and choice of design variables.

Lastly, research was done on developing an open heat market in the Province of Zuid-Holland by Guichard (2018) and van der Ende (2018). The focus of Guichard was on how to deal with transport losses and heat energy should be priced in order to allow for cost recovery while simultaneously pursuing affordability. The research aimed to understand the effects of different pricing mechanisms and cost allocation methods on the performance of a heat market according to a nodal pool model. A system model and price calculation algorithm were used to measure the effects of average cost pricing (ACP), system marginal pricing (SMP), locational cost pricing (LCP), locational marginal pricing (LMP) and locational hybrid pricing (LHP). It was concluded that LMP performs most consistently on both affordability and cost recovery, followed by ACP, SMP. The LHP alternative that was developed performed worst overall. The conclusions are based on the premise that producers offer energy at cost levels and strategic bidding behaviour was neglected.
Van der Ende investigated the cost efficiency of two approach for CO_2 abatement by developing district heating in the province of Zuid-Holland. The Netherlands Environmental Assessment Agency (PBL), and the Province of South Holland (PZH), think differently about how district heating should be implemented. The PBL adopts a local market-driven perspective on energy transitions, forecasts depend on the Vesta/MAIS model. The PBL expects that this approach will result in the distributed development of small-scale district heating networks. The PZH adopts a regional, plan-driven perspective on energy transitions, the approach is plan-driven and the forecasts depend on negotiated knowledge with large uncertainty margins. Based on this comparison of the approaches, she found a trade-off between cost-effective CO2 abatement, and maximizing the overall reduction of CO2 emissions. The scenarios of the PZH in general result in higher levels of CO2 abatement and the scenario of the PBL is more cost-effective. In the research, it was assumed that horticulture companies are active on the same market as small consumers (household and small businesses), which is not the case. Although this was not considered, the research of van der Ende had similarities with the scope of this research. Therefore it provides insights in plans and developments of district heating in Zuid-Holland.

The literature mentioned above provides meaningful insights into our problem, but a knowledge gap remains. Bijvoet has provided the most relevant insights but lacked technical validation and real actor behaviour. The others had a different scope or similar one but investigating another problem. Nevertheless, they provide insight into the tools that can be used for market design. However, there still remains a knowledge gap on how a short term market can be designed and how this market will perform as a result of producer and consumer behaviour.

[2] A matured DHS is one with multiple producers and multiple consumers, where heat energy is transport through a heat network (transport and/or distribution network).

1.3 Research Objective and Relevance

To fill the knowledge gap, the aim of this research is twofold. The first goal is to investigate how a short term market can be designed for a DHS in the Netherlands. The second goal is to find out how producers and large consumers behave in the short term market and how this affects the performance of the market. A DHS with only horticulture companies as consumers is selected as a case for which a short term market will be designed. Market design refers to the organization of the market place (de Vries & Verzijlbergh, 2018).
In the first part of the research, the current system will be discussed in more detail and it is explained what institutional and technical changes have to be made in the case system for a transition towards a new market design. The second part discusses a short term market experiment that is used to find out if the degree of competition in the market of the case is sufficient to drive the market price to marginal cost levels or if market power from producers dominates the level of the market price.
The case that is selected is a DHS in the province of Zuid-Holland. In the region of Oostland (see Figure 3) a lot of progress is made in the development of heat networks and connecting more producers and horticulture companies to the DHS. This region is situated between three municipalities: Berkel en Rodenrijs, Bleiswijk and Berschenhoek. This area and the DHS is locally, and from now on, referred to as “the B3-Hoek” (B-triangle). Here, the horticulture companies are connected to different heat production sources: a large Combined Cycle gas turbine (CCGT), a waste incineration plant, biomass plants and geothermal plants. This DHS is selected as a case because this research is developed in cooperation with AgroEnergy. They have the desire to implement a short term heat market within their DHS. They also provide the necessary data for this research and give the opportunity to come in contact with stakeholders.

The underlying societal relevance of the research is to provide more insight in the functioning of heat energy markets for the heat energy debate in the Netherlands. The Ministry of Economic Affairs is investigating how to develop a policy for heat energy markets, since the revision of the Heat Law (Ministerie van Economische Zaken, 2019).

This thesis will contribute to the knowledge on heat energy markets and build upon the work of Bijvoet (2017), Guichard (2018), Oei (2016), van der Ende (2018) and van Woerden (2015). The amount of research on DHS is growing, but there is still a lack of cases where heat energy trade is investigated in a short term market. Most research in DHS is aimed at the small consumer market, where there are different market conditions and regulation compared to the large consumer market. This research explores the market design variables for large consumer markets. Compared to the attributes found in the small consumer heat sector, horticulture companies have certain attributes that are much more promising for the development of a short term market. Testing and investigating these attributes will tell us more about de validity of economic models and effects of policy measures used in designing energy markets. Therefore this research contributes to the theory of energy markets.

1.4 Research Questions

To achieve our objective for this research, the following research question has been formulated:

How can a short term market be designed for large consumers in the DHS of the B3-Hoek?

To answer the main research question, the following research sub-questions have been formulated:

SQ 1) What market design for the DHS in the B3-Hoek can be used to facilitate short term energy trade?
SQ 2) What is the behaviour of actors in the market and how does this affect the performance of a short term market?

1.5 Research Approach

The approach for answering the main research question is twofold. First, we do a qualitative analysis and develop the design space for a short term heat market to answer the first research sub-question. Institutional design variables for energy systems have been identified by Correljé & de Vries (2008). These were distilled from the electricity system but were also used in similar studies for developing a market design for DHS, see Oei (2016) and van Woerden (2015). For each of the design variables, there are different alternatives that can be chosen to support a short term market in a DHS. The development towards a new market model is an evolutionary process. The old system has to be taken into account when designing a new one. It can constrain the possibilities for changes in the system. Therefore, an analysis of the system and market activities in the DHS in the B3-Hoek is done by doing interviews with system experts from AgroEnergy. A conceptual market model of the current system is presented and constraints for the design space are identified. Throughout this process the design framework of Scholten & Künneke (2016) is used to identify what market and system activities have to be analysed. It is used to structure the explanation of these activities in the old and new system and to ensure alignment between the institutional design variables and technical characteristics of the DHS. Koppenjan & Groenewegen (2005) stressed the importance of alignment between technological and institutional design in their work on design energy markets and systems.
When the design space is identified the next step is to select which alternatives support the implementation of a short term market in the DHS. Choices are made by consulting literature on energy systems and markets, and by reviewing the benefits and drawbacks of each alternative. The result is a final design proposal and a new conceptual market model is presented. By comparing the old and the new market model, changes in roles, responsibilities and coordination in the DHS can be identified. This concludes the first research sub-question.

For the second part of this research, an analysis is done on the performance of a short term market that is based on the case. A virtual short term market is created to simulate the market activities of the DHS. During the simulation horticulture companies and producers trade energy by bidding and offering in a double-sided day-ahead auction. An online platform is used where each participant can arbitrate on the virtual market. After each settlement data is collected of the bid/offer blocks, market prices and traded volumes. By analysing the bid/offer blocks the behaviour of producers and consumers can be identified. The financial results of the producers and consumers during the simulation are compared with two scenarios. One scenario (alternative cost scenario) is used to calculate whether consumers are financially better off when buying from the market or producing heat energy themselves. The other scenario (marginal cost scenario) is used to calculate how much profit producers make in the simulation compared to the scenario where all producers and consumers offer/bid energy at marginal cost levels. In both the simulation and in the scenarios all exogenous variables are the same (ceteris paribus). This allows us to compare the three market scenarios based on price. The results of the simulation and comparison with the scenarios are used to evaluate the performance of the short term market. This concludes the second research sub-question.

Lastly, the conclusion summarizes the findings of both parts of the research. The combined results answer the main research question and give concrete steps forward for the implementation of a short term market in the B3-Hoek and suggestions for future research.

Thesis outline

In the first part of this thesis, we start by presenting the theoretical background of this research. This is done in Chapter 2. Here Neo-Classical Economics (NCE) and New Institutional Economics (NIE) theory are discussed. Also, the design variables and design framework are explained in this chapter. These theories are used to explain actor behaviour in markets and how it is shaped. The design framework helps us to contextualize the economic theories and give us a systematic approach to identify design variables and align system artefacts. In Chapter 3 we will examine the DHS in the B3-Hoek and present the current market model in terms of the design variables. We finish the first part with a design proposal for a short term heat market for the DHS in the B3-Hoek in Chapter 4.

In the second part, the design proposal will be conceptualized in Chapter 5 to develop a simulation of a short term market, answering the second research sub-question. By doing a quantitative analysis actor behaviour is identified and the performance of the market measured, in Chapter 6. Finally, based on the previous analysis we can give recommendations for the implementation of a short term heat market in Chapter 7. We conclude our findings in Chapter 8 and answer the main research question. Lastly, the reflection on this research is discussed Chapter 9.

2

Theoretical Exploration

In the first chapter we have discussed the scope and problem definition of this research. We developed research questions based on the problem formulation and knowledge gap. The aim of this chapter is to find knowledge in theories that will help us answer the first and second research sub-questions. We start by discussing the theories that form the theoretical background of this research. We use Neoclassical Economy and New Institutional Economy literature as a foundation of our analysis and design. We summarize what they entail and why they are chosen as a theoretical framework for this research. Lastly, we presented the design variables and the design framework. The next chapter will introduce the case.

2.1 Theoretical background

The previous chapter clarified the goals of this research: investigate how a short term market can be designed for a DHS in the Netherlands, and finding out how producers and consumers behave on a short term market and how this affects the performance of the market. In this chapter we discuss the theoretical background that has been used for the analysis of market design and behaviour of producers and consumers.

We begin this paragraph by discussing the economic theories that form the basis of our analysis, namely Neoclassical Economics (NCE) and New Institutional Economics (NIE). NCE describes how agents in markets behave and how the performance of a market can be evaluated. NIE describes how and why institutions support economic activity. The next paragraph discusses the theoretical background of market design.

Neoclassical economics

The term "neoclassical economics" is developed by Thorstein Veblem, who was the first to use the term in 1899. The framework of NCE can be summarized as follows, taken from Weintraub (2007):

> *" Buyers attempt to maximize their gains from getting goods, and they do this by increasing their purchases of a good until what they gain from an extra unit is just balanced by what they have to give up to obtain it. In this way they maximize "utility"—the satisfaction associated with the consumption of goods and services. Likewise, individuals provide labour to firms that wish to employ them, by balancing the gains from offering the marginal unit of their services (the wage they would receive) with the disutility of labour itself—the loss of leisure. Individuals make choices at the margin. This results in a theory of demand for goods, and supply of productive factors.*
>
> *Similarly, producers attempt to produce units of a good so that the cost of producing the incremental or marginal unit is just balanced by the revenue it generates. In this way they maximize profits. Firms also hire employees up to the point that the cost of the additional hire is just balanced by the value of output that the additional employee would produce.*
>
> *The neoclassical vision thus involves economic "agents," be they households or firms, optimizing (doing as well as they can), subject to all relevant constraints. Value is linked to unlimited desires and wants colliding with constraints, or scarcity. The tensions, the*

decision problems, are worked out in markets. Prices are the signals that tell households and firms whether their conflicting desires can be reconciled.

At some price of cars, for example, I want to buy a new car. At that same price others may also want to buy cars. But manufacturers may not want to produce as many cars as we all want. Our frustration may lead us to "bid up" the price of cars, eliminating some potential buyers and encouraging some marginal producers. As the price changes, the imbalance between buy orders and sell orders is reduced. This is how optimization under constraint and market interdependence lead to an economic equilibrium. This is the neoclassical vision (Weintraub, 2007).“

Neoclassical economics is a base for much of the economic theories that are developed. It is built upon three main fundamental assumptions. These assumptions are not open to discussion in that they define the shared understandings of those who call themselves neoclassical economists, or economists without any adjective. Those fundamental assumptions include the following:

1. People have rational preferences among outcomes.
2. Individuals maximize utility and firms maximize profits.
3. People act independently on the basis of full and relevant information.

Theories based on, or guided by, these assumptions are neoclassical theories. Thus, we can speak of the neoclassical theory of profits, or employment, or growth, or money. We can create neoclassical production relationships between inputs and outputs, like in our case: heat energy trade. Producers produce heat energy, the good, that growers (horticulture companies) want to use for the growth of their crop, consumption. Neoclassical theory can help us explain the dynamic between these agents and predict behaviour in a market, where competitive forces determine the price of a good (market price).
The analysis of competition in the neoclassical theory is contained in the model of perfect competition. It describes the ideal desired conditions that must hold in the market, to ensure the existence of perfectly competitive behaviour from the typical firm and, by extension, the characterisation of the industry as competitive or not. As describe by Tsoulfidis, it is:

“ a market form consisting of a large number of small —relative to the size of the market— firms selling a homogeneous commodity to a large number of consumers. All market participants have perfect information about the prices and the costs of each good, consumer preferences are given and finally, there are no impediments whatsoever in the mobility of the factors of production. The result of the above conditions is that the producers and consumers — because of their large number and small size— are incapable of influencing the price of the product, which becomes a datum for each and every individual firm or consumer in the market. The behaviour of the firms becomes completely passive with respect to the price of the product (“price-taking behaviour”) and as for the production, the firm simply chooses the level of output consistent with the maximization of profits which is achieved at the point where the price equals with the marginal cost of the product. The same price also maximizes consumers utility and by extension society's welfare. The conception of perfect competition is therefore required for the neoclassical theory to render static equilibrium determinate (Tsoulfidis, 2011, p. 6)*.”*

The important thing here is that in the desired market equilibrium, the price of heat energy is equal to the marginal cost of production. That price point maximizes the consumer's utility and society’s welfare. The larger the number of firms operating in an industry the more vigorous their competitive behaviour is and, so is the establishment of a uniform rate of profit across firms. By contrast, the smaller the number of firms in an industry, the more monopolistic or oligopolistic the form of competition is. Firms are then no longer price takers but are able to set a higher price. This refers to the notion of market power.

A firm exercises market power if it engages in strategic manipulation of its prices with the purpose of raising its profit. However, market power can take many forms besides direct price manipulations, like quantity adjustments, entry deterrence and limiting capacity investments. The most widely used measures of market power are based on the difference between the output price and the marginal production cost, the cost of producing an additional unit (Fridolfsson & Tangerås, 2009).

In this non-competitive state of equilibrium, prices can be set above the marginal production cost, so society as a whole suffers welfare losses from the underproduction and the underutilisation of disposable productive resources. This happens in so-called Cournot competition. In the situation of perfect competition a company is price taker and sets its production output accordingly to maximise profit. In Cournot competition the production level becomes a strategic choice variable (Söderholm & Wårell, 2011). A company actively lowers or increases production to maximise profit in response to the production output of the few competitors. Such a situation can lead to lower prices than in the case of monopolistic price setting, but it is still higher than the marginal cost. This profit-maximizing strategic behaviour makes sense according to the second fundamental assumption in NCE. This behaviour has been studied extensively for electricity markets in the past when there were a limited amount of producers. For further reading, see Green & Newbery (1992) and Klemperer & Meyer (1989) who studied producer behaviour and market outcomes during the early electricity market in the United Kingdom.

In microeconomics there are two ways to indicate the amount of competition in a market and if a firm has market power: the Herfindahl-Hirschman Index (HHI) and the Lerner Index (LI) (Rich, 1994). HHI measures the size of firms in relation to the industry/sector and is an indicator of the amount of competition among them. The HHI is calculated by squaring the market share of each firm competing in the market and then summing the resulting numbers. For example, for a market consisting of four firms with shares of 30, 30, 20, and 20 percent, the HHI is 2,600 ($30^2 + 30^2 + 20^2 + 20^2 = 2{,}600$).

The HHI takes into account the relative size distribution of the firms in a market. It approaches zero when a market is occupied by a large number of firms of relatively equal size and reaches its maximum of 10,000 points when a market is controlled by a single firm. An H below 0.01 (or 100) indicates a highly competitive industry. An H below 0.15 (or 1,500) indicates an unconcentrated industry. An H between 0.15 to 0.25 (or 1,500 to 2,500) indicates moderate concentration. An H above 0.25 (above 2,500) indicates high concentration. The HHI increases both as the number of firms in the market decreases and as the disparity in size between those firms increases. The HHI only shows the degree of concentration and not necessarily if a firm has market power and the ability to misuse it. This index is, therefore, not used as a determinant of market power.

The LI describes the market power of a firm. It is defined by:

$$L = \frac{P - MC}{P}$$

where P is the market price set by the firm and MC is the marginal cost of the firm. The index ranges from a high of 1 to a low of 0, with higher numbers implying greater market power. For a perfectly competitive firm (where P=MC), L=0; such a firm has no market power. When MC=0, Lerner's index is equal to unity, indicating the presence of monopoly power.

The difference between the marginal production cost and the market price will be the determinant to evaluate market power, strategic behaviour and the level of competition in the heat market. The LI is similar to our approach in looking at the difference between P and MC, but it looks at the power of one firm whereas in this research the heat market as a whole is evaluated. In the simulation, we know what the cost of production is for each producer. The price level of the producer’s offer and the settlement price will be used to determine if a producer is trying to drive up the market price and if he succeeds.

Even though NCE is still considered to be a dominant theory in economics and understanding markets, it has been widely criticized for its practical implications. The fundamentals of the theory are hardly seen in practice. First of all, people sometimes act in a way that is not considered fully rational. Individuals and firms have other maximisation goals than utility and profit, respectively. It is impossible to obtain full and relevant information and act upon it. Lastly, markets are hardly in a state of perfect competition, because of a limited amount of firms. When studying systems and imperfect markets, like a DHS, they cannot be entirely described by NCE. We need rules and policy instruments to deal with market imperfections. Other economic theories have been developed, that extend NCE by focusing on the (change of) social and legal norms and rules (institutions) that underlie economic activity. It can be seen as a broadening step to include aspects excluded in neoclassical economics. This economic perspective is called New Institutional Economics.

New Institutional Economics

New Institutional Economics focuses on so-called institutions to support economic activity. Institutions or institutional arrangements are, as Koppenjan and Groenewegen put it, a set of rules that regulate the interaction between parties involved in the functioning of a (technological) system, which actors choose to implement (Koppenjan & Groenewegen, 2005). A framework for this economic perspective has been developed by Oliver E. Williamson. He identified four levels of social and institutional arrangements and integrated them in a way to analyse complex institutions (Williamson, 2000).

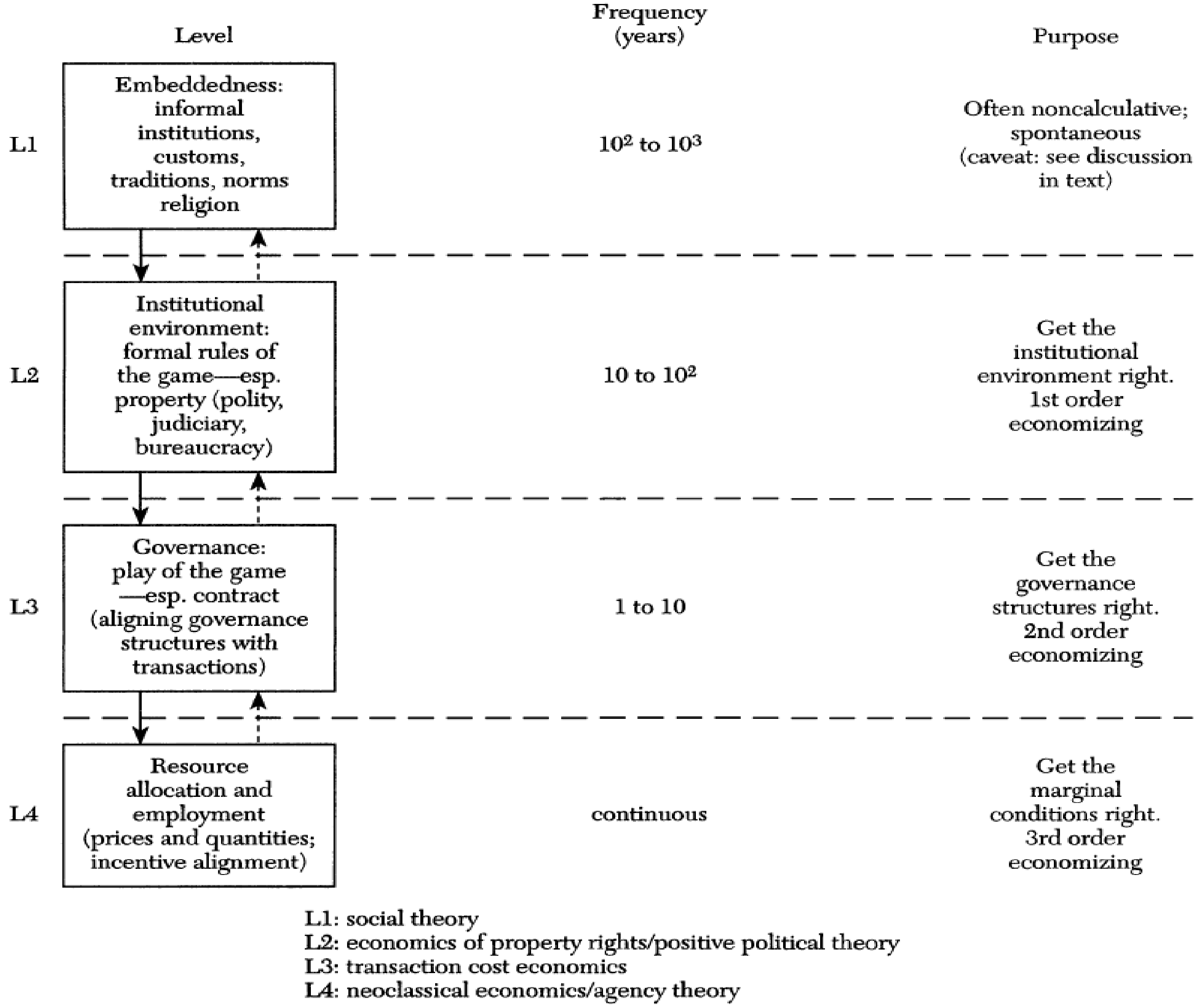


Figure 5 - Four layer model Economics of Institutions (Williamson, 2000)

NIE theory discusses the way institutions change over time. In Williamson's framework, level 1 is the social embeddedness level. This is where the norms, customs, mores, traditions, religion etc. are located. These have an embedded influence on the way how societies act and operate. They change very slowly over the course of a generation and most economist take this input as given in their analysis (Correljé, Groenewegen, Künneke, & Scholten, 2015).
The second level is referred to as the institutional environment. The structures observed here are partly the product of evolutionary processes in level 1. Going beyond the "informal constraints (sanctions, taboos, customs, traditions, and codes of conduct)" of a level 1 kind, we now introduce "formal rules (constitutions, laws, property rights), as Williamson put it. These rules are shaped by policies and regulation, which can be developed and changed.
Level 3 is where the institutions of governance are located. The reorganization of transactions among governance structures is re-examined periodically, on the order of a year to a decade, often at contract renewal or equipment renewal intervals. Given the context of the institutional environment, actors shape their transaction through contracts. This level encompasses how transactions should be managed and how coordination between actors should be developed.
The last level describes how individual firms make decisions about prices and quantities. The combination of their behaviour results in a certain market outcome. Their behaviour is influenced by the institutional environment (the rules that are in place) and the governance environment (contractual and process binding). It is this last level where NCE theory allows us to explain actor decision-making.

Concludingly, NCE theory gives insight into the behaviour of agents in markets and provides the contours of the desired end state of a restructuring process by defining the characteristics of an ideal market. It also provides a framework for diagnosing market imperfections (Correljé & de Vries, 2008). However, NCE does not explain why there are institutions. That is where NIE goes further. In this theory, the behaviour of market actors, as regards pricing, production, resource allocation, investment, strategies of horizontal and vertical integration, and so on, is assumed to be influenced by a market-specific body of rules and conventions: the institutional arrangements (Correljé & de Vries, 2008).
In our case, we are interest in how institutions can be changed to design a short term heat market. Researchers that looked into institutional changes in the district heat sector (see, Åberg et al., 2016; Bijvoet, 2017; Gatautis, 2004; Oei, 2016; Söderholm & Wårell, 2011; van Woerden, 2015) drew lessons from the literature on institutions changes in the power sector, because more has written about it and both systems are utility networks with similar characteristics. The work of Correljé & de Vries (2008) and Scholten & Künneke (2016) provide an excellent framework for the design of a short term heat market, which will be discussed in the next paragraph.

2.2 Towards the design space

In their paper about the design of (hybrid) electricity markets Correljé and de Vries (2008) identified thirteen design variables that together structure the design space for the market design of the electricity sector. Each design variable has a set of alternatives which can be chosen according to how a market should be designed. These design variables are: (1) degree of market opening, (2) pace of market opening, (3) integrated versus decentralized markets, (4) public versus private ownership, (5) competition policy and horizontal unbundling, (6) network unbundling, (7) network regulation of network tariffs and access conditions, (8) congestion management method, (9) arrangements with neighbouring networks and interconnector congestion management, (10) balancing mechanism (in decentralized markets), (11) wholesale and end-user price regulation, (12) capacity mechanism, (13) position of the regulator.
Oei (2016) and van Woerden (2015) used these design principles to form the design space of the Dutch heat sector market design in general. Some variables were omitted from the design space because they were outside of their scope. We will use these design variables for the design of a short term heat market for our case as well. While we acknowledge the importance of all thirteen design variables, like Oei and van Woerden, we will omit some of the design variables from our design space, as some are outside the scope for the analysis of the case. The reason is that some design variables are predefined, meaning there is only one alternative that

can be selected, or the design variable itself does not need further analysis. First, the design variables are discussed that are included in the design space of this study and afterwards we will discuss the omitted variables and the reason they are not included.

Public vs private ownership (1)

Ownership of part(s) of the DHS determines who controls the functions of the DHS. One can also distinguish ownership in (1) public, (2) private or (3) a public-private (hybrid) ownership for each link in the value chain of a DHS. Different utilities in the system can be (in part) owned by a public entity, which is usually a governmental entity such as the state (found in the Soviet Union and in China), a municipality (found in Denmark, Sweden and Finland) or a public company (Werner, 2017). The main driver behind public ownership is the safeguarding of public values. They offer a service at the average cost price of the system and do not have incentives to make profits beyond what is needed for future investments. This is beneficial for the costs of the consumer, but this ownership form does not have the incentive to innovate and improve efficiency. Private companies are considered profit-maximizing entities and therefore seek to increase profit by reducing costs through innovation and improvement. Sometimes the best of both worlds are combined in a hybrid form to serve both cost and improvement incentives. This is also done to spread the risk of investment.

The choice for public or private ownership comes down to the ability of market power abuse by a company. Competition and regulation can be put in place to reduce this power. When there is a lack of one or both it can be chosen to give ownership (partly) to a public entity. However, poor financial status and lacking experience of municipalities often prevent public ownership (Werner, 2017). Path dependency also influences the choices that can be made (van Woerden, 2015). Many DHS have historically been developed by public bodies such as municipalities or publicly-owned energy companies which means the starting conditions often include public ownership of at least parts of the value chain (Oei, 2016a). Main variables to consider when privatizing include (1) the degree of privatization (ranging from a government monopoly to full privatization), (2) which system segments should be privatized (generation, wholesale and/or the networks?), and (3) the character of the new private owner's (anonymous shareholders, national of foreign financing institution, foreign energy company?) (Correljé & de Vries, 2008).

Network unbundling (2)

There are two forms of unbundling: vertical and horizontal. Vertical unbundling is the separation of production, transport, distribution and (sometimes) retail functions. This form of unbundling allows for the separation of potentially competitive segments (generation and retail) where many actors can participate, from uncompetitive segments (transport and distribution) that generally require a single actor to manage the grid infrastructure in a specific area. The degree of vertical unbundling is weight in terms transaction cost reduction versus cost reduction as a result of competition. Vertical integration reduces the transaction cost between parts of the system, but it may result in higher prices due to market power and lack of the incentive to improve. To counter this it is suggested parts of the systems should be unbundled and operate by different companies in order to reduce prices and improve efficiency as a result of competition, but in turn, this results in higher transaction costs between the different companies. Five different levels of unbundling can be distinguished: "(1) no unbundling, (2) separate accounting of system parts, (3) administrative separation (separate business unit), (4) juridical separation (separate legal person – but can be part of a larger firm), and finally (5) ownership unbundling (juridical separate and with different owner)" (Oei, 2016a; van Woerden, 2015). Lastly, horizontal unbundling is the separation of any of the system functions into multiple actors, that compete with one another or provide services in different areas. However, applies mainly to the production and retail functions, because of the network effects and scale benefits of having one actor responsible for the transport and/or distribution grid. The degree of unbundling determines the possible amount of competition within a DHS.

Network access conditions and tariffs (3)

Access to the network is commonly referred to as “Third Party Access” (TPA). TPA implies that a third party can access the district heating network in a non-discriminatory way, in order to supply its heat or consume. Regulated TPA refers to a situation of full access to the district heating networks, where the network owner has a legal obligation to allow access to the network. The network operations are regulated ex-ante, i.e., the conditions for access to the network (e.g., fees, etc.) are determined in advance. Negotiated TPA implies that the district heating network owners are required to negotiate about access to the network with the producers of heat. The main difference between regulated and negotiated TPA is thus that the latter form implies that the network operations are determined ex-post. The specific conditions for network access are negotiated between the network owner and the third party (Söderholm & Wårell, 2011).

Also, the degree to what TPA is introduced can be distinguished in TPA on a wholesale level/ for producers and TPA on a retail level/for suppliers (Bijvoet, 2017). TPA on a wholesale level/for producers allows access to the district heating network for third parties (eligible producers) to feed-in heat. The owner of the network/single supplier buys the heat from multiple competing producers and transports the heat to consumers. With TPA on a retail level/for suppliers, third parties are not only granted access to feed-in heat but also to transport heat to consumers. In the first case, only competition between multiple producers is introduced, whereas in the second case also competition between suppliers is created, allowing consumers to choose their own supplier. This implies full TPA by all parties accept transport and distribution companies.

Access conditions also apply to the use of the capacity of the network. Klein (1996) identifies three options how access to the networks capacity can be organised: (1) open access, (2) pooling and (3) timetabling.

In the case of open access, every producer is allowed to make use of the network as long as the capacity permits it. When the owner of the network is not involved in any production activity he will have the incentive to allow as many producers on his network as he can, because that will increase the revenue for his asset. This would entail that there must a degree of unbundling between production and transportation (Klein, 1996). If it is not unbundled the network owner will have the incentive to give priority to his production and only allow other producers access if there is enough capacity left in the network. This would, in essence, defeat the purpose of “open access”.

Another way to organize access is pooling. In this configuration, a central dispatch system collects production offers from producers and optimises system flows, while also balancing supply and demand. There is open access, in the sense that winning offers will always be dispatched until demand is met. The way that winning offers are determined is not discussed by Klein. In the Dutch electricity, the dispatch is determined by cost/price in an auction. Producers that are settled after a market-clearing earn the right to access to the network for a certain timeframe (at the APX the market is cleared for every hour of the day and access timeframe is divided in blocks of 15 minutes). Varmelast, the dispatch operator on the DHS of Copenhagen, uses a combination of costs of producers and politically prioritized generation units (waste incinerators and geothermal wells) to determine the dispatch. They send a demand forecast to producers, who then make a production offer. Varmelast collects these offers and clears the market to determine the dispatch (Cai et al., 2018; Nielsen et al, 2016; Wang et al, 2015).

The last access condition identified by Klein (1996) is timetabling. Instead of limiting access based on prices, it is also possible to limit access by selling capacity time slots. Timetabling is a form of competition where slots of time or space on the network are auctioned, and optimal routing is calculated. Timetabling for systems with homogeneous products becomes a “simple network optimisation problem” (Klein, 1996). Timetabling is an approach that is more easily applied to systems such as district heating where it does not matter whether a customer receives the exact heat produced by the supplier it has a contract with since the product is identical enough with that of other suppliers. Whereas in railway systems or airlines, it does matter because a certain person needs to be transported from A to B and it does matter whether it is you or your neighbour for example (van Woerden, 2015).

Integrated vs decentralized markets (4)

Matching the production and demand for heat can be organized either through integrated or decentralized markets. According to Correljé & de Vries (2008), an integrated market is where the system operator operates a mandatory pool and in which the physical and economic aspects of heat trade are strongly connected. This means that both the economic and physical control over the system is in the hands of a single party. An example of this is the electricity system in the United States of America, which is a nodal pool market. In this market dispatch is determined by optimization of supply, demand, costs and available transport capacity by a party that controls also the physical system.
A decentralized market supply and demand is determined elsewhere and is not done by the system operator, who only has a technical function. In this case, the exchange of heat energy is done through bilateral contracts or in a voluntary exchange (Correljé & de Vries, 2008). The drawback is that the physical and economic aspects of energy trade are no longer directly connected which could result in the requirement for additional regulation or contracts to manage congestion and secure generation and delivery adequacy (Oei, 2016a).

Balancing mechanism (5)

Supply and demand have to be equal, otherwise overload or shortages occur in the network. In the electricity network, this has to be balanced in real-time and has a dedicated market. A balance should also be maintained in heat networks, but the difference is that heat energy can be stored. For DHS balancing can either occur via a dedicated market, organised via contracts or demand-side management using buffers. In a market, producers with regulating capacity can offer to in- or decrease production to maintain balance in the system. In the electricity market, the system operator Tennet functions as a broker. A system operator could also put contracts in place, where producers receive a compensation for using their regulating capacity. Lastly, a form of demand-side management can be used where horticulture companies use a buffer to manage imbalance. If more heat energy is put in the network, this can be stored in the buffers for later use. When there is not enough heat available in the network, horticulture companies must use their buffer first before taking heat from the network. AgroEnergy is developing a model, called "WarmteVerdeelModel", that takes care of this demand-side management.

These design variables combined form the institutional design space for our short term market. We will discuss the pros and cons of the alternatives for each design variable in more detail in Chapter 4 where we will select and combine them in a market design. Some design variables of Correljé & de Vries (2008) are not included in the design space. Below it is explained why this choice was made.

Degree of market opening

The degree of market opening refers to the market structures for introducing competition and access to the market where the trading takes place. Different market structures allow competition on specific parts of the system. From the electricity market, we can identify four different market structures: wheeling, single-buyer, wholesale and retail competition (van Woerden, 2015).
The simplest structure in terms of the organisation is wheeling. In this market structure, one company is responsible for production, transport and distribution (Correljé & de Vries, 2008). Trade can take place between integrated utilities, but there is no competition within the utility. The other market structures do have a form of competition.
In a single-buyer market structure there is one company that purchases all the energy from different producers and then sell it to one distribution company. It can also be the case that the single-buyer has production assets itself and/or also acts as the distributor. In this structure, competition takes place at the producers' side of the system (Correljé & de Vries, 2008).
In a wholesale competition market structure, the single-buyer is removed and producers can sell their energy to multiple large consumers or distribution companies with a retail franchise. The transport operator has to unbundled from production and distribution activities. Competition takes place at the producer and the distributor side for the system (Correljé & de Vries, 2008).

The last market structure also introduces competition on the retail level. Here small consumers are able to choose their energy supplier. Transport and distribution are unbundled from the other system activities (Correljé & de Vries, 2008).
The design of our short term market presupposes that multiple producers can sell, and multi large consumers can buy heat energy. Since our focus is on horticulture companies who directly operate on this market, there is no retailer in between. Therefore the degree of market opening has a wholesale competition market structure.

Pace of market opening

The pace of the market opening refers to the process of organizing institutional change and the timing. The objective of this study is to present a short term market design and identify technical and institutional conflicts with the current market model. In this research 2025 is taken as time horizon for the design proposal. In 2024 the contract of the largest producer in the DHS (Uniper) expires, which gives an opportunity to restructure the market by that time. A five year period is seen as sufficient to implement the necessary institutional and technical changes. We will not propose how the process of change should be organized. However, we acknowledge the importance of the pace and process for the implementation of our proposed design and therefore discuss this matter in our discussion and conclusion of this research and give recommendations to stakeholders for the implementation of our design.

Competition policy and horizontal unbundling

Competition policy refers to the policy instruments a regulator has implemented (or can) to influence the level of competition in a specific sector. A regulator monitors abuse of market power and acts when horizontal integration might cause competitive pressures to decline is very different from a regulator that allows horizontal integration to occur as long as the companies in question do not make “socially unacceptable profits” (Oei, 2016a).
In this research, the role of the regulator is outside our scope, since there is no regulation for the DHS with which we are concerned. We assume the competition between producers and horticulture companies will result in the desired market performance. This is one of the things we set out to investigate. The results of the simulation will indicate if this is the case. If not, additional measures will be discussed in the discussion and conclusion of this research.

Congestion management method

When the transport capacity of a network is inadequate to fulfil the required/desired flow congestion arises in a the network. There are different ways to prevent or manage congestion such as, (1) integrating transport costs and capacities into the matching process of demand and supply (integrated markets), (2) using dynamic tariffs to provide incentives to not use congested pipelines or (3) explicit (capacity) auctions that allocate the limited transport capacity over the heat companies that would like to make use of the network (Oei, 2016a). However, what will be discussed in more detail in chapter 3, there is currently no congestion problem in the DHS of our case. There is plenty of transport capacity for now and the foreseeable future, according to AgroEnergy. Therefore we do not further discuss congestion management methods.

Arrangements with neighbouring networks and interconnector congestion management

The DHS of our case is assumed to be an islanded network. In reality, the district heat network of the horticulture companies in the B3-Hoek is connected to the district heat network of Rotterdam via Uniper. However, Uniper operates both networks separately. This is explained and illustrated in Chapter 3 as well. Therefore we assume no neighbouring networks now and in the foreseeable future (2025). For this reason, the analysis of arrangements with neighbouring networks is taken outside the scope of this research.

Wholesale and end-user price regulation

In our design, the end-user price will be determined in the short term market. We assume that the price of the short term market will not need any additional regulation as competitive forces will be enough to achieve a “desired end-user price”. These competitive forces will be the result of competition between producers and the availability of alternatives (gas boiler and/or CHP) that horticulture companies have for their heat demand. We will test this in our simulation, but the findings of Bijvoet (2017) were already promising. In case we find different results or see the need for regulation, we will discuss this in the discussion and conclusion.

Capacity mechanism

Capacity mechanisms are means to stimulate the investment in energy generation capacity when there is a concern for underinvestment by market parties. This could theoretically happen when there are price restrictions, because foregone revenues may cause generating companies to underinvest insufficient capacity (Hogan, 2005; Stoft, 2002). In our case we assume there is no lack of production capacity. All horticulture companies can produce heat energy themselves and according to AgroEnergy, there are sufficient producers in the network with enough capacity to produce the demand of the consumers. Therefore we will not further discuss capacity mechanisms.

Position of regulator

The Dutch Heat Act regulates the district heat sector in the Netherlands. However, our case is exempted from this because it concerns a large consumer market. Therefore we do not discuss the position of a regulator in our market design.

2.3 Alignment between institutions and technical functions

So far we have discussed the institutional design variables for the design of a short term heat market. However, a DHS is a complex socio-technical system, where technological, economic, political and social features strongly interact with each other (Künneke, Groenewegen, & Ménard, 2010; Scholten & Künneke, 2016). Until now we have touched upon the institutional side of our system, but not yet on the technical side. The performance of a DHS depends on the continuous interaction between its techno-operational characteristics and institutional arrangements. Designing socio-technical systems presuppose coordination of the behaviour of parties necessary to make the system function, but also a technological or substantive dimension (Koppenjan & Groenewegen, 2005). The two design logics may be complementary, but may also be at odds. They can generate different, or even conflicting, solutions. System operation and market organization can pose conflicting requirements on actors (Scholten & Künneke, 2016). An example of this is the liberalization of the electricity sector. The markets were opened up for a variety of actors and existing incumbents were unbundled, which led to diverging economic interests among actors creating a more decentralized mode of organization. Meanwhile, the technical operation remained a vertically integrated monopoly controlled from a central control room, leading to discrepancy in the system (Künneke & Finger, 2007). Therefore, one must make an effort in the design process to make sure economic and technical aspects complement each other. Scholten & Künneke (2016) made a comprehensive design framework for this purpose. It is based on the four level framework of Williamson that was discussed in the first paragraph. Hence, that framework only touched upon the institutional aspects. In their framework, Scholten & Künneke aligned the economic activities with the corresponding technical activities found in energy systems. We already identified the institutional design variables in the previous paragraph. We will use the framework to identify the corresponding technical activities and make sure that they are aligned with their institutional counterparts in the design process. The framework allows us to systematically analyse both the system and market activities and present it in a structured way. Scholten & Künneke (2016) included many of the institutional design variables identified by Correljé & de Vries (2008) in their framework. However, not every variable was included thus the framework was adapted by including all the variables identified by Correljé & de Vries. Design variables we added to the framework are described in the following table:

Table 3 - Added design variables and explanation

Design variable	Included in layer	Explanation
Integrated vs decentralized markets	Layer 3	Refers to the organization of the market
Pace of market opening	Not included	Outside our scope
Competition policy	Layer 2b	Refers to regulation (sector laws and decrees)
Congestion management	Layer 2b	Aligns with grid capacity and planning
Arrangements with neighbouring networks	Layer 2b	Aligns with network topology and decision rights
Balancing mechanism	Layer 2b	Aligns with grid capacity and planning
Wholesale and end-user price regulation	Layer 2b	Refers to regulation (sector laws and decrees)
Capacity mechanism	Layer 2b	Aligns with production and grid capacity
Position of regulator	Layer 3	Refers to the organization of the market

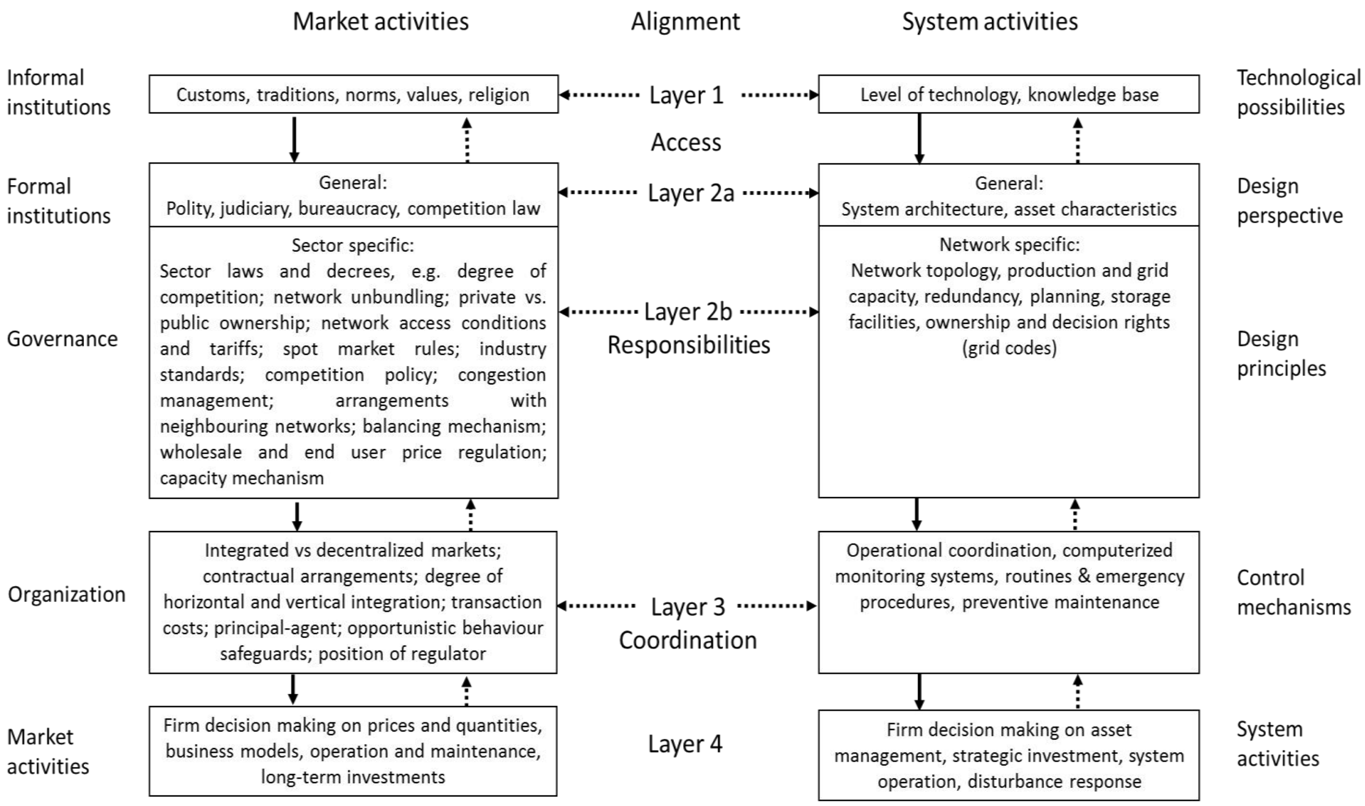


Figure 6 - Design variables framework, adapted from (Scholten & Künneke, 2016)

The framework allows us to systematically describe the different activities of a DHS from the market and system perspective. Each layer discusses market and system activities that are related on same level. This helps us to align the design variables identified by Correljé & de Vries (2008) with the technical configuration of DHS in our case. This idea can be summarized in a way that the same layers in both dimensions revolve around similar concepts and/or design knobs: access, responsibility and coordination (Scholten & Künneke, 2016):

> *"<u>Access</u> refers to the generic design of infrastructures. On this level we relate the systemic and institutional environment (layers 1 and 2a of Figure 6), i.e. the system architecture and asset characteristics to the formal state institutions and perceptions on energy service provision.*

Responsibilities refer to the specific design of infrastructures. On this level we relate the technical design principles and market governance arrangements (layer 2b of Figure 6); essentially we are looking at the way in which control and intervention tasks regarding technical operations and ownership and decision rights concerning market transactions are or should be divided at a specific location and time within the systemic and institutional context.

Coordination refers to the interaction between the different actors. On this level we relate the techno-operational coordination and market transactions among actors in realizing a specific good or service (layer 3 of Figure 6). (Scholten & Künneke, 2016, p. 16 t/m 18)"

The first layer deals with informal institutions and existing conceptual knowledge and the level of technology. It refers to the way we think about how markets in our culture and the technological possibilities we can use to facilitate our needs. Its change is slow and emerges spontaneously out of inventions. In our analysis, this layer describes the given institutional context in which we will design our DHS with a short term market. It is seen as an external factor that influences the design space, which we consider to be layer two and three.

