

Short term heat market in horticulture District Heating System

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Abstract

In order to reduce CO₂ emission, district heat networks and carbon-neutral heat energy production are being developed in the Netherlands. This resulted in an increasing amount of district heating systems (DHS) in the horticulture areas. A DHS in a region called the "B3-Hoek" connects multiple producers with horticulture companies in a single-buyer market model with long term bilateral contracts. This market model has some undesirable aspects that contribute to the willingness of introducing a short term heat market model in the system. However, such a short term market is still prone to market failures, if producers have considerable market power. The aim of this paper is to find out if in a short term heat market, the degree of competition is sufficient to drive the market price to marginal cost levels or if market power from producers dominates the market price. An interactive simulation of a short term heat market was created, based on the DHS in the B3-Hoek to investigate this.

The findings in this research show that in a short term heat market prices will converge to marginal cost levels when market conditions are not tight. There is a balance of market power between the producers and the horticulture companies collectively. The results of short term market will not be comparable to the case of a perfectly competitive market due to Cournot competitive behaviour, but they can still be considered desirable for both horticulture companies and producers.

Keywords: District Heating, Heat Networks, Heat Market, Competition, Energy Systems

1. Introduction

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 gas production decrease 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 CO₂ emissions and become climate neutral by 2040 (LTO Glaskracht Nederland, 2018).

To reach these goals, different parties have started the development of district heat networks and 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. Here, a distinction can be made between small consumers and large consumers because of the Dutch regulation of DHS (Ministerie van Economische Zaken, 2019). The Heat act, the legislature that regulates district heating in the Netherlands, covers the legislation for 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
- When a heat supplier can 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, with a connection capacity larger than 100kW, are outside the scope of the Heat Act. These are heat networks that connect producers with other industrial companies and/or horticulture companies. In this

research, the focus is on networks with only horticulture companies connected in a DHS, because there is a desire to change the way these systems are configured.

DHS are characterised by a high degree of asset specificity, high sunk costs of the infrastructures, they are localized, large transport losses, high entry barriers and limited availability of resources (Oei, 2016a; van Woerden, 2015). The result is that most DHS in the Netherlands are closed systems with a vertically integrated structure (CE Delft, 2015; Ecorys, 2016). Stakeholders (CE Delft, 2015) in a DHS situated in the municipality of Lansingerland, locally referred to as the “B3-Hoek”, want their heat system to have a more open character, where competition can be introduced among multiple heat energy production facilities. This DHS connects multiple producers with horticulture companies where trade is organised through long term bilateral contracts in a single-buyer market structure. There is one supplier (AgroEnergy) in the system that contracts producers for heat energy production and then sells this to the horticulture companies. There are three aspects to this market model that create an undesired situation for horticulture companies and producers.

The first aspect is that the supplier of heat hedges the risk of long-term supply to the consumer. Consumers, therefore, pay a risk premium. The producers take a risk too when they commit themselves to the future production of heat energy. Prices that are set in the past might not cover future costs as a result of changing fuel costs or market conditions. Therefore they have the incentive to also include a risk premium in their prices.

The second aspect is the way heat energy is currently priced in the contracts. 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. However, it does not have its own commodity price. Currently, the price of gas is the dominant indicator of the price of heat. This is because a lot of heat production systems use natural gas as fuel and it is, therefore, the main component of the marginal cost of production. Other heat energy sources used in biomass, residual waste heat and geothermal plants have different marginal costs. However, the price of heat from these sources is still connected 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 that is needed is very depended on the weather. Especially during the winter, a cold or warm winter influences energy usage significantly. Correct long term weather predictions are very difficult to make, thus there is a risk of not contracting enough or too much energy. Currently, the supplier offers heat energy in the short term by applying a

cost-plus pricing method for the supply of additional heat energy. The disadvantage is that under cost-plus pricing mechanism, the supplier has incentives to increase profits by inflating costs. Moreover, there is no incentive to replace older less efficient technologies to reduce costs (Li, Sun, Zhang, & Wallin, 2015; Zhang, Ge, & Xu, 2013). If horticulture companies bought too much energy, they still pay for the total amount even though it is not all used. This is referred to as “Take-or-Pay” contracts.