The second layer concerns the formal institutions, i.e. the "rules of the game", such as the official state bodies, laws and regulations. Three core design issues here are: where competition is introduced in the system, who has ownership of systems artefacts (allocating property rights), what regulation and legislation are implemented in the system. It also concerns the infrastructure design. When choosing the network topology and capacity, the ownership and decision rights with regard to who is responsible for the planning, development, operations, and maintenance of particular assets should be aligned. In this layer, we establish the relations of actors to one another.

The third layer concerns the "play of the game", given the rules in layer 2. Attention goes to the modes of organization that accommodate market transactions and operation. Control mechanisms are used to coordinate systems to ensure reliable operations. This layer describes the coordination of flows (energy, payments, service, information etc.) in our DHS.

The fourth and last layer concerns the individual actor decisions regarding short term market activities, internal company decision making on prices, quantities, and investments, business models and optimization of operation and maintenance. The sum of these activities results in a certain market outcome. In the energy sector, this translates into how the availability, affordability, and acceptability of electricity, gas, oil, or heat can be most efficiently achieved. The institutional environment (layers 1 and 2a) frames the setting for the governance and organizational arrangements (layers 2b and 3) which in turn incentivize actor behaviour in this last layer. Therefore it is not part of the design, but it is used to judge it. It is the output which we can measure to determine if our design produces the desired results. If not, alterations have to be made in layer 2 and 3.

To conclude this chapter, we have discussed the theoretical background of this research. NCE theory allows us to investigate agent behaviour and analyse the performance of markets. NIE adds on top of NCE, as it explains how and why rules structure markets as well. For the design of a short term market model, we have identified design variables and the design framework, developed by Correljé & de Vries (2008) and Scholten & Künneke (2016) respectively. Together they form the theoretical background to answer the two research sub-questions.

In the next chapter, we will give a systematic description of the DHS that is used as a case for this research, presenting the market and technical activities currently present in the system. For the implementation of a short term market, changes will have to be made to the current system. Therefore we first describe the current system in terms of market and system activities (Chapter 3), and afterwards present our design for a short term market (Chapter 4). By comparing both we can identify the changes that will have to be made and see if any conflicts arise for the implementation of a short term market. This concludes the first research sub-question. In Chapter 5 and 6 covers the second research sub-question.

3

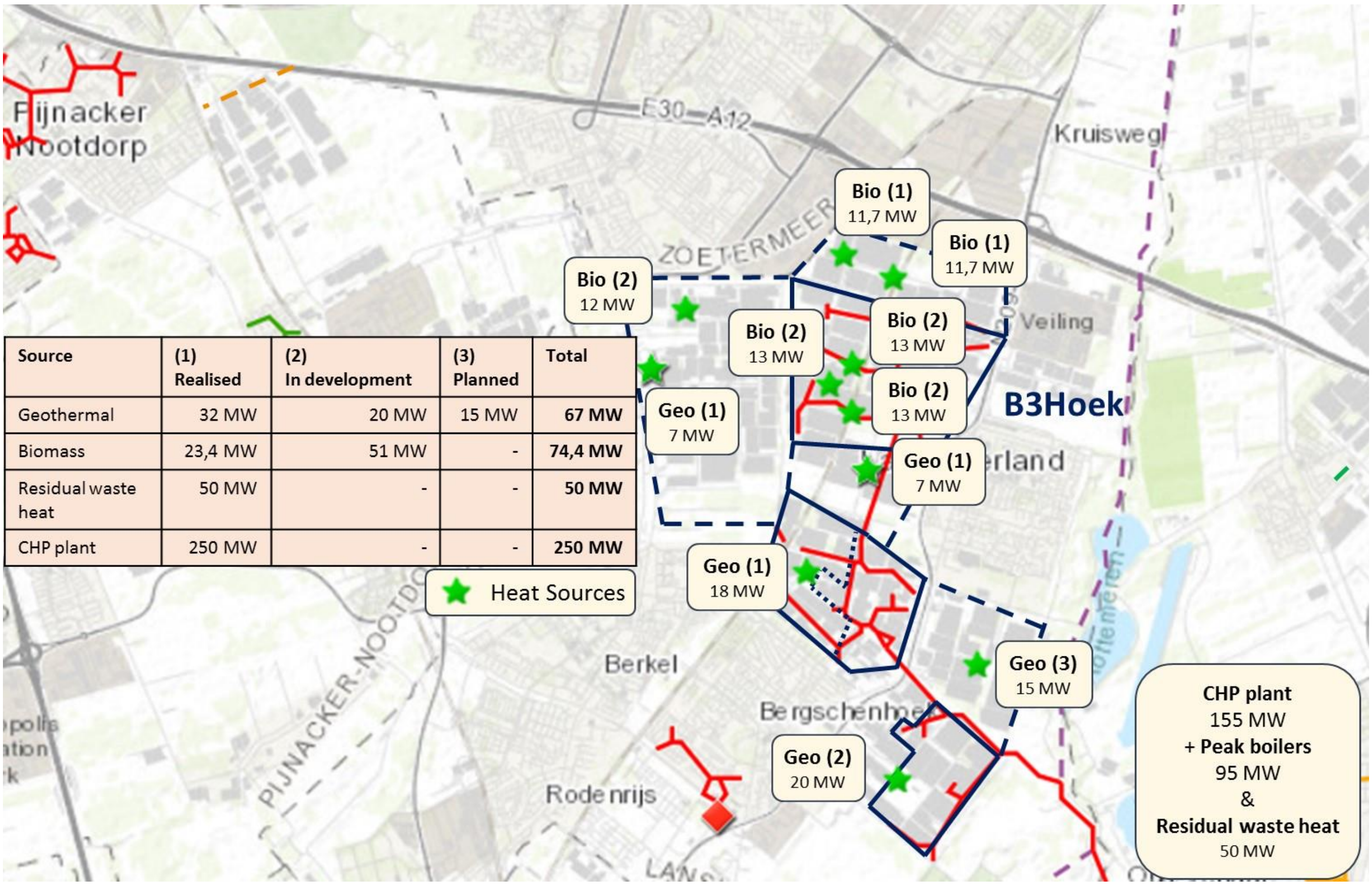
Present Heat Market in the B3-Hoek

In the previous chapter, we have discussed the theoretical background, design variables and design framework to create a short term heat market for the DHS in the B3-Hoek. In this chapter, we start by explaining why this DHS was selected as a case for this research. Then a system description is given of how heat energy is currently traded among producers and horticulture companies. Afterwards, we identify market failures in the current system and discuss the goals of the new market design. We describe the objectives and constraints of the design and what performance indicators we will use the evaluate our design in a simulation. In the next chapter, we will select and align the institutional design variables with the technical characteristics of the system for our short term market design. Here we discuss what changes will have to be made from an institutional and technical perspective.

3.1 Case introduction

In Chapter 1, we introduced the DHS in the B3-Hoek. This is the name for the area situated between the municipalities of Berkel en Rodenrijs, Bleiswijk and Berschenhoek. In this DHS horticulture companies are connected to different heat production sources: a large Combined Cycle Gas Turbine (CCGT), waste incineration plant, biomass plants and geothermal plants.

In this DHS heat energy trade is facilitated by AgroEnergy (part of Eneco) on a network owned by Eneco, a Dutch energy company. AgroEnergy has the vision to develop an open heat network where producers and large consumers can easily trade heat energy. The DHS in Figure 7 is our system of interest. Our aim is to develop a system where heat energy can be traded between producers and horticulture companies in the short term. The reason we select this case is that this DHS is already very matured. There are different producers involved in the network and there are a lot of large consumers connected already. The system is rapidly expanding with the introduction of more biomass and geothermal heat producers and more consumers are soon to be connected to the system as well. Therefore this system is more ready for the implementation of a short term market, than other DHS where only one producer is active or that have not been developed yet. This research is done together with AgroEnergy, who provides us with data and the ability to come in contact with stakeholders. They have done a small scale simulation of a short term market prior to this research. The lessons learned from that simulation were used for the development of the interactive simulation used in this research. Together, AgroEnergy and the researcher developed a new simulation, based on the previous one and included elements to investigate the knowledge gap of this research. This is described in more detail in Chapter 5. In this chapter, we discuss in more detail the institutional and technical characteristics of the DHS in the B3-Hoek.



Source	(1) Realised	(2) In development	(3) Planned	Total
Geothermal	32 MW	20 MW	15 MW	67 MW
Biomass	23,4 MW	51 MW	-	74,4 MW
Residual waste heat	50 MW	-	-	50 MW
CHP plant	250 MW	-	-	250 MW

Figure 7 - B3-Hoek district heat network and sources (source: AgroEnergy, 2018)

3.2 System Description

In this paragraph, we discuss the DHS in the B3-Hoek in more detail. The framework of Scholten & Künneke is used to systematically describe the market and system activities, see Figure 6. Data and information of the DHS are gathered from the AgroEnergy database and expert interviews with stakeholders. First, we discuss the access to the system; the informal and formal institutions and perceptions on energy service provision. Secondly, we discuss the responsibilities; formal institutions, identify the different actors and their roles in the DHS. Thirdly, we describe the coordination among actors and give a procedural description of how energy is traded. Lastly, we describe the market and system activities; how actors make decisions at the operational levels.

3.2.1 Access

As explained in the previous chapter, access refers to the generic design of the infrastructure. Access to electricity and heat energy are considered a primary necessity. This means that everybody should have access to heat energy and the government is tasked with the duty of care. In the past, this handled in the Dutch Gas Act. For a long time, we used mainly natural gas of heating purposes and therefore access to the gas network was guaranteed by the Gas Act. In the recent years, the use of gas for heating purposes has shifted towards the use of District Heating systems for city heat. Consumers were forced to use the heating network, instead of the gas network. This changed required a change in legislation to guarantee heat supply for consumers.
In the Netherlands heat supply is regulated by the Heat Act (Warmtewet). This law regulates the tariffs of heat suppliers and guarantees reasonable conditions for the supply of heat. The main goals are consumer protection for high prices and security of supply. Tariffs are not allowed to be higher than the cost of a consumer that uses natural gas for heating purposes. There is also a periodic monitoring on the profits of suppliers to make sure they are not unreasonably high.

The Heat Act is a policy instrument mainly to protect small consumers. It only applies to consumers with a connection smaller than 100 kW. Companies and industries that have a heat connection larger than 100 kW are considered large consumers and they are excluded from the Heat Act. They are free to make arrangements with suppliers and producers themselves. Horticulture companies have a larger heat connection than 100 kW and thus the Heat Act does not apply to them.

The supply of heat energy requires a network. Network ownership, production and supply of energy are unbundled in the gas and electricity system. Companies that take care of the transport (public) and distribution (private) and the cost of the networks is socialized between its users. For heat networks this is different. During the development of the Heat Act, it was chosen not to unbundle production, supply and ownership of the network. Therefore there are currently a lot of heat networks where these tasks are done by one company (Ecorys, 2016).

Market & system activities (Layer 1 & 2a)

From the institutional analysis, it is clear that there is not much legislation that regulates our case. This has resulted in a lot of vertical integration in the DHS. Heat is considered a primary necessity, but only the small consumer market has a form of access regulation and price protection. In our case, system access is organized by negotiations and contracts. Therefore there is more freedom to design a new market system in the layers 2b and 3 of the design framework, than if the system was regulated.

3.2.2 Responsibilities

Before we discuss who is involved in the DHS of the B3-Hoek, let us first look at the network. System experts of AgroEnergy have been consulted to describe the institutional and technical characteristics of the system shown in layer 2b of the framework.

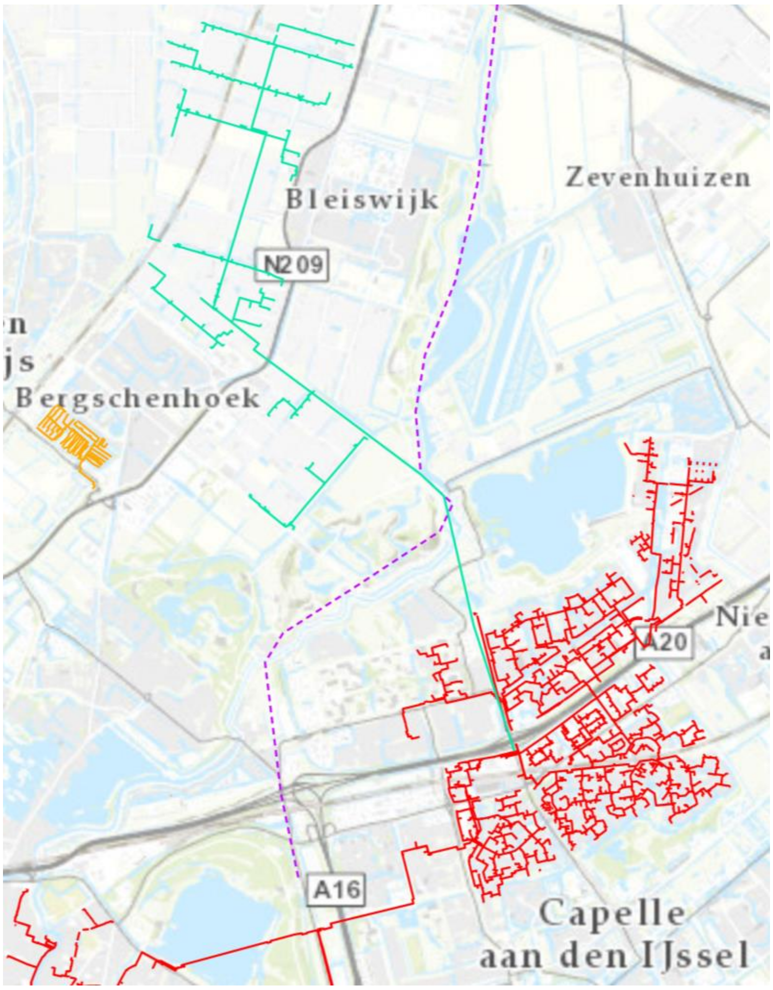


Figure 8 - District Heating Network in the B3-Hoek

In Figure 8 the DHS in the B3-Hoek is showcased. Note that this is the network layout as it is today. The turquoise network is the B3-Hoek network and the red network is part of the DHS of the city of Rotterdam. The red network is out of our scope of analysis. For this analysis, we distinguish nine different roles/responsibilities in the DHS: transport, distribution, system operator, supplier, producer, consumer, regulator, market operator and measuring.

The B3-Hoek network starts from the location of the CCGT plant of Uniper at the Capelseweg in Rotterdam. From here a transport line stretches all the way to the north of Bleiswijk. This forms the backbone of the network. That part of the network is owned and controlled by Uniper, who acts as the system operator. From this transport line, branches run throughout the region. These are the distribution lines that deliver heat energy to the horticulture companies. These distribution lines are owned and controlled by Eneco. One distribution line is not connected to the transport line. This small islanded network (owned and controlled by Eneco) that distributes heat from a local heat source (geothermal plant) to neighbouring horticulture companies. From an organizational and procedural point of view, the transport and distribution network can be seen as separate. However, from a technical point of view, it could better be described as one big distribution network. That is because there are usually heat exchangers between the network that clearly separate the transport from distribution. However, in the B3-Hoek there are no heat exchangers within the network. The water flows from Uniper through the entire network and heat exchangers located at the consumers transfer the heat to the greenhouses. Nevertheless, we consider the DHS having both a transport and a distribution network, because ownership and responsibilities are clearly separated in the current market model. However, the non-distinctive technical characteristics of the DHS must be taken into account when designing a new market model.

The supply of heat is handled by AgroEnergy. They sign contracts with the producers for the production of energy and with the horticulture companies, the consumers. AgroEnergy takes care of billing and customer service. They also actively seek to expand the network, connecting more producers and consumers to the DHS. AgroEnergy is owned 100% by Eneco. Therefore the role of the supplier also belongs to Eneco. However, we distinguish both companies from each other because their roles are clearly separated in the structure of Eneco and in the network.

Currently, there are four producers connected to the network: Uniper, AVR, TBM and Wayland Energy. The main producer in the network is Uniper. Their CCGT plant and boilers produce most of the heat demand. The other sources of heat are residual waste heat from waste incineration (AVR), biomass boilers (TBM) and geothermal energy (Wayland Energy).

The consumers in the network are all horticulture companies and clients from AgroEnergy since it is the only supplier in the network. There are many different horticulture companies in terms of size and crop type. All have a boiler and some have a CHP. All growers who have a CHP have a buffer and only some growers without CHP have one too. The buffer can be used to balance the supply of heat throughout the day. The amount of CHPs in the current DHS is very low because the production capacity in DHS is high enough to supply the maximum demand at almost any time. It is also cheaper than heat production with a boiler. Therefore the need for a CHP for the connected horticulture companies is now very low. Compared to other horticulture companies in the region, who are currently not connected to the DHS, the usefulness of a CHP is much higher and therefore most of them have a CHP installed, depending on the type of crop. Therefore the heat demand and consumption pattern differs from company to company.

There are multiple regulatory authorities involved in the DHS. At the highest level the Ministry of Economic Affairs develops legislation for DHS and subsidies for sustainable heat energy production. Also, the Province of Zuid-Holland is involved in the planning of the network topology. This is done together with municipalities that are located around the network.

Currently, there is no market operator, since there is no open trading platform. AgroEnergy acts as a single buyer for the producers and developed contract packages for consumers. The responsibility of the market operator is to provide a platform where energy trade can take place. The market operator clears the market periodically. In the Dutch electricity system, this is done by EPEX (APX Group).

The last responsibility we identified is measuring. The amount of energy production and consumption need to be measured at different locations in the system to gather the data required for billing. Currently, there is no independent measuring authority. Eneco and Uniper both use their own measuring systems and exchange data for billing.

We can summarize the roles and responsibilities in the following table:

Table 4 - Roles and responsibilities DHS B3-Hoek

Role	Actor	Responsibilities
Transport	Uniper	- Managing flows - Maintenance transport line
Distribution	Eneco	- Building connections to the network - Maintenance distribution lines - Programming
System Operator	Uniper	- Balancing - Dispatch
Supplier	AgroEnergy (Eneco)	- Billing - Contracting consumers - Contracting producers
Producer	Uniper (CHP plant) AVR (Waste incineration plant) TBM (Biomass power plant) Wayland energy (Geothermal plant)	- Production of heat energy
Consumer	Horticulture companies	- Consumption of heat energy
Regulator	Ministry of Economic Affairs Province Zuid-Holland Municipalities	- Legislation heat supply - Location permits - Subsidies for energy production
Market operator	-	- Market clearing
Measuring	Uniper Eneco	- Supply, installation and maintenance of measuring devices

Market activities (layer 2b)

In terms of market activities in layer 2b, we can deduce the following:

- Current sector laws dictate that the Heat Act does not apply to the DHS in the B3-Hoek. Companies are free to organise production, transport, distribution and supply.
- The degree of market opening in the DHS in the B3-Hoek is characterised as a single-buyer market. There is a single-buyer (Eneco/AgroEnergy) that purchases heat energy through contracts with different producers. The heat energy is then sold to consumers connected to the network, who have multiple contractual options.
- In terms of vertical unbundling, there are some parts of the system that are bundled and controlled by one company. Production, transport and balancing are bundled within Uniper. Distribution and supply are bundled in Eneco. There are other independent producers active on the network who are contracted by the supplier. It is unknown to what degree Uniper has bundled their activities. According to AgroEnergy, Unipers activities are only separated on the accounting level. The tasks of Eneco and AgroEnergy, however, are administratively separated.
- Companies in the system are privately owned, except for Eneco. Eneco currently is a public company whose shares are owned by multiple municipalities. 3.38% of the shares are owned by Lansingerland, the municipality of the B3-Hoek. However, Eneco is now in the process of being sold and will likely be privately owned, as of next year.
- Network access conditions and tariffs are organized in contracts with AgroEnergy (Eneco). Access conditions are also determined by the system operator (Uniper). Eneco determines the programming for producers on a yearly basis. Thus access to the capacity of the network is organised via timetabling.

When new producers want access to the network they must take into account the efficiency of the system, as there are many technical system-specific characteristics to must adhere to (temperature, pressure, flow speed, production pattern, etc.). Therefore access to the network is ex-ante negotiated with Eneco. Eneco has contractual arrangements with Uniper for the use of the transport line by other producers. Therefore Uniper has a level of control over who can gain access to the system. For new consumers, a business case is made to evaluate the connection to the network. They pay a connection fee based on contracted capacity. Since there is only one supplier in the network, there is no retail competition. Therefore TPA is on a wholesale level.

- There is currently no spot market, so no spot market rules. Consumers can contract energy for Q1 and Q4. In Q2 and Q3 a variable price is contracted. Producers are contracted on the basis of the amount of operating hour for a year.
- Industry standards for codes and guidelines for measurement have recently been developed by multiple stakeholders in the DHS sector (Warmtenetwerk, 2019). Unlike the gas and electricity sector, where such grid codes are adopted in legislation, the codes for the heat sector are voluntarily to adhere to. There are many standards for technical installations and transport networks in DHS, but explaining them in detail is outside the scope of this research. The main message is they are there, but they are not regulated.
- Competition policy (in our DHS) is left to the market, meaning there is no regulator that monitors the market. The DHS in the B3-Hoek competes with the gas infrastructure since all horticulture companies can produce heat themselves. This drives suppliers of the DHS to negotiate price equal or slightly below the price of the alternative.
- Currently, there is no form of congestion management. The transport and distribution capacity in the networks is large enough for now and expansion to other horticulture companies in the area, according to AgroEnergy.
- Although the DHS can be seen as an independent system, there are some arrangements with the neighbouring DHS of the city of Rotterdam. The waste incineration plant delivers heat via the Rotterdam network to the B3-Hoek and Uniper most allocate production capacity to the city DHS, before using it for the DHS in the B3-Hoek.
- Balancing the network is the task of Uniper. They simply increase or decrease production if imbalance on the network occurs. The cost structure for this service in tied the production contract of Uniper with Eneco. There is potential for storage in buffers of the horticulture companies and AgroEnergy is currently developing a model to distribute heat among consumers for the purpose of balancing production and consumption, called "WarmteVerdeelModel".
- Contracts determine the end price for consumer. This is either a variable price connected to the electricity and gas price, or a price for contracted volume (Take-or-Pay). There is no regulator that monitors these tariffs, but prices are kept equal or below the alternative costs (using gas). Otherwise, horticulture companies would not sign a contract for heat supply, because it would be cheaper to produce themselves.
- There is currently no capacity mechanism, because Uniper has enough production capacity and horticulture companies can supply their own demand with boilers or CHPs. Uniper is contracted to operate until 2024. Hereafter it is unsure if they maintain in operation. AgroEnergy is actively searching for new producers and business cases in the case production capacity becomes scarce after 2024 when Uniper decides to shot down.

System activities (layer 2b)

In terms of system activities in layer 2b, we can deduce the following:

- The network is given in Figure 8. The topology has a tree structure where the branches are the distribution pipelines and the root is the transportation pipeline. The root starts at the CHP of Uniper and stretches all the way to the end of the B3-Hoek. There is a small distribution network that is islanded from the large DHS in the B3-Hoek. In this network, heat is provided by a single geothermal power plant. This small network operates independently, due to different technical characteristics. That network operates on a lower temperature compared to the main network.

- The production capacity and location of the producers is given in Figure 7. Currently, Uniper has by far the largest production capacity of 250 MW (155MW CCGT, 95 MW boiler), followed by AVR with 50 MW. The total geothermal heat energy production is 32 MW and total biomass heat energy production is 23,4 MW. More capacity is being developed for the latter two. The data on grid capacity is unknown to the researcher, but according to AgroEnergy there is sufficient grid capacity in the transport and distribution network to supply heat to all the consumers who are currently connected and remaining potential consumers in the B3-Hoek. Also, the production capacity is deemed sufficient until 2024. For now, it is unclear if Uniper will still be able to provide heat energy after 2024. Until then the production capacity in the DHS is increased by connecting additional biomass and geothermal power plants to the network. Horticulture companies all have a boiler capable of producing their heat demand throughout the year and some also have a CHP. Grid or production capacity problems can, therefore, be dealt with by self-production.
- The fact that horticulture companies have self-production assets is one of the main technical redundancy measures. It is too costly to build parallel or secondary networks. The tree topology is generally the least expensive to build, but in terms of redundancy, it is not the best option. Problems in the root branches can cause downstream problems. The network is able to reroute flows to use other production facilities as sink/sources. Uniper is currently the main sink/source. AgroEnergy does not guarantee the supply of energy.
- Programming is done by Eneco. Each year contracts are closed with producers for how much operational hours each producers gets. Biomass and geothermal heat are subsidized production assets, thus need to meet a minimum amount of operating hours. This is their minimum amount of contracted production. On the day to day operation, the producers produce their contracted amount according to the demand. Uniper calls producers to increase or decrease production to maintain balance on the network. During times of insufficient production volume by others, Uniper produces extra heat energy.
- Storage of heat energy is easier compared to the storage of electricity. Heat energy can be stored in large water buffer tanks or below the surface in underground heat storage facilities. The main storage facilities are located at the horticulture companies. There is no buffer capacity in the system elsewhere.
- Table 4 shows what parts of the DHS are owned by the different actors. Furthermore, decision rights and grid codes are specified in contracts, standards and Richtlijn Warmtelevering. Discussing the specifics is outside the scope of this research.

3.2.3 Coordination

Now we have identified the actors in the DHS, we will discuss the coordination between them.

Producers ←→ Eneco/AgroEnergy

Eneco/AgroEnergy acts as a single-buyer in the B3-Hoek and purchases heat energy from the producers. Contracts are put in place for the price of energy and the dispatch. The price of heat is based on EUR/GJ. The amount of energy that is produced is measured by the difference between supply and return temperature, multiplied with the flow speed and a constant value. This is called “Contract for Difference”. The programming of each plant is determined by Eneco. They have long term contracts with the different producers for when a specific amount of energy can be supplied. Therefore optimization of assets is currently very limited. Some producers have subsidized production assets, so they must run a minimum amount of operational hours to optimize the granted subsidy. These producers are typically contracted for at least that amount of hours per year. The remaining demand is generally produced by Uniper and some by AVR.
The producers use the transportation pipeline which is owned and operated by Uniper. The costs of the transportation line is currently included in the price of energy production from Uniper. Therefore production cost and transportation cost are currently not split in the contract. The cost of energy loss during the transportation is paid by Eneco, but these costs are eventually passed onto the consumer in their price.

Uniper (as system operator) ←→ Producers
The production programme determines who is producing heat energy throughout the year. As system operator Uniper ensures the balance in the system. Uniper calls the producers if production has to be in- or decreased. Uniper can also decide to balance the system with its own production assets, but the contracts define the limits to what extent Uniper can do this. Uniper is eventually held responsible by Eneco if other producers were not able to produce the minimum amount of operating hours in a year.

Eneco ←→ AgroEnergy
Although AgroEnergy is owned 100% by Eneco, the role of supplier (AgroEnergy) and distributor (Eneco) is clearly separated between the companies. AgroEnergy takes care of the contracts with clients for supply, while Eneco focuses on building and operating the distribution grid. Because optimization of the production side is very limited due to the long term contracts, AgroEnergy tries to strategically contract consumers to balance the production with heat energy demand. This can be done by contracting consumers with buffer capacity and/or by contracting growers with different heat demand patterns. However, contracts are signed with Eneco and AgroEnergy has the executive and organizing role.

Consumer ←→ Eneco/AgroEnergy
AgroEnergy is the only heat energy supplier for horticulture companies connected to the DHS in the B3-Hoek. AgroEnergy also supplies electricity and gas to most of them. AgroEnergy offers different supply packages based on the needs of the grower. The consumer pays for the contracted amount of energy, the distribution costs and indirect the transport costs (cost of energy loss).

Market activities (layer 3)

- The DHS in the B3-Hoek is organized as a decentralized market. The economic and physical control is split in the system because Eneco determines the programming and Uniper is the operator. The relation between Eneco and Uniper makes it difficult to state this black or white, because Uniper has a degree of influence in the programming and is responsible for balancing. Therefore there is some degree of integration between economic and physical control.
- Above, we already touched upon many contractual arrangements between the actors. We will not go into more detail as these specific arrangements are unknown and outside the scope of this research.
- The degree of vertical integration is high. A large part of the production is integrated with transportation and balancing, and distribution and supply are integrated as well. There is some degree of horizontal separation in competition on the production side. However, there are still a few other producers in the network. The main competitive force comes from the horticulture companies being able to produce heat energy themselves.
- Transaction cost are assumed to be relatively low due to the high degree of system integration. Most transaction costs arise during the development of contracts and solving disputes. Exact amounts are unknown, but this is outside the scope of our analysis.
- A principal-agent relationship can be found between Eneco and Uniper. Being producer, owner of the main transport line and system operator puts them in a powerful position. This translate to a strong bargaining position towards Eneco and other producers. It is unknown if and to what degree specifically Uniper abuses this power. It is assumed their dominant role allows them to negotiate prices in their favour. Also, access to the network for other producers are handled under the influence of Uniper. Besides contracts, there is currently no mechanism in place to balance the power.
- Contracts are the main safeguard to counter opportunistic behaviour. However, contracts are hardly watertight so opportunistic behaviour is not excluded. We identified possibilities for opportunistic behaviour when hedging price risks, network access for other producers and how transport costs versus production costs are translated into the price for consumers.
- As far as the position of a regulator, as we have mentioned before, the DHS is outside the scope of the Heat Act that regulates the DHS in the Netherlands. The regulatory body, Autoriteit Consument en

Markt, is not involved in the DHS of our case. Only the province of Zuid-Holland and municipality of Lansingerland are involved as governmental bodies. They give permits for infrastructure and production facilities. Also, geothermal and biomass heat energy producers are able to obtain subsidies (SDE+ and SDE++) from the Ministry of Economic affairs.

System activities (layer 3)

Most of the operational coordination is explained at the beginning of this paragraph. A more highly detailed description is beyond the scope of this research. Therefore we do not discuss the monitoring systems, routines & emergency procedures and preventive maintenance. We acknowledge their importance for system design and their function in a short term market, but we assume these mechanisms are in one way or another implemented and ensure the system functions well.

3.2.4 Firm decision (layer 4)

In this paragraph, we explain how individual actors make decisions on prices and production/demand quantities for heat energy in their daily operations. At this level of the framework, market and system activities are so closely related that we do not distinguish them as was done in the previous paragraph. We focus only on producers and horticulture companies because their behaviour is of interest in this research. Describing the specific operations of the system operator and distributor/supplier is beyond our interest. The description of their roles and responsibilities presented in paragraph 3.2.2 and 3.2.3 is sufficient to understand how they set boundaries for the behaviour of producers and consumers.

Horticulture companies (Growers)

The weather, type of crop and time of the year determine how much heat energy a horticulture company needs. The sun is a large source of heat energy, but in general, there is always a demand for additional heat energy. Even in the summer, there is a demand for heat energy. Horticulture companies can produce their own heat demand. Every horticulture company has a boiler that produces heat energy from natural gas. Companies that are connected to a DHS are obligated by insurance companies to have a least two heat sources: the connection to the DHS and a boiler. This reduces the operational and financial risk if there is any form of system failure in a DHS. Although some companies have a CHP as a source of heat production, they also have a boiler because the electricity/gas price determines whether it is economically attractive to operate the CHP.

Horticulture companies with a CHP can be divided into two categories: illuminated and unilluminated. Some types of crop require an illuminated longer than normal daylight. Because of the financial benefits of producing electricity in a CHP themselves, companies produce a lot of electrical power for lamps that illuminate the crops. CHPs have the characteristic that they produce electrical power as well as a significant amount of heat energy. This is generally more than they require themselves. For them, heat energy is a side product that could be sold to others. Therefore this type of grower can be considered a prosumer. Sometimes energy can be sold to the market, but when market conditions change he purchases energy from the market. It is currently not possible for horticulture companies to act as prosumer in the DHS.

Growers that do not illuminate their crops use the CHP to produce their heat demand. The operation period is determined by the APX day-ahead and intraday market. They produce energy (heat and electricity) when the spark spread is favourable. “Spark spread” is a term for the difference between income from sold electricity and cost of gas. A positive/favourable spark spread means the income for electricity is higher than the costs, so horticulture companies can make a profit by selling electricity. All the electricity is then sold to the electricity market. The buffer is used to balance the heat demand and production within the day. They generally do not produce more heat than they need, unless they have some buffer capacity left and the electricity price is very high.

Horticulture companies can buy (Take-or-Pay) heat energy from AgroEnergy for Q1 and Q4 of the present and the next year. In Q2 and Q3 heat energy is bought for a variable price that is determined by the electricity and gas price on the day ahead markets. Electricity and gas are bought on the APX and TTF, who have different markets for long term positions and short term trade. It differs per horticulture company at which market (day-ahead, intraday, OTC) is used to buy electricity and gas. These markets offer more flexibility to deal with the financial and volume risks of purchasing energy, than the bilateral heat market of today.

Horticulture companies also need CO_2 to stimulate the growth of their crops. When they produce energy themselves, CO_2 is captured and transported to the greenhouse. Companies that use the DHS for their heat supply need another source for their CO_2 demand. This is supplied by OCAP via a large CO_2 network.

Each day Horticulture companies can draw energy from the network, whenever they want (up to their contracted amount). Uniper takes care of balancing by using their regulating capacity. This is the reason why horticulture companies without CHP currently have no need for a buffer because Uniper takes care of the balance and supply throughout the day.

Producers

There are different heat energy production facilities that can supply heat energy in the B3-Hoek: a combined cycle gas turbine, biomass heating systems, geothermal power plants and residual waste heat from a waste incineration power plant. Each power plant has a different marginal cost structure for heat production.

The CCGT of Uniper generates electricity (55%) and heat (45%). The ratio of electricity and heat production can be altered to some degree in the generation process. The electricity is sold on the APX markets and the heat is sold partly to the city of Rotterdam and partly to the DHS in the B3-Hoek. Their marginal cost for heat energy depends on the electricity prices each day or the positions they have taken in the past and the price they have paid for gas. Like horticulture companies, the spark spread indicates how much profit Uniper can make by selling heat energy. Therefore is a high degree of fluctuation in the marginal production costs for producers with co-generative (electricity and heat) assets. However, Uniper has limited freedom to steer production on price signals of the electricity market due to their contracts. They must run when there is heat demand, even though the spark spread is unfavourable. In this case, they use their boilers to produce only heat energy, because that is cheaper than using the CCGT.

The marginal cost level of the biomass plants is for mostly based on the cost of biomass fuel. They mainly produce heat energy (90%) and a small fraction of electricity (10%). The electricity is sold on the APX markets. Subsidies are given for biomass power plants that run for at least a certain limit of operating hours. Therefore these producers aim to contract at least this amount of operating hours to improve their business case. The operation time of these plants is determined by Uniper (day-to-day) and Eneco (year programming).

Geothermal power plants can also obtain subsidies. The main cost driver is the electricity price and the initial investment costs. Heat energy is therefore cheap to produce, but the large fixed cost component must be paid back within the lifetime of the system, usually 15 years. In terms of marginal cost, this results in a very low price point based on the cost of electricity, and could even be negative when subsidies are included. However, a geothermal power producer will add the fixed cost component to the cost production in some way for the return on investments. The technical characteristics of a geothermal well make it hard to scale energy production up and down quickly. Preferably a well operates at a constant level to achieve the highest efficiency. This is one of the reasons, besides operational temperature, why these wells are connected to separated district heat network. The whole system is integrated to keep the production stable to improve efficiency and reduce financial risk for the producer. Buffers from horticulture companies are used to balance the supply and demand in these networks. Production output changes over the course of weeks from a winter production level to a summer production level.

The last type of producer in our case is the waste incinerator of AVR. Here heat and electricity are generated by burning waste. The marginal cost for heat production is difficult to determine for this plant. The fuel that is used is waste, but AVR is paid to burn it. They also receive income from the sold electricity. Therefore their marginal cost has a negative fuel cost component and a variable cost component for maintenance. Via the contracts, AVR receives a price based on the electricity and gas market conditions, so this does not reflect their true marginal costs. Currently, AVR is only allowed to produce heat energy for the B3-Hoek in Q2 and Q3.

3.2.5 Case System Diagram

The following diagram shows the roles and relations of actors in the DHS of the B3-Hoek. It shows how the current market is organized. This market orientation will be compared with the short term market design in the next chapter to identify the differences and changes that have to be made to the DHS.

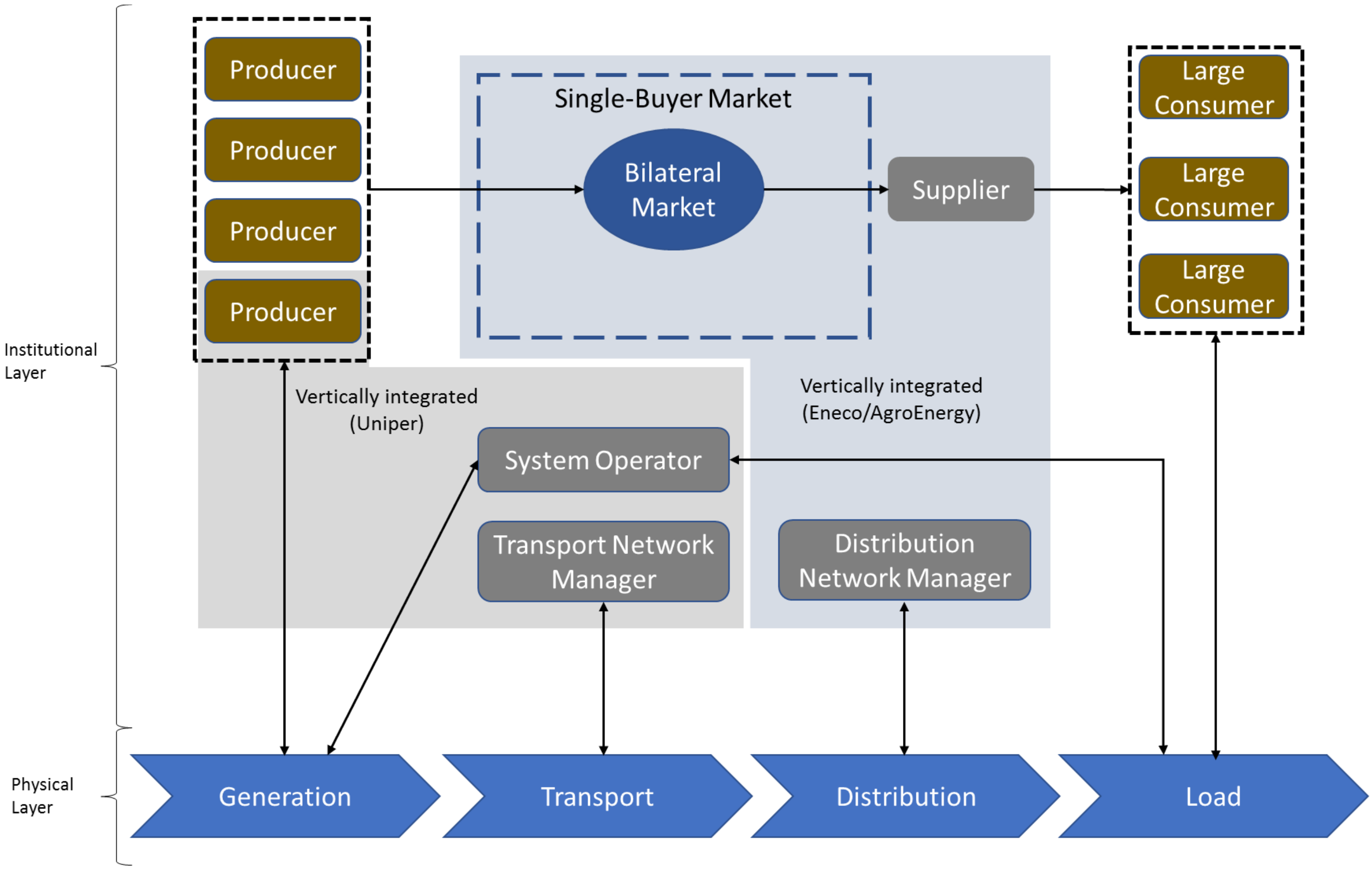


Figure 9 - Market model of the DHS in the B3-Hoek

We can describe the current market organization in terms of the design variables defined by Correljé & de Vries (2008) as following:

Table 5 - Design variables currently used in the DHS of the B3-Hoek

Design variable	Implementation
Public vs private ownership	Hybrid. Only distribution and supply are owned by a public company. The other parts of the system are privately owned.
Network unbundling	Part of production, system operation and transport are bundled (accounting). Distribution and supply are bundled (administratively).
Network access conditions	Access to the network: ex-ante negotiated. Access to capacity: timetabling. TPA wholesale level
Integrated vs decentralized	Decentralized, but some degree of integration.
Degree of market opening	Single-buyer market
Pace of market opening	-
Competition policy	Unregulated. Competition with the natural gas system
Congestion management	Not implemented
Arrangements with neighbouring networks	The waste incineration plant delivers heat via the Rotterdam network to the B3-Hoek and Uniper most allocate production capacity to the city DHS, before using it for the DHS in the B3-Hoek

Design variable	Implementation
Balancing mechanism	System operator with production assets
End user price regulation	No regulation. Contracts determine price (connected to gas).
Capacity mechanism	Not implemented
Position of regulator	No regulation for price or access. Province and municipalities give construction and production permits. Some production is subsidized by the Ministry of Economic Affairs.

3.3 Design Goals

In this paragraph, we identify market failures within the current system based on its description in the previous paragraph. This will be followed by the objective to design a short term heat market. We also define performance indicators to evaluate the design proposal and the market performance (discussed in chapter 5 and onward).

Market failures

In the problem statement of the introduction, we already explained the undesired aspects of using long term bilateral contracts for heat energy trade: incentive to increase prices as a result of hedging risks and bargaining power, gas price is dominant in the heat price and risks of long term volume positions. From the system analysis, it becomes clear that Uniper and Eneco have a strong bargaining position relative to other producers and consumers. Uniper is by far the largest producer. Also, being the system operator and owner of the transport line makes the DHS very reliant on Uniper and prone to market power abuse. Uniper largely influences the heat price and who gains access to the system and its capacity. It is now very difficult for other (or new) producers to enter the market. AgroEnergy is the single buyer/supplier in the DHS, so there is no other way for producers and consumers to trade heat energy. There are price and volume risks for all parties due to the long term contracts. These financial risks are hedged causing the heat energy price to go up.
The price of heat energy in the system is predominantly determined by the price of gas, even though there are multiple different producers who do not have the price of gas in their cost structure.
Lastly, the long term programming of production in advance causes "must run" situations, especially for Uniper, that are sometimes not profitable.

Objective

To deal with these market failures it is suggested to implement a short term market for producers and consumers. Similar to the spot market for electricity and gas, this market allows for heat energy to be traded short term between producers and consumers. Production and consumption contract volumes are determined and sold much closer to the point delivery, decreasing price and volume contract risks. It gives producers more flexibility to determine how much energy they are willing to produce given the present market conditions, and horticulture companies can purchase energy more efficiently based on short term weather predictions. The price for heat is determined by the market, instead of gas price based. Also, the new heat market should make it easier for new producers and consumers to enter the market.
The objective of the design proposal of the short term market for the B3-Hoek is to show what institutional and technical system arrangement would facilitate short term trade between producers and horticulture companies. Also, the short term market should co-exist beside the long term bilateral market. The goal is not to change the market to one where only short term trade is possible, but to include it as an additional way to facilitate heat energy trade in the DHS. The other objective is to evaluate the performance of a short term market under market conditions of the case.

Performance indicators

In order to evaluate the new market design and the performance of the market, the following performance indicators (PI) have been identified. Below it is explained why they are selected as PI.

1. There should be non-discriminatory access to the system for new producers and consumers
2. The short term market price should remain below the cost of heat production with a boiler for horticulture companies
3. Competition forces should drive the market price (close) to the marginal cost level of producers, but they should still be able to make profits to recover their long term costs (capital costs and future investment costs).
4. A high amount of heat energy volume that should be traded on the market
5. Stakeholder satisfaction should be high

The first PI has been selected to evaluate the market design proposal. In the short term market it is important that producers and consumers can freely arbitrate on the market. This means that they should be allowed to gain access to the system. The natural monopoly character of a district heat network prohibits the construction of parallel networks. Therefore the possibility for new entrants to use the network of the incumbent monopolist is a necessary prerequisite for effective competition (Klein, 1996; Söderholm & Wårell, 2011). These access conditions should be non-discriminatory to ensure that the access procedure of new producers and consumers is fair. This PI will be measured qualitatively because it is difficult to quantify non-discriminatory access conditions.

The other PIs are selected to evaluate the market performance. The second PI is used to see whether heat from the short term market is cheaper than self-production with a boiler. In the case where the market price is equal or higher than the cost of self-production, it is expected that horticulture companies are inclined to no longer purchase heat energy for the short term market. It would be cheaper to produce energy themselves, thus this leaves the short term market obsolete. This PI is measured quantitatively by comparing the cost of self-production with market prices.

The third PI is used to evaluate the level of the market price. The objective of marginal cost pricing is to bring about an efficient allocation of resources. In the case where the market price equals the marginal cost price of producers, there would be no producer surplus, and all intra-marginal rent would be captured in the form of consumer surplus (Schramm, 1991). This case is widely viewed as “fair”, but it is also criticized. That is because only when perfectly discriminatory pricing is used, marginal cost pricing yields the highest resource allocation efficiency (Schramm, 1991). Marginal cost pricing is based on the ideal market theory, but in reality, this is difficult to guarantee, particularly in natural monopoly markets, such as a heat market (Zhang et al., 2013). Cramton (2004) goes further by stating that bidding behaviour in electricity markets should not be assessed on the norm of marginal cost offering, as it applies only in the theoretical extreme of perfect competition. In real bid-based electricity markets operating under a range of supply and demand conditions, individual producers should be bidding to maximize their profits, which will inevitably involve bidding above marginal cost. Bidding above marginal costs is and should be the competitive norm in uniform price electricity auction markets, according to Cramton. However, if the market price is above marginal cost level there is more producer surplus. This is beneficial for producers because this results in profits to recover their fixed costs and pay for future investments. Nevertheless, this also means a smaller consumer surplus. There is a balance between a low market price for consumers and a price high enough for producers to make a return on investments. The higher the difference between output price and the marginal production cost, the more market power producers have (Fridolfsson & Tangerås, 2009). Thus by checking whether the market price is close to marginal cost levels, we can discuss whether there is market power on the production side. In this research it is considered fair if consumers pay a market price that is close to the marginal cost level of the producers. In a uniform settlement, cheaper producers will earn profits when a more expensive competitor sets the market price. Only if the most expensive producer is always settled on his marginal cost, he will not make profits. Therefore we check whether producers (especially the ones with the highest marginal cost) make a profit under the market conditions of the case because we acknowledge that it is also important for them to make profits for return on investments. Moreover, if there are considerable profits in the market it will give the incentive for new production entrants to enter the market, thus competition will increase eventually. This PI is measured quantitatively by comparing the marginal production costs of the producers with market prices.

The fourth PI is used to evaluate the amount of energy that is traded on the market. Theoretically, the ideal total quantity that should be traded in an efficient market is at the point where marginal cost equals the marginal willingness to pay for a good. However, in real markets, the supply and demand curve do not reflect the true marginal cost and marginal willingness, because producers and consumers will behave strategically to influence the market price in their favour (Cramton, 2004). The result of this behaviour could be that the market settles at a quantity much lower than the total demand for heat energy. When producers aggressively offer high prices there might only be a small number of growers willing to buy. Only a small amount would be sold and a lot of growers would have to produce energy themselves. The other way around, when consumers aggressively bid low prices, there might only be a few producers prepared to sell heat. In this case, only a fraction of the consumers are able to purchase energy as well, while others will have to produce heat themselves. In this research we are mainly concerned with the amount that consumers purchase on the market and if this amount is equal to their demand. The higher the ratio of the demand is supplied by the market the better. Note that there is a high degree of seasonal influence on the demand for heat. Therefore there will likely be an overcapacity in during summer conditions, so a lot of producers will not sell heat energy. However, this capacity is needed in the winter when demand is high. By comparing the total quantity sold to the total production capacity of producers the seasonal influence would make the market performance look worse than it actually is. Therefore we only look at how much consumer demand is satisfied by the market. This PI is measured by comparing the total demand in the market and the amount that is settled. The higher the ratio, the more efficient the market can be considered.

The fifth and last PI is stakeholder satisfaction. The desire of AgroEnergy and other stakeholders was one of the starting points for this research. To confirm if producers and consumers have the desire to arbitrate in a short term market, the participants will be questioned on their experience with the simulation and gather data about their opinions on the implementation of a short term market in the DHS. This PI is qualitatively measured with the data gathered through a survey and interviews.

Concludingly, this chapter discussed the DHS of the case and presented the performance indicators that will be used to evaluate the design proposal and the performance of the market. The next chapter will discuss the design process of the new market model and identify what changes will have to be made from an institutional and technical perspective compared to the current market model.

4

Market Design

In the previous chapter, we showed how the market of the DHS in the B3-Hoek is currently oriented. In this chapter, we will present our market design for a short term market and what choices are made in the design space we have specified in chapter 2. This chapter answers our first research sub-question. We use the first PI to choose the best alternative of each design variable for a short term market. We end this chapter with a system description of the short term market and identify what changes will have to be made to the DHS in the B3-Hoek.

4.1 Design choices

In the previous chapter we discussed the current market model of the DHS in the B3-Hoek. This must be taken into consideration when we design a new market model that includes a short term market. By using the design variables identified by Correljé & de Vries (2008) and the design framework of Scholten & Künneke (2016), we can make a systematic comparison between the old and new model to identify the changes that need to be made.

We start this paragraph by discussing which alternatives of the design variables are chosen for market design proposal. The next paragraph discusses the new market model and the corresponding responsibilities, coordination among actors and the new decision-making process. Lastly, we summarize the main features of the design proposal and identify what technical changes must be made in the system.

In Chapter 2 we presented the design space, which is summarized in the table below:

Table 6 - Design space short term market

Design variable	Alternatives				
Public vs private ownership	Public	Private	Public-private (hybrid)		
Network unbundling	No unbundling	Accounting separation	Administrative separation	Juridical separation	Ownership unbundling
Network access conditions	Regulated	Negotiated			
	Ex post	Ex-ante			
	Open access	Pooling	Timetabling		
	TPA wholesale level	TPA Retail level			
Integrated vs decentralized	Integrated	Decentralized			
Balancing mechanism	Imbalance market	Regulating capacity contracts	Demand-side management		

For each design variable, we will explain what choice is made for the design of the short term market. The design variables are to some extent related to each other. This means that the selection of one alternative has consequences for the selection of the alternatives of other design variables. Also, there might be other (technical) characteristics of the DHS that constrain the selection of alternatives. The goal is to look for a combination that is mostly desired in the short term market. Our goals is not to change the market completely, but to include a short term market as an additional way of facilitating heat energy trade. For each choice, the institutional and technical changes that are required will be discussed.

Public vs private ownership

Economists have long debated whether one is better than the other. Many industries and sectors have been studied to find an answer. Shleifer (1998) concluded in his research that private ownership should generally be preferred to public ownership when the incentives to innovate and to contain costs must be strong. Government ownership is likely to be superior in situations in which: opportunities for cost reductions that lead to non-contractible deterioration of quality are significant, innovation is relatively unimportant, competition is weak and consumer choice is ineffective and reputational mechanisms are also weak. For each link (generation, transport and distribution) in the value chain of the DHS, we will discuss what kind of ownership would best suit the new market model.

Generation is currently done by private companies. For the production of heat energy, innovation and cost reduction incentives are high, because multiple companies compete with each other. This competition is on price only, since there is no quality of heat. Although temperature can be seen as a form of “quality” (the higher the temperature, the more useful), producers are obligated to generate heat at a specific temperature, thus there is no competition on quality of the product. It can be concluded that generation should be privately owned, thus this aspect requires no need for change in the new market model.

Transport is now done by Uniper, who is system operator and owns the transport network. In the energy sector the system operator is also the transport network manager. In the electricity sector in the Netherlands, Tennet is both system operator and responsible for the transport network. Likewise, Gasunie has both tasks in the Dutch gas sector. In other network industries, mainly the transport sector, these roles are split (Prorail and NS). We will come back to the point, whether it should be split in the DHS, when we discuss network unbundling. For now, the question is whether the transport network manager should be a public or private entity? The transport network has a monopolistic character because economies of scale make it inefficient to build parallel networks. It is a bottleneck facility and access to it must be organised by non-discriminatory conditions (Klein, 1996). Therefore it can be argued that it should be publicly owned or by a regulated private entity. However, the DHS competes with the gas network and if it has no interest in production, a private entity would have the incentive to reduce costs and connect as many producers and consumers as possible. A hybrid alternative would combine the best of both, plus financing can be done with both private and public money. Right now a conclusion cannot be made, because choices of unbundling will influence whether transport is owned publicly or privately. Therefore we will come back to this point after discussing unbundling.

Distribution is now done by Eneco, technically Eneco is a public company because all shares are owned by multiple municipalities. Eneco is now in the process of being sold to a private entity, thus will probably be owned privately from 2020 onward. Therefore, Eneco is considered to be a private company in this analysis. Similar to the discussion on transport ownership, the choice of degree of unbundling will determine whether distribution should be owned publicly or privately.

Network unbundling

For the short term market, we want to introduce fair competition between producers and consumers. This means that all actors must be allowed to freely trade energy based on the price by bidding or offering and access to the system should have non-discriminatory conditions. In order to do this it is necessary to unbundle elements within the system.

First, ownership of production activities must be unbundled from the network (Bijvoet, 2017; Correljé & de Vries, 2008). Unbundling networks from generation was necessary in the electricity market for the introduction of competition on a wholesale level and it is found this should be the case for our DHS as well.

Currently, Uniper is producer and owner of the transport line in the network. This might influence the short term market negatively because they can give their own production assets priority in the network. This would result in unfair competition with the other producers. Therefore Uniper should not be considered as a transport network owner.

Eneco has no production activities, so there is no conflict of interest in them being the owner/manager of the distribution network. If they were to maintain this role in the new market model they would maintain a monopoly position in the distribution network. However, this is not necessarily a problem as they must compete with the gas infrastructure, thus attract new consumers with comparable tariffs. Also, they have the incentive to connect as many new entrants as possible to the system to improve their business case. This should result in non-discriminatory access conditions, which we elaborate more on below. Eneco stated that they want to fulfil the role of supplier and distributor in district heating (de Ronde, 2019). The idea of the short term market is that horticulture companies are able to buy heat from an independent market, thus not via a supplier. The long term bilateral contracts could still be handled by Eneco, similar to how it is done today. Therefore it is concluded that Eneco should maintain ownership and control of the distribution network and can act as the supplier in the bilateral market, where AgroEnergy will take care of billing and contracting. This means that distribution is (still) privately owned in the new market model.

For the transport network, we have thus far not concluded who should be the new owner. Recently, the Dutch government has decided that it has taken an interest in obtaining ownership of transport networks in DHS. Page 112 of the Climate Agreement (Klimaatakkoord) states that, from 2019, they will look into how they will financially support the development of heat networks. The revision of the Heat Act in 2022 will clarify this. Recently it has been decided by the Minister of Economic Affairs to investigate if Gasunie, the Dutch gas transport network owner/operator, should also take ownership of heat energy transport networks (Energeia, 2019). Therefore Gasunie is one of the alternatives. The other alternative is Eneco. From a technical point of view the system is not split in a transport and distribution network. It could be considered one big distribution network. Since Eneco is and can remain the distribution network owner, they could take ownership of Uniper's share of the network.
For now, it is assumed that Uniper will be willing to transfer ownership of the transport network. In Chapter 7 we will discuss the implications for the design proposal if they are not willing to give up ownership. The table below identifies the pros and cons of having Eneco or Gasunie as transport network owner.

Table 7 - Transport network owners pros and cons

	Pro	Con
Eneco	- More experience with the DHS - Has a higher interest in the network - Able to combine supply and distribution, thus saving transaction cost	- Private nature could result in less favourable access conditions - Profit maximisation incentive can result in predatory behaviour
Gasunie	- Independent from other responsibilities - Public nature can better ensure non-discriminatory access - Ability to connect to other DHS via multiple transport lines - Makes choices to safeguarding public values (CO_2 emission reduction, socializing costs, guaranteed supply)	- No experience with DHS yet - Lots of technical changes have to be made in the DHS if Gasunie becomes owner of the network - Higher transaction costs

Based on the analysis of who ought to have ownership of the transport network in the B3-Hoek, when a short term market is introduced, it is concluded that a hybrid ownership form is a preferred alternative. As an independent party, Gasunie can better ensure non-discriminatory access conditions to stimulate competition. However, due to the unique and complex technical characteristics of the DHS in the B3-Hoek and Gasunie's lack of experience with DHS, they should partner with Eneco. Eneco already has a lot of knowledge/ experience and monitoring tools necessary to manage the transport network. Gasunie ought to have a majority of the shares to have decision rights on determining access conditions, tariffs and to safeguard public values. The benefit of having both parties involved is that Gasunie will be able to obtain financial support from the government more easily since district heating networks are currently not subsidized. Although it is not analysed, it is assumed that transaction costs in this structure would be lower as a result of the direct involvement of both companies.

The role of Gasunie in the partnership will be to finance and maintain the transport network. Their majority in shares should allow them to set non-discriminatory access conditions and tariffs. Eneco will have a more executive role to monitor and manage the network as a system operator (discussed below).

A short term market needs a market operator that takes care of collecting bids and offers from producers and consumers and clearing the market. This role is currently missing and should be introduced when the short term market is implemented. Two alternatives have been identified: independent market operator and Eneco.

In the electricity and gas market this is the case with the APX and TTF respectively. AgroEnergy has done a market consultation to find a party who would be willing to take responsibility for market-clearing. External parties were interested, but further discussions have been stalled thus we are unable to identify a specific actor for this role. The main advantage of having an independent market operator is that these activities are unbundled from supply activities. The dispatch is independently determined based on prices, instead of a supplier who might have ulterior interests.

If Eneco would perform this task in the new market design, the executive role of the operations will probably become part of the tasks of AgroEnergy, because they are responsible for most of the operations in the DHS of the B3-Hoek. However, they could have to incentive to treat their clients with preferential conditions, compared to non-clients. Moreover, there is a risk of market manipulation. The short term market would reveal prices of producers to AgroEnergy, that could be used strategically in negotiations for long term contracts. Negotiations for these contracts should not be affected by AgroEnergy having market insights that can help them to squeeze producers in order to improve their profit margins when they make a deal. To prevent this conflict of interest another solution is to build a Chinese wall within AgroEnergy that splits the short term and long term bilateral market operations. This is done similarly in Copenhagen DHS by Varmelast and proved to efficient in preventing market manipulation and conflict of interests (J. Wang et al., 2019). This option should be considered as a last resort, as an independent market operator is a preferred choice.

The market operator and system operator should work closely together to ensure the physical flows correspond to the levels of supply and demand, which is decided on the market. Bijvoet (2017) suggests these roles should be carried out by one independent entity. We do agree that this would result in the lowest risk for market failures, but given the technical characteristics of the DHS, we suggest to split the roles as is done in the electricity and gas sector.

Uniper is the system operator and is the only one nowadays with the technical capabilities to perform this role because they have a lot of regulating capacity. Eneco does not have the tools to operate the DHS, nor the assets to ensure balance in the system. They already have a lot of monitoring systems in place and with the acquisition of the transport network, there is complete information on flows in the network. Gasunie & Eneco can take on the role of the system operator, but they will have to contract Uniper maintain balance in the system. In the long run, Gasunie & Eneco could decide to invest in obtaining system operatorship if it will outweigh the transaction costs. This will be discussed in more detail below, when balancing mechanisms are discussed.

Network access conditions

If Eneco gains partial ownership of the transport line, it gains (to some extent) full control over the network and who gets access. This gives them a dominant, but it also lowers the transaction costs of transport and monitoring. Moreover, Enesco does not have production assets, thus will have the incentive to connect as many producers and consumers to make optimal use of the network and collect the highest income for networks fees. Additionally, if Gasunie is the majority shareholder of the public-private transport network company, non-discriminatory access conditions and fair pricing are better ensured. However, due to the technical characteristics of a DHS, Eneco would be inclined to choose system efficiency and a good business case over the guarantee approve every connection request. In the electricity market, such requests are regulated, but in our DHS it is not. All the more reason why Gasunie, as a public entity, should co-own the transport network to introduce a form of regulatory access control. However, for technical reasons such as maintaining the proper pressure and flow direction, ex-ante negotiations will still be required.

We identified three options for access to the capacity of the network: open, pooling and timetabling. Open access to the network capacity is undesired in DHS. In the short term market, the price of bids/offers should decide what producer and what consumer receive heat after a settlement. Pooling is thus the best option for this market. Here producers submit their offers and consumers submit their bids to the market operator, who clears the market and determines the dispatch. Competition on price ensures the cheapest producers can supply and highest bidding consumers receive heat energy. Timetabling would give the wrong incentive for the network owner to allow access to the highest bidding producer. This would make heat prices go up and would defeat the purpose of lowering energy prices through competition. Pooling ensures that supply and demand are not controlled by the owner of the network. In our case, an independent market operator will facilitate the auction platform. In practice, there are two methods for auctioning: Uniform and Pay-as-Bid (Fabra, Von Der Fehr, & Harbord, 2002). In a uniform auction, the market price paid and received by settled consumers and producers respectively is the same. In a Pay-as-Bid auction every consumer/producer that is settled, pays/receives only the amount that has been bid/offered. Uniform auctions are now commonly used in electricity markets and well known by horticulture companies and producers. Therefore we suggest this auction method to be used for the short term market as well. It is also considered more fair, because all producers receive the same price and consumers pay the same price. This is not the case in a Pay-as-Bid auction.

The short term market involves only large consumers, who directly participate in the market without a retailer in between. This direct participation and small character of the DHS make the need for the introduction of multiple retailers in the system unnecessary and undesired. It would only add additional transaction costs in the system. TPA is thus only on the wholesale level.

Integrated vs decentralized market

The decision to split the market activities from the technical operational activities means the short term market functions in a decentralized market. In the current market organization, there is a degree of integration, because Uniper had control over the dispatch in the short term. In the new configuration, an independent market operator determines the dispatch by the settlement of the market. However, the transaction cost would be higher, compared to the case where the market is integrated. Combining the market and system operations allows for better coordination, which results in lower transaction cost. However, we stress the importance of a market operator’s independence from other system activities.

Balancing mechanism

Maintaining balance is the system ensures that all consumers are able to receive their energy demand from the network. The system operator monitors the flows and pressures in the network, thus is responsible for the balance between supply and demand. Gasunie & Eneco do not have the assets to manage balance themselves. Therefore they depend on others to provide them with balancing mechanisms.

The first one, we suggest for the short term, is contracting Uniper to manage the balance within the DHS. Uniper already performs this role and could do this in the new market model as well. One problem is that when

Uniper forfeits the ownership of the transport network, they will not have their own monitoring systems that allow them to directly intervene. The control room is now situated at Uniper and will have to be transferred to Gasunie & Eneco. Transaction cost will increase due to the interaction between the system operator and Uniper, and complex contract structures that most ensure there is no unfair competitive advantage for Uniper, as balance controller, compared to other producers. This mode of organization will also increase the dependence on Uniper. If Uniper decides or is forced to shut the power plant after 2024, there would be a problem.

To decrease the dependence on Uniper, the system operator should look for alternative balancing mechanisms. Another option is to make horticulture companies invest in buffer capacity that can be used to balance supply and demand throughout the day. Heat energy can be stored, but unlike gas where the network itself is the main buffer, this possibility for heat networks is limited. The fact that horticulture companies have no buffers in the current DHS is because of the unique possibility to draw heat energy from the network at any time. Without Unipers regulating capacity, buffer capacity will be needed to maintain balance between supply and demand throughout the day. The other producers have limited regulating capacity. Geothermal plants always operate at a constant level, Biomass plants have not enough regulating capacity and AVR has limited freedom to alter heat production levels due to their contracts with the city and port of Rotterdam. A balancing market is therefore not an option. Installing buffer capacity at the producers is not viable, because they would have to be very large and investments costs would be too high, according to AgroEnergy. Therefore buffers should be installed at the consumers. Only the horticulture companies (without a CHP) in the DHS today have no buffers, but most horticulture companies that will be connected in the near future do have a buffer already. This allows for demand-side management where the system operator can manage the balance in the network by determining when horticulture companies can use the network or most use their buffer for the demand throughout the day. AgroEnergy is currently working on a demand distribution model, called “WarmteVerdeelModel”, that can be used for this balance mechanism.

4.2 Towards a short term market

In the previous paragraph we selected the alternatives of the design variables in the design space. Combined this selection results in a new configuration of the DHS in the B3-Hoek, where a short term market is included. The following figure shows the organization of the market design proposal.

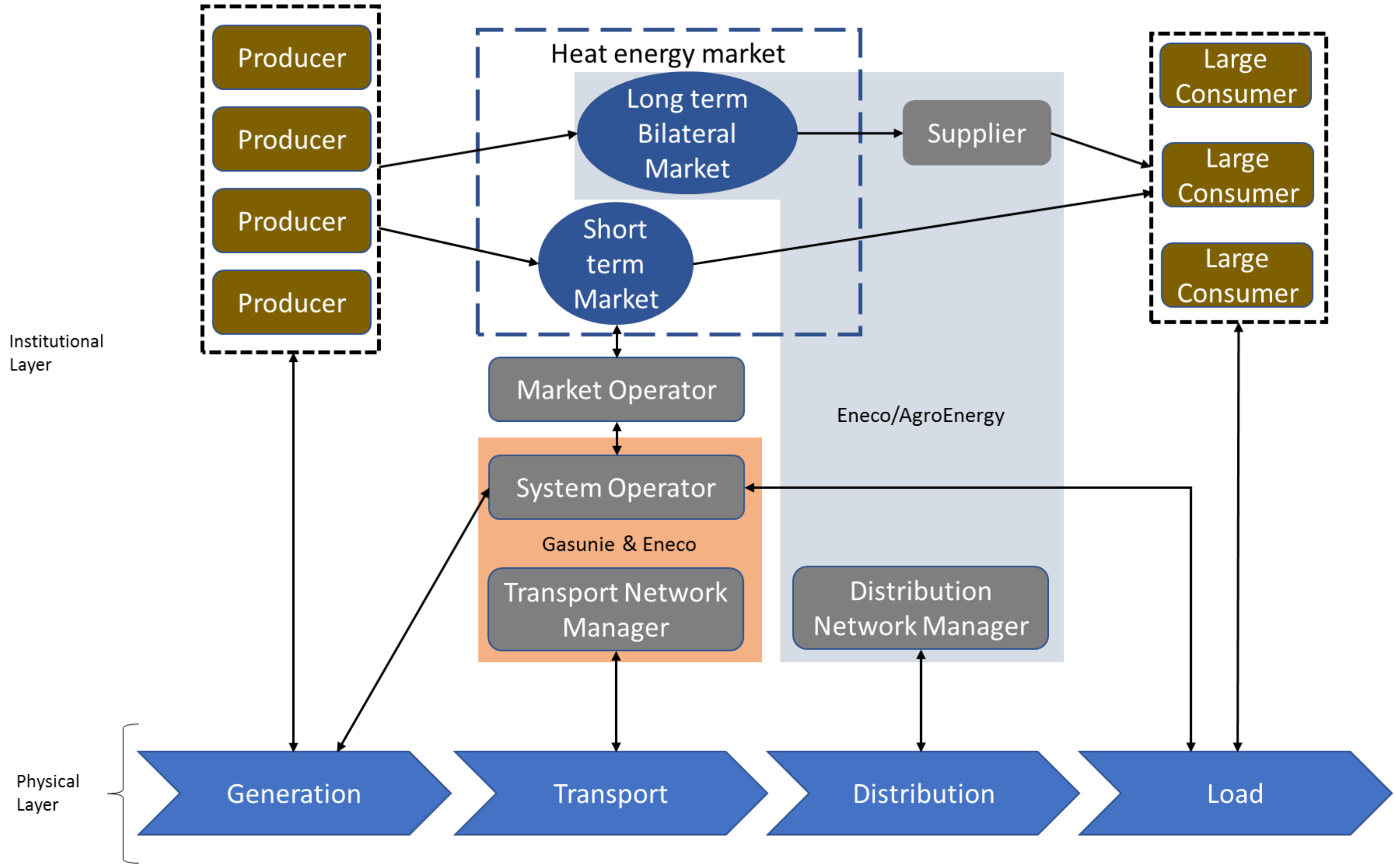


Figure 10 - Market design proposal for a short term market

We can describe the new market organization in terms of the design variables defined by Correljé & de Vries (2008) as following:

Table 8 - Design variables for short term market in the DHS of the B3-Hoek

Design variable	Implementation
Public vs private ownership	Private producers, public-private system operator and transport network manager, private distributor, private market operator.
Network unbundling	Production unbundled from network activities, system operation and transport management are bundled (ownership). Distribution and supply are bundled (administratively), Market clearing unbundled from system activities.
Network access conditions	Access to the network: ex ante negotiated. Access to capacity: pooling. TPA wholesale level
Integrated vs decentralized	Decentralized, contracts between market operator for dispatch and system operator for balancing.
Degree of market opening	Wholesale market
Pace of market opening	By 2025, see paragraph 2.2
Competition policy	Unregulated. Competition with natural gas system
Congestion management	Not implemented, see paragraph 2.2
Arrangements with neighbouring networks	The waste incineration plant delivers heat via the Rotterdam network to the B3-Hoek and Uniper most allocate production capacity to the city DHS, before using it for the DHS in the B3-Hoek
Balancing mechanism	System operator contracts Uniper for regulating capacity in the short term. In the long run demand-side management with distribution models combined with the buffers at horticulture companies

Design variable	Implementation
End-user price regulation	Regulatory control on transport costs. No regulation for market prices. Market clearing determines the market price.
Capacity mechanism	Not implemented, see paragraph 2.2
Position of regulator	Regulatory control on access and tariffs in the transport network. Province and municipalities give construction and production permits. Some production is subsidized by the Ministry of Economic Affairs. Public investment in the transport network is possible.

Referring to the framework of Scholten & Künneke (2016), in the new market model responsibilities (layer 2b) and coordination (layer 3) are organized differently compared to the present situation, which results in a change in how firms make decisions (layer 4). We discuss the changes below. The short term market runs parallel to the long term bilateral market, thus a lot of responsibilities and coordination in that market remain the same but are done by a different owner/company. From here we focus mainly on the responsibilities and coordination of the short term market, so we will not go into detail on the specific changes in the long term bilateral market. In Chapter 7 we come back to this point. The next table gives an overview of the actors and their roles in the new market design:

Table 9 - Roles and responsibilities in the new market design

Role	Actor	Responsibilities
Transport	Gasunie & Eneco	- Managing flows - Maintenance transport line
Distribution	Eneco	- Building connections to the network - Maintenance distribution lines
System Operator	Gasunie & Eneco	- Balancing
Supplier	AgroEnergy (Eneco)	- Billing - Contracting consumers - Contracting producers
Producer	Uniper (CHP plant) AVR (Waste incineration plant) TBM (Biomass power plant) Wayland energy (Geothermal plant)	- Production of heat energy
Consumer	Horticulture companies	- Consumption of heat energy
Regulator	Ministry of Economic Affairs Province Zuid-Holland Municipalities	- Legislation heat supply - Location permits - Subsidies for energy production
Market operator	Independent/ external company	- Market clearing - Dispatch
Measuring	Gasunie & Eneco	- Supply, installation and maintenance of measuring devices

4.2.1 Responsibilities

In the new market design Gasunie & Eneco are the owner of the transport network. Therefore they are responsible for managing all the flows, network maintenance and connecting new producers and consumers to the network. Eneco will be responsible for this in the distribution networks.

They do not have the tools to control the flows in the network as system operator, thus they need to contract Uniper to provide regulating capacity. Contracts will have to be developed to give the system operator decision power in the network, where Uniper will only perform the executive role. The responsibility of the system operator is to monitor the balance in the network and contact Uniper when additional energy is required in the network.

AgroEnergy will still provide the option to supply heat energy to the consumers via the long term supply contracts. In the future, this market model might change towards an over-the-counter (OTC) market, where consumers and producers negotiate or trade long term deals directly, without a third party in between. In this research, it is assumed that the current market model will remain and function parallel to the short term market in the short run. Other research could investigate what changes need to be made to change the single buyer structure of today.

For consumers, it is now possible to choose whether they want to purchase heat energy in the short or in the long term. Some consumers might also become prosumer, as they could be able to supply heat energy to the market with their CHP.

The role of the regulator (Ministry of Economic Affairs) changes in the new market design when Gasunie is co-owner of the transport network. They can impose a form of regulatory control in the DHS by determining the access conditions and tariffs.

The role of the market operator is introduced by the short term market. An independent company will be responsible for market-clearing and communicating the daily dispatch to the system operator. The type of market will have the form of a double-sided uniform day-ahead auction. It is double-sided because both producers and consumers arbitrate in the short term market. The market-clearing is uniform, thus each settlement will result in one market price. This is similar to how the day-ahead market in the electricity sector works. A day-ahead market is chosen because this auction interval period allows for balancing supply and demand throughout an entire day. This is also the case in the gas sector, where a day-ahead auction is also used. Real-time auction and balancing, like in the electricity sector, is not possible in DHS, because of system lag and it is not necessary.

The system operator takes into account the programming conditions determined by network constraints and the supply of via the long term contracts. When the dispatch program is checked and executable, it is sent to the producers and consumers.

Eneco is responsible for measuring, supplying and installing the measuring devices in the transport and distribution network. Gasunie can check whether Eneco is not abusing their monopolistic position as being the only monitor is the system.

4.2.2 Coordination

Producers ←→ Market Operator

Producers now have two markets in which they can sell their energy. Long term contracts give financial security and set a minimum amount of operating hours, which is necessary for subsidies. The short term market allows them to optimize the use of their production assets in the short run. The process of selling through long term contracts remains the same as is described in paragraph 3.2.3. On the short term market the producers will have to submit their production offers (in €/GJ per volume in GJ) in advance and after the market is cleared they are allowed to produce heat energy and put it in the network. The dispatch is price-based, thus the cheapest producers are settled until demand and supply meet at the same price. After the settlement, the producers know the amount of heat that must be produced the next day. Each producer receives the settled price per GJ for this total amount.

System operator ←→ Producers

The settlement volume only specifics the total amount of heat that must be produced. Each producer can determine their own production program for the day as long as the total settled volume is supplied. These production programs must be sent to the system operator, who checks whether they are executable given the system constraints and demand patterns throughout the day. Once confirmed, the system operator sends their approval of the production programs or requests for modifications to the program.

Throughout the day the system operator monitors the flows in the network to check the balance in the system. He calls the producers if production has to be in- or decreased according to the agreed program. Uniper can be called upon to use there regulating capacity to keep the balance in the system. Controlling mechanisms should be in place to check what production by Uniper is according to their program and what is used to balance. This would be the balancing mechanism in the short run if there is insufficient buffer capacity in the DHS. In the long run, when buffer capacity is added, the system operator can perform demand-side management.

Eneco ←→ AgroEnergy
The role of the supplier (AgroEnergy) and distributor (Eneco) remain the same within the company. AgroEnergy takes care of the contracts with clients for supply, while Eneco focuses on building and operating the distribution and transport network.

Consumer ←→ Market Operator
Consumers also have two markets in which they can purchase energy. In our short term market consumers also compete for heat energy. They must submit bids (in €/GJ per volume in GJ) and receive energy if they are settled. This results in a settlement for all consumers that initially bid more than the settlement price. Consumers whose bids were lower either have to bid more or used an alternative way to purchase heat.

Consumers ←→ *AgroEnergy*
For consumers who want to purchase heat long term, AgroEnergy can still provide long term supply contracts until a different long term market structure, such as an OTC market, is available in the DHS.

Producers ←→ *AgroEnergy*
For producers who want to supply heat long term, AgroEnergy can still provide long term contracts until a different long term market structure is available.

4.2.3 Firm decisions

Based on the new market design, horticulture companies and producers are able to make different decisions to optimally allocate their resources and manage financial risks. This paragraph explains how these actors make decisions in the new market environment.

Horticulture companies (Growers)

In the new market, design growers can purchase heat energy according to demand predictions for the short term. Based on short term weather predictions, they are capable to calculate with high certainty the amount of heat energy they need in the coming days. The short term market allows them to capitalize on this. The grower will look at the cost of each alternative to see how he will fulfil his heat demand: long term contracted heat energy, buying on the short term market or produce heat himself. Some growers prefer to take care of their energy-related business once every year. For those, it is more suitable to negotiate long term supply contracts with AgroEnergy. Others will prefer to be more flexible and want to trade more frequently. For those growers the short term market is a welcome addition in the DHS.
Growers without a long term position must decide how much heat energy they want to purchase and what price they are willing to pay on the short term market. Rationally, this decision is based on the cost of their alternative: producing heat himself with a boiler or CHP.
Every horticulture company has a boiler that produces heat energy from natural gas. The costs related to this form a benchmark of how much he is willing to pay for heat energy on the short term market. It is rational to think a grower will produce heat himself if he cannot buy it anywhere else for a lower price. Therefore the bid of a grower will always be equal or lower than costs of his alternative. Some horticulture companies also have a CHP. A CHP has a more difficult cost structure than a simple boiler because the electricity price affects the cost of running a CHP every hour of the day.
As we mentioned in 3.2.4, horticulture companies with a CHP can be divided into two categories: illuminated and unilluminated. Illuminated growers will purchase heat energy and electricity if the combined costs are lower than running their CHP for their energy demand. High heat energy prices influence the choice to use the CHP because using it might cheaper and they need a lot of electricity. They will also produce heat and therefore do not need it from the heat market. However, if the spark spread is unfavourable it could be cheaper to buy

electricity and heat rather than producing it. Some often produce so much heat, they might be willing to sell this at the market. Therefore the short term market could introduce prosumers in the DHS.
Unilluminated growers use the CHP mainly to produce their heat demand or when they can earn a lot of money on the electricity market. When they produce heat is determined by the APX day-ahead and intraday market. When the spark spread is favourable they run their CHP to sell the electricity and use the heat themselves. The buffer is used to balance the heat demand and production from time to time. They will not produce more heat than they need unless they have some buffer capacity left and the electricity price is very high. Thus when electricity prices are low, it could be cheaper to buy heat energy from the market. If not they rather sell electricity. Arbitrating in an energy market comes with a program responsibility, meaning that the energy produced must be equal to the amount that is settled. Fines have to be paid if production is too much or too low. This must be kept in mind when arbitrating at both the electricity, gas and heat market. Additionally, when heat is bought from the market, CO_2 must be bought from the OCAP network as well.

Producers

Producers are also affected by their positions and changing conditions in the gas and electricity market some more than others. Flexibility in the short term market allows them to compensate for changes in these markets into their heat price. As described in 3.2.4, producers like Uniper have a highly fluctuating marginal cost for production. The long term positions in the heat market, that cause must run situations can cost them dearly if negotiated heat prices are much lower than the costs, as result of a very low electricity price and expensive gas price. For them, it would be more interesting to supply more energy to the short term market. Producers like geothermal power plants have a more stable marginal cost, but also have a fixed production output. The volatility of supply in a short term market might not be in their best interest. They are better off by negotiating a long term position for a price point where they can keep production maximised.
When producers make an offer on the market, they will take their marginal cost as bottom-line. When the settlement price is below that price point they do not get to produce. If their offer is below their marginal cost and it is settled, they make a loss on their production. If the settlement price turns out to be higher than their marginal cost, they make a profit. Therefore it is rational for the producer to offer at marginal cost levels.
However, if a producer has market power they can set the price point of their offer much higher and still be settled. As we have mentioned in Chapter 2, the measure of market power is based on the difference between the output price and the marginal production cost (Fridolfsson & Tangerås, 2009). If this is the case for a producer in our market, we expect to see him offering high above his marginal cost. This behaviour is limited to a certain degree, even when a single producer has significant market power. If they offer at a high price, horticulture companies would just switch to producing heat themselves. Producers know this so they will also take into account how much the alternative costs are for growers to produce heat themselves. If those cost are higher than the producers' marginal cost, the producer will make an offer somewhere below the alternative costs of the grower and above his marginal costs.

Strategic behaviour

We already discussed what decisions producers and horticulture companies can make when they trade heat energy in the short term market. The choice for each alternative is expected to be based on financial arguments. We expect that growers will not purchase heat from the market when the market price is higher than the cost of producing heat in your own boiler or CHP. Producers ought to understand this and therefore we expect that they will not ask a higher price as long as their own production costs allow it. However, both are considered profit-maximizing entities. The growers want cheap heat energy, thus want the market price to be low at the marginal cost level of producers. Producers want to maximise their profits, thus want the market price to be high at (or just below) the growers' cost level of self-production. We can therefore theoretically expect them to behave strategically in an auction to influence the level of the market price in their favour. In this section, the auctioning method and these behavioural strategies are explained in more detail.

The short term heat market works with a double-sided uniform auction. In this auction method, potential buyers submit their bids and potential sellers simultaneously submit their offers to a market operator, who then chooses some price p that clears the market: all the sellers who asked less than p sell and all buyers who bid more than p buy at this price p. The market operator determines p, by taking the offers of each producer and adds them together in the quantity dimension to form the aggregate supply curve. Similarly, the market operator aggregates the price-quantity bids of each consumer to form the aggregate demand curve. The auctioneer then determines the market-clearing price (p) as the price where the aggregate supply and demand curves intersect. All producer offers below p are winning offers and they are asked to supply the quantity of the offer. Offers above p are declined, thus the producer does not get to supply the quantity of the offer. Each producer is paid the clearing price, also referred to as the market price. All consumers receive the quantity they bid above p and pay the clearing price. Bids below p are declined, thus the consumer does not receive the quantity of his bid.

Every day producers and consumers (horticulture companies) have to decide how much energy they would like to trade on the market. Both are able to create multiple price-quantity bid blocks. A bid/offer block is an amount of heat energy one wants to buy/sell for a specific price. The chosen price point level for a bid or offer block used by a producer or consumer tells us something about his strategical behaviour and how he deals with the risk of missing a settlement.

Producers and consumers must carefully determine the price points of their offers/bids. A too high or too low price point can result in missing a settlement, which is when a producer offered above the clearing price (offer is declined) and when a consumer bid below the clearing price (bid is declined). One way of offering by a producer to not miss a settlement, that can only have a positive outcome, is setting the price of a bid block equal to marginal cost. If the offer of the producer determined the clearing price, he will not make a loss because his payment equals the production costs. In case an offer of another producer is lower and price-setting, the producer’s offer will be declined, which is good because the market price is lower than the production cost. If he would have been settled, he would have made a loss. In case an offer of another producer is higher and price-setting, the producer’s offer will be accepted and make a profit because the price he is paid is higher than the cost of production.

There is a downside to the strategy of offering at marginal cost in the long term. In the case a producer is always the price setter, he will neither make a profit nor loss. Such offers only contain the short term costs of production and do not include capital costs. Profits need to be made to pay back the capital costs and allow for future investments. There is short-run marginal cost (SRMC) and long-run marginal cost (LRMC). Investment is fixed for SRMC and variable for LRMC (Zhang et al., 2013). In this research marginal costs are referred as the former. Therefore in practice, producers will always want to offer some energy for a higher price than marginal cost to ensure profits are made.

For consumers bidding at the cost level of their production assets (alternative cost bidding, which is the true marginal willingness to pay) is the best way to not miss a settlement, while achieving a positive result. If the consumer is settled it means that the market price is lower than the cost of self-production, thus he receives energy from the market for a lower price. If the consumer is not settled it means that the market price is higher than the cost of self-production, thus it is better to produce heat himself.

Theoretically, offering at marginal cost and bidding at marginal willingness yields in the highest economic efficiency in a market, see Chapter 2. In a perfect market, the high degree of competition forces producers and consumers to apply these strategies. However, the DHS of the B3-Hoek has an oligopolistic form of competition, due to the limited amount of producers. In such a competitive environment, producers and consumers are not price-takers, but can influence the market price by making strategic choices when determining their bid/offer block.

Producers can use price and quantity as strategic instruments to drive the market price up by offering some production capacity for high prices. Consumers can do the same with their bids by asking their demand for very low prices to drive the market price down. This rent or profit-seeking behaviour is this research identifies as strategic behaviour. The behaviour comes at the risk of missing settlement. Therefore there is a trade-off to

be made between taking a chance to gain high rewards and the risk of not getting settled. The number of bid blocks used by a producer of consumer tells us something about how he deals with the risk of missing a settlement. By using multiple bid/offer blocks with different price points, there is a higher chance of being included in the settlement (at least for a part of your supply/demand). Also, the distance between the price point of each block indicates the risk-taking behaviour. High price points (equal to the alternative costs) of growers indicate low risk-taking behaviour, low price points (equal to marginal costs) of producers also indicate low risk-taking behaviour.
The risk decreases when multiple bid blocks are used with prices that range from marginal cost price to a profit-seeking price (high price for producers, low price for growers). To judge if one is risk-taking, the volume and the corresponding price of an offer have to be analysed together. When the price of an offer/bid is close to marginal cost price or true marginal willingness to pay, a participant is considered risk-averse. The more difference between the price of an offer/bid and marginal cost price, the more risk-taking and profit-seeking a producer or consumer is considered.
In short, there will be an interesting dynamic between producers and growers that will result in a specific market price. Market power at the side that able to maximize their profits. In order to find out if producers have market power in the B3-Hoek, we investigate the behaviour of actors and find out how this impacts the market outcome. This will be discussed in the next chapters.

4.3 Market design proposal

In this chapter we answered the first sub-research question: *"What market design for the DHS in the B3-Hoek can be used to facilitate short term energy trade?"*. Our design proposal is visualised in Figure 10 and Table 8. Throughout this chapter, we discussed the different alternative of the design variables for a short term market. The most important aspect of the new market design is to allow producers and consumers to trade heat energy short term. They should be able to free arbitrate on the short term market and new entrants should face non-discriminatory access conditions, the main performance indicator of the market design that we have specified in paragraph 3.3. The main changes that will have to be made, compared with the present market model, are as follows.

Firstly, it is important that production activities are separated from network activities. Producers should operate in a fair competitive environment, thus it is important that none of them determines who gets access to the network and how much can be produced. In the present market model, this is still the case with Uniper being both producer and owner of the transport network. For the short term market, it is necessary to unbundle the production and network activities of Uniper. A private-public hybrid company of Gasunie & Eneco are suggested as new owners of the transport network. Combined they have the necessary experience and tools to manage this part of the network. Non-discriminatory access condition and tariffs can be determined by Gasunie if they have a majority in shares.
Secondly, the short term market requires a market operator who will determine the dispatch, based on a uniform double-sided auction. An independent party should take care of this role to guarantee a level playing field for competition between producers and horticulture companies.
Lastly, the role of the system operator should be transferred to Gasunie & Eneco. However, due to the technical characteristics of the DHS they will have to contract Uniper in the short run to maintain balance in the system. In the long run, if horticulture companies invest in buffer capacity, demand-side management can be applied to balance supply and demand in the network throughout the day.
The short term market is supposed to be the new alternative for short term trading. Producers and consumers will still have the desire to make long trade deals. Therefore they should still be able to negotiate contracts with AgroEnergy for long term supply, similarly how it is done today. The new design proposal has implications for the long term bilateral market as well, because the roles and responsibilities in the DHS change. Thus far we have not discussed these implications, because the focus of the design proposal is to identify what market design can be used to facilitate short term energy trade. In Chapter 7 this will be further discussed.

Based on the market design alone we cannot evaluate the other PIs. This is because the design is a mere conceptual model of the rules, operations and coordination deemed necessary for a short term market to function without the negative influence of undermining incentives, market power and opportunistic behaviour. The actual performance outcome will be known when such a market is implemented. In order to evaluate the short term market before its actual implementation, we need to know how actors will behave. The simulation used in the study of Bijvoet (2017) gives some insights but has its shortcomings. Some technical characteristics of actors were not included, nor were actual actors arbitrating in the market. From economic theory, we have described how agents can behave strategically, but will this be the case in practice?

This brings us to the second research sub-question: *"What is the behaviour of actors in the market and how does this affect the performance of the market?"*. In order to test the remaining performance indicators of a short term market and answer the second research sub-question, an interactive simulation was created based on the DHS of the B3-Hoek. The next chapter introduces how this simulation has been developed.

5

Experiment Setup

In the previous chapter we answered the first research sub-question with a design proposal for the DHS in the B3-Hoek to mitigate the problems that were defined in Chapter 1. In order to evaluate the performance of a short term market, an experiment was created to simulate the market conditions of the case. We will answer the second research sub-question by simulating the market to test its performance and actor behaviour. This chapter will explain in detail how the experiment has been developed and who participated. First, we will give a system description of the market that is used in the experiment. We will elaborate on how the physical real-world system is translated into a virtual system, its scope and the assumptions that were made in the experiment. Then we will discuss the play and rules of the simulation. Afterwards, an explanation is given about the external parameters that influence the heat market and how they were developed for the experiment. Hereafter we discuss what verification procedures have been taken to verify the experiment and the validation of the simulation.

5.1 Simulation

To test the performance of our market design and find out how actors behave, an interactive simulation has been set up to simulate a short term market in the B3-Hoek. In the context of this research, a simulation is a case study of physical reality, in which participants take on roles with well-defined responsibilities and constraints in order to reach a goal. The simulation can take different directions, depending on the actions and reactions of the participants (Gredler, 2004). It is interactive, because participants act and interact via the simulation.

The goal of the short term market simulation is to allow producers to offer their production capacity, and allow consumers to purchase heat energy on a daily basis. The choices they make on this market inform us about their behaviour in determining price points for heat energy. The process of designing and applying a simulation is discussed by (Peters, Vissers, & Heijne, 1998) and can be represented as follows:

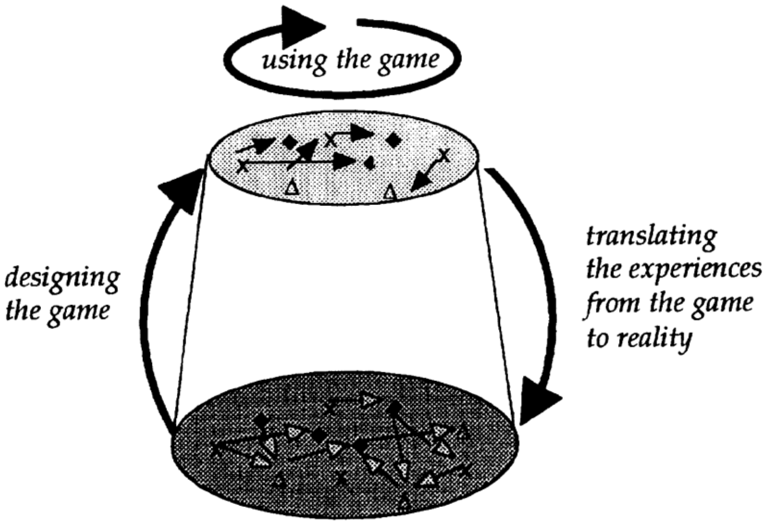


Figure 11 - Designing and Applying a Game, taken from Peters, Vissers, & Heijne (1998)

The left arrow indicates the process of the simulation[3] design. The reference system has to be translated into a useable game. That is, we have to get a good understanding of the characteristics of the reference system and transform these characteristics into the elements that constitute a simulation. In this research the reference system is the DHS in the B3-Hoek with the short term market model, see Figure 10. Next, the simulation is played by participants; this will result in new information and/or new knowledge and experiences, e.g. actor behaviour and performance of the short term market. Depending on the kind of application and the objectives of the simulation, the output of playing the game can be of interest for the research or for participants themselves. For this, observations and experiences made in the simulation have to be translated back the reference system, indicated by the arrow on the right. This part of the research is discussed in the next chapter.

In the simulation, we created an environment where we mimic a short term heat market, but where there are no real consequences to transactions. For this reason, models, simulation and games are often used to explore effects policy measures (Duke & Geurts, 2004). The aim was to make it as life-like as possible so that actors would feel and act the same way as if the market was actually real (Peters et al., 1998; Raser, 1969). The results of the settlements in the simulation allow us to quantify the performance of the short term heat market. We check whether the market prices converge to marginal cost levels or if there are producers with market power who drive prices up.
If the settlement price is always at the level of marginal cost the producers experience fierce competition among each other and from the growers who drive the market price down with their bids. This is financially the best result for the growers as this results in the lowest cost for heat energy. This is not the best case for producers, as some might make no or limited profit. The other way around would be the best case for producers, not the growers. When the settlement price is always at the level of the heat energy production costs with a boiler, this results in the highest cost for heat energy for growers. This is the best case for producers as they will make the most profit in the case. In order to check which of the two is the case in the simulation, we developed two reference models: alternative cost model (based on the boiler costs) and the marginal cost model. Because we designed the simulation, we have complete information about all costs for producers and growers, production capacities and heat energy demand. Also, we are able to create simulation runs ourselves by choosing what decisions (offers and bids) each producer and grower make, given that all other parameters remain the same (ceteris paribus). The cost of heat energy for growers and the sales and profits for producers in each of the models can be calculated. We will compare the interactive simulation with each model based on the worst-case for either the producer or the consumer to enable us to evaluate the 2nd and 3rd PI, see paragraph 3.3.