Producers are tied to production output determined by their contracts. However, the gas and electricity markets determine a large part of the production cost. 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. Contracts now cause unprofitable ‘must run’ situations as producers lack the flexibility to determine production output and trade energy in the short run. Changing this would give producers and more flexibility to deal with changing market conditions.

In summary, 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 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. 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, Färling, & Forssell (2016) have found that in Sweden, where the heat market is also not regulated, 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 if 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 asset, 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. Therefore all horticulture companies have a gas-fired boiler, and some also have a combined heat and power unit with enough capacity to produce their heat demand. This alternative source of heat makes a horticulture company less reliant on a producer, meaning that the market power of a producer is limited. When the producer asks a high price, a horticulture company will

decide to produce heat by itself if that option is cheaper. Horticulture companies also have a buffer, meaning that energy can be stored. This can be used to balance production and consumption throughout the day.

The aim of this paper is to find out if in a short term heat market, the degree of competition is sufficient to drive the market price to marginal cost levels or if market power from producers dominates the market price. This research uses the DHS in the B3-Hoek as a case. An interactive simulation is developed where producers and horticulture companies trade heat energy in a virtual day-ahead market. The data from this simulation is used to identify the behaviour of the actors and to evaluate the performance of the market. The results of this research can be used to evaluate the implementation of a short term market in the DHS.

This paper is structured as follows. Chapter 2 explains the methodology of this research. Chapter 3 discusses the literature on the research topic. In Chapter 4, the market simulation that was developed is explained. Chapter 5 shows the results of the simulation. In Chapter 6 the results are discussed. Lastly, Chapter 7 concludes this research and recommendations are given.

2. Method

First, a literature review is done on short term markets and competition in DHS. This body of knowledge is consulted to find out how the degree of competition in a DHS can be measured and actors behave in markets. This is done by using the Google Scholar search engine with keywords such as “competition in district heating”, “district heating market”, “heat energy wholesale market”. More papers were found by a process of snowballing and going back and forwards between papers. Papers were selected if they discussed competition in energy systems, short term/wholesale trading, district heating markets or economic behaviour related to energy markets.

Afterwards, by using what was found in the literature, an experiment was constructed where producers and horticulture companies (growers) trade energy in a virtual market. Real growers and producers were recruited to participate in the experiment so that the results are representative. The goal of the simulation is to identify how they behave and what the results are in terms of market price and traded volume, when both growers and producers arbitrage on a short term market.

During the simulation, the participants trade heat energy in a virtual market. There was no real exchange of power or money. An online trading platform was used where producers could offer their production capacity and where growers could bid their heat energy demand. Throughout the simulation each participant was given an Excel-based calculation tool to do the necessary calculations and keep track of how much energy they had sold or bought.

After the simulation, the data of the settlements, bids/offers and the heat energy costs/profits per participant were

collected. This data was then compared to two simulation scenarios: one where every participant would always bid/offer at marginal cost level (marginal cost scenario) and one where the market price would always be equal to the alternative costs (costs for a grower to produce heat energy himself), called the alternative cost scenario. In both the simulation and in the scenarios all variables are the same, thus *ceteris paribus*. This allows us to compare the three market scenarios based on price. The marginal cost scenario is used to evaluate how much more profit producers were able to make during the simulation. The alternative cost scenario is used to evaluate how much value the heat energy delivery had for growers during the simulation.

The results of the simulation are also used to determine the behaviour of the participants. Their bids/offers price points were compared to their marginal cost price points and interviews were done to gain insight into the decisions that were made. The performance of the market is evaluated by comparing the market prices to the marginal costs of the producers.