Alternative cost model

In the alternative cost model, we run a simulation in which the market price during the 14 days is always at the level of the cost of heat production by the growers themselves. This is the worst case for growers and the best case for producers scenario. We compare the costs of heat energy for growers in this model with that of the participant in the simulation. This tells us how much better or worse growers are off in a short term market.

Marginal cost model

In the marginal cost model, we ran a simulation where all agents offer and bid at marginal cost levels. Producers offer all of their capacity at a price point equal to their marginal cost. Growers all bid their total demand at a price point equal to their alternative costs (boiler or CHP). Each of the fourteen days the market is clear at the marginal cost level of an agent. This scenario is the best case for growers, but the worst case for producers. We compare the sales and profit in the interactive simulation with this model. This tells us how much better or worse producers are off in a short term market.
For growers, the marginal cost scenario is considered the best-case scenario for the market outcome of the simulation, and the boiler cost scenario is the worst case. The difference between the results of the simulation and the results in the scenarios quantify how well the short term market performs.

[3] Peters, Visser & Heijne (1998) use the term “Game”, whereas in this research is referred to as simulation

To assess the performance of the market, we specified the following PIs in paragraph 3.3:

- The short term market price should remain below the cost of heat production with a boiler for horticulture companies: This PI is measured quantitatively by comparing the cost of self-production with the market prices.
- Competition forces should drive the market price (close) to the marginal cost level of producers, but they should still be able to make profits to recover their long term costs (capital costs and future investment costs): This PI is measured quantitatively by comparing the marginal production costs of the producers with the market prices.
- Amount of heat energy volume that is traded on the market: This PI is measured by comparing the total demand in the market and the amount that is settled. The higher the ratio, the more efficient the market can be considered.
- Stakeholder satisfaction: This PI is qualitatively measured with the data gathered through a survey and interviews

The conclusion of these analyses answers our second research sub-question: *"What is the behaviour of actors in the market and how does this affect the performance of the market?"*.
Because we are limited in using all the elements, effects, factors and parameters of a real heat market in a simulation, we had to scope the set-up, make assumptions and impose limitations/constraints. In the following paragraphs, we explain how the simulation was developed.

5.1.1 Conceptual simulation design

In chapter 3 a detailed system description of the DHS in the B3-Hoek is given. Combined with the market design in chapter 4, we have the blueprint to develop the simulation. In the simulation, only the short term trading activities were included, because we are interested in the market performance and not in the physical performance of the DHS. Therefore the roles of the system operator and network manager were not present in the simulation. It is assumed that the physical flows are facilitated by both these actors in accordance with the results of the market settlement, without the need for balancing or congestion management. Also, the long term bilateral market was taken outside the scope of the simulation, because we wanted to see what decisions would be made in the short term by producers and horticulture companies when all of the supply and demand is traded. The impact of this decision will be discussed further in paragraph 5.3.2. The conceptual model of the short term market is given below.

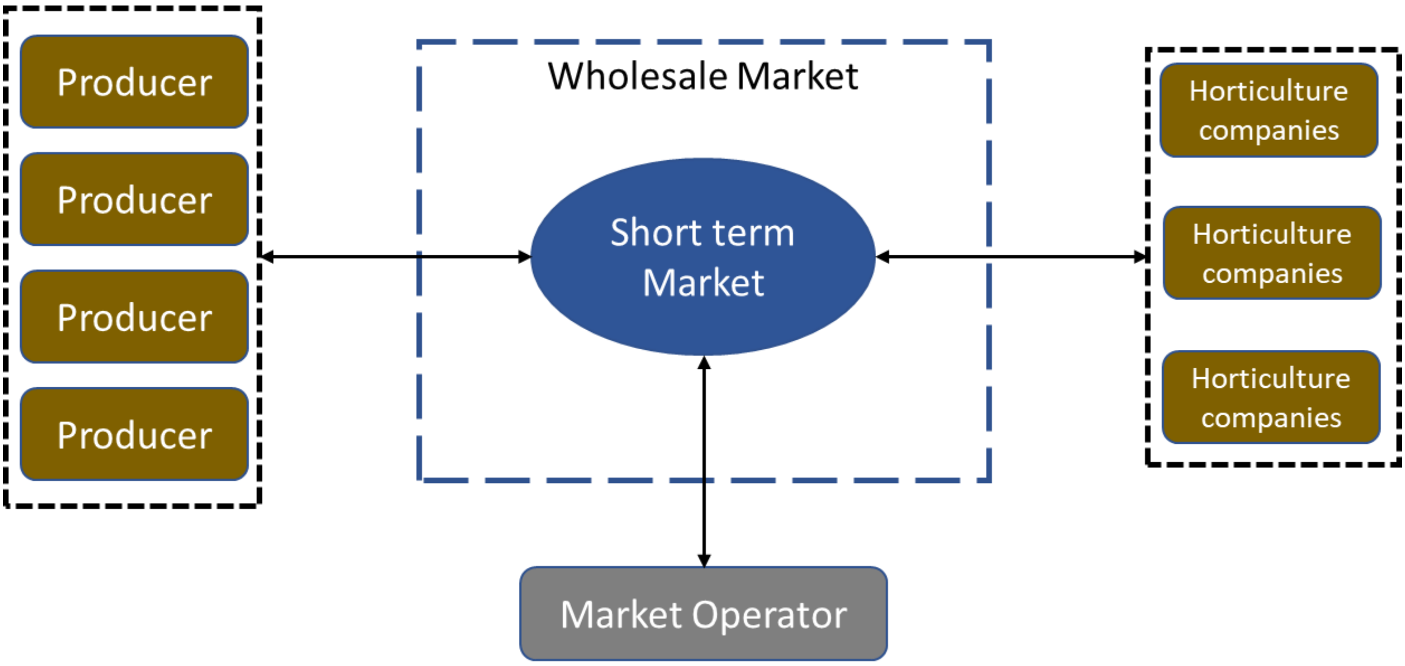


Figure 12 - Simulation market design

The interactive simulation used in this study was developed together with AgroEnergy. Prior to this research, AgroEnergy had developed a simulation where seven horticulture companies bought heat energy from a virtual day-ahead market where three producers offered their production. The goal of this simulation was to get horticulture companies acquainted with daily heat energy trading. The results of the growers were positive and it was decided to develop a more sophisticated simulation that better represents the actual heat market and DHS. The first simulation had some shortcomings in order to answer the research question of this thesis. In summary, these were: a lack of actual producer participation, lack of horticulture companies with a CHP and the link with the electricity market and gas market was missing. Given the time in which this research had to be conducted it was chosen to use the same format of the simulation developed by AgroEnergy, instead of developing a new type of simulation or trading game. Developing a different type of board or role-playing game to simulate a short term heat market was considered, but developing such games was not found not possible within the timeframe of this research. The online trading platform of AgroEnergy had all components to mimic real heat energy trade and allowed us to gather data from the bidding procedures easily. Also, this platform is very similar to the platform used by horticulture companies to buy electricity and gas. They are already familiar with this, so it makes sense to present the format of the short term heat market in a similar way. Together with AgroEnergy, the researcher developed an improved simulation design that would better represent the heat market and the DHS in the B3-Hoek, include more and different types of horticulture companies, and to invite real producers to join.
Other forms of simulation could also have been used to answer the research question. Bijvoet (2017) already used an agent-based computer simulation, but lacked technical validation and real actor behaviour. The scope of this research, short time span and the lack of experience with agent-based models were reasons not to make improvement to the model of Bijvoet or develop a new one.

The simulation took place over the course of 14 days. Two weeks were used because 14 settlements would be enough to test multiple market conditions. A longer duration was seen as too much of a burden for the participants. The 14 simulation days represented the changing market conditions (weather, gas/electricity price) from winter to summer of each month from January until July. This choice was made because we want to identify actor behaviour in both the winter (when demand for heat energy is high) and during the summer (when demand is low) to see if the market performance is different in both seasons.
In the B3-Hoek there are over 100 different horticulture companies. Their cultivation ranges from different types of vegetables to different types of floriculture. Every type has a distinct harvest and heat demand pattern that determine the demand for heat energy. Therefore it was important to recruit horticulture companies with different crop types.
There are different heat energy production facilities that can supply heat energy in the B3-Hoek: a combined cycle gas turbine (Uniper), biomass heating systems, geothermal power plants and residual waste heat from a waste incineration power plant (AVR). Each power plant has a different marginal cost for production. This difference creates a merit order that changes every day depending mainly on the gas and electricity price. To increase the feasibility of the simulation, we aimed to include all the producers in the B3-Hoek. However, this was difficult and not practical, so it was decided that only each type of powerplant was included and each was operated by one producer. The goal was to recruit real producers that would play their role in the simulation. We were able to recruit a participant from the combined cycle power plant (Uniper) and from a geothermal power plant. The biomass plant and AVR were done by two employees of AgroEnergy. They were competent enough to perform the role of a producer in the simulation, because they have experience and knowledge about energy trade, DHS and the production technique of the power plants.

5.1.2 Organization of the simulation

In the recruitment phase of the simulation, we made an effort to recruit a sample group that represent the system and stakeholders in the B3-Hoek. For practical reasons specific costumers of AgroEnergy have been contacted about the simulation and asked if they would like to participate. Their contact details and company data were available, making it easier to develop the simulation. Some of the participants have previously taken part in the earlier simulation that was developed by AgroEnergy. Their positive experience of the previous simulation contributed to the willingness to join another more elaborate simulation. Other new participants have been selected, based on company attributes, by AgroEnergy. Participants remained anonymous to each other to make sure they do not contact each other and discuss their strategy and biddings.

When the participants were confirmed, each one was visited to provide information for participating in the simulation. The goal, process and rules for each participant were explained and they were introduced to the trading platform and the calculation tool. Each was given login credentials to access the trading platform where they would trade energy during the simulation. The calculation tool is a pre-made Excel sheet made by AgroEnergy. It is used by the participants to calculate multiple variables to determine how much energy they want to produce/purchase and for what price. More details about the calculation tool are described in the coming paragraphs. There is no actual transaction taking place, so participants were asked to pretend if the trade was real, with real financial consequences. To further motivate the participants a prize was given to the best performing participants of their category.

Prior to the start of the simulation, they had time to get familiar with the trading platform environment and how they had to use the calculation tool. There were no practice days before the start of the simulation, so the first time they completed a trading day was during the simulation. In hindsight, it would have been useful to have some practice days before the start of the simulation, to get more familiar with the simulation.

However, the platform and calculation sheet were straightforward and explained during the visit. The questions from participants about how to use them were also answered before the start by phone or e-mail. After the last trading day of the simulation a survey was sent to the grower participants. The goal of the survey was to gather an initial understanding of their experience with the simulation, feedback on how they made choices when determining their bids and how their bidding strategy developed throughout the simulation. Additionally, a plenary session with the participants was organized to gather more feedback on the simulation and the results of their survey. Here we discussed their bidding strategies in more detail and how they evaluated the performance of the short term market. Not every participant was able to respond to the survey or come to the plenary session. Therefore the researcher made additional visits to those participants to gather more data on their experience with the simulation and decision-making throughout. Besides the qualitative data from the survey and interview, the trading platform and the calculation tool were the two quantitative sources for data necessary to identify behaviour and measure the performance of the market. Below we present the interface of the trading platform and the calculation tool that was used by the participants in the simulation and discuss the measurement methods.

Interface

The online trading platform is accessed via an internet browser. Each participant had their own account to access the platform. Figure 13 shows the interface of the portal. When a participant logs into the trading portal, bids and offers could be made on the dashboard page. At the “Resultaten” page, the participant can find his settlement information after each market clearing. Here it is shown which bids/offers got accepted and how much energy was sold/purchased in total for the market price of that day. The participant cannot see how much heat was sold/purchased by other participants. The only market information that was visible was the settlement graph of the aggregated supply and demand, the total volume that has been traded that day and the corresponding market price.

The researcher had a special admin account for the portal that does allow to gather the information of all the bids and offers made by the participants each day. This information was used to determine the behaviour of the participants, see the next paragraph.

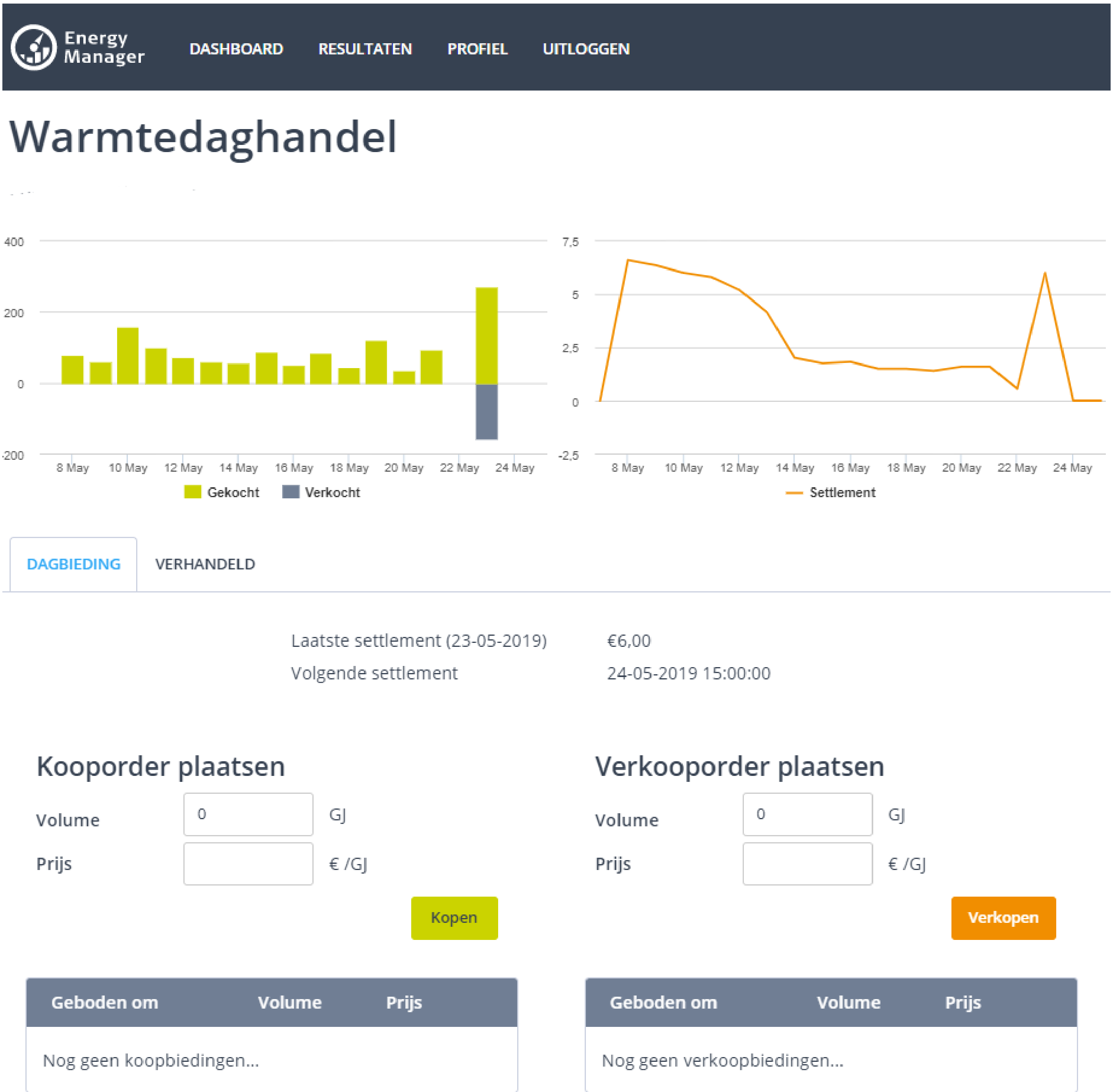


Figure 13 - Interface online trading portal

The trading portal was both the interface for the market simulation and a source of data that the participants had to use in the calculation tool. Other data that was sent via e-mail.

Dag Handelsdag		1 8-5-2019	2 9-5-2019	3 #######	4 #######	5 #######	6 #######	7 #######	8 #######	9 #######	10 #######	11 #######	12 #######	13 #######	14 #######
In te vullen info voor handelsdag															
Status buffer	[-]	50%	50%	50%	50%	50%	50%	50%	76%	100%	85%	100%	78%	100%	79%
Beschikbare buffer warmte	[GJ]	94	94	94	94	94	94	94	142	188	160	188	147	188	149
Temperatuur morgen	[°C]	-1	0	-3	1	3	4	9	10	11	14	17	19	21	20
Totale warmtebehoefte morgen	[GJ]	256	241	286	227	201	189	138	129	121	101	86	79	74	76
Kostprijs warmte ketelgas	[EURct/m^3]	24.04	23.01	22.61	23.01	22.6	21.98	21.16	19.46	19.73	18.99	18.79	18.27	18.18	18.11
Kostprijs warmte ketelgas	[EUR/GJ]	7.60	7.27	7.14	7.27	7.14	6.94	6.69	6.15	6.23	6.00	5.94	5.77	5.74	5.72
APX-peak prijs	[EUR/MWh]	55.9	54.85	57.25	44.75	54.2	48.6	44.85	39.2	37	40.05	37.05	34.25	33.9	35.8
WKK-gasprijs	[EUR/MWh]	21.77	20.72	20.31	20.72	20.30	19.66	18.82	17.08	17.36	16.60	16.40	15.87	15.77	15.70
Draaiuren WKK (max 12 uur-peak)	[hrs]	12	12	12	12	12	12	12	8	4	4	0	0	0	0
Kostprijs warmte uit WKK	[EUR/GJ]	1.11	0.78	0.02	3.05	0.70	1.62	2.01	2.35	2.99	1.90	2.47	2.81	2.84	2.38
Warmteproductie WKK	[MWh]	35.66	35.66	35.66	35.66	35.66	35.66	35.66	23.77	11.89	11.89	0.00	0.00	0.00	0.00
Warmteproductie WKK	[GJ]	128	128	128	128	128	128	128	86	43	43	0	0	0	0
Resterende warmtebehoefte	[GJ]	128	113	158	99	73	61	10	43	78	58	86	79	74	76
Maximaal in te kopen warmte WDM	[GJ]	222	207	252	193	167	155	104	89	78	86	86	120	74	115
Minimaal te verkopen warmte WDM	[GJ]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
In te vullen NA settlement															
Verkochte warmte WDM	[GJ]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ingekochte warmte WDM	[GJ]	80	60	158	99	73	61	58	89	50	86	45	120	35	95
Settlementprijs	[EUR/GJ]	6.6	6.35	6	5.8	5.2	4.15	2	1.75	1.82	1.5	1.5	1.4	1.6	1.6
Resterende warmtebehoefte	[GJ]	48	53	0	0	0	0	-48	-46	28	-28	41	-41	39	-19
Minimale inzet ketelgas	[GJ]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximale inzet ketelgas	[GJ]	142	147	94	94	94	94	46	0	28	0	41	0	39	20
Inzet ketelgas	[GJ]	48	53	0	0	0	0	0	0	0	0	0	0	0	0
Warmte in/uit buffer	[GJ]	0	0	0	0	0	0	-48	-46	28	-28	41	-41	39	-19
Nieuwe buffer warmte	[GJ]	94	94	94	94	94	94	142	188	160	188	147	188	149	168
Klaar met handelsdag?	[-]	JA	JA	JA	JA	JA	JA	JA	JA	JA	JA	JA	JA	JA	JA
Gaskosten Ketel	[EUR]	365	385	0	0	0	0	0	0	0	0	0	0	0	0
Gaskosten WKK	[EUR]	142	100	3	390	90	207	258	202	129	82	0	0	0	0
WDM verkochte warmte	[EUR]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WDM ingekochte warmte	[EUR]	528	381	948	574.2	379.6	253.15	116	155.75	91	129	67.5	168	56	152
Gemiddelde warmte prijs handelsdag	[EUR/GJ]	4.04	3.59	3.33	4.25	2.34	2.44	2.01	2.05	2.36	1.63	1.50	1.40	1.60	1.60

Figure 14 - Example calculation tool of grower with CHP

Figure 14 shows an example of an excel sheet (the calculation tool) of a participant who had the role of grower with a CHP. The excel sheet of the growers without a CHP had the same structure, but only lacked the CHP related rows. Similarly, the excel sheet for the producers had the same structure but only contained rows related to their production assets. Both the growers and the producers did not know each other's marginal costs, only the cost of producing heat with a boiler.

Dag Handelsdag		1 8-5-2019	2 9-5-2019	3 #######	4 #######	5 #######	6 #######	7 #######	8 #######	9 #######	10 #######	11 #######	12 #######	13 #######	14 #######
In te vullen info voor handelsdag															
APX-peak prijs	[EUR/MWh]	55.9	54.85	57.25	44.75	54.2	48.6	44.85	39.2	37	40.05	37.05	34.25	33.9	35.8
Kostprijs warmte ketelgas	[EURct/m3]	24.04	23.01	22.61	23.01	22.6	21.98	21.16	19.46	19.73	18.99	18.79	18.27	18.18	18.11
Kostprijs warmte ketelgas	[EUR/GJ]	7.60	7.27	7.14	7.27	7.14	6.94	6.69	6.15	6.23	6.00	5.94	5.77	5.74	5.72
Gasprijs	[EUR/MWh]	21.77	20.72	20.31	20.72	20.30	19.66	18.82	17.08	17.36	16.60	16.40	15.87	15.77	15.70
Kostprijs warmte AVR	[EUR/GJ]	0.67	0.73	0.58	1.35	0.77	1.11	1.34	1.69	1.82	1.63	1.82	1.99	2.01	1.89
Boetebedrag te veel geproduceerde GJ	[EUR/GJ]	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maximale afzet	[GJ]	276	276	276	276	276	276	276	276	276	276	276	276	276	276
In te vullen NA settlement															
Verkochte warmte WDM	[GJ]	276	276	276	276	276	276	276	276	138	0	0	0	0	0
Settlementprijs	[EUR/GJ]	6.6	6.35	6	5.8	5.2	4.15	2	1.75	1.82	1.5	1.5	1.4	1.6	1.6
Klaar met handelsdag?	[-]	JA	JA	ja	ja	ja	ja	ja	ja	ja	ja	ja	ja	ja	ja
Te veel verkochte warmte	[GJ]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Opwekkosten warmte	[EUR]	184	201	161	372	212	307	370	465	251	0	0	0	0	0
Boete te veel geproduceerde GJ	[EUR]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inkomsten verkochte warmte	[EUR]	1822	1753	1656	1601	1435	1145	552	483	251	0	0	0	0	0
Totale opbrengsten	[EUR]	1822	1753	1656	1601	1435	1145	552	483	251	0	0	0	0	0
Totale kosten	[EUR]	184	201	161	372	212	307	370	465	251	0	0	0	0	0
Bruto winst	[EUR]	1638	1551	1495	1229	1223	839	182	18	0	0	0	0	0	0

Figure 15 - Example calculation tool of a producer

The sheet automatically calculated the production costs of the assets, based on temperature, electricity and gas prices had to be filled in manually (Orange cells). This information was sent to the participants each day. After the market-clearing the participant had to copy his settlement details from the portal (purchased/sold volume and market price) into the excel sheet. In paragraph 5.1.4 we describe the participation process in more detail.

Measurement method

In paragraph 4.2.3 we described strategic behaviour and how it can be identified. In order to identify the behaviour of each participant, all bids or offers that were made each day were collected after the simulation. This data was gathered from the admin account on the trading portal. The excel sheet calculated the costs of producing heat with a boiler for growers and the marginal costs for producers for each day. By comparing the bids/offers blocks per day with the corresponding marginal cost/alternative cost, the difference of the price levels could be calculated. The bigger the difference, the more a participant is considered profit-seeking and considered to behave strategically. By making a comparison between the trading days, it could be seen if bidding/offering strategies changed. Via interviews and surveys, more data about the decisions of the participants was gathered. This provided additional sense and arguments for the choices that the participants made. They were also the source to determine the performance indicator "stakeholder satisfaction".
The performance indicators were measured by data from the trading portal and calculation tool. Whether the market price remained below the cost of boiler heat production each day was checked via the calculation tools of the growers that specified both the boiler costs and trading portal that determined the market price. By comparing the marginal production costs of the producers with the market prices each day we can give an indication of how much competition forces there are in the market and if the drive the market price (close) to the marginal cost level of producers. The amount of heat energy volume that is traded on the market measured by comparing the total demand in the market and the amount that is settled. The total demand in the market is the accumulation of all the quantities used in the bid blocks. This data is gathered from the trading portal via the admin account. Also, the settled volume can be found here. Lastly, stakeholder satisfaction is measured in terms of attitude towards a short term market. The qualitative data is gathered via the survey, plenary session and interviews. The survey used a 1 to 5 scale of positivity (5 indicates very positive, 1 indicates very negative), see Appendix A. The researcher's discretion was used to evaluated if the interviewees were positive or negative.

5.1.3 Roles

In the simulation participants were divided into two groups of actors: horticulture companies (growers) and producers. 14 acted as growers in the heat market. Their goal was to achieve an as low as possible average heat cost for their total heat demand in the two weeks. Two growers acted as prosumers, so their goal was to buy energy as cheap as possible or to produce energy and sell it for as much as possible. The goal of the producers was to maximize their profit by selling heat energy.

Horticulture participants

In 3.2.4 Firm decision (layer 4) we identified three types of horticulture companies based on their heat assets: boiler, boiler + CHP illuminated and boiler + CHP unilluminated.

Table 10 shows the participating horticulture companies and their attributes. These attributes represent the actual characteristics of each company[4].

[4] Except for Stichting Exploitatie Energie Cluster Bergschenhoek who was altered to fit the type of CHP unilluminated. This was done to introduce competition between the participants in that category, so they would have the incentive to actively participate. This grower was specially selected for the altered role, because he is very knowledgeable on energy trade and how different types of horticulture companies operate. All other growers represented their own company in their role as consumer.

Table 10 - Horticulture company simulation participants

Horticulture participants	Heat source	Crop type	Areal [ha]	CHP_el [MW]	CHP_th [MW]	Buffer [m^3]
Grower 1	Boiler	Cymbidium	3,8	0	0	570
Grower 2	Boiler	Paprika	3,5	0	0	525
Grower 3	Boiler	Paprika	2,2	0	0	330
Grower 4	Boiler	Paprika	7,2	0	0	1080
Grower 5	Boiler	Potplanten	2,5	0	0	375
Grower 6	Boiler	Potplanten	11,5	0	0	1800
Grower 7	CHP unilluminated + boiler	Paprika	5	2,4	2,97	1000
Grower 8	CHP unilluminated + boiler	Tomaat	11,2	5,1	6,31	2300
Grower 9	CHP unilluminated + boiler	Tomaat	3,1	1,75	2,17	1100
Grower 10	CHP unilluminated + boiler	Bromelia	7,4	3,475	4,30	1700
Grower 11	CHP unilluminated + boiler	Paprika	3,5	1,75	2,17	1100
Grower 12	CHP unilluminated + boiler	Paprika	5,3	2,4	2,97	1500
Grower 13	CHP illuminated + boiler	Divers	2,5	2,325	2,88	2175
Grower 14	CHP illuminated + boiler	Rozen	2,15	2	2,48	2000

Producers

In the table below the attributes of the producers are presented:

Table 11 - Producer simulation participants

Producer	Intern or extern	Capacity [MW]	Max daily production [GJ]	Eff. Electric	Eff. Thermic
Uniper	Extern	9,88	854	0,42	0,35
Biomass plant	Intern	4,74	410	0,1	0,9
Geothermal plant	Extern	4,27	369	COP = 15	-
AVR	Intern	3,19	276	0,22	0,78

Intern means this participant is an employee of AgroEnergy. External participants are real producers

5.1.4 Play of the Game

This paragraph discusses the actions and objective for each role in the simulation. As explained in the system description there are three types of actors: producers, growers and the market operator. The process of participating in the simulation is for every producer and grower generally the same. We will use a participant storyline to clarify their process and actions in the simulation.

Producer

At the start of the simulation, before the first trading day, the producer is sent information by e-mail about the temperature, APX base price and TTF day-ahead gas price for the following trading day. The producer uses this information as input for the Excel sheet to calculate the following:

- The marginal cost of heat production with a boiler [EUR/GJ]
- The marginal cost of heat production with the heat source of the producer [EUR/GJ]
- Available volume that can be sold to the market [GJ]

The outcome of these calculations will be used to determine a price and volume to offer to the market. The price for which the producer wants to sell heat energy is determined by the participant himself. The Excel sheet only shows the cost per GJ to produce energy. It also shows how much volume he can produce given his production capacity. This is the maximum amount of energy he should offer to the market. The participant eventually decides how much energy he will offer to the market. It is possible to offer more energy, even though the production capacity is not sufficient. If a producer sells more energy to the market than he can produce, the Excel sheet calculates the difference with the production capacity and adds a fine for each GJ that could not be produced.

Before the first trading day, the producers and growers have no additional information about the heat market. Over the course of the simulation, they can also use information about past settlements to help them determine a price and volume. Earlier market settlements indicate the trend of the market price, that informs the producers what the market price of the next settlement could be. The supply graphs give the producer an idea of how much energy he sells compared to his competitors.

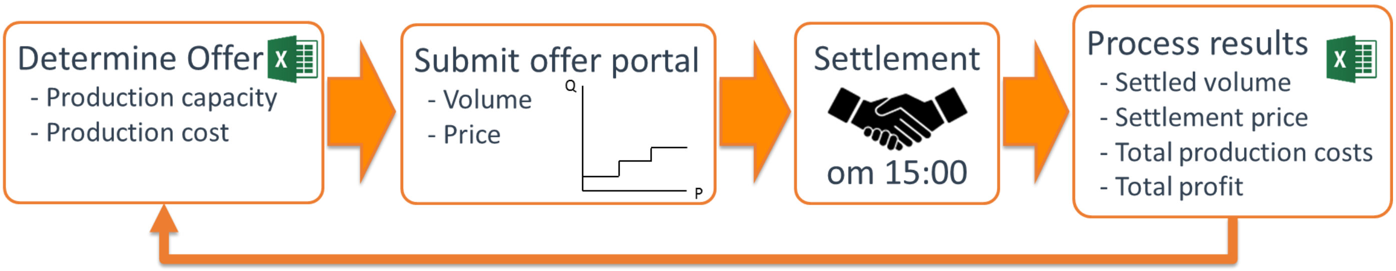


Figure 16 - Process flow diagram producers

To make an offer on the heat market, the producer logs in on the market platform. Here he finds information about previous settlements (market price and total sold volume), how much energy he has sold each trading day and for what price. He must declare his offer before the settlement of the trading day. He can select a specific volume and set a price for which he would like to sell energy. He can make multiple offers on each trading day, so he can sell different volumes at different prices. Once he made his offer(s), he must wait until the end of the trading day when the settlement takes place. The settlement takes place every day at 15:00. A few minutes after the settlement the producer receives new information about the temperature, APX and TTF of the next trading day via e-mail. This e-mail also contains the market price and total volume sold in the past settlement(s).

After the settlement took place the producer can check the platform to see how much energy he has sold and what the market price was for that trading day. He can also see the settlement graph of the trading day. This gives him information about offers from other producers and biddings of growers. Next, he has to manually enter the amount of energy sold and the market price in the Excel sheet. The sheet calculates his total costs, revenue and the profit he made that day. When all the necessary input is entered in the sheet, the producer sets the cell "done with trading day" to yes. When everything is done correctly the column for the second trading day becomes visible in the excel sheet and the whole process repeats. The subsequent trading days are invisible until a previous trading day has been properly filled in. Producers are unable to calculate and make offers for future trading days, other than the next trading day. This is done on purpose by sending only the information of each subsequent trading day and making it impossible to send in offers for the days other than the next trading day. We wanted participants to repeat the trading process every day and make decisions based on what happened at the previous trading day.

Growers

The grower also receives the same e-mail prior to the first trading day. The information is used to calculate:

- Energy demand volume [GJ]
- Marginal cost to produce heat with a boiler [EUR/GJ]
- Marginal cost to produce heat with CHP (if available) [EUR/GJ]
- Energy production volume with CHP (if available) [GJ]

The outcome of these calculations will be used to determine a price and volume to offer to the market. The price for which the grower wants to buy his energy is determined by himself. The Excel sheet only shows the cost per GJ to produce energy himself with a boiler and CHP, if available. Growers with a CHP have to enter how much hours they want to run. They can do this before or after the settlement. A rational grower determines the amount of operational hours for their CHP based on how much energy he has bought at the market and how much of his demand is unmet. When they still have an energy demand they fill in an amount of operating hours until their demand is met or until their buffer is full, but it is maxed at 12 hours. The Excel sheet will also inform the grower what the maximum amount of energy is, based on the remaining energy demand and the empty buffer volume, that he can purchase on the market. He can decide to buy more energy, but once the buffer is full the excess energy he bought is lost but it is paid for.

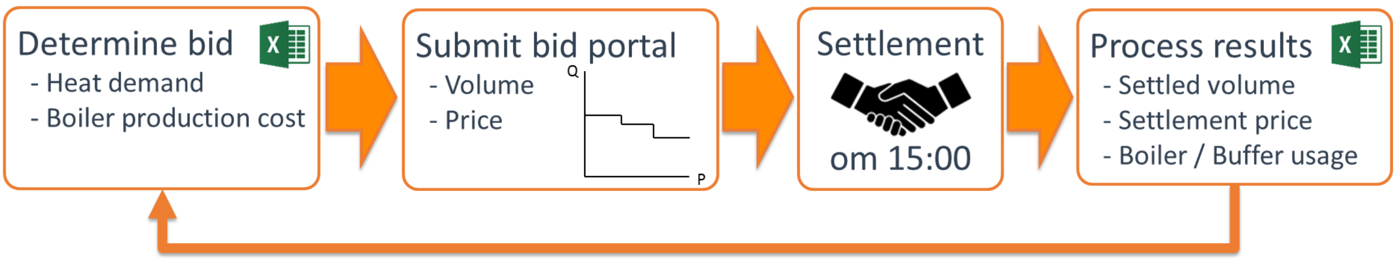


Figure 17 - Process flow diagram growers

Once the grower is done filling in the excel, he can determine the volume and price for which he wants to purchase energy. He logs in on the platform where he can see the same information about previous settlements, how much energy he has purchased each trading day and the corresponding price. Also, the grower must do their bidding before the end of the trading day, which is at 15:00. He enters a volume and a price on the trading platform to make a bid. It is possible to create multiple biddings with different volume and price combinations. After the settlement has taken place the grower can see the amount of energy he has bought and receives an e-mail with new information about the temperature, APX and TTF of the next trading day via e-mail. This e-mail also contains the market price and total volume sold in the past settlement(s). The grower then enters the purchased volume and the market price in the Excel sheet. At this point, growers with a CHP can alter their CHP production to meet their demand. The sheet checks if the energy demand for the day is met with the purchased volume, CHP production and/or remaining buffer volume. If there is not enough energy bought and/or produced, the grower has to use his boiler to produce more heat energy. When everything is filled in correctly and the grower sets the cell "done with trading day" to yes, the second trading day becomes visible and the whole process repeats. The subsequent trading days are also invisible like the sheet of the producers.

It is important to understand that on a trading day it is decided how much energy is bought for the next day. The transaction takes place at t, and the delivery is at t+1. Therefore growers can decide how much energy they produce after a settlement. It is assumed that growers with a CHP use all the electricity themselves or is sold on an electricity market.

Market operator

The market operator takes care of the settlement procedures and distribution of information to the participants. This role has been fulfilled by the researcher. The settlement procedure is mostly performed automatically. At 15:00, the platform is programmed to collect all the offers and bids, aggregates them in the quantity dimension on price and calculate the settlement volume and settlement price. The calculation algorithm is developed by AgroEnergy and the computational model behind it is unknown to the researcher, but it works the same as any uniform market clearing procedure, described in paragraph 4.2.3.

The settlement information is sent to the platform accounts of the participants so they can be viewed. The external parameters, like temperature, APX and TFF, are shared with the participants through a daily e-mail. This is done manually. These external parameters have all been set by the researcher prior to the start of the simulation and the right information is shared during the simulation. The market operator also responds to questions from the participants and is able to make offers and bids on behalf of a participant.

5.1.5 Rules of the Game

In the simulation, there were rules participants had to follow. However these rules were communicated during the visits or participants would find them out by trial and error, as some were implicitly built into the simulation. There was no rulebook developed, but there were many failsafe functions built into the simulation to ensure participants did what they were supposed to do. In the previous paragraph some rules were already mentioned, but below all the rules are listed:

- Every producer and grower received a personalized Excel sheet and a personal market platform account that had to be used throughout the simulation. They had to manually enter the external variables prior to the settlement and the amount of energy sold/bought pls the corresponding market price after the settlement in the Excel sheet.
- Participants ought to use the information that is sent to them or presented in the platform. All Excel sheets of the participants were checked after the simulation to see if data was filled incorrectly. Mistakes in temperature, electricity and gas price, purchased volume and market prices were corrected by the researcher.
- Producers only produce the cumulative amount of volume of the offers that got accepted.
- Growers only consume the cumulative amount of volume of the bids that got accepted.
- Quantities offered by producers above the settlement price are not traded.
- Quantities asked by growers below the settlement price are not traded.
- The price and volumes offer blocks are determined by the seller himself.
- The price and volumes bid blocks are determined by the buyer himself.
- The price of an offer or bid must be a positive number (the settlement algorithm could not handle negative numbers)
- It is possible to offer more energy, even though the production capacity is not sufficient. If a producer sells more energy to the market than he can produce, the Excel sheet calculates the difference with the production capacity and adds a fine for each GJ that could not be produced.
- It is possible to buy more energy, even though demand is met and there is no buffer capacity left for storage. The excess energy is then lost but paid for.
- When more energy is bought or produced than the demand for the day, it goes automatically into the buffer until it reached 100% of its capacity.

- The settlement takes place every day at 15:00. Bids and offer had to be submitted before this time, otherwise it is a submission for the next day. Once submitted there is an option to delete it before the settlement takes place.
- The use of CHP by a grower has a maximum of 12 hours for unilluminated growers and 24 hours for illuminated growers.
- Heat energy volume can only be offered or bought in integers.
- Heat energy prices can only be offered or bought in euro's with two decimals.
- Growers have to fulfil their heat demand. If a grower has not met his demand for the day, he cannot open the column for the next day (see Figure 14).
- Each grower had four alternatives to fulfil his demand (depending on his properties):
    - Purchasing heat energy from the day-ahead market
    - Produce heat with his CHP using natural gas
    - Produce heat with his boiler using natural gas
    - Using the available energy stored in his buffer
- Buffer volume has to be at least 50% on after the last trading day. This is corrected by the researcher if it is not the case.

5.2 External Parameters

In this paragraph, we will explain in greater detail how parameters and other elements in the simulation have been developed. Prior to the start of the simulation these parameter values have been set by the researcher.

5.2.1 Energy Demand

The energy demand of a grower, in reality, is dependent on many factors, but mainly on weather and cultivation. We have chosen to make the process of calculating the heat energy demand for the grower as easy and short as possible. This means that we had to make assumptions and simplify the calculation process. We chose to use the outdoor average day (24 hours) temperature to calculate the amount of heat for a whole day that would be required for a specific type of crop. We were able to predict the use of natural gas (later converted to total heat energy) based on data of natural gas usage for each type of crop at a specific average outdoor day temperature. Other factors such as rain, solar radiation and wind speed were too complex to be used in the calculation and the use of just the outdoor temperature was deemed sufficient. Data of natural gas usage on a specific day from 2017 was gathered from the database of AgroEnergy. The corresponding average outdoor temperature of those days was used to create a formula, by making a trendline, with the gas usage as dependent and temperature as an independent variable. The daily amount of gas usage was converted into gigajoules of heat energy. This was done for every type of crop. Each type of crop has its own formula to calculate the energy demand based on temperature. The average day temperature as the main variable for growers to calculate their heat demand for a whole day (KNMI, 2017).

Table 12 - Temperature progression during the simulation

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Temp in C°	-1	0	-3	1	3	4	9	10	11	14	17	19	21	20

In the simulation it was chosen to simulate the decline of heat demand from winter to summer temperatures. As mentioned before, every two days represent temperatures from January until July. Day 1 and 2 represent temperature conditions in January, day 3 and 4 of February and so on. The outdoor temperatures that were used in the simulation were based on the typical outdoor day temperatures in winter, spring and summer months. At some days we chose to implement "extreme cold" and "extremely hot" temperature that occurred in 2017 to test the performance of the market on those days. An extreme cold day results in high demand for heat energy, so the price might skyrocket on such days. On a very hot day, heat energy demand is very low and producers might be struggling to sell energy. We wanted to find out if this would occur in the simulation. Also, the period from winter to summer is very interesting for two other reasons. The spark spread varies in these months and the market conditions change from tight during winter to wide in the summer. From theory, we know this affects the price for heat, but it is unknown how great the effect will be in the B3-Hoek.

The following figure shows the total energy demand compared to the total production capacity for each day in the simulation:

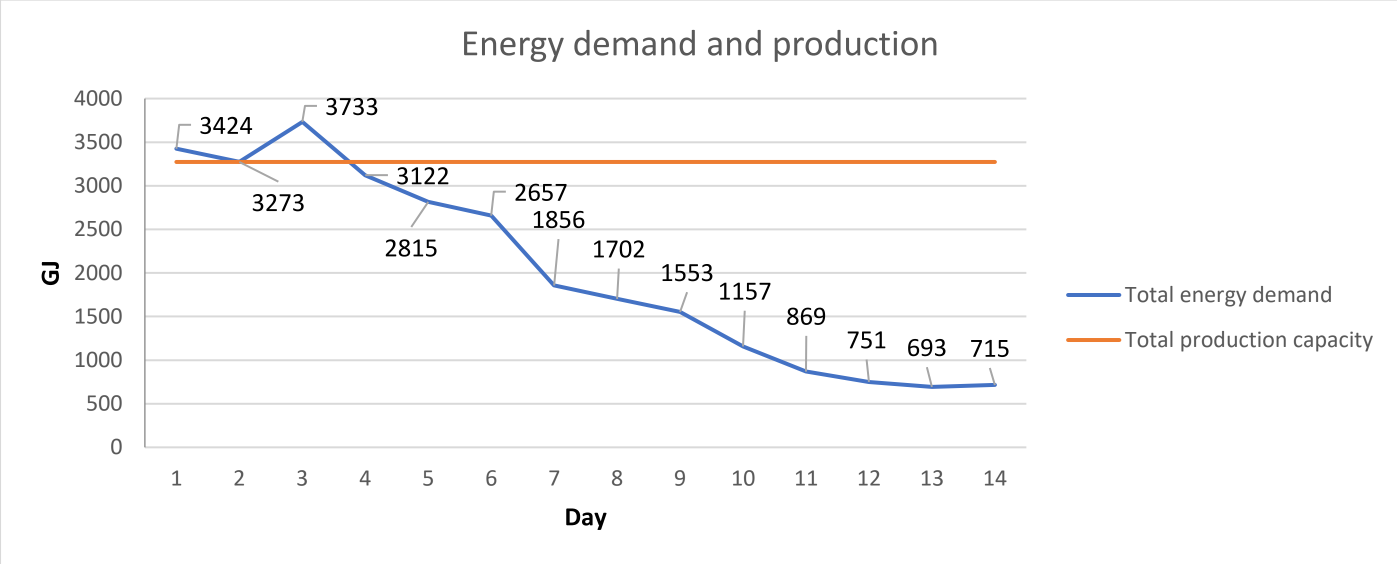


Figure 18 - Energy demand and production capacity in the simulation

The graph shows the total production capacity, which is the accumulation of the capacity of Uniper, the biomass plant, geothermal plant, AVR and all the CHPs of growers in the simulation. Note that the capacity of the boilers is not included. In the simulation they are considered to have an infinite capacity, thus horticulture companies are always able to fulfil their heat demand. The total energy demand is the accumulation of the daily demand of each grower. In the simulation the capacities of production asset do not change, therefore the graph is horizontal. The difference between both graphs tells us if the heat market is tight or wide. It can been seen that on the first and third day the capacity was insufficient to supply the whole heat market. Therefore some growers would have to use their boiler on these days. The idea is that this should result in fierce competition between growers for the available capacity in the market. In the summer it is the other way around. Here competition is fierce between producers for the small demand of the consumers. In the results of the simulation, we can see if this will actually be the case.

5.2.2 Energy production

Figure 7 shows the DHS in the B3-Hoek with the different producers and their location. Currently, not all of them are connected to the DHS, but it is assumed that this will be the case in the near future. Therefore all the producers in the B3-Hoek are connected to the DHS in the simulation. The different biomass and geothermal plants are represented in the simulation by one producer with a production capacity equal to the sum of the plants.

The production capacity of the producers in the simulation is scaled to the real total production capacity. Because we use the heat demand of real horticulture companies, their summed demand is a fraction of the real heat demand. If we would use the real capacities of the producers, one producer could easily supply the total heat demand in the simulation. Therefore the capacities are scaled to the point where they are of the order of magnitude in the simulation, compared with the real DHS. The downscaling is done by accumulating the CHP capacities of horticulture companies that participated and divide it by the sum of the CHP capacities of growers in real life. This gives the multiplication factor that shows how much smaller the simulation DHS is compared to the real one. The real production capacities of the producers is multiplied by this factor to determine how much capacity we should give to the producers in the simulation. After this process there were some minor alterations made in the capacity of the producers to ensure two days of tight market conditions. This was necessary because, we recruited one real prosumer, but to make the simulation more feasible we changed the attributes of one grower with a CHP (unilluminated) to a grower with CHP that illuminates their crop. This specific grower has experience with illuminated cultivation so assumed this would cause no implications for his behaviour in the simulation. Because of the increase of his CHP capacity, the total supply in the simulation increased and the demand decreased. This disturbed the balance between supply and demand we initially had, so therefore we chose to decrease the production capacity of the other producers a bit more. Eventually, the whole process of determining the production capacities for the simulation resulted in the following market share for each producer based on the total available capacity of 3273 GJ:

Table 13 - Market share of the producers

Producer	Market share in real-life [%]	Market share in the simulation [%]
Uniper	30%	26%
Biomass plant	13%	11%
Geothermal plant	14%	13%
AVR	10%	8%
Sum grower CHPs	33%	42%

It is clear that the market share of the producers is lower in the simulation. The difference, however, is not very big and the ratio between them is very similar. Therefore this configuration was deemed feasible enough for the simulation.

5.2.3 Gas Price

The cost of natural gas in the simulation was based on the TTF day-ahead price from price data of 2017, recovered from the database of AgroEnergy. Most producers and growers use natural gas as the source of heat energy. This is also the case in the simulation. The cost of natural gas for each producer is depended on where and when it is bought. Producers and growers can chose to purchase gas on the TTF long term market or on the TTF day-ahead market. In the simulation, we chose to take the TTF day-ahead price as a reference. Gas prices are generally higher in the winter when there is more demand. We took this correlation into account by collection the gas prices that occurred at different rounded temperature in 2017. We took the average of different gas prices that occurred at a specific temperature and used that price in the simulation. This way we could come up with a gas price based on the outdoor temperature and improve the feasibility of the simulation. The TTF price is measured in [EUR/MWh] but was converted to [EURct/m^3] because that is a more familiar unit for horticulture companies. For this conversion, the lower heating value of 31,65 MJ/m^3 was used (Energieleveranciers.nl, 2019).

Table 14 - Gas prices in the simulation

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Gasprice [EURct/m^3]	24,04	23,01	22,61	23,01	22,6	21,98	21,16	19,46	19,73	18,99	18,79	18,27	18,18	18,11

5.2.4 Electricity Price

The electricity price scenario was determined in a similar way as natural gas. However, we first had to decide what would be our reference price. Electricity can be bought and sold on the APX exchange (long term, day-ahead and intraday). We chose to use the day-ahead electricity price in the simulation because this is more pragmatic. Normally electricity is priced per hour. Therefore we choose to create a day-ahead average of the prices during peak hours (the hours between 09:00 and 21:00). These are generally the hours the CHPs are in operation because of the good spark spread. The average of these prices was taken to select the APX day-ahead price. Similar to gas, the temperature was used to set an electricity price for a day in the simulation.

Table 15 - Electricity prices in the simulation

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Electricity price [EUR/MWh]	55,90	54,85	57,25	44,75	54,20	48,60	44,85	39,20	37	40,05	37,05	34,25	33,90	35,80

5.2.5 Marginal Cost

Every producer has a different marginal cost price for heat energy. However, they are calculated in a similar way based on electric and thermal efficiency, fuel costs variable cost and income for subsidies and electricity sales:

$$Marginal\ cost\ of\ heat\ energy = \frac{Fuel\ cost\ -\ Electricity\ price\ *\ \eta_{electric}}{\eta_{thermal}} + Variable\ cost - \ Subsidy$$

Marginal cost of heat energy	$[EUR/MWh_{th}]$
Variable cost[5]	[EUR/MWh]
Fuel cost	[EUR/MWh]
Electricity price	$[EUR/MWh_{e}]$
Production efficiency $\eta_{electric}$	[-]
Subsidy	$[EUR/MWh_{th}]$
Production efficiency $\eta_{thermal}$	[-]

In order to calculate the marginal cost for each producer the following variable values have been used.

Table 16 - Marginal cost variable values

Producer	Variable cost	Fuel Cost	Subsidy	$\eta_{electric}$	$\eta_{thermal}$
Uniper	4 [€/MWe]	TTF price	-	0,45	0,35
Biomass	-	16,2	8,70	0,10	0,90
Geothermal	-	APX/COP	1,10	COP = 15	1
AVR	47	-25	-	0,22	0,78
CHP illuminated	9 [€/MWe]	TTF price	0,36	0,42	0,52
CHP unilluminated	9 [€/MWe]	TTF price	-	0,42	0,52
Boiler		TTF price	-0.5 [EUR/GJ]	-	0,9

[5] The variable costs represent the maintenance cost that are involved for heat production. For some production methods it is specified as cost per MW electric and others cost per MW heat.

This results in the following marginal cost prices for the producers during the week.

Table 17 - Marginal cost price per producer[€/GJ]

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Uniper	-1,26	-1,72	-2,90	1,89	-1,82	-0,32	0,35	0,99	1,99	0,30	1,21	1,79	1,84	1,10
Biomass	1,03	1,06	0,99	1,34	1,08	1,23	1,34	1,49	1,56	1,47	1,55	1,63	1,64	1,59
Geothermal	0,73	0,71	0,75	0,52	0,70	0,59	0,53	0,42	0,38	0,44	0,38	0,33	0,32	0,36
AVR	0,67	0,73	0,58	1,35	0,77	1,11	1,34	1,69	1,82	1,63	1,82	1,99	2,01	1,89
CHP (ill)	0,75	0,42	-0,34	2,69	0,34	1,26	1,65	1,99	2,63	1,54	2,11	2,45	2,48	2,01
CHP (unill)	1,11	0,78	0,02	3,05	0,70	1,62	2,01	2,35	2,99	1,90	2,47	2,81	2,84	2,38
Boiler	7,60	7,27	7,14	7,27	7,14	6,94	6,69	6,15	6,23	6,00	5,94	5,77	5,74	5,72

By ordering the marginal cost for every producer you get the merit order of the producers for each day. Combined with the total production capacity per producer results in the following figure of the merit order per day during the simulation:

Table 18 - Merit order of the producers throughout the simulation

Day	Merit order				
	Most expensive ←				→ Cheapest
1	CHP unil	Bio	CHP il	Geo	AVR	Uniper
2	Bio	CHP unil	AVR	Geo	CHP il	Uniper
3	Bio	Geo	AVR	CHP unil	CHP il	Uniper
4	CHP unil	CHP il	Uniper	AVR	Bio	Geo
5	Bio	AVR	CHP unil	Geo	CHP il	Uniper
6	CHP unil	CHP il	Bio	AVR	Geo	Uniper
7	CHP unil	CHP il	AVR	Bio	Geo	Uniper
8	CHP unil	CHP il	AVR	Bio	Uniper	Geo
9	CHP unil	CHP il	Uniper	AVR	Bio	Geo
10	CHP unil	AVR	CHP il	Bio	Geo	Uniper
11	CHP unil	CHP il	AVR	Bio	Uniper	Geo
12	CHP unil	CHP il	AVR	Uniper	Bio	Geo
13	CHP unil	CHP il	AVR	Uniper	Bio	Geo
14	CHP unil	CHP il	AVR	Bio	Uniper	Geo

Table 18 shows the merit order for each day in the simulation. The order each day is sorted based on the marginal cost price for the producer. The producer on the left has the highest marginal cost for the production of heat energy that day, the one on the right has the lowest. The merit order is different throughout the simulation, because of the different electricity and gas prices every day.

5.3 Experiment verification and validation

In this paragraph, we describe how we verified the different components of the simulation, by running tests to make sure all functions work accordingly. Also, the validation of the simulation is discussed to see if it accurately represents reality and can be used to answer the second research sub-question.

5.3.1 Verification

To check whether the calculation tool and the platform worked accordingly, they have been tested prior to the start of the simulation. For each, it described what tests were developed and performed.

Calculation tool

Every participant had a personal Excel sheet that they could use for the calculation that had to be made during the simulation. All sheets originate from one source sheet. By hiding cells and secure the visibility with a password, participants were unable to see or alter calculation and look-up procedures. The calculation codes in the source sheet were checked by manual calculation. No errors were found, so the functions in Excel were working properly.

The data from all the participants was collected and stored in such a way that multiple lookup functions developed personalized Excel sheets containing the specific parameters of each participant. For each of them a sheet was generated and all were checked with the database to see if they corresponded. Each sheet was found to contain the proper information of the participant. An additional test in the sheet from one of each participant type was done to check if generated the proper costs per GJ and buffer volume. It was found that if the right parameters were used, the right results would be shown in the Excel sheets. At this point, we confirmed that all sheets were functioning appropriately. Results could only be different if participants entered the wrong input parameters. Therefore all sheets were checked after the simulation and corrections were made by the researcher. At that point it had no influence on the market results, as this could not be altered after a settlement. We checked and discuss in the next chapter if misinterpretations or using the wrong input parameters affected the offers/biddings of producers/growers and resulted in unexpected outcomes.

Trading platform

The trading platform is a web-based interface where energy could be traded during the simulation. Each participant had a secured account to get access. The research/market operator had an admin account and was able to monitor the activity of each of the participants.

Prior to the simulation, the researcher checked every account, by logging into the platform with each account and check whether the profile parameters corresponded to the participant. The functions on the website were checked by a test developed at AgroEnergy. This was done before the experiment they had done earlier. During that test and the previous experiment, there were no errors on the trading platform. The functions remained the same and only a few interface design changes were made. Prior to this simulation, all functions have been checked by the research via one of the participants accounts. No errors were found.

The trading platform automatically calculated the settlement price and volumes based on the offers and bids that were submitted. Those offers and bids were monitored throughout the simulation by the researcher. The platform generated settlement graphs to visualize the collects of offer and bids. This corresponded to the data table of all offers and bids that were submitted on each day. This table showed how much energy each participant wanted to trade each day, and how much he actually delivered/received. By adding those numbers it was checked if it corresponded to the total traded volume of that day, which was always the case. The settlement price and volume calculation were double-checked by copying the submission table into excel and manually calculate the settlement price and volume for each day.

We can conclude that by extensive testing of the calculation sheet and the trading platform no errors were found. Therefore it is safe to say the simulation is verified and calculation/functions work appropriately. Besides verifying the simulation it must also be validated.

5.3.2 Validation

The design process of the simulation is based on three principles: reduction, selecting relevant elements and leave out less important ones; abstraction, simplify elements to make the simulation less complex; symbolization, creating a resemblance with simulation elements and their counterparts in reality (Peters et al., 1998). The extent to which the translation of the reference system was successful, depends on the degree to which the simulation is a valid representation. To evaluate the degree of validity, the four criteria of (Raser, 1969) are used: psychological reality, structural validity, process validity and predictive validity.

Psychological reality

In this criterion it is evaluated if the simulation environment is seen as realistic by the participants and so that behaviour in the simulation corresponds to reality. The fact that there were no real financial and technical consequences in the simulation can cause the behaviour of every stakeholder to be different in reality. Since there are no consequences, participants could be more risk-taking in the simulation than in reality. To counter this incentive, a prize was introduced for the ones who had the lowest average energy cost at the end of the simulation. Competitive elements in serious games are important to stimulate motivation and performance (Cagiltay, Ozcelik, & Ozcelik, 2015).

Growers estimate their demand for heat energy based on many factors. In the simulation it was chosen to use average day temperature as a predictive variable for heat demand. It was chosen to simulate the changing market conditions from winter to summer period, but there were only 14 days in which this could be tested. Therefore the temperature drop was rather extreme. This could influence the behaviour of the participants. A trade-off had to be made between testing seasonal patterns or using a realistic temperature variation. The former was more essential for testing the market performance under different conditions. In Chapter 7 we discuss this influence of this choice on the results. The model that was developed for the calculation of the heat demand was obtained from historical data, thus to a large degree it did resemble the actual heat demand of each grower participant.

The interface that was used for participants to trade heat energy, was extracted from the online portal that is currently used by horticulture companies to trade electricity and gas. Therefore there was a high resemblance with reality. The calculation tool was developed especially for the simulation. Normally, companies have a slight indication of their marginal production cost, but the tool provided them with complete information. In reality, such information is only partly known, thus companies use key figures for costs that are common in the horticulture sector. Therefore they could behave differently in reality, but in the simulation, it was important to distil the behaviour based on complete information. Because of the additional tool that was provided, the simulation was successfully developed in this regard.

Concludingly, the simulation is considered to have a sufficient degree of reality, thus it is expected participants will behave as they would have in reality. Chapter 7 discusses this further after the results have been presented.

Structural validity

This criterion refers to the fact the simulation should resemble reality in structure. Figure 12 shows the conceptual model of simulation that was distilled from the market model in Figure 10. Here many simplifications have been made and system elements have been taken out of the context of the simulation. First of all the long term bilateral market was taken outside the scope of the simulation, because we wanted to see what decisions would be made in the short term by producers and horticulture companies when all of the supply and demand is traded. In reality, they will have some of their demand contracted long term. A part of the demand is therefore hedged, thus the lesser dependence on the short term market could result in different behaviour. Moreover the CO_2 requirement for horticulture companies was not included in the simulation, but in reality, it is part of the valuation of heat energy from the market.

For the producers, we included the variable production costs based on fuel costs, electricity prices, subsidies and variable maintenance costs. Transport fees, cost of energy loss, connection costs and fixed investment costs were not included in the simulation. Therefore these are not reflected in the final price consumers had to pay for heat energy or the production cost for the producer. Also, the marginal production cost that was calculated in the simulation appears not to reflect the real cost. We used multiple sources to justify the variable productions costs used in the experiment but failed to make them accurate. Stakeholders confirmed this by stating the production costs in the simulation we too low compared to reality. However, the goal of the simulation was not to have perfectly accurate cost levels, but rather have a good reflection of the cost structure.

The cost structure of each producer plays a major role in the merit order. Although the cost does not compare to reality, AgroEnergy confirmed that the merit order during the simulation is representative. They compared the merit order in the simulation with the merit order that is currently determined by contracts. This is more important than the actual production cost because the merit order determines the position of producers in the market. It plays a major role in the competitive forces producers feel to lower their offer prices. We, therefore, consider this aspect of the simulation valid.

The sample of growers was representative, but the producers were not. The DHS has four different types of producers, while only a CCGT and geothermal producer were initially recruited. Therefore it was decided to add two additional producers (representing the waste incinerator and biomass plant) to the simulation, of which the role was fulfilled by two different employees of AgroEnergy. They chose because they are very knowledgeable about energy trade and the function of a short term market. Therefore they are considered suitable replacements of the actual producers.

For the experiment, the size of the DHS and the market were based on the DHS in the B3-Hoek. However, we must note that only a fraction of the consumers and producers are currently connected in this DHS. Figure 7 shows the present network layout in red. The regions marked with the dashed blue line are at the time of writing not included in the DHS. For this research, we made the assumption that the entire B3-Hoek region will be connected in the near future (by 2025) and the short term market would be implemented in that period. In the case these development are stalled or the DHS remains as it is today, then this will have consequences for the interpretation of our results. This is discussed further in Chapter 7.

The trading platform of AgroEnergy set to function as a day-ahead market. A short term market can have different trading frequencies/periods. The electricity system in the Netherlands is an hourly day-ahead. For heat energy this could be implemented as well, but in the design proposal, it is suggested to use a day-ahead format with an uniform double-sided auction. This has successfully implemented in the simulation.

It is concluded that the structure of the simulation has a sufficient degree of validity. It resembles the most important elements of case DHS, needed to investigate the behaviour of actors and outcomes of the market under the conditions of the DHS. However, we must acknowledge that it is assumed that from a technical perspective there are no hindering factors that influence behaviour and market outcomes.

Process validity

This criterion evaluates if the process within the simulation is similar to that of reality. As we have mentioned before, the interface for heat trading is similar to what is used for electricity and gas trade. Therefore the process of bidding/offering and clearing the market has a high resemblance of the real process in the future. The important difference that must be stressed is that, in the simulation, only the process of heat trading is included. In reality, a similar decision process must be done to decide how much electricity, gas and CO_2 should be bought on the designated markets. We have excluded this, because it would make the simulation too complex and time-consuming. The process in the simulation is simplified and shortened because all relevant information was sent each day. Also, the calculation tool allowed the participants to quickly gain insight into the important factors (such as production costs, available production capacity, heat demand, buffer volume etc.) to determine their bids and offers.

In the simulation, the focus was only on the heat energy trade, but in reality, this must also be delivered. The delivery process has not been included, nor did we analyse how this could affect the trading process. Delivery constraints can restrict the trade of heat, which we will discuss further in Chapter 7. Nevertheless, it is concluded that the trading process in the simulation is sufficiently valid.

Predictive validity

This last criterion of validity concerns the degree that the simulation can reproduce historical outcomes or predict the future. Since there is no similar case to compare the simulation with, we can only reflect back on the theory of (energy) markets and the findings of Bijvoet (2017). The goal is that the simulation allows us to identify the behaviour of horticulture companies and producers and how it affects the performance of the heat market. The fact that the actual actors participated in the simulation improves the predictive validity of what their behaviour will be in the future. However, there are so much more elements that affect behaviour and market performance in the future, such a size of the market, level of the technology, alternative heat sources, that we acknowledge that this simulation is not able to predict it. The goal of this research is not to predict, but rather generate insights in the interactions between elements of the DHS and actors and how they affect market performance. Whether this goal was reached will be discussed in Chapter 7. For now, it is concluded that the scope and structure of the simulation, plus the fact that the participants are the actors of the system, generates a sufficient degree of predictive validity.

In this paragraph we have discussed the verification and validation of the simulation. It was concluded that after the verification process, the simulation worked accordingly. After discussing the four criteria of validity, it is concluded that the simulation has a sufficient degree of validity. Therefore the simulation is able to help us to answer the second research sub-question. In the next chapter, the results of the simulation are presented.

6

Simulation Results

In the previous chapter we explained how the simulation is developed. In this chapter, we will look at the results of the simulation and answer the second research sub-question. First, we will give an overview of the market results. We will discuss the bids and offers, market price development and the volume of energy that is traded. Secondly, we will discuss the results for each of the participants. We will use alternative cost and marginal cost model to compare the participant results in the simulation with what could theoretically be expected in the worst-case scenario. A survey and semi-preconstructed interviews have done to gather qualitative data about the experience of the participants. Finally, we evaluate the behaviour of participants and the results of the simulation with the performance criteria. The results are validated to conclude the answer to the second research sub-question.

6.1 Market Results

In this paragraph, we show the results of the market. After the simulation ended, all the data of the bids, offers, settlement prices, traded volume etc., were gathered. A total of 346 bids blocks growers, 202 offer blocks and 14 settlements (market prices and trade quantities) were the result of the simulation, see Appendix B.
First, the bids and offers of the growers and producers are discussed to identify their behaviour. Then the market price development in comparison to two reference models (boiler cost price and marginal cost price) is discussed for the evaluation of the 2nd and 3rd PI. Hereafter the results of the traded volume are shown together with the total energy demand and production capacity for the evaluation of the 4th PI. Lastly, the results of the survey and interviews are discussed for the evaluation of the 5th PI.

6.1.1 Biddings

Every day producers and growers had to decide how much energy they would like to trade on the market. they were able to create multiple bid blocks. All the bid blocks during the simulation have been analysed to learn more about the bidding behaviour of participants. The behaviour analyses are based on the combination of volume and price that each participant had submitted on a trading day. For every trading day, the marginal willingness (alternative cost) for each grower was compared with the price point of his bid blocks. Similarly, the marginal costs were compared with the price point of the offer blocks of each producer. The difference between the two gives an indication of profit-seeking behaviour. In order to verify this most participants 11 of the 14 growers and all producers) have commented on their behaviour in the survey, during the plenary session or an interview. The notes of the comments were used to create strategy profiles of growers with and without a CHP. The results of the bidding and offering analyses are discussed below. We start by discussing the bids of growers and afterwards we discuss the offers of producers and prosumers.

Behaviour of growers

For growers, without a CHP the bidding behaviour was generally the same. They split their demand in different price/volume combinations. The majority of the energy demand was bid for at a high price and some of the demand was asked at a lower price. This is to make sure there is a higher chance of settling at least a (large) part of the energy demand. The lower bids were used to put pressure on the market price. Alternative cost bidding was not used, because at that price point the growers would use their boiler instead of the DHS. Price

points for biddings later in the simulation were determined by previous settlements and a prediction for the new market prices. All the growers followed the fast decline of the energy price that occurred after day 6 by bidding far below the cost of their alternative. The buffer was generally not used as a strategic asset, but more as back-up in the case a settlement was missed.
The growers with a CHP (unilluminated) behaved different, because of their extra energy production asset. They only had to purchase a small part of their energy demand from the market during the cold days. This was sometimes done through bids with a higher price point than the costs of using a boiler. They tried to guarantee the purchase of the majority of their energy demand on the market (the amount they could not produce themselves). After day 6 and 7, when the market price dropped, the CHP was more expensive than the market price. The results were an increase in energy demand from the market because the growers with CHP turned them off and requested their full demand from the market. The price point was generally set close to the marginal cost price of the CHP. They continued the strategy of bidding high for the most part of the demand and put pressure on the market price by bidding a part of the demand for a low price.

Behaviour of producers

Uniper

The first day of the simulation Uniper offered their energy for a price close to the marginal cost price of a growers boiler. They thought that growers are willing to buy energy for a price that is slightly lower than their alternative costs, because of the cold period. However, a lot growers bid a lower price than what Uniper offered. Therefore the settlement price of the first day was much lower and Uniper did not sell a lot of energy (27 % of his capacity). In the subsequent days, they lowered their offer. They used multiple price/volume combinations offers to spread the risk of missing a settlement and to try to drive up the market price. After the first few settlements, Uniper had more knowledge about the market (prices and traded volume) and their position in the market compared to the other producers. Previous settlements were used to speculate on the future market prices and offers were adjusted accordingly. Because there was always an inelastic part in the demand curve, Uniper tried to shift the settlement price towards the beginning of this part. Here they could sell energy for a much higher price. Even though they would sell less energy in total, the profit would be higher if the settlement occurred at the border of the elastic and inelastic part of the demand curve. This worked until day 7. After this day the market price dropped drastically and Uniper was forced to drop the offers towards marginal cost prices, because of the competitive pressure for the lesser demand. At this point, the marginal cost of the plant became the determining factor for the price point of the offer. In the days before, the market predictions determined the price point of the offers. According to Uniper, until there is sufficient competition, the price point of bids of producers will be at the level of the market price. With enough competition they will bid at the marginal cost price point.

Geothermal plant

The geothermal energy producer offered energy for high prices in the hope to make a lot of profit. It was not known to him that he could split his capacity in multiple price/volume combinations. Therefore he made only one offer each day until day 8. That is when he learned he could spread the risk by making multiple offers at different prices. The prices were determined by previous settlements and a prediction for the coming settlement. This strategy resulted in missing three settlement completely. Although the marginal cost was very low the producer decided to ask a much higher price, because he thought he could make more profit this way.

Biomass

The biomass producer made multiple price/volume offers each day. The highest price point was set at the expected market price. The largest part of the volume was offered at a lower price. The remaining capacity was strategically offered at higher prices in order to raise the market price. When the market prices dropped from day eight onward, the marginal cost became the main factor for the price point of the offers. On day 11 and 13 the producer tried to increase the market price by offering at higher price points. However, this resulted in not being settled, thus it was not a good idea. It had no effect due to the competitive prices of other producers.

AVR

Throughout the entire simulation, the participant for the waste incinerator offered all his capacity at the marginal cost price point. This first seven days the offer was slightly above, because there was a shortage in the market. When the competitive pressure among the producers increased from day eight onwards, he offered energy at exactly the marginal cost. However, the producer was not able to sell energy in this period, because this price was still too high compared to the other producers.

Behaviour of prosumers

Prosumers in a DHS act different from regular energy producers in a DHS. The first objective is to satisfy their own energy consumption. Then they try to make a much profit from selling excess capacity to the market. They also have a buffer that significantly influences the way offers are determined. When a buffer is full, energy can be sold for low prices, even lower than the marginal cost price point. When the buffer is more empty a prosumer is more reluctant to sell energy. In this case he will prefer to use the excess capacity to fill the buffer. Only if energy can be sold at a very profitable price point, the prosumer will be more eager to sell energy to the market.

CHP illuminated Grower 13

Grower 13 offered a lot of volume during the first days of the simulation. This volume comprised of the extra capacity of his CHP that he could not use himself and energy stored in his buffer. The price/volume combination was determined in such a way that the extra capacity could be sold for a lower price and the energy stored in the buffer could be sold if the market price was very high. On day three a mistake was made, which resulted in selling all the CHP capacity to the market and using the more expensive boiler as energy source for his own energy demand. The last eight days of the simulation the CHP was not competitive with the other producers. Heat energy was predominantly bought during this period. Grower 13 continued to try to sell stored buffer energy to the market because it was rather full and demand was low.

CHP illuminated Grower 14

Grower 14 mainly sold the excess capacity of his CHP to the market and tried to keep his buffer volume at 50%. The price point he chose was predominantly determined by expectations of market price developed based on previous settlements. From day 8 onward no energy was offered to the market, as the CHP was more expensive than the alternatives. This is when he switched from selling to purchasing energy. Bid price points were set a bit higher than a predicted market price. Predictions were not always accurate, therefore there were two occasions where he was not settled.

6.1.2 Price Development

Figure 19[6] shows the market price development during the simulation, the cost of heat energy production with a boiler (alternative cost model) and the market price development in a marginal cost offering scenario, ceteris paribus.

[6] The graphs in the figures of this paragraph are represented by lines. One must carefully interpret these graphs as the data points are not really related. Each point is a data point for different market conditions. The 14 simulation dates represent a time period from January to July thus there is a chronological order. The proper presentation of the graphs would be to present it as dots. However, these figures are shown to visualize the difference between the graphs and a continues line suits this purpose better.

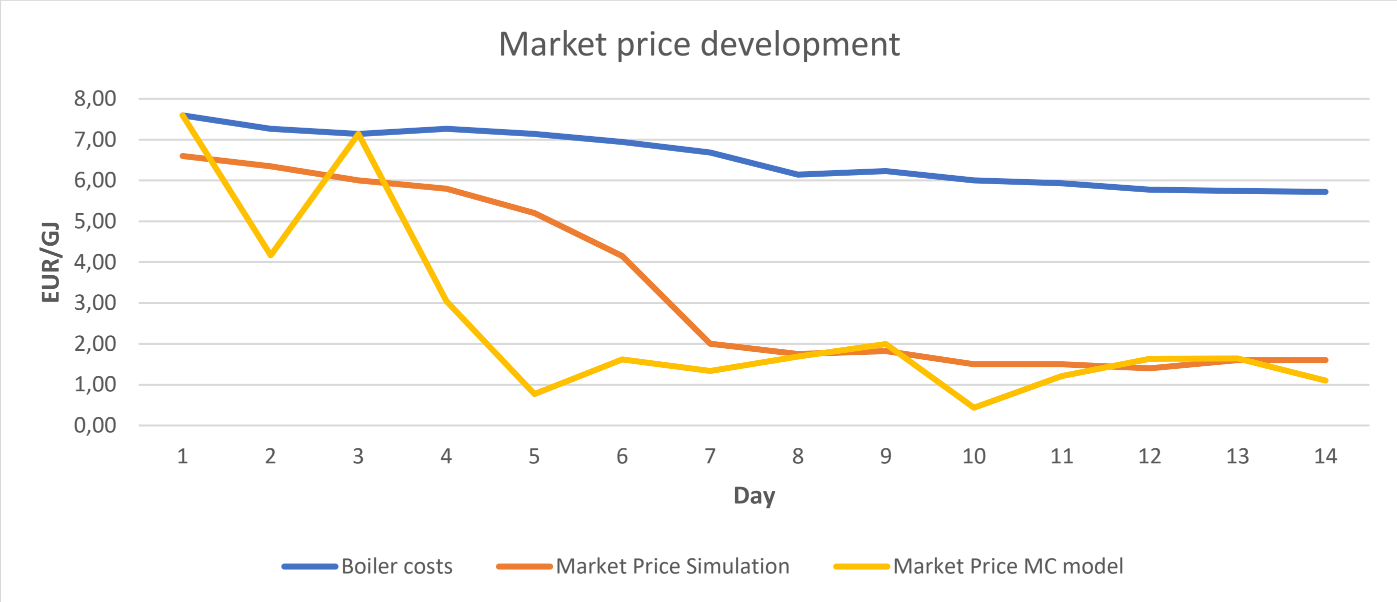


Figure 19 - Market price development in the simulation

The second performance indicator specifies that the short term market price should remain below the cost of heat production with a boiler for horticulture companies. As can be seen in Figure 19, the market prices during the simulation (orange line) were always below the level of the alternative cost price point (blue line). Every day it was cheaper for growers to buy heat energy from the market than to produce it themselves. There is a noticeable smaller difference between the two during winter market conditions (tight) and summer conditions (wide).

The third performance indicator specifies that competitive forces should drive the market price (close) to the marginal cost level of producers, but they should still be able to make profits to recover their long term costs (capital costs and future investment costs).
The first seven days the difference between the simulation and the MC model is noticeably large than afterwards. On day 1 and day 3 the market price in the MC model is equal to the boiler costs. This can be explained by the fact that on those two days there was less production capacity in the market than the demand. Therefore the market price had to be equal to the true marginal willingness of growers to buy heat energy, which is equal to the boiler costs. However, this did not occur in the simulation, because in general, the participants always bid lower than this price point.
From day 7 onward the market price is very close to the marginal cost reference scenario, see Figure 19. Figure 20 shows that the market price was significantly higher than the marginal cost of producers in the simulation, prior to day 7. Hereafter they were very similar.
We went from tight market conditions to wide market conditions. The market price development corresponds to this. In the summer, there is enough competition to drive the market price to marginal cost. In the winter, there is less competition and the producers are able to drive prices up.
In the simulation and the models there were not capital costs included, thus it cannot be checked whether profits were high enough to cover them. However, we were able to calculate the amount of profits that were made in the different scenarios. This is further discussed in paragraph 6.2.2.

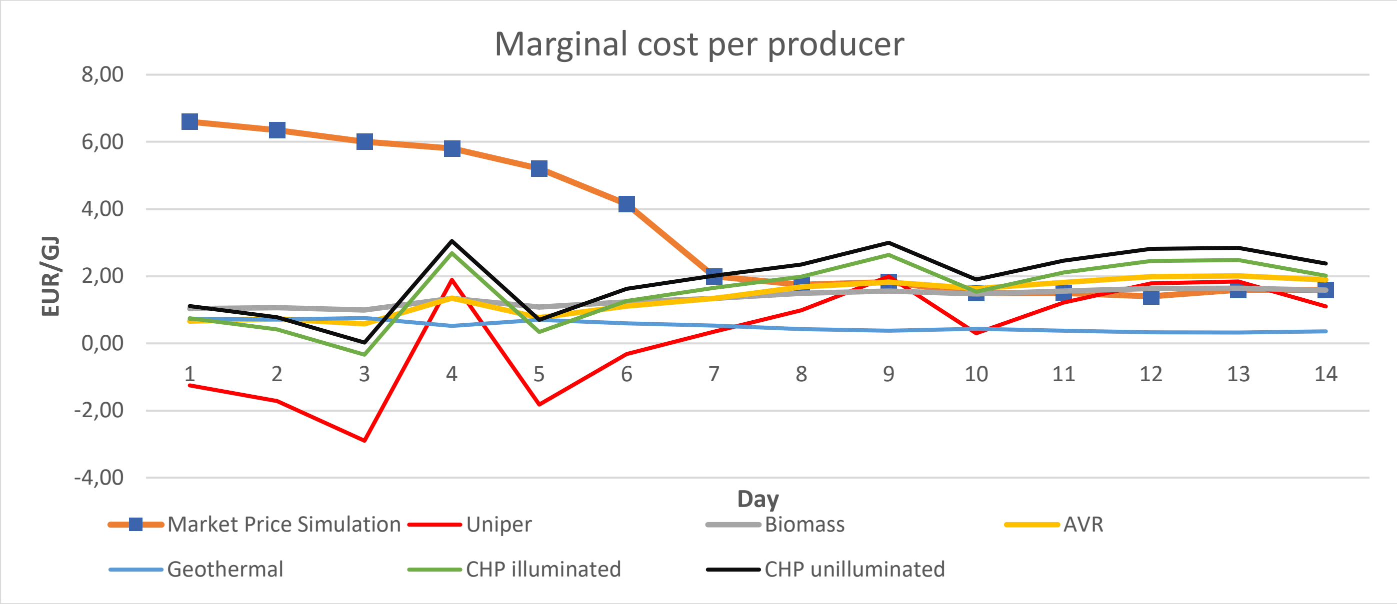


Figure 20 - Marginal cost development per producer in the simulation

6.1.3 Traded Volume

Price is not the only criteria for a well-function market. The fourth performance indicator specifies that a high amount of heat energy volume that is traded on the market. In reality, a proportion of the demand will likely be fulfilled through long term contracts[7]. These were not included in the simulation, thus it can only be judged whether the short term market was able to provide the demand of the growers.

The main criteria here is that growers are able to purchase their energy demand on the market. The more the market fulfils their demand, the better the result. Figure 21 shows all the elements to evaluate our volume criteria.

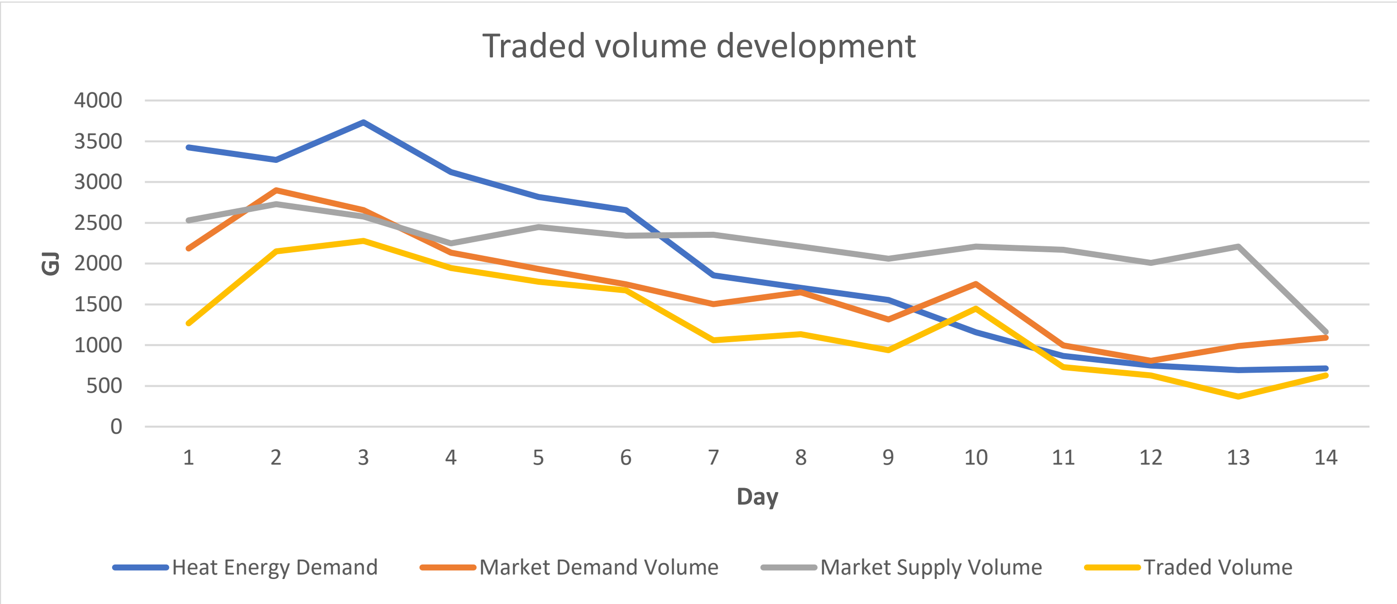


Figure 21 - Traded volume development in the simulation

The heat energy demand is the total energy that is needed on each day. The market demand volume shows the sum of all the volumes of the bid blocks of the growers. The market supply volume shows the sum of the volumes producers offer each day. Lastly, the traded volume shows how much energy is settled each day. When we compare the heat energy demand and the market demand volume, there is quite a big difference.

[7] Long term contracts provide stability and assurance for horticulture companies that they will be supplied with heat for a price they consider acceptable

This is mainly caused by the fact that the heat energy demand includes the demand of growers with a CHP. Since the CHP was cheaper than the market in the first 6 days, a large proportion of the heat energy demand was not even demanded on the market. From day 7, when the CHPs were more expensive than the market, the demanded volume follows the total heat energy demand. Also, some growers requested additional heat energy for a low price that could be stored in buffers. Drained buffers from the cold period were filled in the warmer period of the final simulation days. Therefore the market demand volume exceeds the actual heat energy demand on the last days of the simulation. The most important thing to consider is the difference between the market demand volume and the traded volume. In total, the amount of traded volume was 76% of the total market demand. This means that 24% of the demanded heat energy had to come from somewhere other than the market (boiler, CHP or buffer).

When we compare the traded volume with the market supply volume, the difference is larger. During the first days, the difference is small, but it increases in the subsequent days. That can be explained by the decline in demand, while the total production capacity remained the same. The producers generally always offered their total production capacity. The reason the graph varies from day to day is the result of the CHPs of growers who illuminate their crop. At the beginning of the simulation, they used their capacity for themselves and as the temperature increased they were able to sell more energy to the market. There were also two offers during the simulation from growers who cannot actually supply energy to the market. The simulation was not fool-proof enough to stop this from happening. These offers were not settled, thus had no influence on the market price and traded volume.

6.2 Participant Results

In this paragraph, we analyse the results for each of the participants to assess the financial benefit of a short term market. We will focus on the financial difference between the results of the simulation and a reference scenario. First, we look at the results of the growers. We compare the simulation results with a scenario where there is no short term market, the alternative cost model. Then we look at the results of the producers, which we will compare to the scenario where all actors use marginal cost offering and marginal willingness bidding (marginal cost model). Lastly, we discuss the survey and interviews that have been held to gather qualitative data on the experience of participants.

6.2.1 Growers

For this analysis, we divide the growers into three categories: growers with only a boiler (GB), growers with a boiler and CHP that illuminate their crop (GCHPil, this type of grower is a prosumer) and growers with a boiler and CHP that do not illuminate (GCHP). Growers in each category have the same attributes, which we need to take into account when we interpret the results. Having a CHP has a large influence on the cost of heat energy for a grower. Especially in winter periods a CHP is generally cheaper than the market price, see Figure 20.

We measured the cost of the growers daily and calculated their total average cost for heat energy of the course of the entire simulation. This thus includes the costs of purchasing heat at the market and the costs of producing it themselves. The following figure shows the results of GB:

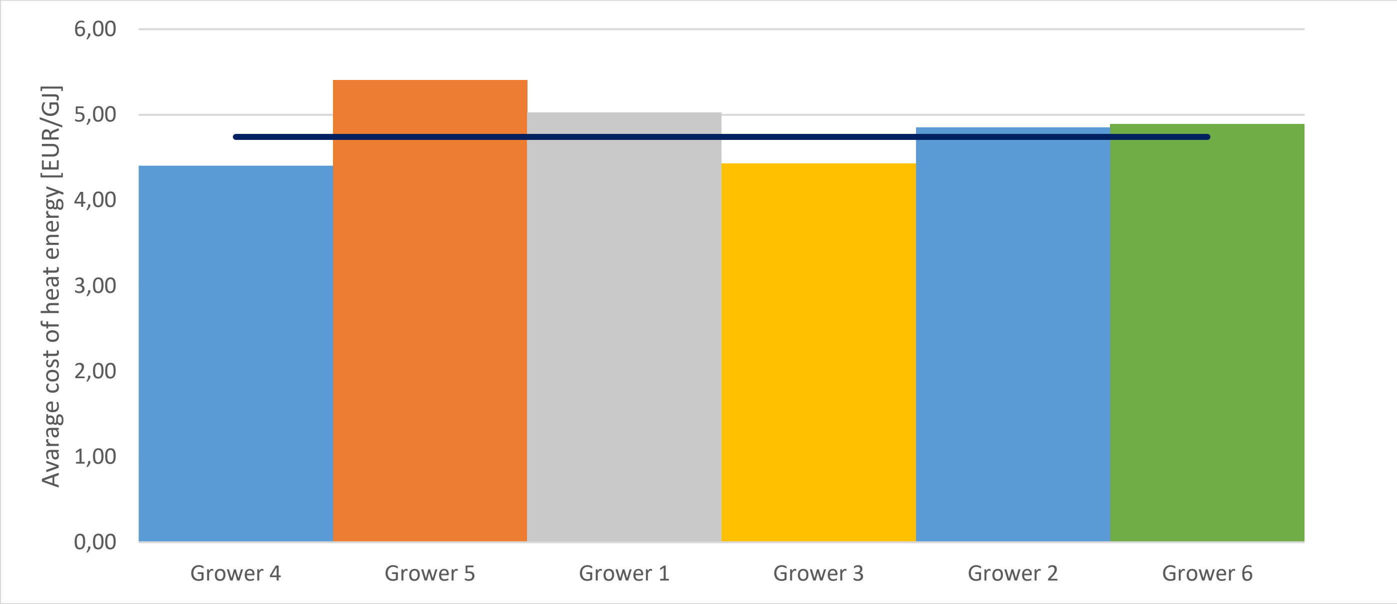


Figure 22 - Average cost of heat energy (GB)

The average cost of each participant is indicated by the level of the bar chart. The weighted average result of this group is €4,74 per GJ, shown by the horizontal line. The demand for heat energy per grower in this category is on average the same. There are two growers who have achieved a lower price, Grower 4 and Grower 3. These growers have not missed a settlement and purchased sufficient energy daily through on the market. The difference with the rest is mainly due to the fact that they have missed settlements (partly). As result, they had to use their (more expensive) boiler to meet their heat demand.

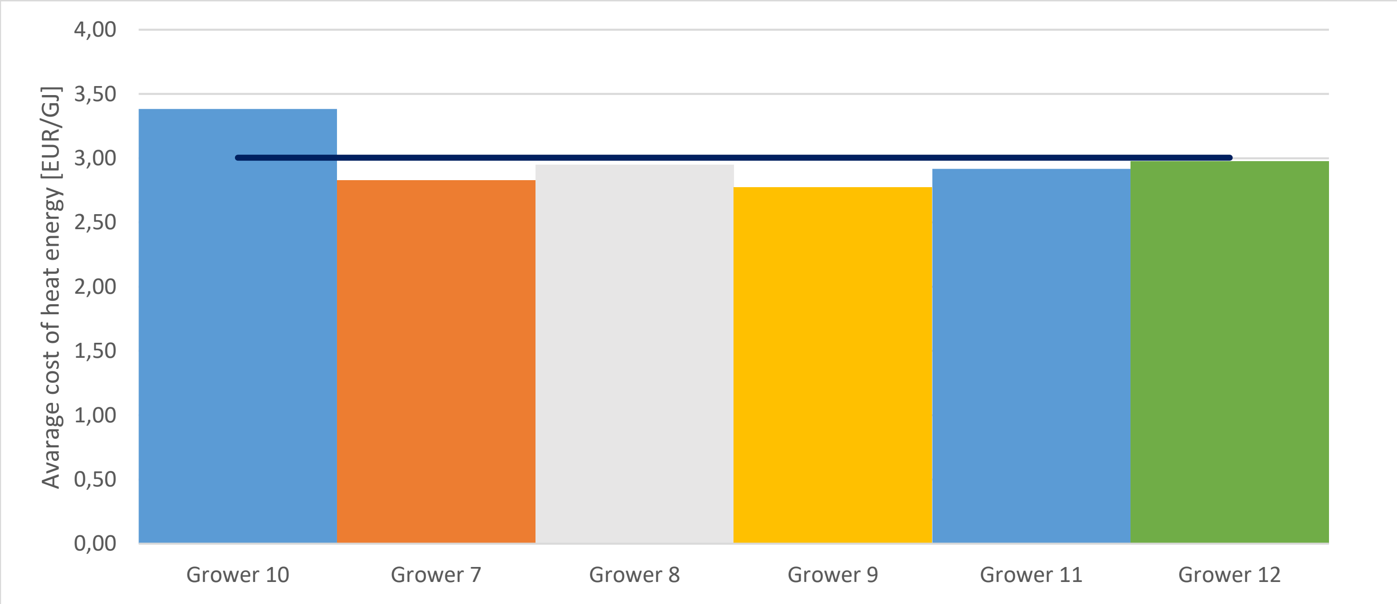


Figure 23 - Average cost of heat energy (GCHP)

In the category of growers with a CHP that do not illuminate their crop, the weighted average result of the group is €3,00 per GJ. The differences are small accepted for the result of Grower 10. Compared to the results of this group he has a high average. This can be explained by the relation between daily heat energy demand, buffer and CHP capacity. Grower 10 has a relative small CHP compared to his heat demand. Therefore he has to buy more energy from the market or produce it with his boiler. His costs were higher in the first few days, what contributed to a higher average cost of heat.

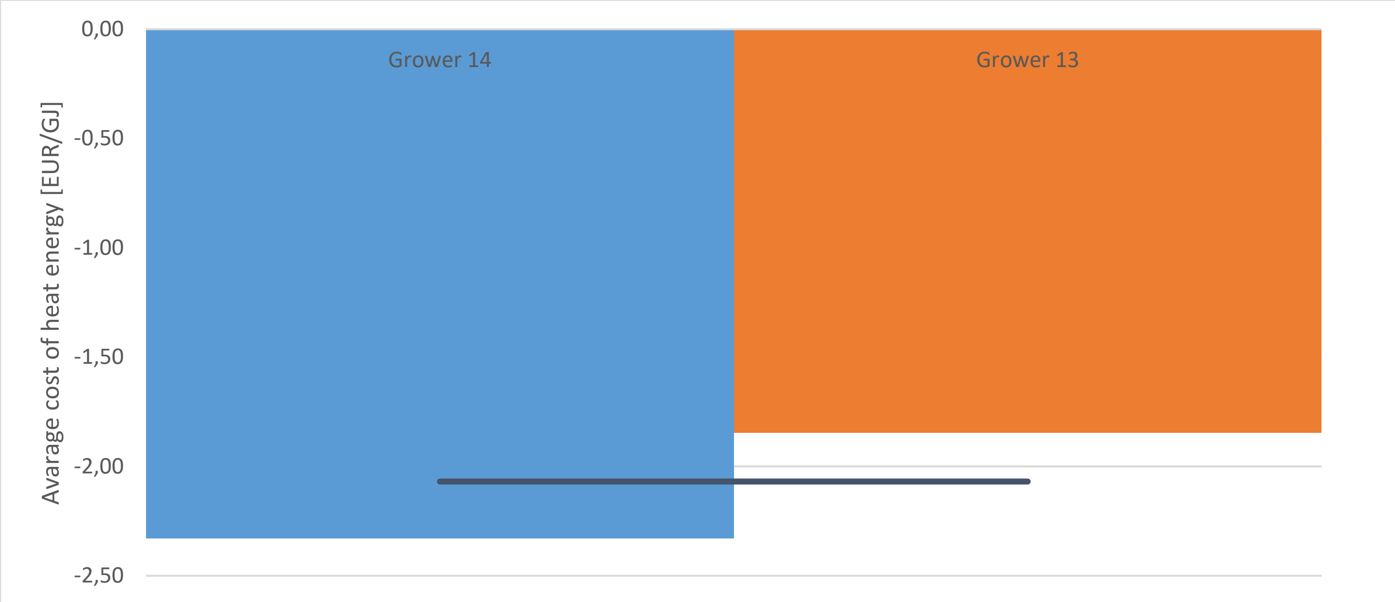


Figure 24 - Average cost of heat energy (GCHPil)

In the last category of growers the weighted average is €-2,07 per GJ. The average is negative because they have sold energy the first six days of the simulation. Their total income from these days was higher than their total cost of energy of all 14 days.

If there was no DHS, all the growers would have to produce energy themselves with their boiler or CHP. The results of the simulation are compared with what would have been the results if there was no DHS and a market, to see if using a market is more beneficial. The following tables show the results of the simulation and the results of a no market scenario (ceteris paribus):

Table 19 - Financial results grower with boiler

Grower	Average heat energy cost No market scenario	Average heat energy cost Simulation	% difference
Grower 1	€ 7,01	€ 5,03	-28%
Grower 2	€ 6,82	€ 4,85	-29%
Grower 3	€ 6,83	€ 4,43	-35%
Grower 4	€ 6,83	€ 4,40	-35%
Grower 5	€ 7,03	€ 5,41	-23%
Grower 6	€ 6,92	€ 4,89	-29%

Table 20 - Financial results growers with CHP unilluminated

Grower	Average heat energy cost No market scenario	Average heat energy cost Simulation	% difference
Grower 7	€ 3,42	€ 2,83	-17%
Grower 8	€ 3,84	€ 2,95	-23%
Grower 9	€ 3,07	€ 2,78	-9%
Grower 10	€ 3,86	€ 3,38	-12%
Grower 11	€ 3,30	€ 2,92	-12%
Grower 12	€ 3,57	€ 2,98	-17%

Table 21 - Financial results growers with CHP illuminated

Grower	Average heat energy cost No market scenario	Average heat energy cost Simulation	% difference
Grower 13	€ 1,39	€ -1,85	-233%
Grower 14	€ 1,39	€ -2,33	-267%

The results show that every grower had a lower average heat energy cost in the simulation, compared to the no market scenario. Especially the prosumer growers have much higher financial results, because a market allows them to sell excess heat energy. Keep in mind that we have not included other financial aspects such as transaction costs, network costs and investments. Only the variable cost of heat energy for the growers is reduced in the simulation.

6.2.2 Producers

The highest economic efficiency in a market is reached when the market price is equal to the marginal cost of production, see Chapter 2. However, the producers can gain higher profits if they sell for prices higher than marginal costs. We know from the bidding results and interviews with the participants that some used a profit-seeking strategy. They tried to drive the market price up by offering volumes of energy for a price higher than marginal cost. This comes of course at a risk, which we explained in 4.2.3. To see if this behaviour paid off we will compare the financial results of the producers in the simulation with the results of the marginal cost model (MCM).

Table 22 - Producers sales comparison

Producer	Sales simulation	Sales MCM	Difference
Uniper	6448	9029	- 29%
Geothermal	3284	5100	- 36%
Biomass	4229	3985	+ 6%
AVR	2346	2173	+ 8%

Table 23 - Producers profit comparison

Producer	Profit simulation	Profit MCM	Difference
Uniper	€ 28976	€ 24923	+ 16%
Geothermal	€ 8948	€ 9268	- 3%
Biomass	€ 11095	€ 6330	+ 75%
AVR	€ 8175	€ 4472	+ 83%

The results show that Uniper and the geothermal plant sold less energy in the simulation, compared to the MCM. These producers both tried to drive up the market price with their offer blocks. This has resulted in less energy sold, but when we look at the profit difference it is clear that Uniper's strategy had a positive result. They managed to get 16% higher profit in the simulation, than what they would have earned if they used a marginal cost offering (MCO) strategy. The geothermal plant achieved a 3% lower profit. Even though the plant did not run some days during the simulation, the profits earned when it did were much higher compared to the MCM.

The biomass producer mostly used an MCO strategy with some bid blocks of a higher price. AVR always offered heat energy at marginal cost. Their results are much more positive. They both sold more energy because the other producers offered energy for a higher price and did not settle. There were many occasions where both the biomass plant and AVR were settled, even though they were higher in the merit order than Uniper and the geothermal plant. Basically, they were able to sell energy, that should have been sold by the other producers based on the marginal cost. Moreover, the price for which the heat energy was sold was higher in the simulation, than in the MCM. This had a large positive influence on their profit.

The results of the producers show that those who used a marginal cost offering strategy had a higher increase in profits than the producers who tried to drive up the market price. However, they were only better off because the other producers used a profit-seeking strategy. If all the producers used marginal cost offering, the results of the simulation would be the same as in the marginal cost model scenario. It is in the interest of everybody to have at least one producer who tries to drive up the market price, but it is in the interest of each individual to use an MCB strategy. This dilemma has clear elements of a volunteer's dilemma, that is studied in game theory. We will elaborate on this further in paragraph 6.3.

6.2.3 Survey and interview results

When the simulation was finished a survey was sent to the participants (growers only) with questions about their experience and opinion of the simulation and the concept of a short term market in general (the design proposal). A plenary session with the participants was held to share and discuss the results of the simulation and those of the survey. The survey was completed by 10 of the 14 growers. The meeting was attended by 11 participants. Additional semi-constructed interviews were held with a few participants to learn more about their strategy. The goal of the survey, plenary session and the interviews were to gather more information to describe the behaviour of participants. Until that point, only the bid and offer blocks were analysed. This gave an indication of how participants behaved during the simulation. Talking to the participants gave more supportive information on the indicated behaviour. It also provided the participants with an opportunity to comment on the research and give feedback on the concept of a short term market in a DHS. They gave additional information and discussion points for the implementation of a short term market that were valuable to this research. The results are summarized and discussed in this paragraph.

Survey

The overall experience of almost all participating growers was positive (70%). There was a large variation in knowledge among participating growers. There were growers who are not involved in energy trading (6 participants without a CHP) and growers who are involved on a daily basis (every participant with a CHP). There were also a number of participants who had previously done a smaller but similar simulation (4 of the 6 participants without a CHP and 3 of the 8 with a CHP). Everyone but one had a reasonable or good feeling about their results in the simulation.

The growers received information before and during the simulation to determine their bids. The information and explanation was generally thought of as sufficient. A few indicated that they needed more explanation about how the Excel sheet works. The daily mail was also assessed as sufficiently informative. However, there was a need for more weather forecasts, so that a strategy could be formed in the longer term. It was not clear to everyone that the temperature followed the pattern from winter to summer. The only information that has hardly been used, for growers without CHP, is the APX price. Although this has a major impact on the marginal cost price of different producers, the non-CHP growers did not take this information into account. This makes sense because it does not directly affect their costs.

On average, participants were involved with the simulation activities for between 5 and 10 minutes a day.

When bidding, many growers have used bidding steps. The motivation for this was mostly the spread of risk and purchasing more heat energy when prices were low. Because the growers had access to a buffer, there was a risk that part of the heat demand would not be settled. In addition, some tried to fill the buffer with cheap heat and therefore sometimes demanded more than they needed. The price that is offered per bid block varies per participant. Some have bid just below their marginal cost, but some bid higher. High bidding provides more certainty that you will be purchasing energy, but it was apparently not clear that the usefulness of this strategy is limited to the boiler gas reference price. Bidding higher than the reference price could potentially cause a settlement where the energy from the market is more expensive than producing it yourself. However, this only done in the first six days. The moment that the market price fell quickly, non-CHP growers bid far below their reference price. At this moment the CHP growers started bidding competitively around their reference price (their CHP) and partly below. Many have indicated that they have tried to make a forecast of the market price and use this to decide upon the height of the asking price. However, most growers indicated that their bids were not intended to influence the market price.

The general reactions about a possible future implementation of a day-ahead heat market were positive. Almost everyone indicated that the price is the most important factor for success. Other benefits/opportunities of a short term market that were indicated by the participants were:

- Price advantage, participants expect to be able to achieve a better heat price with market competition forces.
- Optimization of the chain and use of assets. Through arbitrage on gas and electricity market, opportunities are created for those who invest or give time/attention to energy.
- Increase in energy sources. An "open" playing field in a heat network will be able to attract potential heat producers.
- Ability to produce with CHP and sell on the day-ahead heat market.
- A better appreciation of installation flexibility / better use of buffers in the area / possibly an interesting business case for extra buffer capacity.
- More operational security in the event of a boiler or CHP failure.
- A mix of heat sources that can be used flexibly to form the best market price. In addition, sustainable heat is important for the future
- Lower energy costs.

The expected disadvantages/threats mentioned by the participants:

- Price instability, to be able to assess an investment proposal in, for example, buffers, a realistic price expectation is required.
- More work, trading on the short term market will have to be facilitated or even automated so that the task of bidding does not require too much attention.
- Monopoly at sources, too few heat producers on the network places market power with a single party.
- Price increase, due to the risk of missed bids.
- Preconditions are still unclear. How do you deal with deviating heat usage compared to bids? Imbalance market for heat energy? Fines?
- You must still be able to run completely independently on your own. This provides little certainty with regard to the sale or supply of heat.

We will reflect upon these points in the next paragraph. The producers did not take part in the survey, so their feedback was gathered through semi-structured interviews. Only Uniper and the geothermal energy plant were questioned because the people who did the bidding for the biomass plant and AVR were not real stakeholders. The latter two did comment on how the researcher described their behaviour for validation purposes. A summary of each interview is given.

Uniper

The reaction of Uniper about the simulation was positive. They learned a lot about how they can operate in a day-ahead heat energy market, but also identified hurdles that had to be overcome before it could be implemented. For Uniper, there is a lot of value in the flexibility of production that the market provides. Long term contracts cause inefficient operations when the electricity market is unfavourable. If a part of the production capacity can be allocated to the market that allows more efficient daily planning, Uniper would be willing to operate on this market. The flexibility is bounded by the freedom of programming and transport capacity. A CHP producer needs to be free to determine the production schedule throughout the day in order to in- or decrease production according to the conditions on the electricity market. Also, there should be enough transport capacity for moments of peak production. A buffer could technically also help, but the amount of energy that has to be stored in these periods is very high. A high buffer capacity would be required, but this is very costly and economically inefficient. Currently, there is a good amount of production capacity, but this could change in the future if more producers require the use of the network.
Currently, Uniper is the system operator of the DHS and they identified other technical problems that need to be solved. One of these problems is the influence of lag when operating the system. Unlike the electricity network, where transportation happens with the speed of light, DHS have a fundamental operational lag due to the relatively slow flow of water in the network (max 2.2 m/s). Transportation of hot water from producers to consumers takes several minutes up to an hour. In the gas network this problem does not occur, because the network itself is a huge buffer. During the night the network is filled with a lot of gas so that each consumer

has access to gas during peak hours. System control lag is a special characteristic of DHS. It cannot be solved by increasing the flow speed, as this would decrease the efficiency of heat exchangers. In a day-ahead market, programming the day ahead production and consumption can help to cope with lag. Deviations in the program in the electricity system are dealt with in the intra-day market. Such a market is likely to be needed alongside a day-ahead heat market, but from a technical point of view, that market would be very difficult to operate. Dealing with this is outside the scope of this research. System buffer capacity is also needed besides programming. Currently, there is a lot of buffer capacity installed at the individual growers. However, it is unclear if they are willing to allow the system operator to control their buffer levels when operating the system. Lastly, there are several issues with the monitoring of the system. There is a quarrel between Uniper and Eneco about the monitoring of energy usage and production. Both have their own measuring data and they often do not match. This problem could be solved if there were grid codes and measuring guidelines implemented in the system, like how it is done in the electricity sector.
In 2019 the foundation Warmtenetwerk introduced codes and guidelines for measurement, developed by multiple stakeholders in the DHS sector (Warmtenetwerk, 2019). These stakeholders were, for the most part, the dominant large energy companies. Unlike the codes and guidelines in the gas and electricity sector, which are set in legislation, the ones for heat networks are honoured voluntary by companies. Therefore companies can still implement their own guidelines for measuring heat energy. This would still cause problems, so the desire of Uniper is to make measurement codes and guidelines binding by law. An independent controlling/enforcing agency would be needed to enforce these laws. For electricity and gas, this is done by the Authoriteit Consument en Markt, so it would make sense if they would become the supervisor.

Geothermal plant

The feedback from the geothermal plant was also positive. He believes than in the future when more producers want to connect to the network, trade should be facilitated by an open heat market. This would require unbundling of production and distribution, where an independent distributor is regulated and checked by a governmental supervising agency. However, there are some technical issues that were not implemented in the simulation, but who make geothermal energy technology unsuited for a day-ahead market. Firstly, the temperature on which a geothermal plant operates is lower than what is used in the system (75-80 degrees Celsius compared to 100 degrees). Therefore they cannot be connected to the main DHS. Currently, geothermal plants have their own parallel network, where all operations are based on a temperature of 75-80 degrees Celsius.
Secondly, if the operating temperature would match that of the system, the inflexible production of a geothermal plant imposes conflicts that can arise in a day-ahead market. A geothermal well can hardly be scaled up or down, as it is technically and economically best to supply heat energy at a steady rate. Daily fluctuations on a day-ahead market in production as a result of different settlements are therefore not suited for geothermal energy production. Unless the geothermal plant is offering at any price and is always able to sell his full production capacity, the plants runs the risk of not settling on a deal and get stuck with a lot of energy. This could be stored in a buffer, but it would have to be very big and costly. The plant owner, therefore, suggests that he would only be willing to sell about 10 to 30% of his production capacity on a day-ahead market and the rest on the bilateral market. He could install a buffer that would be capable of storing unsold energy for the next day. Only the eventual market conditions would tell if this is economically feasible.
In the simulation, it occurred several times that the producer missed a settlement, which would have dear economic consequences if it would have happened in real life. However, this was caused by the producer himself, because of his high price points (compared to his marginal costs) and shortcomings of the simulation compared to real life. In the simulation there was no incentive to make sure all the energy would be sold. The producer indicated that his bidding behaviour would be different in a real day-ahead market by playing it more safe to ensure the daily production capacity is sold.

6.3 Synthesis

6.3.1 Behaviour

In general, we can conclude that the bidding behaviour of growers is very similar. The larger part of the demand is bid at a high price level, close to the cost of the alternative. A small part of the demand is strategically used to lower the market price by bidding lower. Horticulture companies can do this because their buffer volume allows them to fulfil their total demand when not everything is bought at the market. In general, this results in a demand function that is for the most part highly elastic, see Appendix B. The tail of the demand function is very inelastic. This means that prices could very much fluctuate depending on much energy producers are offering at a specific price.

For producers, it would be the most profitable if the settlement takes place at the end of the elastic/beginning of the inelastic part of the demand function. Here the settled price is relatively high and a lot of volume is sold. The producer behaviour results show they tried to achieve this by strategically offering some of their production capacity for higher prices, even though the marginal cost does not change based on the production volume. This profit-seeking behaviour is the reason why during the first 6 days the price was much higher than the marginal cost level of the most expensive producer.

The elastic demand function lowered and shortened over the course of the simulation. This left less and less room for the profit-seeking behaviour of producers, until the point where they had to start offering at marginal cost levels in order to get settled. The lowering can be explained by the fact that almost all growers based their cost levels on a market prediction for the next day. When the price is trending downward, they would bid a lower price the next day and do not consider their alternative costs as a price point. Also, producers tended to lower their highest offers. This is supported by their bidding results. Since growers had no contact with each other this cannot be attributed to price agreements among growers. The shortening of the elastic demand function is the result of the decline in demand. In the setup of the simulation, it was chosen to let demand decline each day, because we went from winter to summer conditions. Therefore we cannot conclude if the elastic demand function would go up or become longer again when conditions change the other way. This must be tested in future research.

Concludingly, the growers collectively managed to put pressure on the producers to lower their offer price over the course of the simulation. When demand is high, producers are more able to increase their profits by strategically offering some of the capacity at higher prices. When demand decreases the room for this profit-seeking behaviour because less as it will yield a higher risk of not being settled. When market prices are low, the growers start neglecting their alternative costs as a bid price level. This results in a market where prices are reflected by trends and strategic behaviour, rather than alternative or marginal costs. In order to evaluate if this market outcome is desirable, we have developed performance indicators in paragraph 3.3. The first PI is discussed in paragraph 4.3. In the next paragraph, we interpret the results of the simulation to evaluate the rest of the PIs.

6.3.2 Market performance

Our second PI is that the market price should stay below the cost of producing heat with a boiler. Figure 19 clearly shows that this is the case. Throughout the simulation, the market price stayed under the boiler cost level. In the winter the market price was closer to the boiler cost level. Looking at the bids and offers of the participants, it can be seen that some of them were close to the boiler cost level. However, only a part of the demand and production capacity was offered at this level. There were also bids from growers that aimed to buy heat energy cheaper. Producers also offered some of their capacity for a low price to guarantee sales. Eventually, the market price dropped when the demand decreased. Both the growers and producers started to bid/offer well below the boiler cost level.

The third PI is that the market price should approach marginal cost levels of the producers as a result of competition. This can be seen by looking at Figure 20. From day 7 the market price is down to marginal cost levels. Therefore we can state that when there is less demand (wide market conditions), competition on the

production side increases and producers will offer their energy close to their marginal cost. However, during the first week, there were more tight market conditions that resulted in prices above marginal cost. This was predominantly caused by Uniper and the geothermal plant owner who offered heat energy at higher prices, and a lot of growers who were willing to accept these prices. Also, it cannot be stated with certainty if competitive forces resulted in the declining in market price. Most participants indicated that they determined there price points for bids/offers based on market predictions for the next day. Because the market was in a downward trend from the beginning, this could have affected their choice to subsequently bid/offer lower prices. It is clear that from the producer side this decline stopped when the market price approached the level of marginal cost.
Concludingly, based on the results of the simulation it is shown that during the winter it is not likely that there is enough competition among producers to force the market price down to marginal cost levels, but the price is still lower than the cost of self-production. This changes during the spring when the market price drops due to changing market conditions when approaching the summer. The lower demand increases the competition among producers, that result in market prices close to marginal cost levels.

The fourth criteria has been briefly discussed in paragraph 6.1.3. Figure 21 shows the differences between the total heat demand, demand and supply in the market and how much heat energy is traded. The most important thing to consider is the difference between the market demand volume and the traded volume. In total, the amount of traded volume was 76% of the total market demand. This means that 24% of the energy demand had to come from somewhere else than the market (boiler, CHP or buffer). This is a high result, considering the main factor of missing settlements were relative high offers from producers and low bids from growers. Some participants requested energy for an unreasonably low price or high price in an attempt to purchase cheap or sell expensive energy, even though they knew it was very unlikely the offer would be settled. When we compare the traded volume with the supply volume, the difference is more striking. During the first days, the difference is small, but it increases in the subsequent days. That can be explained by the decline in demand, while the total production capacity remained the same. The producers generally always offered their total production capacity. The reason the graph varies from day to day is the result of the CHPs of growers who illuminate their crop. At the beginning of the simulation, they used their capacity for themselves and as the temperature increased they were able to sell more energy to the market.
Concludingly the results of the simulation indicate that sufficient energy was traded. The larger part of the supply and demand was settled throughout the simulation. It must be noted that in the simulation only included the short term market for energy trade, not the bilateral market. Our market design includes both and the amount of energy traded is depended on the conditions in both markets. Also, the conditions in the gas market and electricity will influence the valuation of heat from the DHS, as it determines the cost of self-production of heat energy using a boiler or CHP. The cost of heat energy on each market will mainly determine on which market consumers will buy it.

The last criteria concern the stakeholder satisfaction about the short term market. The survey and interviews indicate a general positive attitude among producers and consumers. The main selling points were the extra flexibility to trade energy, optimize production assets in the short term and a more fair way to price heat energy. However, there were also concerns and unknowns about what would be the market price in the real world, the price influence of producers with market power and security of supply.

The findings of this research cannot conclude what the market price will be in the DHS of the B3-Hoek, because the prices and costs that were used in the simulation do not reflect reality. Also, the security of supply can be answered by a more technical analysis of the DHS, which was out of the scope of this research. However, based on the findings of the behaviour of growers/producers and the market performance, answers can be given to whom has market power in the system. The conclusion of this research is that both horticulture companies and producers have market power depending on the market conditions. In the tight market conditions, producers are able to drive up market prices, but only until a limited that is set by the horticulture companies where market price equals the cost of the alternative. When total supply exceeds demand, in more wide market conditions, the horticulture companies gain market power over the producers. This conclusion can be deduced by the optimal strategic behaviour of producers and growers that can be identified in both conditions.

6.3.3 Reciprocity between behaviour and market performance

In tight market conditions when all producers must operate to supply the market demand, there is a dominant strategy for producers to offer higher prices than MC to the point of the alternative cost price point. There is a limited risk of losing market share, because all producers are technically needed to supply the demand. For the individual producer, the risk of missing a settlement gives him the incentive to offer prices slightly below his competitors. Moreover, it is actually in his favour to let another producer offer very high to cause the market to settle at a high price. The benefits are uniformly distributed among the other producers (in a uniform auction), so they all benefit from one producer who strategically offers at high prices. To increase the chance of profiting from the other producer's behaviour, he would have a dominant strategy to offer closer to marginal costs. There must be at least one high offering producer, otherwise, everyone would offer low and the market price would also settle low, resulting in fewer profits for all the producers. Therefore they must somehow agree who will be the high offering producer, who will also have the risk of losing market share. This dilemma is called the "Volunteer's dilemma" in game theory research. Lucas & Taylor (1993) and von der Fehr & Harbord (1993) give proof and further explanation of this mechanism in oligopolistic and duopoly competition respectively. The simulation has given empirical evidence that the marginal cost offering producers (AVR and Bio) performed better than the profit-seeking producers (Uniper and Geo). The volunteer's dilemma explains why this is the case (for a summary see von der Fehr & Harbord (1998) p. 29 t/m p. 36). In a reality, the only profit-seeking producer will probably be the producer with the highest possible market share, because he has more room to differentiate the amount of heat energy he is offering for a specific price.
For individual growers, there is a dominant strategy to bid close to the alternative price point, because there is a risk of not settling when lower prices are bid. However, if growers would collectively agree to bid lower the total (highly elastic) demand will have a lower price point. The producers would have no choice but to follow this trend, as long as marginal costs allow it, for fear of losing market share. This strategy yields a positive result for all growers, but the chances of achieving this at the individual level is increased when grower offers a bit more than his competitors. This incentive undermines collective agreement to bid low.

When the market conditions are tight, the dominant strategy for producers is to undercut their competitors and strategically use prices and production quantities to maintain market share and receive a price higher than marginal cost (Cournot competitive behaviour), thus making a profit. The result is that producers start offering closer to MC price levels, the more market conditions become wider.
For the growers, the dominant strategy is to also lower their bids to pressure the market price trend downward even more. The risk of not settling, when lower prices are bid, is reduced by the competitive pressure among producers who offer their capacity for a lower price as well. In these conditions the best strategy of growers would also be to collaborate, but here too the individual has the incentive to deviate.

The results of the described strategies in different market conditions are clearly visible in the market price development of the simulation. It can be concluded that the horticulture companies can use market power by collaborating on the price levels of bids and the producers have a volunteer's dilemma who should use market power to drive up the market price. The strategic offers of Uniper and the geothermal plant were most of the times the cause for high market prices. However, this behaviour only resulted in a positive outcome for Uniper, not for the geothermal producer.
In the simulation, collaboration was impossible because participants did not have contact during the simulation. The growers still managed implicitly to collectively lower their bids, when their demand decreased. These findings show that implicit collaboration can also occur when there are no explicit agreements made among horticulture companies. This last conclusion must be interpreted with care because just the one simulation used in this research does give proof this will happen.

The results of the short term market will not be those of a perfectly competitive market, meaning that the market price will always be at the marginal cost level of the price-setting producer. This is because producers will behave in a Cournot competitive way and strategically use prices and quantities to make more profits under tight market conditions. When supply exceeds the demand in wide market conditions, the market price will be at the marginal cost level of the producers. Nevertheless, the market outcomes in both periods are considered desirable for both horticulture companies and producers. Horticulture companies benefit from lower costs of heat in a short term market compared to their alternative costs and producers are able to make profits. It must be noted that the former assumption is only true when the marginal costs of different heat energy producers are actually lower than the cost of self-production. Otherwise, there will probably no settlement in a market, because horticulture companies are better off financially by producing heat energy themselves.

In conclusion, we described in this chapter the behaviour of horticulture companies and producers and how it affects market performance. Hereby we have answered the second research sub-question. The simulation has shown that market outcomes of the short term market are desirable because it scores well on the performance indicators that we have specified. However, the simulation has its limitations and it needs to be addressed how the results can, therefore, differ from reality before we draw our final conclusions. The next chapter discusses the limitations of this research and their implications for both the first and the second part of this research.

7

Discussion

In the previous chapter, the results of the experiment showed the bidding behaviour and the performance of the market and answered the second research sub-question. In this chapter we reflect on the goals of this research, discuss its limitations and give recommendations for the implementation of the short term market.

7.1 Reflection upon the research goals

During this research, we focused on introducing a short term heat market for a DHS in the B3-Hoek. Stakeholders have the desire to change the bilateral market structure that is currently implemented. In paragraph 1.3 we specified clear objectives for this research. The first learning goal is to investigate how a short term market can be designed and the second learning goal is to find out how producers and horticulture companies behave on a short term market and how this affects the performance of the market. We proposed a design, where roles and responsibilities are reassigned in order for a short term heat market to function well. In a simulation, the performance of such a market was investigated. Looking back at the design proposal and results of the simulation we can evaluate if the research goals were achieved.

7.1.1 Design proposal

In order to investigate what market design facilitates short term trading for the DHS in the B3-Hoek, we first looked at what is described by economic theory. We have found that both NCE and NIE discuss the functioning of markets and how agents behave. NCE predominantly describes competition and choice made by agents, whereas NIE main focal point is that of the institutions and how they shape the market and behaviour of agents. It also formed the basis of the market design process. In this process, the work of Correljé & de Vries (2008) and Scholten & Künneke (2016) were used. It provides us with the design variables and a framework to align the system activities (technical) with the market activities (institutional). They were used to analyse the current market model and the technical characteristics of the DHS to identify the roles, responsibilities and coordination among actors. Afterwards, it was analysed what choices within the design variables should be considered for the addition of a short term market in the market design. The performance indicator for this consideration was that there should be non-discriminatory access conditions. The result is a conceptual market design that includes a short term market. The new roles, responsibilities and coordination of agents in the design proposal were discussed to identify the institutional and technical changes with the current market design were identified. This concludes the first research question, thus the first learning goal was achieved.

7.1.2 Behaviour and market performance

The simulation was developed to answer the question: *"What is the behaviour of actors in the market and how does this affect the performance of the market?"*. The learning points here were:

- Finding out how producers and consumers behave. How do they valuate heat energy? What choices do they make when bids/offers are formed and why?
- What are the results of the heat market in terms of price levels and traded heat energy?
- How were these results are affected by the behaviour?

The first point was achieved by collecting the data of bids and offers of all participant and the interviews with participants. Throughout the simulation, the bids and offers were collected of each participant from the trading platform. By comparing their chosen price levels to their marginal/alternative costs it could be checked whether their bids/offers were close or far from the marginal/alternative cost level. This way the behaviour of each participant could be classified as marginal cost offering or having an alternative strategy. The interviews further classified the behaviour by identifying the different strategies that participants used and why. It is concluded the simulation was successfully developed to achieve the first learning point.

The second point was achieved by collecting the data from the settlements of each day. The trading platform successfully collected the bids/offers that were made each day and cleared the market. After the market-clearing, settlement graphs were visible and trade data (price and volume) were sent to each participant as information to finalize their trading day and prepare them for the next one. Each trading day this data was collected to show the market price and traded volume development throughout the simulation. These results satisfied the second learning goal.

By combining the behaviour data with the market results, the effect of one on the other (and vice versa) could be analysed. A qualitative analysis showed that the price development in the simulation had an effect on the behaviour, because future/trend predictions were used by the participant to determine price points. This change of behaviour than had an effect on the price development. With the simulation and the analysis of the results we were able to identify the reciprocity, thus the third learning point was also achieved.

It is concluded that the simulation was successful in achieving the learning goal and give an answer to the second research question.

7.2 Limitations and interpretation of the results

Throughout this research different assumptions have been made and system elements have been taken outside the scope of the analyses. These limitations have an impact on how the results should be interpreted. In this paragraph this will be discussed for the market design process and the simulation.

7.2.1 Short term market design

Technical constraints

The design proposal identified the new roles and responsibilities for a new market model that includes a short term market in the DHS of the B3-Hoek. The design choices were made from an institutional perspective, but there are also some technical constraints that need to be discussed.

First of all, we suggest that Gasunie & Eneco should take ownership of the transport network. Although this is desired from an institutional aspect (non-discriminatory access conditions), we have not touched upon the technical implications of this measure. Currently, the transport network is technically integrated in the heat production process of Uniper. Changing ownership of the transport network implies that large technical changes have to be made to the DHS. A heat exchanger must be installed at Uniper and the new owner must invest in equipment to manage the flows and change the network topology. Right now it is a tree topology, but this must change to ring topology to connect new producers and allow them to supply energy to the network. This is because, in the roots of the network topology, pipe pressures are too high at the roots to allow other producers to feed into the system. Also, producers would not be able to supply to the whole network if they are connected at the branches. In a ring network, these problems are solved. We have not done a cost-benefit analysis to calculate whether these investments outweigh the social benefits. Nevertheless, we still recommend a change in ownership to better guarantee non-discriminatory access conditions and fairer competition among producers if a short term market were to be implemented.

Uniper, Gasunie and Eneco were both not contacted to comment on the design proposal, so there is no telling if there is a willingness to change ownership. In our defence, it would be very unlikely that they would comment on the our proposal because both Uniper and Eneco are figuring out on their own what to do by 2024 when the contract comes to an end. They will probably not add any relevant information to this research, as it could weaken their negotiation position. Gasunie would also not be able to provide relevant comments to this research, because it very recently acquired the project to develop a heat transport network from Rotterdam to the Hague. They are still in an exploratory phase to determine how they should perform the role as transport network developer/owner. The DHS in the B3-Hoek is a very different case with different technical

characteristics and consumer type, thus ownership in this network is still to be explored as well. Our recommendations will be the first step for their involvement in the B3-Hoek as well.
Besides the technical and economical reason, that also form a potential hurdle for a change in ownership, the fact that Uniper as owner can decide what happens to the network is very relevant for the implementation of a short term market. What if Uniper does not give up ownership of the transport network? Is short term trading in such a case possible? We argue it is not, because it will form a barrier for entree to the market and fair competition. Uniper will have an influence on who can use the network and will very likely prefer to give their production assets priority. This could be countered if contracts are put in place that limits this influence, but their dominant negotiation position should make it hard to pull off such contract structures. Another option is to turn to the Ministry of Economic Affairs for regulatory instruments to demand that Uniper should cooperate with setting non-discriminatory access conditions. We will not go in further detail of such a process, but merely address it as a counter-measure when Uniper blocks change in the DHS.
Also, it is possible that neither Gasunie or Eneco is willing to participate in a hybrid ownership. In that case, Gasunie would be the preferred owner, because their independence and public nature can better ensure non-discriminatory access when having a monopoly position. The hybrid partnership can also be considered as a short term solution, whereas in the long run, Gasunie might take ownership of all DHS transport networks within the province of Zuid-Holland. These plans are currently still in consideration, thus it is unknown what position the Dutch government will take for their involvement in DHS.

Secondly, a technical constraint we must discuss is the fact that most geothermal power plants are technically not capable to arbitrate in a short term market. One of the reasons is that supply temperatures are much lower than the temperatures used in the network. Another reason is that production output is not flexible. Although the market design cannot fix these problems, attention should be paid to this problem when short term markets are introduced. Such plants operate at a constant production output and are not able to scale up/down production fast. These technical limitations result in the desire to vertically integrate DHS that use geothermal heat energy, which is currently the case. This would, however, defeat the purpose of a free market with fair competition. Therefore another option is for them to contract mostly long term supply, but this is only possible if the temperatures in the network can be changed to the operational level of the geothermal plant or vice versa. Besides the problem of the temperature difference, there will be implications for geothermal energy if they want to arbitrate in the short term market. They always have to settle the capacity they offer. Therefore they either have to be the cheapest producer in the market or special arrangements will have to be made to ensure these power plants are always operational. Although geothermal energy is subsidized, it is still not one of the cheaper heat energy production methods because of the high capital expenditures. If gas prices don't increase or more subsidies are allocated to geothermal energy, the only option for including this production method in a short term market is by making special arrangements. Additional research will be needed to find out what these arrangements have to be.

Lastly, the CO_2 requirement for horticulture companies must be discussed. CO_2 is used to stimulate the growth of plants. Horticulture companies who are connected in present DHS get this from the OCAP network, which transports CO_2 emissions from industries in Rotterdam to horticulture areas. Horticulture companies who are not connected to a DHS use the CO_2 emissions from their CHP and boiler to provide additional CO_2 to their crops. When a heat market and the DHS develops, the CO_2 network must also be developed. The use of heat from the DHS must also be evaluated with the inclusion of the CO_2 price. In this simulation, we have neglected this, whereas in reality the value of heat is also determined by the costs of CO_2. Therefore a heat market cannot function if horticulture companies do not have access to alternative CO_2 sources.

Relation to other energy markets

Besides the technical barriers for the introduction of a short term market, attention should be paid to its relation with the other energy markets. Thus far this has not been discussed in-depth.

In our market design, horticulture companies can either buy energy through long term contracts, the short term market or produce it themselves. However, some stakeholders have argued for the need of an intraday market, when a short term market is introduced. Similar to the electricity market, an intraday market for heat energy would facilitate a trading platform for heat energy throughout the day. On an intraday market, additional heat energy can be bought/sold when bids/offers were not settled on the short term market or trade heat energy that is needed when scheduled production or demand changes on the day itself. We acknowledge that the introduction of an intraday market would improve the liquidity of a heat market and it could be used as a balancing mechanism. However, since horticulture companies have production assets themselves and if sufficient buffer capacity is installed, energy deficits and surpluses can be dealt with. Also, unlike electricity, heat energy transport is characterized by longer round trip time and system delay. The time between the transaction and the delivery of energy is much higher in DHS, thus this begs the question if the system is technically capable to handle transactions from an intraday market physically. This could be an interesting topic for future research.

We assumed that for balancing purposes horticulture companies will all have buffers in the future, but what if they are unwilling to invest in buffers? Can regulating capacity match supply and demand throughout the day? This is not addressed in this research, thus needs to be explored by an analysis on production patterns and consumption patterns and the ability of assets to match them. Here too a cost-benefit analysis should give more insight in the most cost-effective way to match supply and demand.

Another thing mentioned by stakeholders is how one must deal with the interaction between the heat market, the electricity market and gas market. Many production assets produce both electricity and heat using natural gas. For most of them, electricity is the main trading product, whereas heat energy is side product. When a heat market is introduced it is very important to determine what energy product is the main determinant. Both the electricity and heat market have a program responsibility, meaning that after the settlement a producer must deliver this settled production volume or face additional costs for deviating from the program. In case a producer settles on the electricity market, the amount of heat production is also largely determined. Some producers have assets that allow for a small variable amount of heat production, based on the amount of electricity that is being produced. However, it is important which market is settled first, because it determines the cost and amount of energy that must be sold on the other market. If both markets have high liquidity this would not be a problem, because energy can then be traded easily. Nevertheless, we consider the heat market having a low liquidity, lower than the electricity market at least. Therefore it is thought its best that the short term heat market settles after the day-ahead APX market. Afterwards, it is clear how much heat energy can be sold to the heat market. If it does not get sold on the heat market, one can try to alter his electricity production by trading on the intraday electricity market or one must store the heat energy or let it go to waste. An example of this process can be found in the Copenhagen DHS, although there is done the other way around (Varmelast.dk, 2018). The heat market (single-buyer wholesale market) settles first in order to give producers the right amount and valuation of electricity that can be sold to the electricity market. It is working so why not use a similar approach? That is because, in that market, the supplier has a delivery obligation to the consumers. Therefore the heat production program must be determined first in order to guarantee the supply of the total demand for heat. In our market design, there is no such obligation, because horticulture companies are themselves responsible for buying heat energy. Similarly, the producer himself is also responsible for selling his energy. From his perspective it is best to let the energy market with the highest liquidity be the determinant of production, thus the electricity market. In this market, the risks of trading energy are much lower. Therefore it is suggested to clear a short term heat market after the electricity market clearing. We have not analysed nor explained in detail how this process should be organized. The could be interesting for another research topic.

Lastly, the relation between the short term market and the current bilateral market must be discussed. Throughout this research, we have assumed that AgroEnergy could still provide long term contracts with producers and consumers. Via the contracts, AgroEnergy allows producers and horticulture companies to take a position for supply long term, see paragraph 3.2. If a short term market were to be implemented and the roles and responsibilities of actors in the system change, these contracts have to be changed as well. It is still possible to have a contractual market in place where AgroEnergy acts as a single-buyer, but this requires new contracts between producers and consumers. In the past Uniper could guarantee the supply of heat energy as system operator and large producer, thus it was easier for AgroEnergy to develop long term contracts with low risks. In the new market model there would be more risks when the responsibilities and control Uniper had are unbundled. Uniper will have no control over the programming and will have to take the dispatch of the short term market into account, when additional heat must be supplied for the contracts. It will be much more complex for AgroEnergy to secure long term supply in the new market model. Therefore it can be stated that the current bilateral market cannot stay the same. For a transition period contracts can be put in place, but we already mentioned that an Over-The-Counter bilateral market would be a suitable suggestion. How this market should be organised can be discussed in other research.

Transaction costs

The last point of discussion is the financial trade-off between present market model and the implementation of our market proposal. The question is whether the extra transaction costs and investments necessary to implement a short term market are outweighed by the financial benefits of such a market. If the new market model proves to be more expensive than in the present situation, stakeholders will not support its implementation. In this research, we have not done a cost-benefit analysis, where we compare the current system with our proposal. We have shown that the market outcomes in the simulation were better than the alternative cost scenario, however we have neglected multiple cost aspects that ought to be included in the consumer end-price. The goal of this thesis was to present a design proposal and show that a short term market scores well on the performance indicators. In this regard we have succeeded, but more research must be done to tell whether our proposal will result in a lower price for heat energy that horticulture companies have to pay. Adding to this point is the fact that the financial aspects of DHS are currently measured against the use of natural gas. For smaller consumers, this is institutionalized by law, but this does not apply to our case. Still, heat prices in contracts include a gas cost component, either because it is part of the production cost or because alternative fuel sources are subsidized based on their cost-comparison to natural gas. On the one hand the goal of horticulture sector is to make a transition to more sustainable sources than natural gas, but on the other hand there is no willingness to compromise as long as natural gas is a cheaper source for heat energy. This conflict is still a big issue in the development of DHS. Fun fact: the TTF day-ahead gas price is currently at the lowest point in 10 years at the time this thesis is written, according to AgroEnergy.
The Dutch government working on plans to impose taxes on CO_2 emissions, besides the price that is already paid in the ETS. This will likely result in natural gas being more expensive in the future. Then again technologies for sustainable heat production are developing and will likely decrease the cost of heat from these sources. We can conclude that given the current market conditions and level of technology, a short term heat market will very likely not be implemented within the coming 5 years. Therefore plans for the implementation must consider a time horizon for at least 2025.

Concluding on the interpretation of the design proposal, it should be noted that the conceptual model in paragraph 4.2 is useful for stakeholders to depict the new way the DHS should be organized. A clear description has been given of the how the system is currently organized. This makes it more clear what changes have to be made for the implementation of the design proposal. The suggestions and recommendations for these change are those of the researcher. Others might disagree or desire a different distribution of roles and responsibilities. The conceptual model can then still be useful as a tool to fill in other design choices and strengthen the alignment between the system and the market activities.

7.2.2 Simulation results

Behaviour

The end-price horticulture companies had to pay in the simulation do not represent the real costs of using the DHS. Including the additional costs will likely cause consumers to bid lower in a market. These bids must compensate for the additional cost not included in the market price when they compare it to their alternative

costs. The grower will value the short term market based on the total average cost per GJ and compare it to the total cost average cost of producing himself. The transport fees, cost of energy loss, connection costs and fixed investment costs for natural gas were also not included in the boiler cost price (where only the fuel price was included), but they are far lower compared to the extra costs in the DHS, according to AgroEnergy. When determining his maximum bid price point a rational grower will include the extra cost and have a lower maximal willingness to pay for heat energy from the market.
For the producers, only their variable costs were included. They need to make a profit to pay for their fixed cost, such as past and future investments. In reality, the producer will thus have a higher valuation for its production capacity and thus offer heat energy for a higher price. By including these costs in the offer, the price point will have a minimum level of the long term marginal costs. In the simulation, we compared its results with the marginal cost model, which represents the short term marginal costs. We considered short term marginal pricing the fairest since it will result in the highest consumer surplus, see paragraph 3.3. However, we acknowledge it would make sense for producers to use long term marginal pricing by including costs for future investments. The DHS is growing, thus investments must be made in the future.
Although we did not include additional costs of the DHS, the results are still valid to describe the behaviour of growers and producers. In the experiment we clearly showed how much it would cost to choose for the self-production alternative to fulfil demand. They could, therefore, make a well-considered choice what price the asked on the market. Our goal was to identify the behaviour, not to investigate how much heat energy will cost in a short term market. As is described above, we succeeded in achieving this goal.

Two participants in the simulation were not actual producers. When we judge their behaviour as a producer, we can conclude that their behaviour corresponded to our expectations and rational economic behaviour. The biomass heat producer acted as a profit-seeking agent when market conditions allowed for higher price offers. As soon as market prices dropped he changed his strategy and used marginal cost offering. We consider this as valid behaviour.
The participant that played the role of AVR, showed very different behaviour than the other producers. Every day the strategy of marginal cost offering was used. This behaviour does correspond to what we theoretically identified as being the best strategy. Although others showed more profit-seeking behaviour, we still classify marginal cost offering as being valid behaviour.
Although the geothermal heat producer in the experiment was a real plant owner, his behaviour is seen as being invalid for a geothermal producer. This is determined by the fact that from a technical point of view a geothermal plant must operate, thus sell energy every day. The risk involved in the profit-seeking behaviour, that this producer showed, cannot be expected in reality unless the producer is certain energy can be traded in a different way. His behaviour is the result of the limitations of the experiment. We have not included the special characteristics of the geothermal plant in the experiment. There were no extra penalties for missing a settlement, which inspired the participant to be very much risk-taking. This participant confirmed his behaviour would be different in a real short term energy market. Looking at our market design, this actor will probably sell most of his energy through the long term bilateral market. As a result we should expect there to be less competition in the short term market than we assumed in the case. This will likely affect the behaviour of other producers to become more Cournot competitive. Otherwise, an intraday market could give the geothermal plant an additional option to sell his heat energy, but this was not included in the scope of this research.

Lastly, we must acknowledge that behaviour could be affected by the duration and demand development in the simulation. Only 14 days were simulated in which after each two days conditions changed relatively fast. The fast decline in temperature (thus heat energy demand) and buffer starting capacity resulted in smaller incentives to purchase heat energy. The growers with a CHP were the ones who used their buffer to take more risk by bidding low prices. If they would not settle, they used the capacity that was left in their buffer. Such behaviour is smart in the sense that it puts pressure on the market price, while the risk is being hedged by the buffer. Horticulture companies with only a boiler could benefit in a similar way by having a buffer. We did not foresee this kind of behaviour, thus the question is whether this affected behaviour and the market

outcomes. Some participants could at some point skip a trading day and only use their remaining buffer capacity. Buffer capacity did not decrease on subsequent days and could be used over a long period, while in reality, the storage time for heat is only a day or two. Normally a buffer is only used to balance production and consumption during the day and is not a strategic long term storage asset.
The unrealistic buffer benefits might, therefore, be causing a snowball effect, that resulted in the fast decline in price. If the simulation would have more fluctuation in demand, this effect could be excluded as a cause for the price decline. It was chosen to focus on the seasonal pattern instead, thus this would be a good recommendation for future simulations to use alternating weather conditions.

Market performance

Without (enough) competition, market power of a dominant producer could potentially undermine the market. To see if this would be the case we tested the market conditions of our case. The results of the simulation show that prices were significantly higher than the marginal cost of the producers during the first trading days. In chapter 2.1 we discussed the notion of Cournot competition, where the output level of production is strategically used to increase profit. This behaviour of producers was identified in the simulation. Not in a way by withholding capacity, but purposely offering a part of the capacity for higher prices. It could, therefore, be argued that there is not enough competition on the production side to implement a short term market. However, Cournot competition only took place in tight market conditions. When the total production capacity in the market is significantly larger than the demand and there are multiple producers, there is enough competition between them to achieve a marginal cost market price level. Market prices will, therefore, be higher in the winter. However, competition is not only found at the producer, but also the consumer side of the market. The fact that horticulture companies can produce their own heat energy imposes a limit on market power abuse. This limiting factor was confirmed by the market results since the market price was always lower than the alternative cost price. Horticulture companies were better off financially in the short term market compared to the scenario where the heat energy had to be produced with their boilers and CHPs.

Our results are based on the market conditions that are assumed to be there in the near future. The main difference with the present market conditions is that Uniper has a 70% market share (based on production capacity) compared to the 36% in our case. This will likely result in too much market power in the short term market. Settlement prices will then likely be much closer to the alternative cost price of the horticulture companies, throughout the entire year. This argument is based on the profit-seeking behaviour of Uniper shown in the simulation and it was found in the analysis of Bijvoet (2017). This could, however, be countered by the fact that there are also less consumers in the present DHS. Therefore the total demand is much lower and could be supplied by other producers if they can offer heat energy for a lower price than Uniper. If the other producers have enough capacity combined to supply the demand, it does not matter how large the market share is of Uniper. If Uniper offers prices higher than its competitors he will never settle. Therefore due to competitive forces, the performance of the short term market will be similar in either case. Again, AgroEnergy indicates that demand is much more than can be supplied by other producers, so horticulture companies in the present DHS are very depended on Uniper. If this does not change, we reckon a short term market will not function well. Therefore one of the constraints of the implementation of a short term market is that more producers must enter the market.

7.3 Implementation of a short term heat market

In this paragraph concrete recommendations are given for the implementation of a short term market in the DHS of the B3-Hoek.

Currently, the dominant position of Uniper in the DHS is a barrier to the implementation of a heat market. By 2024 the supply contracts between Uniper and Eneco come to an end. This is an opportunity to make the necessary changes in roles and ownership of system components. In our design proposal, Gasunie & Eneco should be the future owner of the transport network to improve access condition for other producers. Therefore its recommended to already start drawing up the acquisition process. Since AgroEnergy is mainly concerned with the DHS in the B3-Hoek, they should initiate this process. A business case should be developed first to check whether it is financially interesting for either Gasunie and Eneco to obtain ownership. In case this business case is positive, they can start talks with Uniper about the acquisition. In the event that the business case is negative for Eneco or they are not willing to obtain ownership, they must look for an alternative future owner. It is important that this new owner has a degree of independence in the system and no production activities, thus the government (Gasunie to be more precise) could be persuaded to take full ownership.

The short term market introduces the role of a market operator. In this research, we have not specified who should take this role, but stated it should be an independent/external company. AgroEnergy must (again) start looking for a company that is willing and capable of performing this role.

AgroEnergy could start with an experiment where horticulture companies are allowed to trade their heat energy positions with each other. This can be seen as a step between the present situation and one where a short term market is introduced to increase flexibility in heat energy trade. Growers that do not fully utilise their position, could sell it to those who need more. This lowers the risk of contracting long term positions. The advantage for the selling grower is that he lowers his cost for the Take-or-Pay contract by reselling the energy he does not need. If he offers it at a lower price than variable cost price alternative of AgroEnergy, the buyer of the position would also financially benefit. For AgroEnergy there is no risk in the transaction because the position will be paid for either way.

Furthermore, AgroEnergy should do a technical analysis of the changes that have to be made to support a short term market. Throughout this research we have stumbled on many technical constraints, be it on the production side, consumer side or in the network itself, that need further investigation. How can you cope with the characteristics of a geothermal power plant in the short term market? What changes have to be made to the network topology? What is the actual demand in the market and how does this compare to the production capacity? How much buffer capacity is needed in the system? How do technical characteristics of production assets influence the ability to match supply and demand? This technical analysis will also form the basis of the financial analysis about the costs that are involved for changing the system and its new operational structure. Are the transaction costs and investments worth it when changing the market structure?

Lastly, AgroEnergy should do a market consultation in the B3-Hoek to question more stakeholders about their opinion on the short term market implementation in the future. We have gathered some opinions of stakeholders, but the results of our interviews and survey are not significant for the whole B3-Hoek. This thesis can be used to explain the working of the short term heat market, and show that it can be a good alternative of energy trade compared to the current system. Stakeholder support is crucial for the expansion of the DHS and the implementation of a new heat market. More consumers and especially producers should be connected to the DHS to increase competition. This is an important requirement for the short term market to function well. The analysis of this thesis is built upon the premise that the development that is currently planned is finalized and the scenario welcomes the introduction of a short term market. If developments stall or the DHS remains the same as it is now, it is concluded that a short term market will not work because of dominant producers with market power and also cannot work from a technical point of view.

8

Conclusion

In the previous chapter we discussed the new market design, the performance of a short term heat market and the implementation steps that are required to change the current DHS in the B3-Hoek. In this chapter we conclude this research by answering the main research question by combining our findings on the sub-questions. Afterwards, recommendations for future research are presented.

8.1 Main conclusion of the research

Currently, there is a bilateral contract structure in the DHS in the B3-Hoek where the price for heat energy does not reflect the actual value of heat (due to risk hedges and link to the gas price) and there is no way for producers and consumers to trade energy in the short run. This has resulted in the desire to implement a short term heat energy market, where energy can be traded in the short-run (besides the bilateral market) and where the price of heat energy is determined by supply and demand, similar to the gas and electricity market. This has led to the following research question:

How can a short term market be designed for large consumers in the DHS of the B3-Hoek?

In this research, we have analysed the DHS in the B3-Hoek and looked at the institutional and technical changes that have to be made to introduce a market where producers and horticulture companies can trade heat energy in the short term. The first sub-question that was asked is: what market design for the DHS in the B3-Hoek can be used to facilitate short term energy trade? The answer to this question is presented by the following conceptual market design:

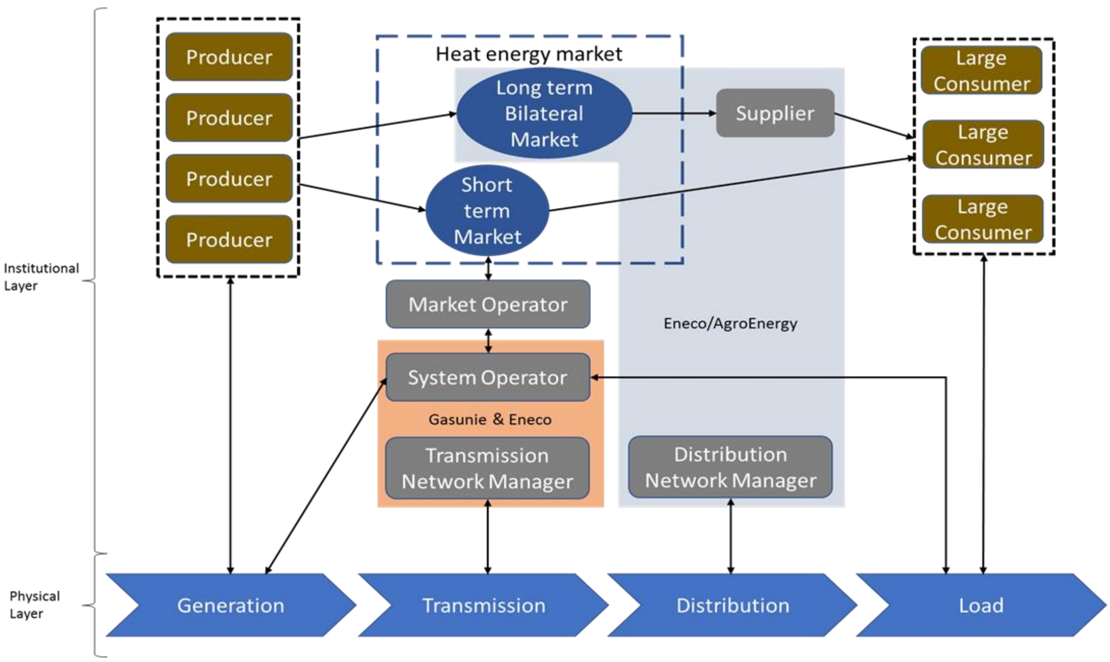


Figure 25 - Market design proposal for a short term market

By comparing the design proposal with the present market model it can be concluded that three changes have to be made in the system. First of all, Uniper is currently the main producer in the DHS and is the owner of the transport line in the network. In the short term market, other producers should be allowed to enter the market. This means that non-discriminatory access conditions are required in the new market model. Therefore it is necessary to unbundle the production and network activities of Uniper. A private-public hybrid company of Gasunie & Eneco is suggested as the new owner of the transport network. Combined they have the necessary experience and tools to manage this part of the network. Non-discriminatory access condition and tariffs can be determined by Gasunie if they have a majority in shares.
Secondly, the short term market also introduces a new way of determining the dispatch of producers. This introduces a new role in the DHS, market operator. The short term market requires a market operator who will determine the dispatch, based on a uniform double-sided auction. An independent party should take care of this role to guarantee a level playing field for competition between producers and horticulture companies.
Lastly, the role of system operator should be transferred to Gasunie & Eneco. However, due to the technical characteristics of the DHS they will have to contract Uniper in the short run to maintain balance in the system. In the long run, if horticulture companies invest in buffer capacity, demand-side management can be applied to balance supply and demand in the network throughout the day. Another option is to implement an Intraday market as well, but this was not investigated in this research.

The new market design introduces an additional way to trade energy in the DHS. However, the small amount of producers raises concerns that a short term market is prone to market failures. Dominant producers could use their market power by increasing the price of heat in the market. Horticulture companies also have their own production assets, so this could potentially limit the market power of producers. It is unknown how they will behave in a short term market because it has not been implemented in practice yet.
In order to find out if this would be the case in the DHS and how this would affect the performance of the market, an interactive simulation was developed. In this simulation horticulture companies and producers participated in a virtual short term heat market (day-ahead) with changing market conditions. The total demand during the simulation followed a trend from winter (where demand is high) to summer (where demand is lower). The simulation allowed us to gather data to answer the second sub-question: what is the behaviour of actors in the market and how does this affect the performance of the market?

Analysing the behaviour of the participants it was found that, when demand is high, producers are more able to increase their profits by strategically offering some of the capacity at higher prices. When demand decreases the room for this profit-seeking behaviour becomes less as it will yield a higher risk of not being settled. The behaviour of producers can be theoretically described as Cournot competition, where the output level of production is strategically used to increase profit. This behaviour of producers was identified in the simulation under tight market conditions. This means that in the DHS during the winter the heat prices do not reflect marginal costs of production.
The growers collectively managed to put pressure on the producers to lower their offer price when market conditions become wide. The demand curve of the horticulture companies is very elastic, because of their own heat production asset (boiler). In tight market conditions, the demand curve is close to the level of producing heat with a boiler. When demand decreases and market prices become lower, the growers start neglecting their alternative costs as a bid price level. They take an expected level of the market price as a new bid price level. The result of this collective behaviour is that the demand curve not only becomes shorter, because of less need for heat energy but also lowers. This puts pressure on the producers to offer at marginal cost levels. This means that in the DHS during the summer the heat prices do reflect marginal costs of production.

For the analysis of the performance of the short term market, five performance indicators have been used for evaluation. The results of the simulation show that a short term market can perform fairly well.

- Non-discriminatory access conditions to the system can be ensured by Gasunie
- The market prices will be lower than self-production

- When there are wide market conditions, competition on the production side increases and producers will offer their energy close to their marginal cost. However, in tight market conditions prices are above marginal costs closer to the cost of self-production. This does allow the producers to make profits.
- Sufficient energy will be traded in a short term market, as long as the production costs of producers is lower than the cost of using a boiler.
- Stakeholders were positive on their experience in the simulation and the concept of including a short term market in this system.

Through this research, we were able to identify the reciprocity between behaviour and market performance. When the market conditions are tight, the dominant strategy for producers is to undercut their competitors and strategically use prices and production quantities to maintain market share and receive a price higher than marginal cost (Cournot competitive behaviour), thus making a profit. The producers have a volunteer's dilemma who should use market power to drive up the market price so that all producers can benefit from this. However, this type of behaviour changes when market conditions become wider. In that case, producers start offering closer to MC price levels.
The best strategy of growers would be to collaborate, but the individual has the incentive to deviate from this collaboration. This research has shown that the behaviour and choices made by horticulture companies could lead to implicit collaboration because they use similar bidding strategies. This put additional pressure on producers and drives the market price downward.
The results of the short term market will not be those of a perfectly competitive market, meaning that the market price will always be at the marginal cost level of the price-setting producer. This is because producers will behave in a Cournot competitive way and strategically use prices and quantities to make more profits under tight market conditions. When supply exceeds the demand in wide market conditions, the market price will close the marginal cost level of the producers. Nevertheless, the market outcomes in both periods are considered desirable for both horticulture companies and producers. Horticulture companies benefit from lower costs of heat in a short term market compared to their alternative costs and producers are able to make profits.

Combining the answers of the research sub-question concludes the main research question. A market design proposal was developed and the changes that need to be made in the DHS to include a short term market were presented. We have identified how producers and consumers behave and shown that the performance of the market meets the criteria. Note that in this research it was assumed that more producers enter the market in the near future and all horticulture companies will have buffers. Neither is the case and it is expected that with the current market share of Uniper and the system properties of the DHS in the B3-Hoek, market prices will be dominated by Uniper. This research has not done a cost-benefit analysis to determine whether changing the system to facilitate a short term market is cost-efficient. Nevertheless, we showed how a short term market can be included in the system and that it can be a promising concept for short term trading.

Scientific contributions

This research has shown how the design framework of Scholten & Künneke (2016) can be applied in a practical manner to design energy systems. In our case, we investigated a DHS and how the market activities must be aligned with the system activities. Although the use of the framework was very straight forward in this research, we recommend to use it more as a frame of thought. We included and excluded some of the design variables within the framework for the choice of our scope. The content of framework how it was originally presented is not final in our opinion, thus it allows for the interpretation of the research to frame the elements of the system design and the market design. This research is an example of how this could be done.

In addition, this research has reaffirmed how the design variables of Correljé & de Vries (2008) can be used to design energy systems. These variables were extracted from an analysis of the electricity system, but their useful application to DHS is again confirmed in this thesis.

Empirical contributions

The empirical results of this research contribute to the knowledge of competition within DHS. Although these results are not extracted from an existing DHS, they do show how competition influences market prices. Lucas & Taylor (1993) and von der Fehr & Harbord (1993) discussed the behaviour of producers and deduced two asymmetric pure-strategy Nash equilibrium outcomes in a game we classified as "Volunteer's dilemma. They found that marginal cost offering is the best strategy as long as another producer uses a high offering (profit-seeking) strategy. The simulation has given empirical evidence that the marginal cost offering producers performed better than the profit-seeking producers.

This thesis is novel in the research towards competition in DHS as we introduced it on both the producer and the consumer side. Even though DHS for horticulture areas is only a small category in the broader research of DHS (that is mainly aimed at the small consumer market), we have given empirical evidence of the ability of production alternatives on the consumer side to limit the market power of producers. These findings are not new as Bijvoet (2017) found similar results. This thesis reconfirms these findings.

8.2 Research recommendations

Thus far, two research topics have looked into the outcome and the behaviour of producers/large consumers in a heat energy market. In this research there was not much attention towards future developments that affect the heat market. All the alternative heat production methods are competing with gas on the cost of heat energy. Much of these alternative methods are subsidized so become cost comparable. The cost of heat production per alternative will become a key factor in the use of DHS in the future. A future exploration study could be done to investigate how the gas prices and costs of alternative heat production methods change in the future. Will these alternative production methods be cheaper than using natural gas and when will this happen? The answer to these questions will inform heat network developers and policymakers on what can expect in the near future and give them the opportunity to take measures that make district heating cost competitive to gas.

The behavioural characteristics of the growers and producers found in this research can be used in a large scale computer simulation. The technical characteristics and constraints have often been neglected or simplified in the research of heating markets. The supply pattern of different heat production methods (CHP, geothermal, biomass, waste incineration and waste heat from industrial processes) and the demand patterns of horticulture companies throughout the year can be modelled to check whether there is enough capacity (production and transport) in the system and how much buffer capacity is needed for balancing purposes. Agent-based modelling could be used to develop such a model.

We have already mentioned that the liquidity of a heat market can be improved by adding an intraday market. This intraday market takes care of shortages caused by production failure or changes in demand for heat energy. This topic was taken outside the scope of this research but forms an interesting topic for others. The frequency of an intraday market settlement is linked to the technical capabilities of the DHS to alter production output or the flexibility to change energy flows in the network. The frequency by which an intraday settlement must take place can be discovered by analysing the production flexibility within the system and the operational time it takes to re-dispatch.

Lastly, it is recommended to do more research towards the market-clearing procedure by means of stakeholder consultation and process analysis. Most of the heat production assets also produce electricity. This means that the two products have to be sold in different markets. This interdependency is only briefly discussed in this research but is of great importance to the producer. The valuation of electricity and heat is co-dependent. If a short term heat market is introduced the producer has two unknowns: what will be the price for electricity and what will be the price for heat? How should producers proceed in his valuation for energy production? In this research, the time of market-clearing of the heat market was set to be after the clearing of the electricity market. However, there is no minute-by-minute procedure schedule that dictates what and when actions must be taken by producers and the market operator.

9

Reflection

In this chapter I reflect on the work I have done as a researcher and this thesis rapport. Firstly, the literature that was used in constructing this thesis is discussed. Afterwards, the methodical approach to answer the research question is reviewed. Lastly, I reflect on the results of the research and how they have let to insights and practical recommendations for stakeholders in the DHS in the B3-Hoek.

9.1 Literature

In this thesis, I sought literature on market design and competition in DHS. I quickly came to the conclusion that not much was written on this specific topic. Much of the research targets the small consumer market, where DHS has a more vertically integrated nature or investigate specific technical characteristics of producers and heat networks. I found that Denmark and Sweden are frontrunners in the liberalization of DHS and Third-Party-Access conditions for other producers. However, these systems are still not of similar scope as was used in this thesis. Lund et al. (2014) and Werner (2017) discuss the status of DHS in the world, the current level of the technology and the future developments of it. They conclude that in general, the DHS does not have the level of technology to allow a so-called "open heat network" where multiple producers can feed into the system and where heat energy is transport to a large number of consumers over long distances. This research also concludes that indeed the level of technology in the DHS is at this point not high enough to allow open access and market activities similar to the electricity system. However, I firmly believe that this will be the case in the future. Consequently, this research topic is somewhat uncharted territory.

After extensive literature research, the knowledge gap of this thesis remained. Therefore I chose to take a step back and decided to analyse the problem from an economical and institutional perspective. This is the reason why NCE was used to analyse market power and NIE was used to identify what new institutional arrangements were required to introduce a short term heat market. Other researchers from my faculty also investigated the institutional change in DHS as a thesis topic. Here I found the design variables that they used to analyse institutional change in DHS. However, they hardly touched upon the technical side of DHS and focused more on the institutional side. Like Künneke et al. (2010) and Koppenjan & Groenewegen (2005) stated in their work, the institutional characteristics have to be aligned with the technical characteristics of socio-complex systems, like a DHS. Therefore I felt the need to pay more attention to the technical side of DHS in this thesis. I needed a tool to structure this technical analysis with the institutional design variables. I found the design framework by Scholten & Künneke (2016) to be very useful in this aspect. However, to the best of my knowledge, this framework has not been applied in practice in a way similar to how I intended to use it. The authors themselves did mention their framework was up for the interpretation of other researchers in its use. By adapting the framework a bit, I found it to be a useful tool to structure my thoughts and present the results of my analyses in structural way.

It was later in the research after I had analysed and interpreted the results of the simulation, I found that there is a wealth of literature on oligopoly electricity markets and auctions that could have been useful as knowledge upfront for Chapter 2. The reason I did not find this sooner was that I focused too much on district heating in my search terms. When I derived my conclusions on behaviour and market performance, I started looking for literature that described similar phenomena's as the ones I found. The conclusions I made on dominant strategic behaviour were already described in the work of (Green & Newbery, 1992; von der Fehr & Harbord, 1998; von der Fehr & Harbord, 1993). This is a positive sign of my analytical capabilities, but it also meant I did not discover something new.

In conclusion, the literature that was chosen in this research is found to be a good enough fit for achieving the research goal. However, much of the literature consisted of thesis research because the scope of this thesis is very narrow and not well explored by others. It, therefore, lacked work of a higher academic level, which I could have found sooner if I consulted the body of knowledge on the early days of the electricity market when they had a more monopolistic/oligopolistic nature. In the last stage of writing this thesis, an effort was made to include this body of knowledge in the theoretical background and analyses on strategic behaviour and market performance.

9.2 Methodology

To answer the main research question, there were to methods used: a design approach and a simulation to test the design. The design approach, to develop the institutional design proposal for the introduction of a short term market, was to do a qualitative analysis on the pros and cons of alternatives that could be identified for each design variable. This method was also used by peers that made an institutional design for DHS. Although this method is found to be a good way to come up with a final design proposal, only brief argumentations were given to support the selection. Improvements could be made by giving empirical evidence (found in other DHS or similar systems such as the electricity and gas system) as an argument for the choice of each alternative and consult experts outside of AgroEnergy. The system experts of AgroEnergy provide much of the valuable information and data for describing the DHS and what should change. However, because one perspective and source of information was used, the results could be considered biased. I want to stress that the design choices were selected by considering what is best for all stakeholders and not only to match the agenda of AgroEnergy/Eneco. This would show up more in the work if I had consulted more stakeholders.

Testing the design proposal was found to be a necessary component in this research because there is a lack of empirical evidence that could also have been used to support the decisions in the market design. However, the link between the design proposal and the simulation can be considered weak to the extent that in the simulation only looked at short-term trading. It did not include a link with the bilateral market, testing the access conditions, guaranteed the availability of heat energy, procedural link with electricity, gas and CO_2 market, nor did it include some technical production and transportation constraints. The simulation was already developed by AgroEnergy in a broad sense. I made an effort to design elements of the simulation so it could be used for this research. The goals of the simulation were to find out how producers and horticulture companies value heat energy and to what extent market power at the production side is dominating the market. I believe this goal is achieved. To connect these results to the market design, I have argued that the design proposal only describes the necessary institutions on higher levels (rules and play of the game) and that the outcome of the market shows the effect of the design on the lowest level (firm decision making). In the validation and discussion, I already discussed the constraints and limitations of the research and how these affect the interpretation of the results.

9.3 Results

In hindsight development of a short term market design, and researching actor behaviour and market performance could have been separate topics for thesis research. Although my ambition was to do both topics within my thesis, the time constraint affected the level of detail of my work. I would have liked to develop a very detailed and concrete design proposal for a short term market, but have now only presented a conceptual design. Also, a large amount of preparational work for the simulation was done prior to the start of this thesis. It was also difficult sometimes to maintain focus and cohesion throughout writing this thesis. Nevertheless, the results of my work have in my opinion provided new insights and relevant recommendations for introducing a short term market within the DHS of the B3-Hoek. The identification of behavioural characteristics of producers and consumers can be used to anticipate the market outcomes of short term energy trade via a double-sided auction. Although the design proposal is conceptual I have given explicit steps Eneco/AgroEnergy should undertake to eventually implement a short term market.

Prior to this research, there were already expectations that defined a short term market and how it will perform. From a rational point of view a grower will never buy heat energy if he can produce it himself for a lower price. Therefore it was expected that the market price would never be higher than the cost of the alternative. But if the market price would always be the same at the cost level of the alternative, why would horticulture companies want to use a DHS with a short term market? It was expected that with the introduction of multiple producers in the DHS, prices would converge to marginal production cost levels as a result of competition. This hypothesis had no empirical evidence prior to this research. Surprisingly, the growers were able to pressure producers to lower their prices. There still is a degree of uncertainty whether this will be the case in reality, given the limitations of the experiment.

Reproducibility

An important aspect of scientific research is the reproducibility of the results. Judging the reproducibility of this research and its results we can conclude the following. The first part of this research, the design of the market model, was done by using a mixture of academic resources and information provided by AgroEnergy. The design variables and the design framework is available for researchers and can be used by others to identify and select design choices themselves. The information of the organization and system properties of the DHS in the B3-Hoek was gathered from AgroEnergy. This information is not publicly accessible. The fact that I worked as an intern allowed me to gather valuable inside information and easier access to data. Although these resources are not available to the public, it is believed that any researcher is able to access similar information if they cooperate with AgroEnergy and respect their interests. Moreover, much of the relevant information on the DHS is obtainable by meeting with the different stakeholders.

For all choices, that were made for the design proposal, arguments were given. Other researchers can contest the proposal and provide arguments as to what choices should have been done differently. This debate would only strengthen the decisions that must be made when a short term market will be implemented. It is concluded that the first part of the research has a sufficient degree of reproducibility. A similar approach can be taken by other research, although different arguments for the design choices might result in a different outcome.

The second part of this research, the simulation, is reproducible to the extent that a similar simulation can be designed and performed by others and/or the data gathered in this research can be reviewed by peers. For the construction of the simulation, many resources of AgroEnergy were used. Others will not have access to these resources, such as the trading portal and participant (clients of AgroEnergy) details. Nevertheless, a simulation can be developed, based on the description that was presented in Chapter 5. The same design (roles, rules, parameters) and the process can be used in a newly created simulation. Additional resources, such as a calculation tool for the participants and market clearing algorithm/trading platform will have to be developed if AgroEnergy does not provide access to the tools I used for this research. Also, the participants were clients of AgroEnergy which made it easier to let real stakeholders participate. For similar research this might be difficult to achieve. Non-stakeholder participants could participate in a different simulation, but this might result in different behavioural outcomes and market performance.

Nevertheless, the data that was generated in the simulation is available at the researcher. Settlement data, survey answers and interview notes were gathered throughout the research process. This can be used to do the same analyses and come to similar conclusions.

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Appendix A

Algemeen

Wat is je gebruiksnaam van de WarmteDagMarkt (WDM) pilot?
Tekstbox (small)

Heb je bezwaar als je naam zichtbaar is bij de resultaten tijdens de evaluatiesessie?
Ja / nee

Hoe is je ervaring met de WDM pilot?
Zeer negatief / negatief / neutraal / positief / zeer positief

Wat is je gevoel bij je behaalde resultaat aan het eind van de pilot?
Zeer onvoldoende / onvoldoende / redelijk / voldoende / ruim voldoende
-> bij Zeer onvoldoende / onvoldoende / redelijk
5. & 6. Follow-up: Wat had je beter kunnen doen? Is dit ook niet een relevante vraag voor mensen die voldoende en ruim voldoende aangeven?

Was de informatie en de uitleg sessie voldoende duidelijk om mee te doen aan de pilot?
Zeer onvoldoende / onvoldoende / redelijk / voldoende / ruim voldoende
8. -> bij Zeer onvoldoende / onvoldoende / redelijk Follow-up: Welke informatie had je nog meer van te voren willen ontvangen?

Was de informatie die je dagelijks per e-mail ontving voldoende duidelijk om je bieding te bepalen?
Zeer onvoldoende / onvoldoende / redelijk / voldoende / ruim voldoende
10. -> bij Zeer onvoldoende / onvoldoende / redelijk Follow-up: Welke informatie miste je in de dagelijkse e-mail?

Hoeveel tijd ben je per dag bezig geweest met de pilot?
0-5 min / 5 – 10 / 10 -15 / meer dan 15

Ben je elke dag ongeveer evenveel tijd bezig geweest met de pilot?
Ja / Nee
13. -> bij Nee FR: Wat is de reden dat je meer of minder tijd met de pilot bezig was?

Wat miste je in de pilot om dagelijkse warmtehandel nog waarheidsgetrouwer / realistischer te maken?
Tekst box

Ben je op de hoogte van kweker(s) die ook mee doen met de pilot?
Ja / Nee

Bied strategie

Vink aan wat voor jou van toepassing was tijdens de pilot;

16. Heb je tijdens de pilot een eigen WKK tot uw beschikking gehad?
Ja / Nee
-> andere antwoorden op de volgende vraag op basis van Ja of nee

Hoe heb je je dagelijkse warmtebehoefte ingeboden op de WDM?

Mijn volledige warmtebehoefte voor één prijs / Mijn volledige warmte behoefte heb ik opgedeeld in verschillende biedingen met ieder een andere prijs / Mijn volledige warmte behoefte minus de warmteproductie uit mijn WKK voor één prijs / Mijn volledige warmte behoefte minus de warmteproductie uit mijn WKK heb ik opgedeeld in verschillende biedingen met ieder een andere prijs
-> andere antwoorden op de volgende vraag op basis van één bieding of meerdere
19. ->Motiveer de reden dat je je warmtebehoefte hebt opgedeeld in verschillende biedingen op een handelsdag

20. Hoe heb je de vraagprijs bepaald bij het inbieden tijdens de pilot?

Hoger dan de referentie prijs van ketelgas / gelijk aan de referentie prijs van ketelgas / Lager dan de referentie prijs van ketelgas
->Motiveer de reden dat je hebt gekozen voor deze prijs.

21. Heb je gedurende de pilot dezelfde strategie gehanteerd of heb je deze in de loop van de pilot aangepast?
-> Motiveer waarom je dezelfde strategie hebt gehanteerd / waarom je je strategie hebt aangepast

22. Geef van de volgende informatie bronnen aan in hoeverre deze werd gebruikt bij het bepalen van je biedstrategie:

Temperatuur/warmtebehoefte van de dag 1-5
beschikbare volume van mijn buffer 1-5
productiecapaciteit van mijn WKK 1-5, nvt voor WKK = Nee
Het volume dat ik de vorige dagen heb ingekocht 1-5
De marktprijs van voorgaande dagen 1-5
Weersverwachting van de volgende dag 1-5
Hoogte van de Ketel gasprijs 1-5
Hoogte van de warmteprijs uit WKK 1-5, nvt voor WKK = Nee
Hoogte van de APX prijs 1-5
Ik heb geprobeerd de nieuwe marktprijs te voorspellen en op basis daarvan mijn strategie bepaald 1-5

31. Heb je je door iemand laten informeren/adviseren bij het vaststellen van je bieding strategie?
Ja / Nee -> 32. Zo Ja, door wie?

-33. >Op de hoogte van andere deelnemers; Heb je contact gehad met andere deelnemers van de pilot?
Ja / Nee

34. In welke mate heb je vertrouwen dat je biedstrategie de juiste was gedurende de pilot?
Zeer weinig vertrouwen / weinig vertrouwen / redelijk / vertrouwen / veel vertrouwen

35. Heb je nadelige effecten ondervonden als resultaat van je biedstrategie?
Geen nadelige effecten ondervonden / te weinig volume ingekocht / te veel betaald voor warmte energie uit de WDM

36. Heb je het idee dat je biedingen invloed hadden op de vorming van de marktprijs?
Ja / Nee

37. Heb je met je biedingen doelbewust geprobeerd om de marktprijs te beïnvloeden?
Ja / Nee

Zo ja, hoe?

Toekomst

39. Zou je de WDM willen gebruiken om warmte in te kopen? Motiveer je antwoord.
Textbox

40. Geef met de slider aan hoeveel van je warmte behoefte je wil inkopen via lange termijn contracten of door dagelijks te handelen.
Slider

41. Wat voor voordelen verwacht je te halen door het gebruik van de WDM?
textbox
-Prijsvoordeel op warmtegebied
-Mogelijkheid tot arbitreren op meerdere marketen (elektra, gas, warmte)
-Een op markt kan mogelijk meer warmtebronnen aantrekken
-Verduurzaming van de warmte productie

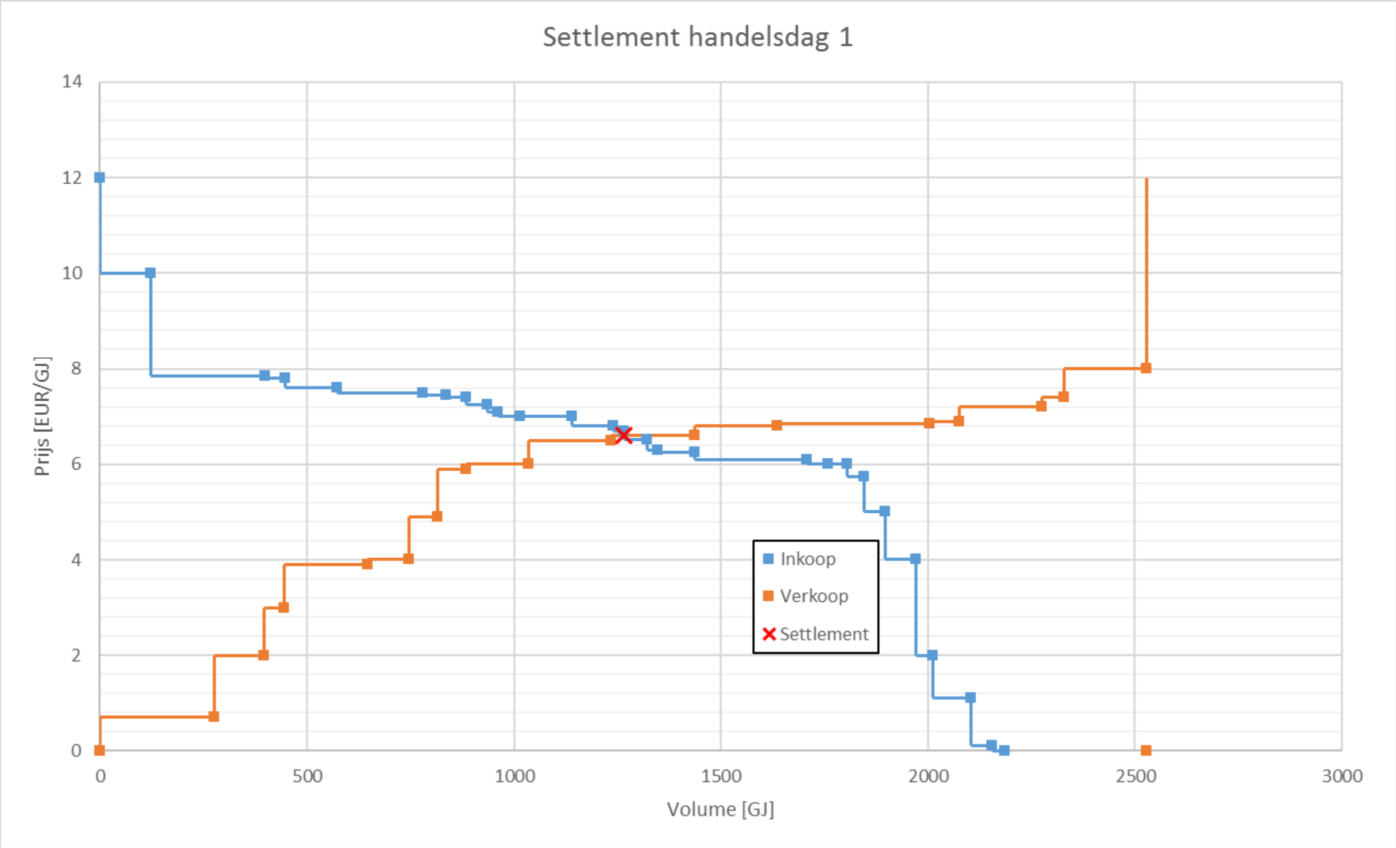
42. Wat zijn risico's die je denkt te ondervinden door het gebruik van de WDM?
-Variabele prijs maakt het lastiger om te investeren
-Plaatsen van biedingen kost veel tijd
-Scheve verhouding op de markt waardoor bepaalde partijen te veel marktmacht kunnen uitoefenen
-prijsstijging door het risico van missen van biedingen

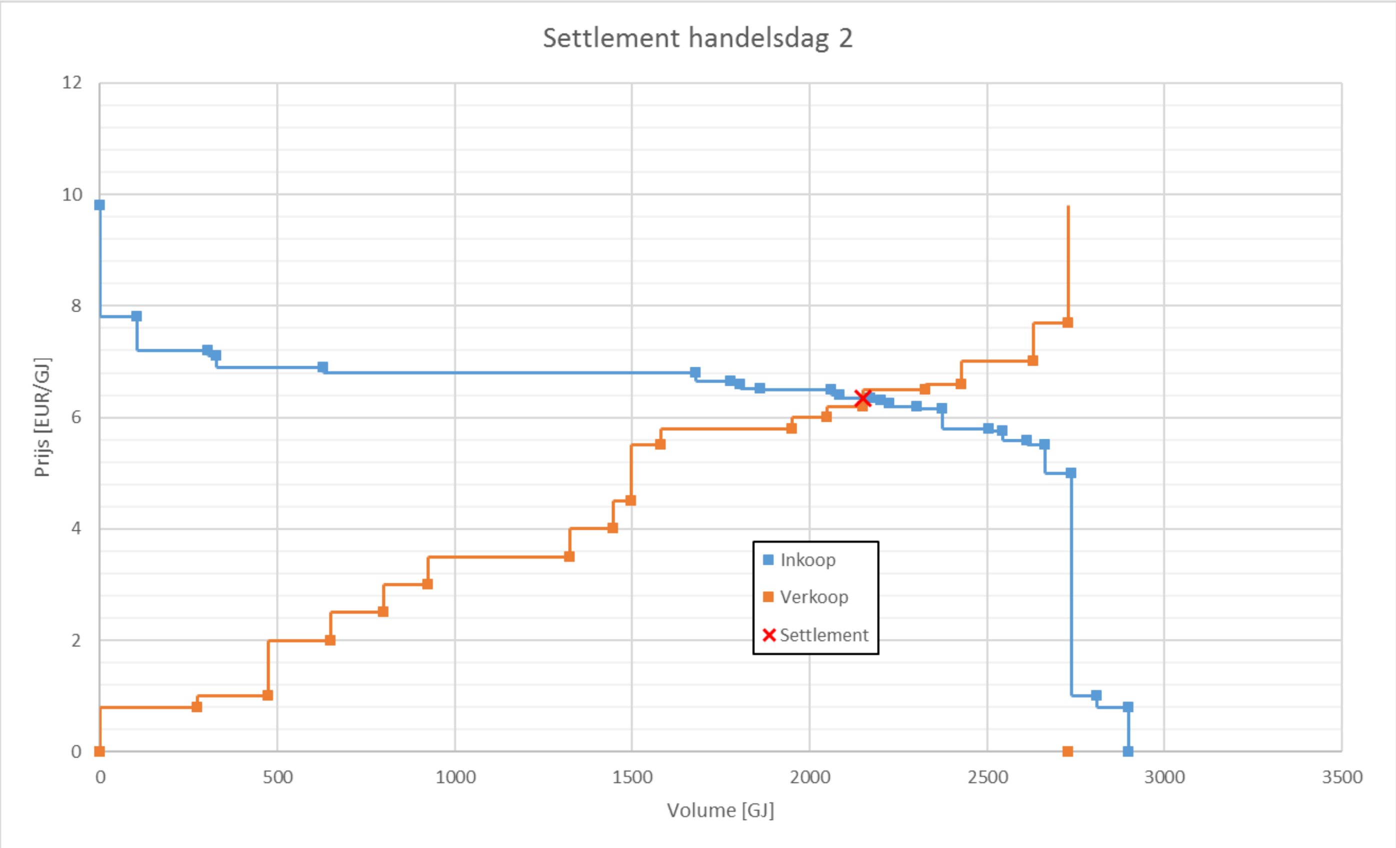
43. Wat zou er nog moeten veranderen om de WDM toe te passen?
Textbox

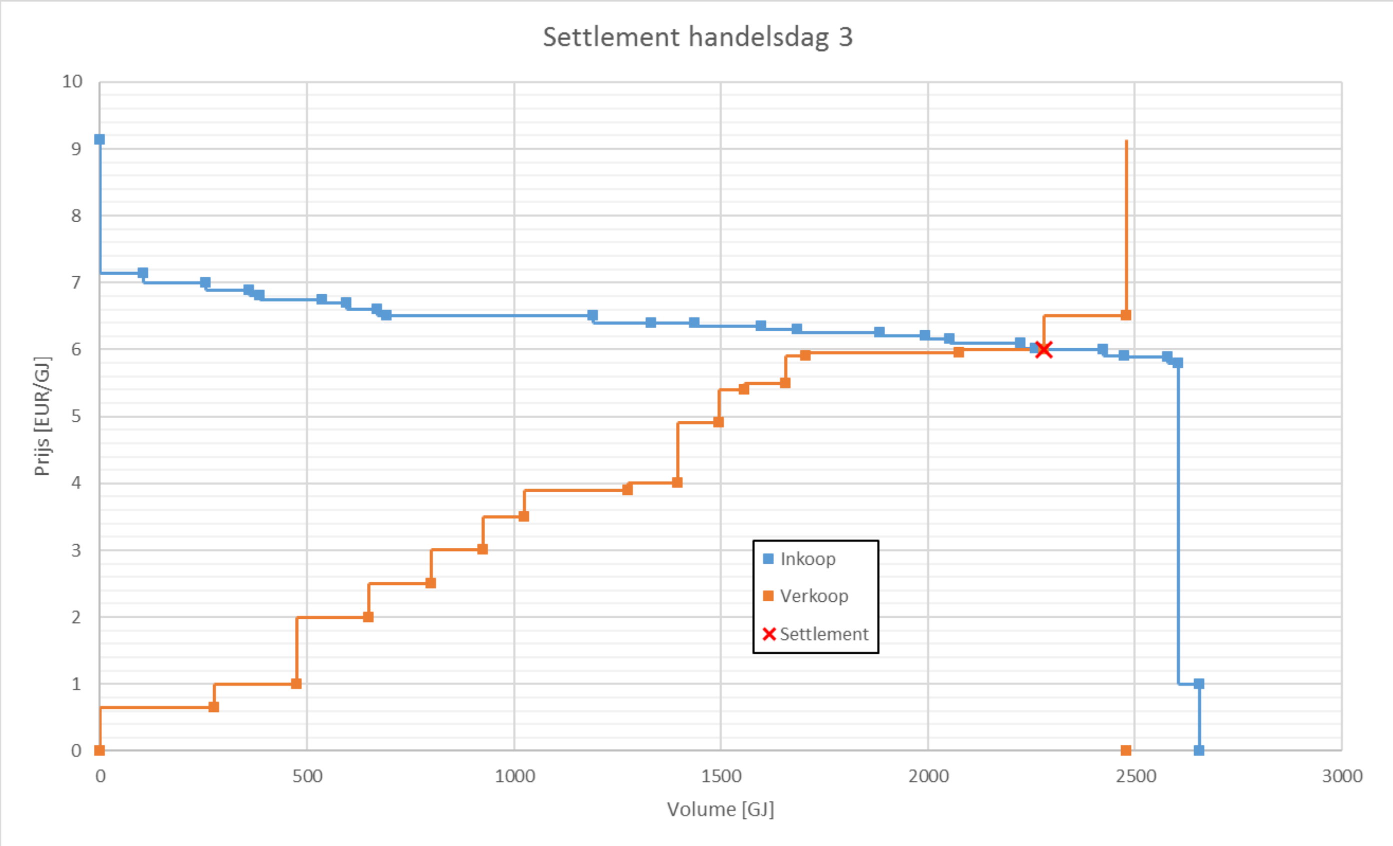
44. Zou je meer warmte afnemen op momenten dat er een heel lage marktprijs is in een WDM? Motiveer je antwoord.
Textbox

Appendix B

Settlements simulations



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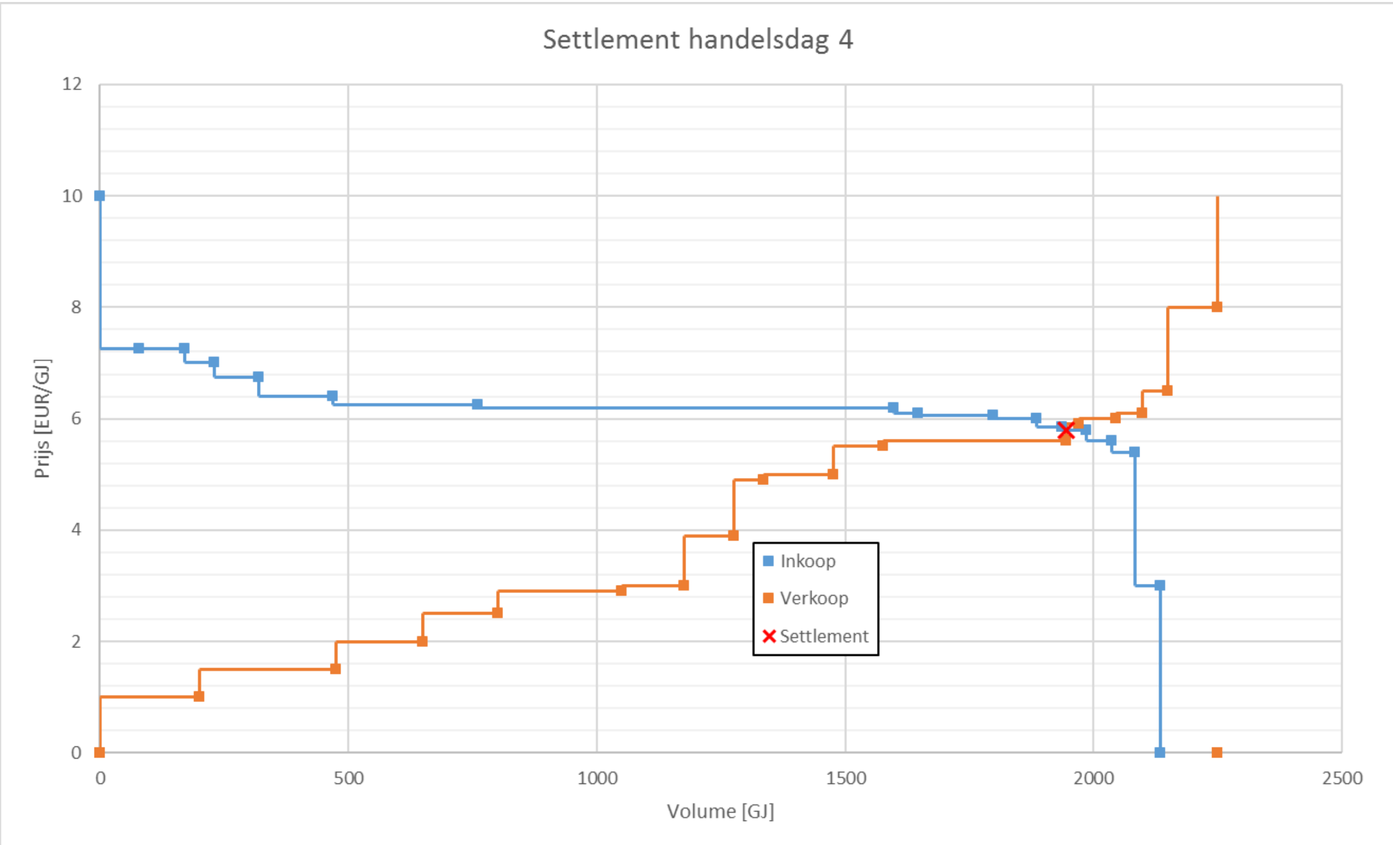
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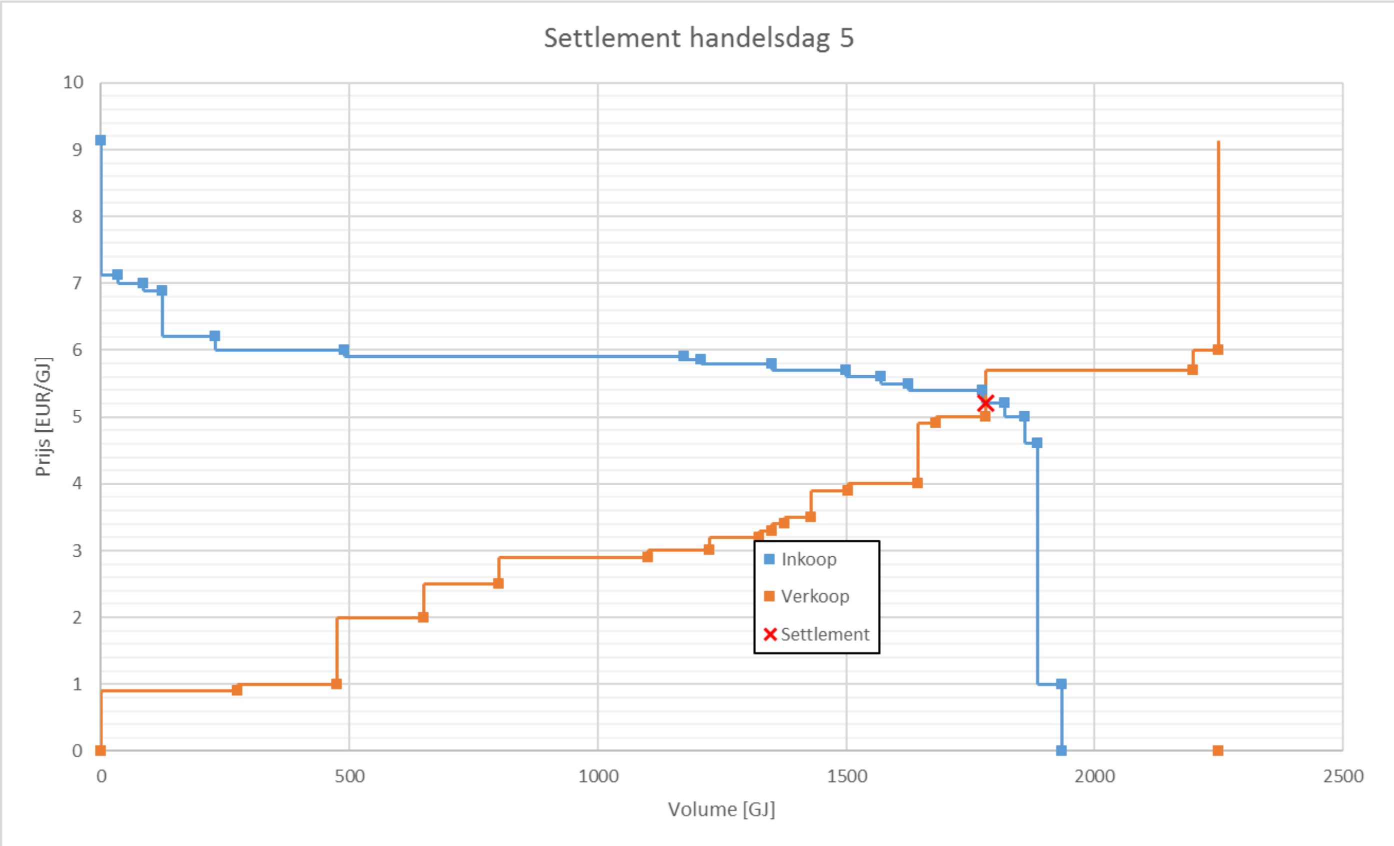

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Volume [GJ]
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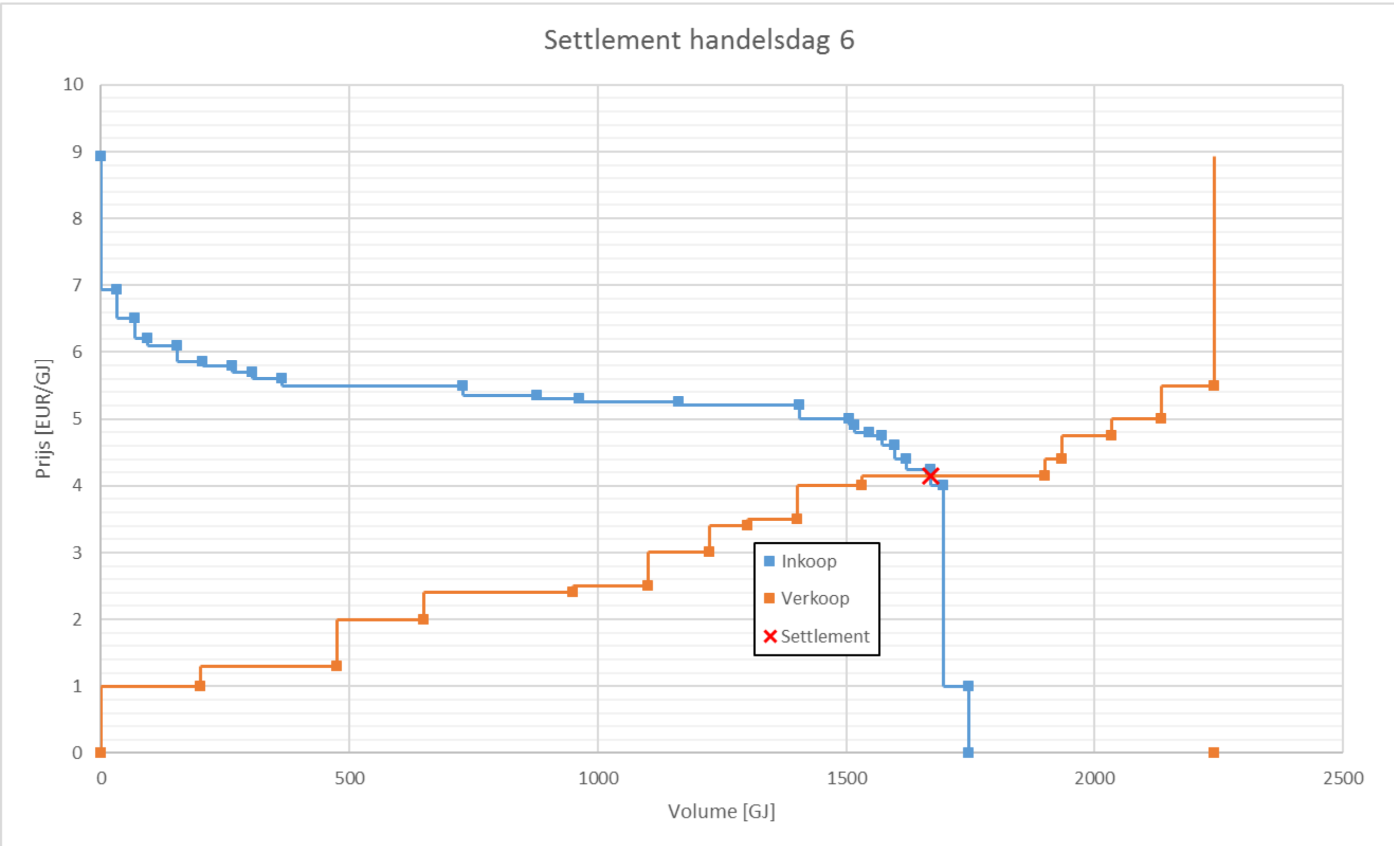

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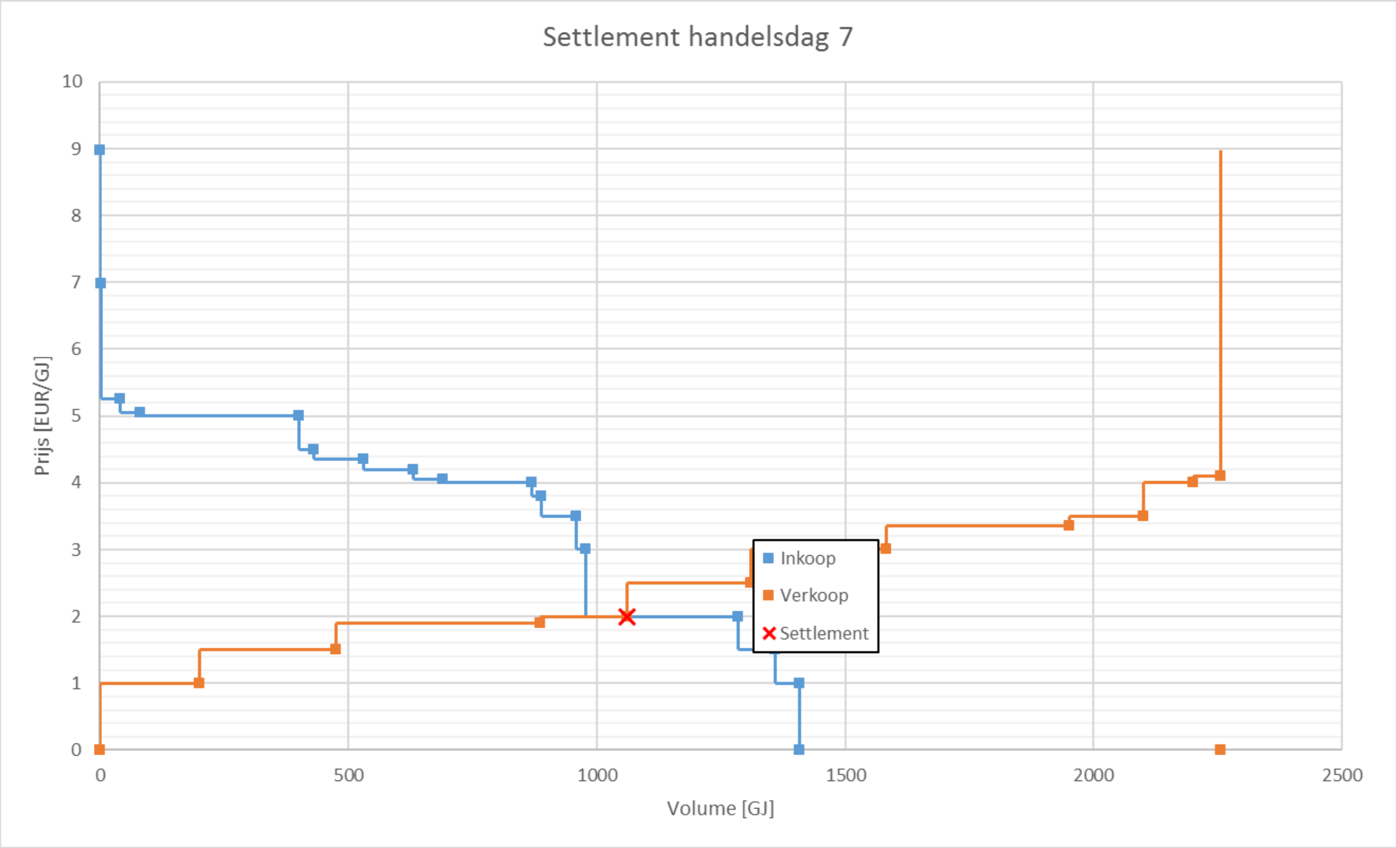

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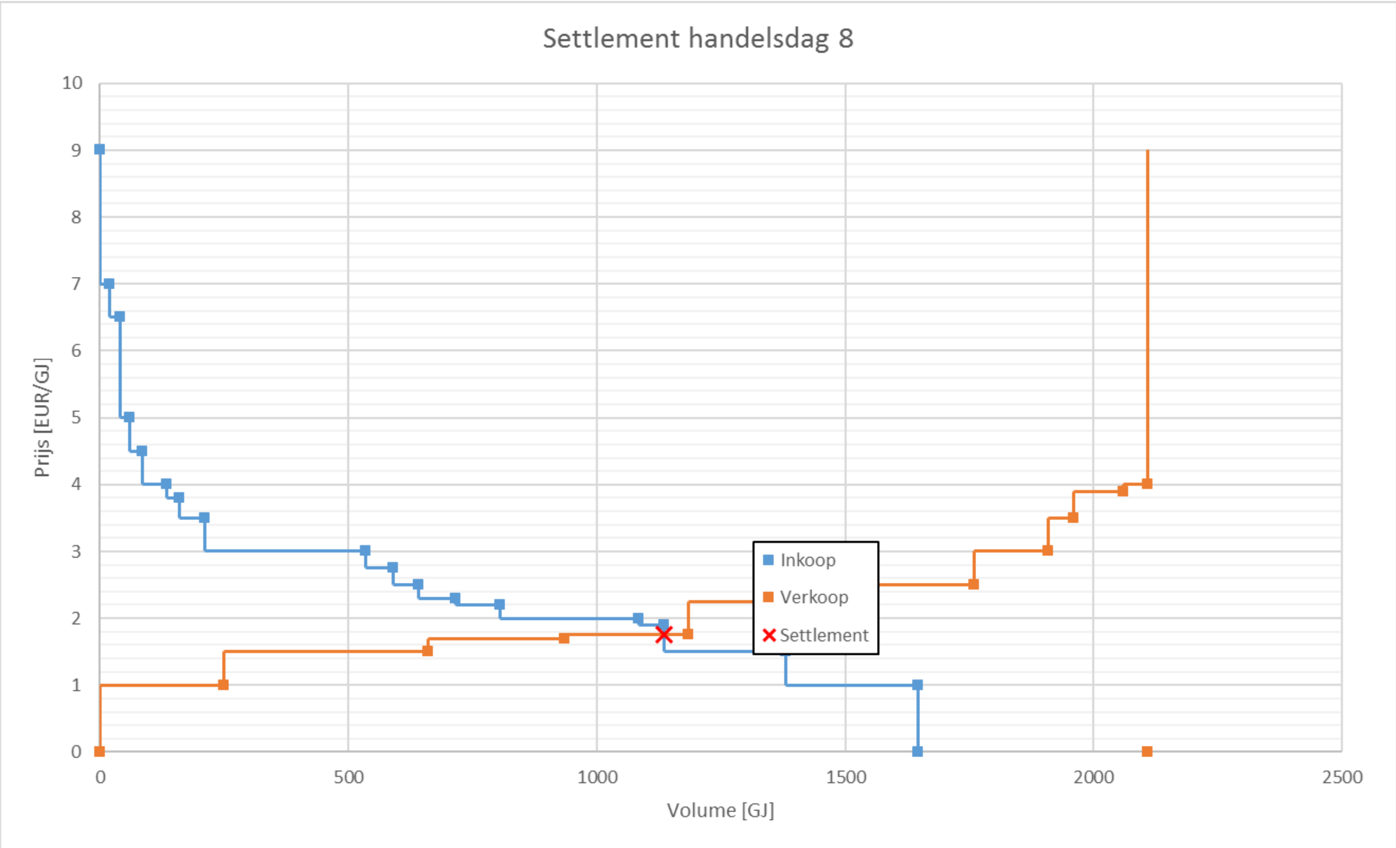

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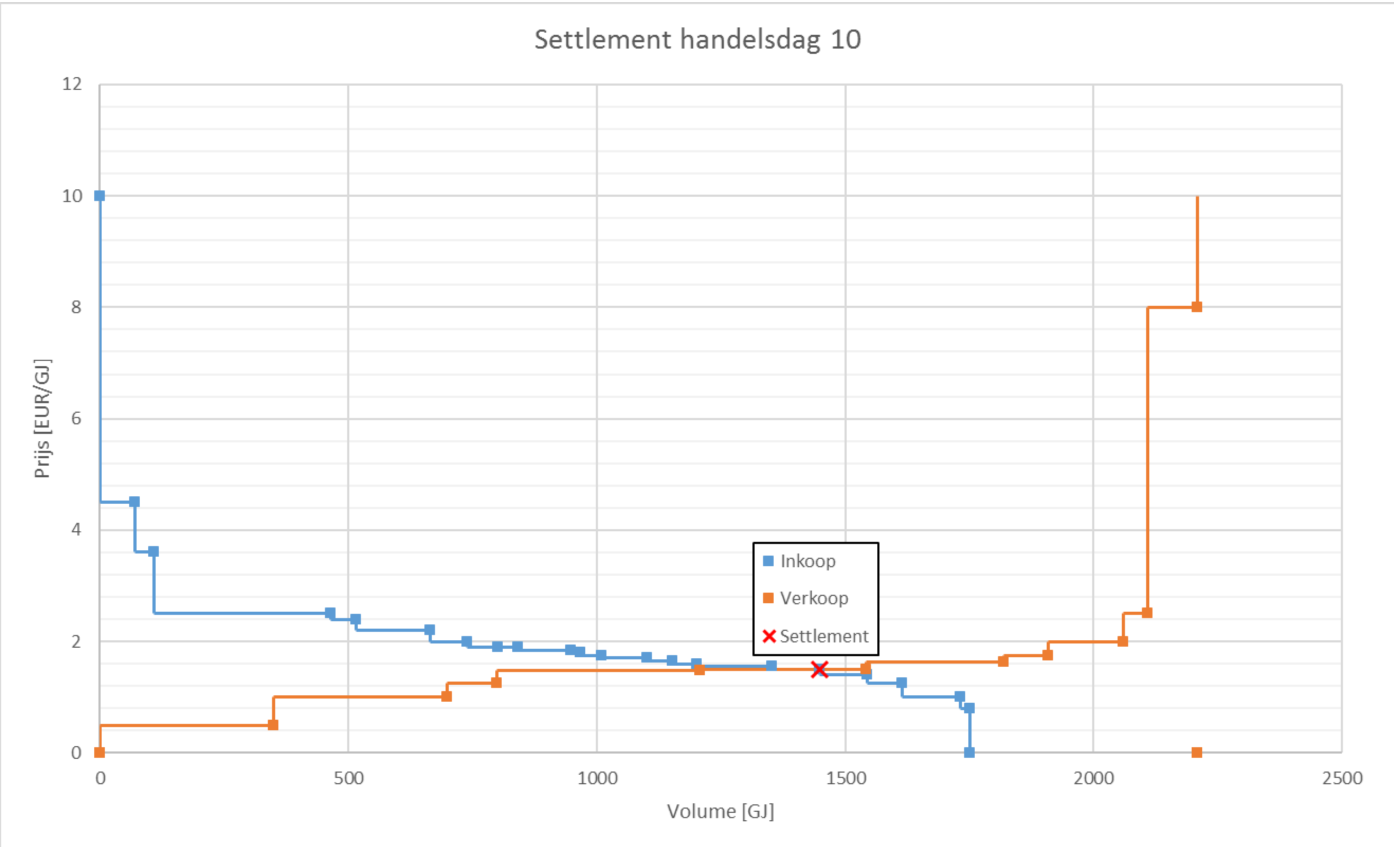

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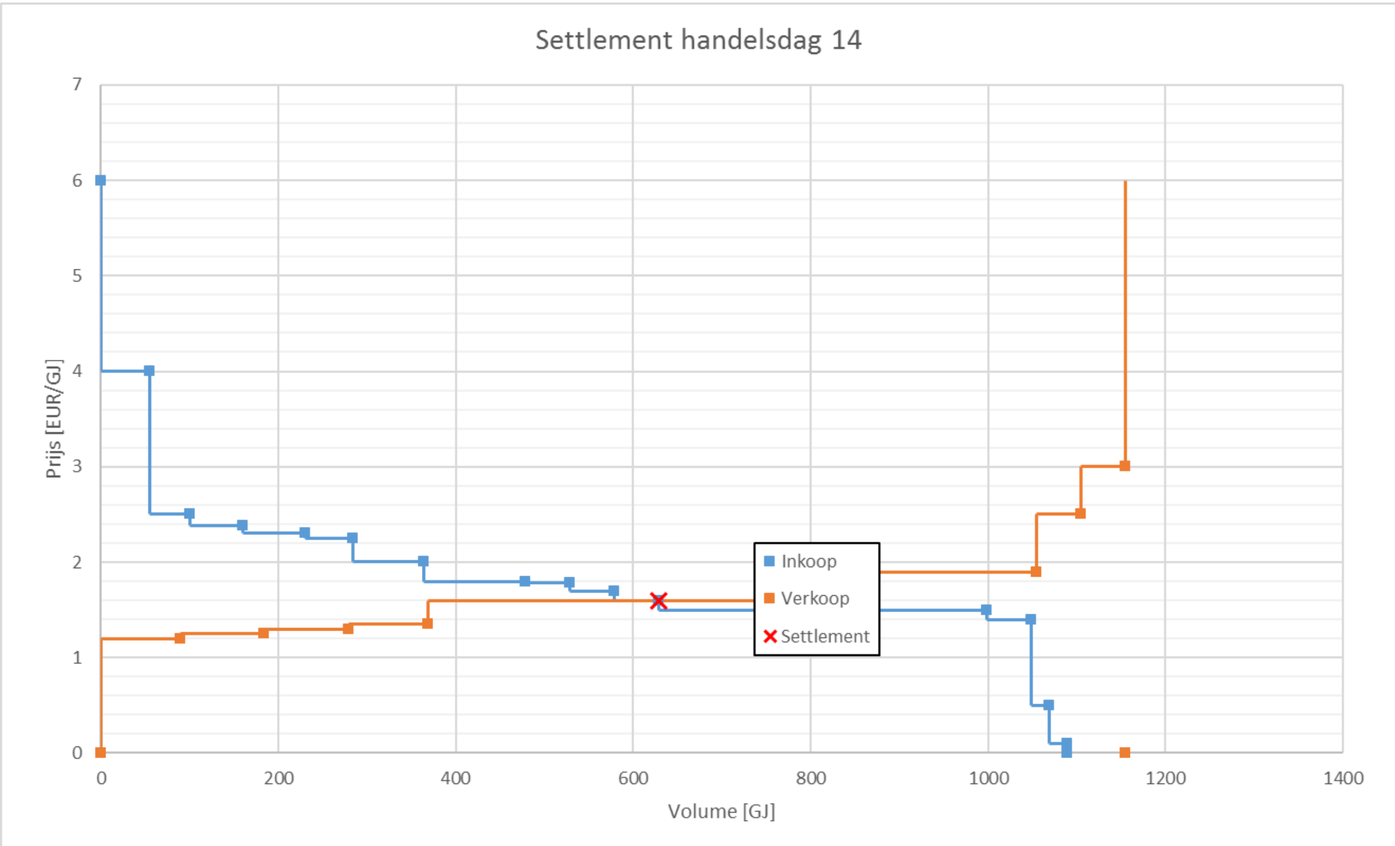
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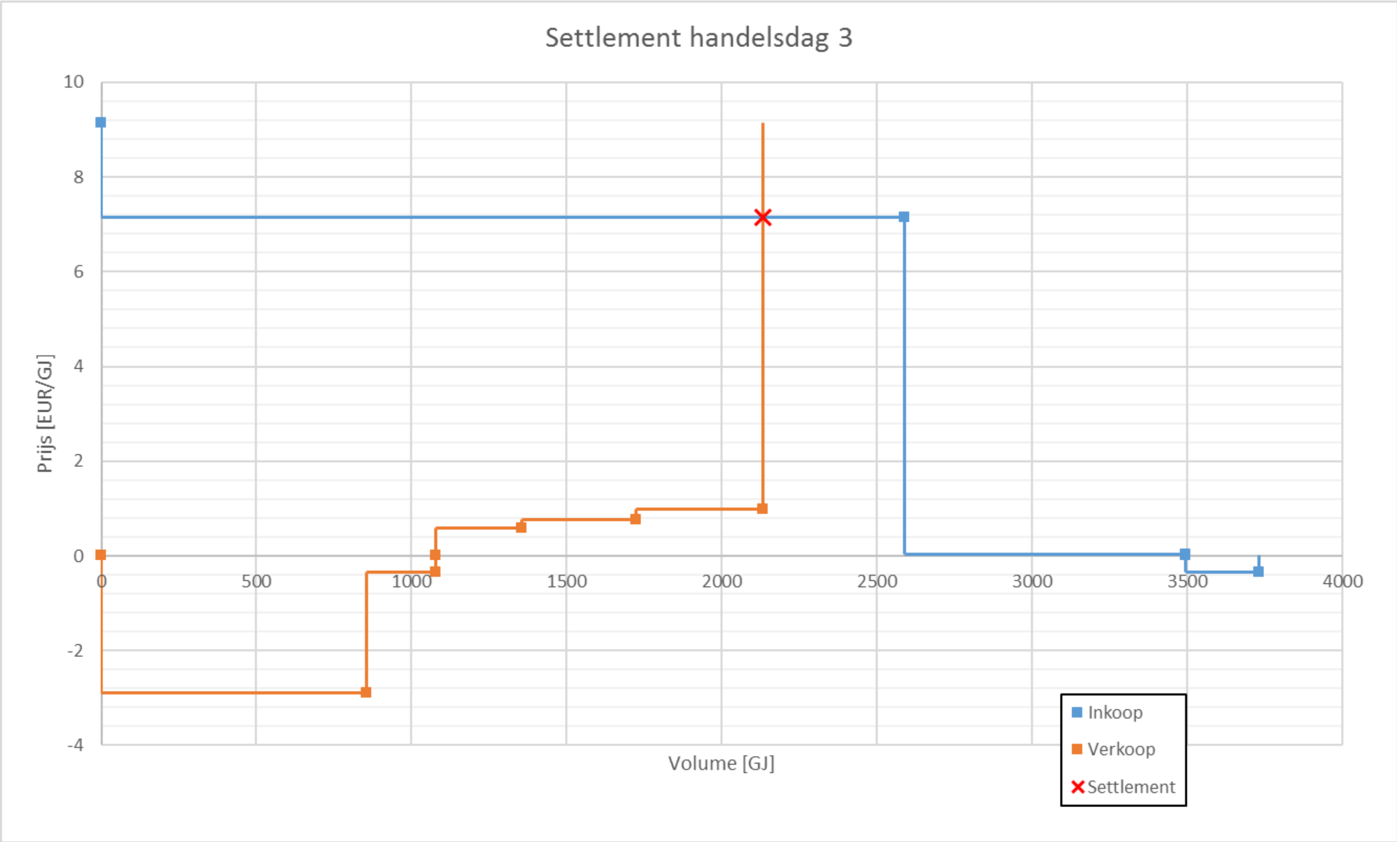
Appendix C

Settlements marginal cost model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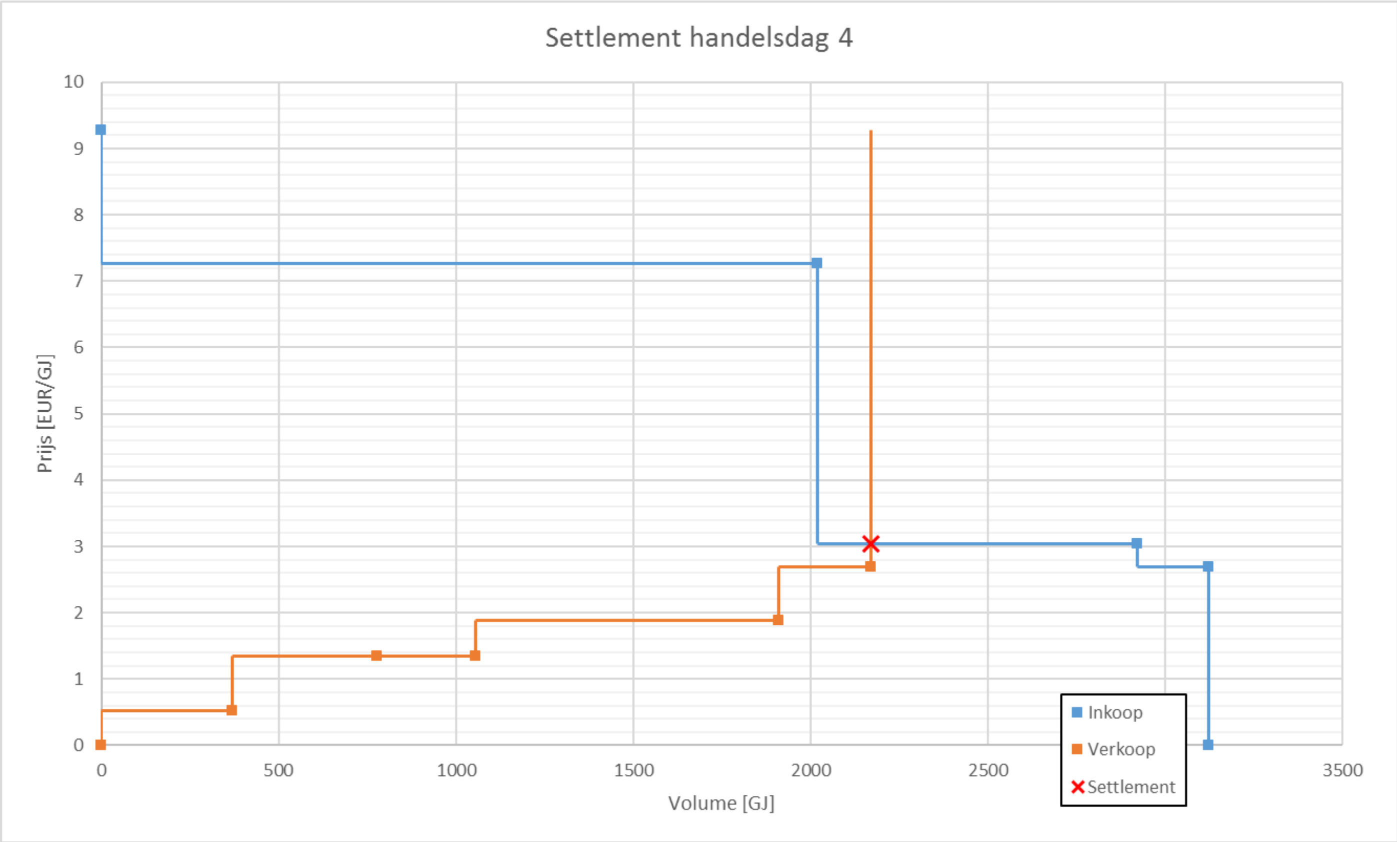
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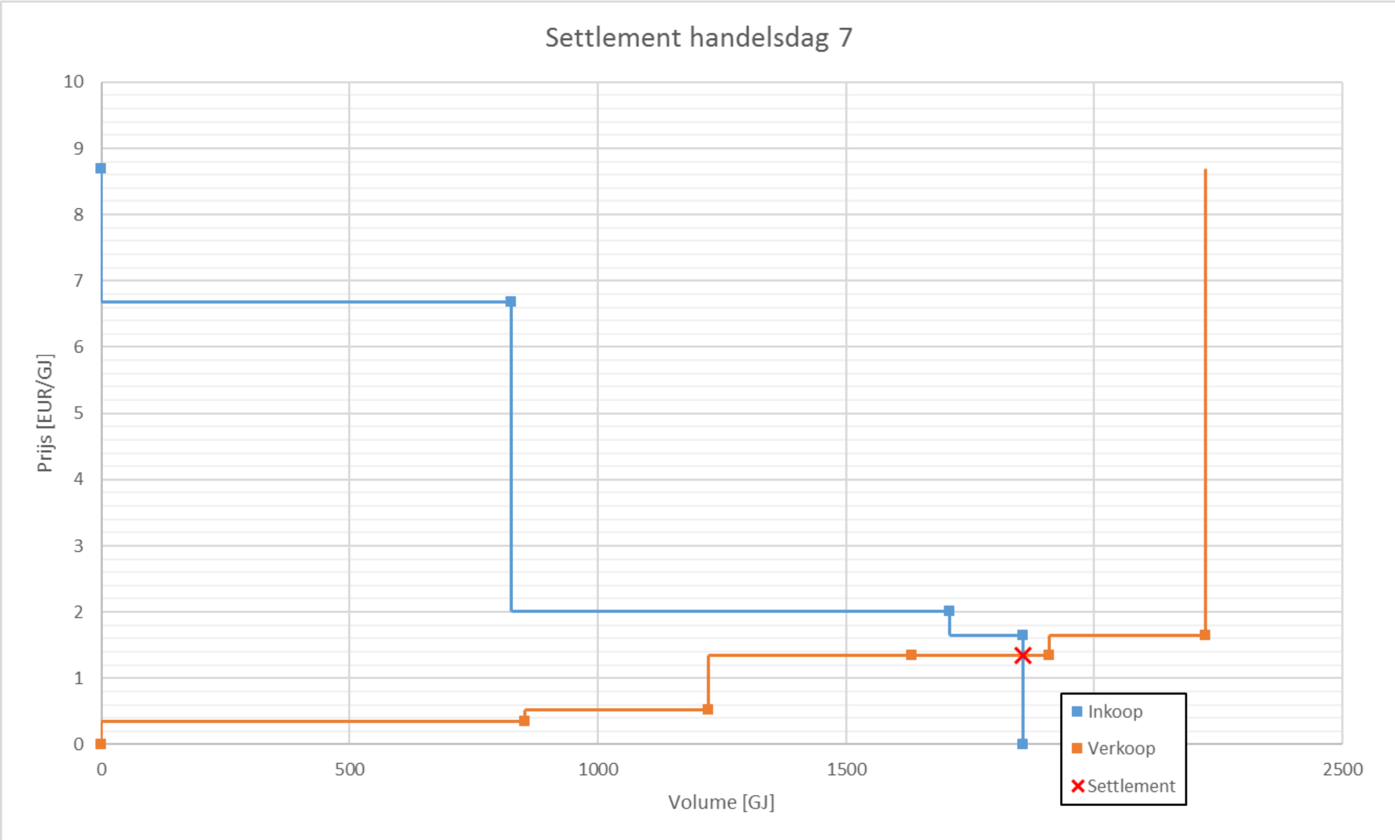
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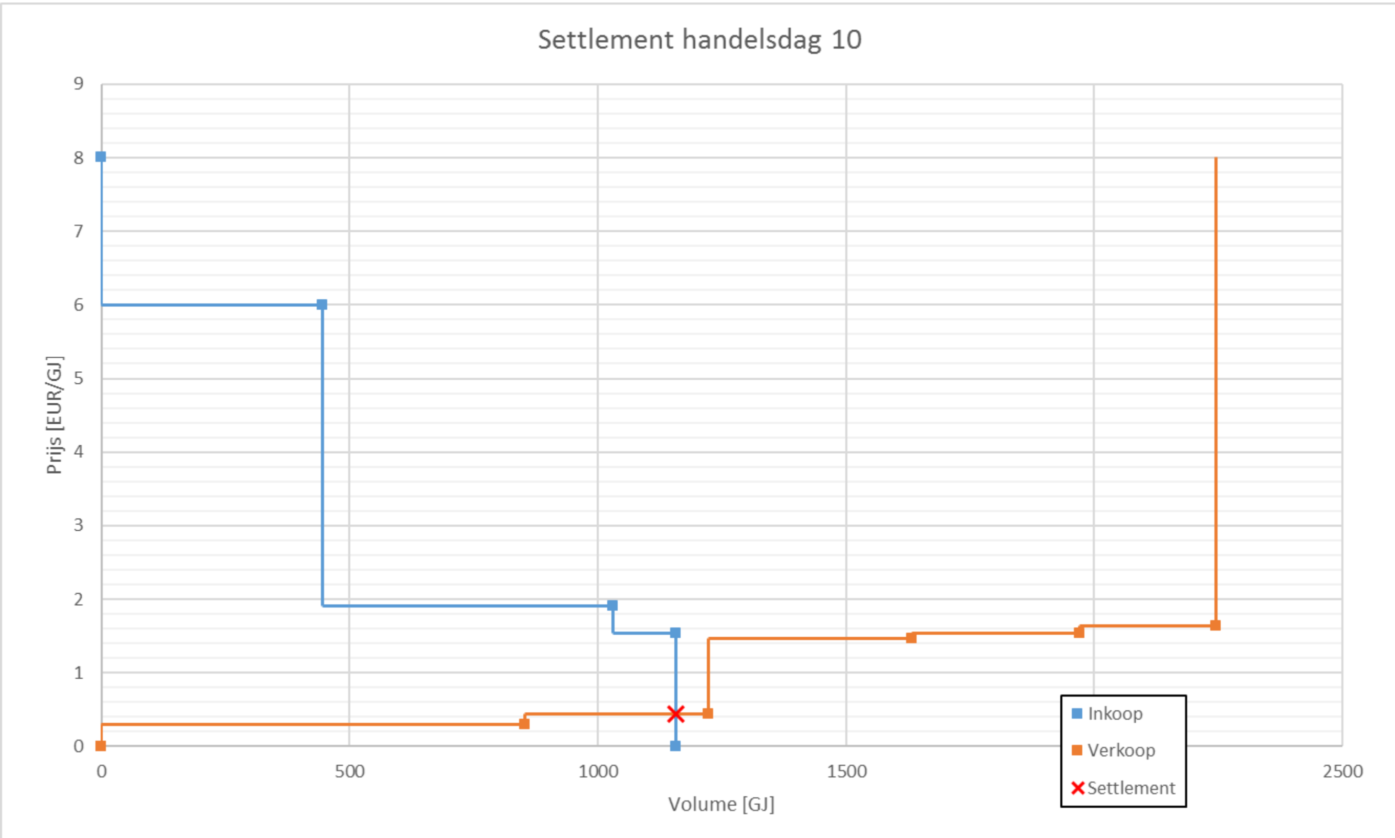
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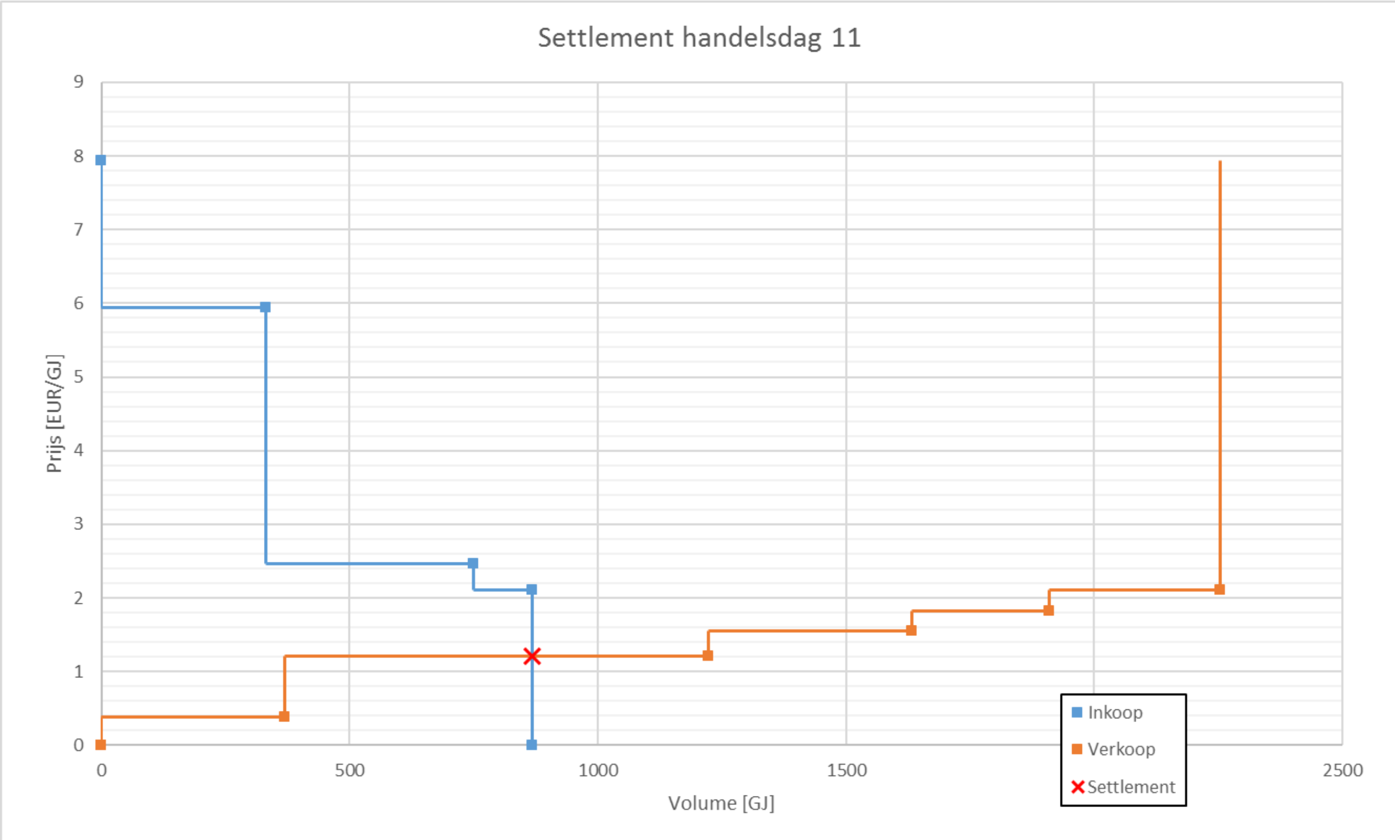
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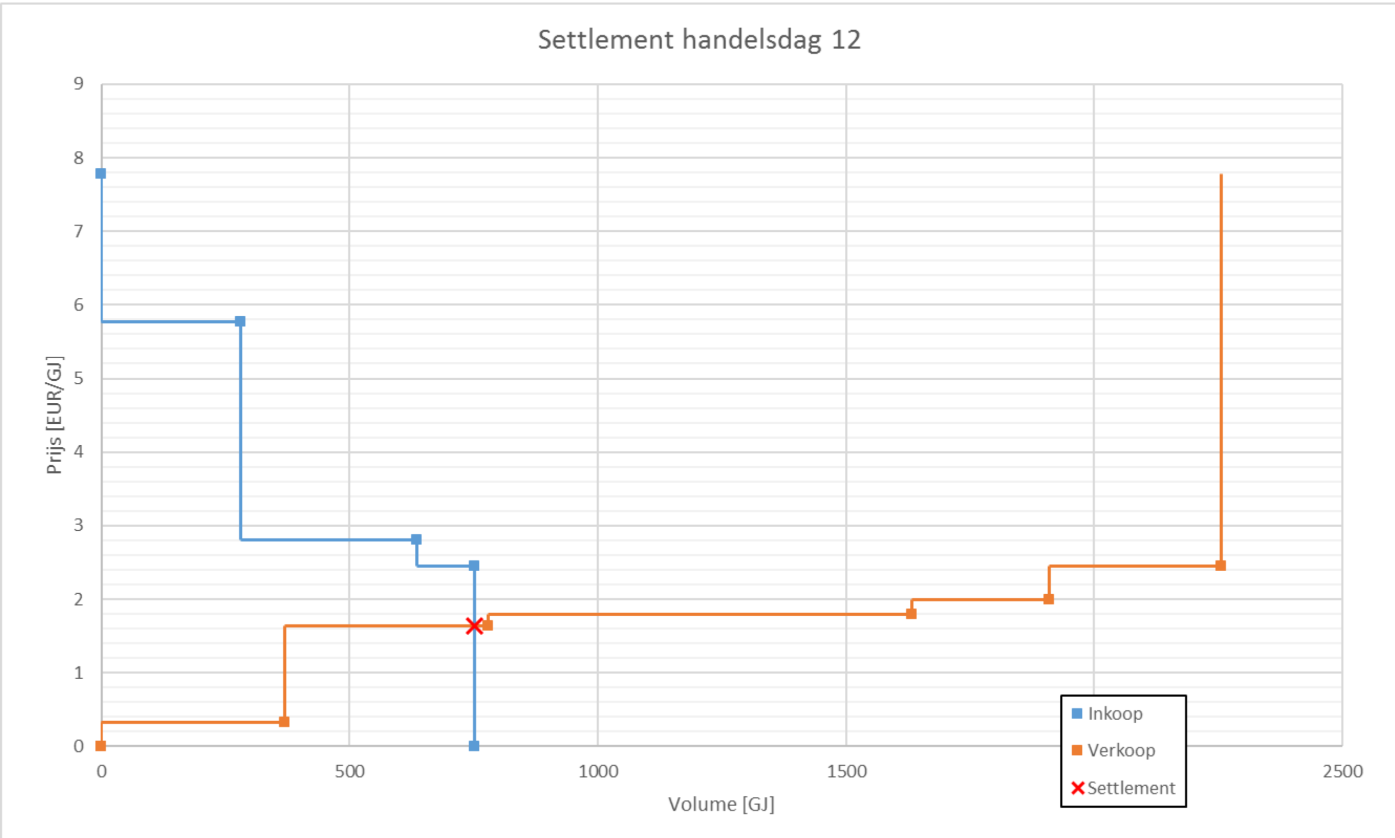
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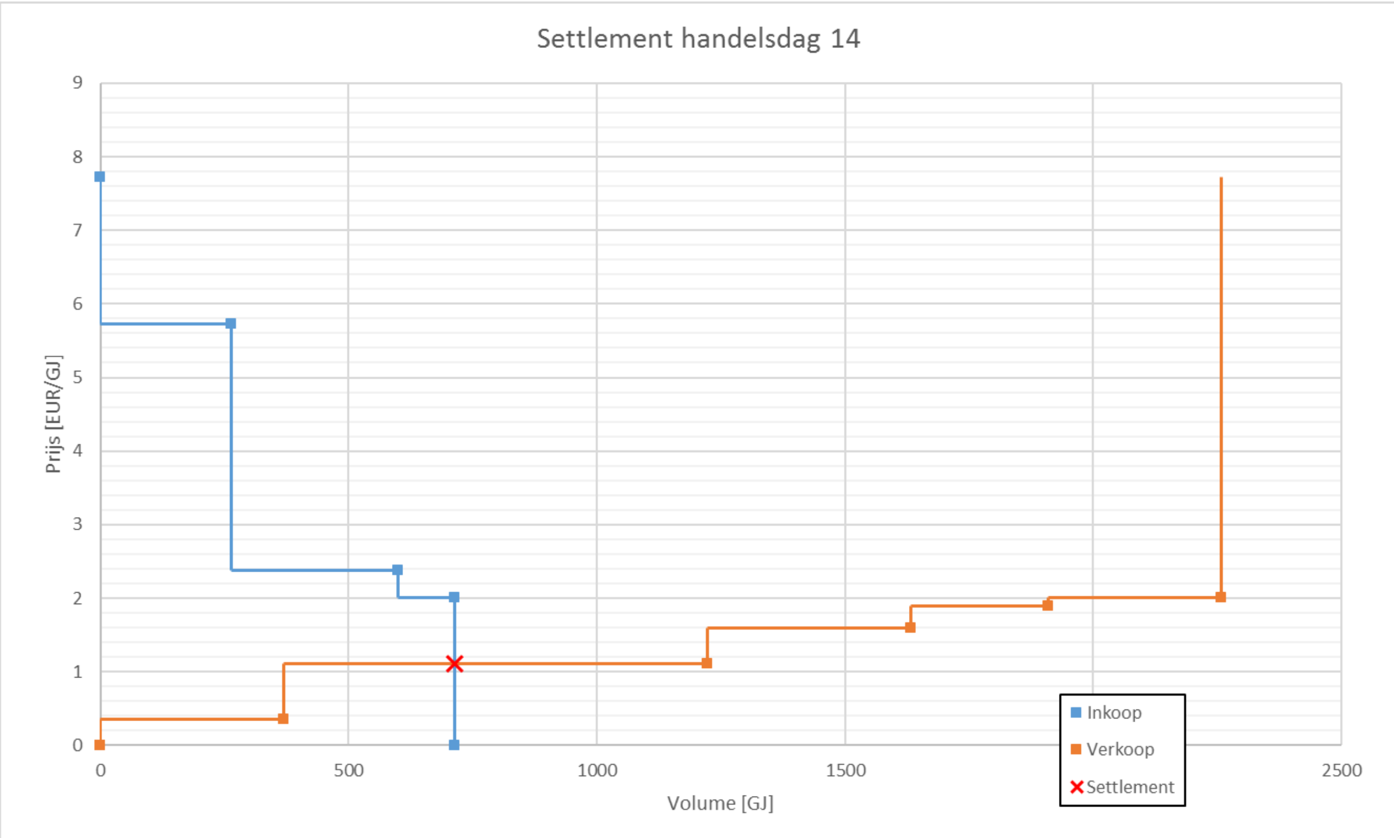
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