Lastly, the results of the simulation are discussed. The limitations and assumption that were used are reflected upon to explain how they affect the performance of the market in reality.

3. Literature review

In the search for literature on the topic of this research, it was found not much has been written about short term energy trade in a wholesale market in a DHS. Most papers focus on production technologies and the development of district heating networks or DHS for small consumers such as households and small businesses. One study was identified with a research scope very similar to the scope of this paper.

In a study done by Bijvoet (2017) research has been done into competitive behaviour of producers and consumers in an open district heating network. An agent-based model was used to investigate the behaviour of producers and horticulture companies in a spot market and its outcomes. Her findings show that that strategic behaviour of greenhouse owners prevents producers from 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, not by actual agents. It would be interesting to find out how actual producers and horticulture companies would develop a strategy if they did the bidding themselves. That would be a more valid way to investigate their behaviour and the outcome of a spot market. Also, Bijvoet only looked at tight market conditions, where production capacity was insufficient. In this research, both tight and wide market conditions are simulated.

Because there is a lack of other cases and studies on competition in large consumer markets for district heating, the analysis of competition and market power is based on the principles of Neo-Classical Economic theory. The model of

perfect competition 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 described by Tsoulfidis in his article, 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 consumers’ utility and the welfare of society. 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 a 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 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 marginal cost. Strategic price setting in auctions has been extensively researched of the electricity market. For further reading, see (Contreras, Candiles, De La Fuente, & Gómez, 2001; Elmaghraby & Oren, 1999; Fabra, Von Der Fehr, & Harbord, 2002; Klemperer & Meyer, 1989; Nicolaisen, Petrov, & Tesfatsion, 2001; Ren & Galiana, 2004; Son, Baldick, Lee, & Siddiqi, 2004; N. H. von der Fehr & Harbord, 1998)

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. Therefore this index is 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.

In the next chapter, the design of the simulation is discussed, that was used to evaluate market power, strategic behaviour and the level of competition in the heat market of the B3-Hoek.

4. Simulation

An interactive simulation has been set up to simulate a short term market in the B3-Hoek. The goal of the short term market simulation is to allow producers to offer their production capacity, and 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. In the simulation, we created an environment where we mimic a short term heat market with a sealed double-sided uniform auction, but where there are no real consequences to transactions.

4.1 Conceptualization

The DHS in the B3-Hoek connects four different heat energy sources to the horticulture companies in the area. Figure 1 shows the topology of the network as it is today. Developments predict that more production capacity will be introduced and more horticulture companies (dashed outlined areas) will be connected to the network. There are four types of heat producers: Combined Cycle Gas Turbine (CCGT), Biomass heating systems (Bio), Geothermal power plants (Geo) and residual waste heat from a waste incineration power plant (WIP). Their maximum production capacities are respectively, 155 MW, 74.4 MW, 67 MW and 50 MW. The horticulture companies all have a boiler and some also have a Combined Heat and Power (CHP) unit with a capacity ranging from 2 MW to 6 MW. In the simulation, it was chosen to use the heat demand of real horticulture companies in certain weather conditions. Therefore the sum of their demand is a fraction of the real heat demand in the entire DHS. The production capacity of the producers in the simulation is scaled to the real total production capacity. 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 decreased until the point where they are of the same scale in the simulation, as in 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

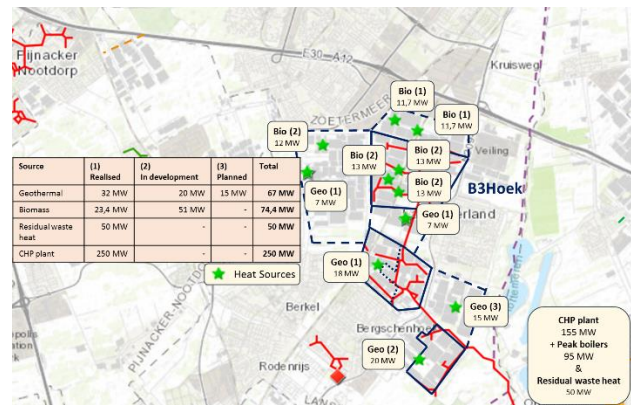
factor to determine how much capacity we should give to the producers in the simulation. In the tables below the capacities in the simulation and a comparison of the market share in terms of production capacity is given below:

Table 1 - Production capacity in the simulation

Producer	Capacity [MW]	Max daily production [GJ]
CCGT	9,88	854
Bio	4,74	410
Geo	4,27	369
WIP	3,19	276

Table 2 - Market share of producers

Producer	Reality [%]	Simulation [%]
CCGT	30%	26%
Bio	13%	11%
Geo	14%	13%
WIP	10%	8%
Sum of CHPs	33%	42%



to recruit the other producer types as well, but they were not available. Therefore the other producer roles (Bio and WIP) were played by two employees of AgroEnergy. Their knowledge of energy trade/markets was sufficient to act as a producer in the simulation.

Tools were provided to them (premade Excel sheet, online market platform, information sent by e-mail) that had to be used for calculations and decision making. The Excel sheet had to be filled in manually and should not be shared with other participants. In order to prevent this, measures have been taken to make it impossible to know who the other participants were. This was also to make sure they do not contact each other and discuss their strategy and biddings.

The 14 simulation days represented the changing market conditions from winter to summer. On average each two simulations days represented the market conditions (weather, gas/electricity price) of each month from January until July. This choice was made 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 outcomes are different in both seasons.

4.2 Experiment design

Growers

The group that consisted of growers was divided into three groups that represent the three types of horticulture companies: Boiler, CHP unilluminated and CHP illuminated. Six of the growers only have a boiler to produce heat themselves. Six other growers had a boiler and a CHP. This group does not illuminate their crop, meaning their CHP is used to full-fill primarily the heat demand. This group is considered to be unable to produce extra heat energy for the heat market. Two growers have a boiler and a CHP that is used to illuminate their crop. Here electricity is the main energy source, whereas heat energy is a by-product. In the process more heat is generated than needed, thus a fraction of the heat production can be sold to a heat market. All growers have a buffer that allows them to store heat energy. Normally the energy can only be stored from day today. During the simulation, energy could be stored throughout the entire experiment. The buffer capacity depended on the size of the company.

In order to stimulate active participation a reward was introduced in each group for the grower who had the lowest average heat energy costs after the simulation.

Energy demand

The energy demand of a grower, in reality, is dependent on many factors, but mainly on weather and type cultivation. The process of the energy demand calculation for the grower had to be easy and quick. Assumptions were made and the calculation process was simplified. The outdoor average day (24 hours) temperature was chosen to be the determinant of

the heat energy demand per day, because it captures the total demand of a day. A formula was created, based on the use of natural gas at a specific average outdoor day temperature, to calculate the heat demand with temperature as an independent variable. Data of natural gas usage on a specific day from 2017 was gathered from the database of AgroEnergy with the corresponding outside temperature from the KNMI database (KNMI, 2017).

In the simulation it was chosen to simulate the decline of heat demand from winter to summer temperatures in order to represent the change in market conditions from tight to wide. As mentioned before, every two days represent temperatures from a day in January until July. Therefore the outdoor temperatures that were used in the simulation were based on the typical outdoor day temperatures in winter, spring and summer months. The temperatures and the corresponding heat demand is showed in the table and graph below:

Table 3 - Temperature per simulation day

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

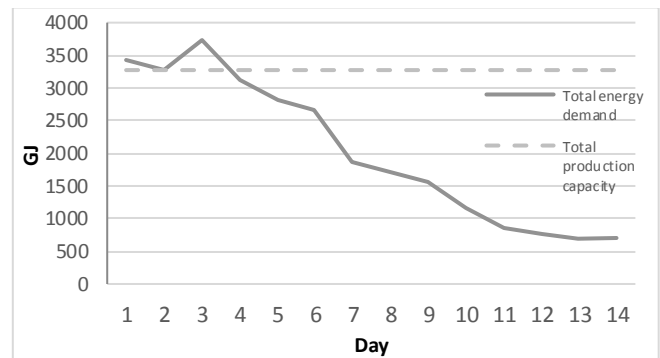


Figure 2 - Total energy demand and production capacity in the simulation

The graph shows the total production capacity, which is the accumulation of the capacity of the CCGT, the biomass plant, geothermal plant, the WIP and all the CHP's of growers in the simulation. 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 be 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 or make use of stored heat energy from their buffer. 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.

During the simulation the grower had four alternatives to fulfil his demand (depending on his properties): purchasing

heat energy from the market, produce heat with his CHP using natural gas, produce heat with his boiler using natural gas or using the available heat energy stored in his buffer. Every day the growers had to meet the demand. If not enough energy was bought at the market they had to either use their own production assets, and pay the respective costs, or drain their buffer. Buffer capacity started at 50% and had to be at 50% at the end of the simulation to make sure that the energy demand in the end was not fulfilled by the initial available heat energy from the buffer.

Marginal Cost calculation

The marginal cost of heat energy production was calculated with the following general formula:

Marginal cost of heat energy

=

$$\frac{\text{Fuel cost} - \text{Electricity price} * \eta_{\text{electric}}}{\eta_{\text{thermal}}} + \text{Variable cost} - \text{Subsidy}$$

For the producers that use natural gas as an energy source, the TTF day-ahead price data of 2017 was used. The gas price per day was coupled to the average day temperature. This is done similarly for the electricity price, that can be seen as income for produces that generate both electricity and heat energy. The electricity price in the simulation was based on 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 most profitable. Both the electricity and TTF price data from 2017 were obtained from the database of AgroEnergy.

The marginal cost per heat production source per day is shown in the following tables:

Table 4 - Marginal Cost price per producer (1/2) [€/GJ]

Day	1	2	3	4	5	6	7
CCGT	-1,26	-1,72	-2,90	1,89	-1,82	-0,32	0,35
Bio	1,03	1,06	0,99	1,34	1,08	1,23	1,34
Geo	0,73	0,71	0,75	0,52	0,70	0,59	0,53
WIP	0,67	0,73	0,58	1,35	0,77	1,11	1,34
CHP (ill)	0,75	0,42	-0,34	2,69	0,34	1,26	1,65
CHP (unill)	1,11	0,78	0,02	3,05	0,70	1,62	2,01
Boiler	7,60	7,27	7,14	7,27	7,14	6,94	6,69

Table 5 - Marginal Cost price per producer (2/2) [€/GJ]

Day	8	9	10	11	12	13	14
CCGT	0,99	1,99	0,30	1,21	1,79	1,84	1,10
Bio	1,49	1,56	1,47	1,55	1,63	1,64	1,59
Geo	0,42	0,38	0,44	0,38	0,33	0,32	0,36
WIP	1,69	1,82	1,63	1,82	1,99	2,01	1,89
CHP (ill)	1,99	2,63	1,54	2,11	2,45	2,48	2,01
CHP (unill)	2,35	2,99	1,90	2,47	2,81	2,84	2,38
Boiler	6,15	6,23	6,00	5,94	5,77	5,74	5,72

The merit order of the producers changes throughout the simulation, because of the different electricity and gas prices every day. It shows that using the boiler to produce heat energy is always the most expensive. For simplicity reasons the boiler production capacity per grower is infinite, so they are always able to produce their heat demand themselves.

It is expected that producers and horticulture companies make offers and bids based on financial arguments. Producers will offer price points above marginal costs and growers will bid below their alternative cost price point. The settlement price will be somewhere between the two price points. The distance between the settlement price and the price point of the price-setting producer/consumer tells us something who has market power. 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 two reference models were developed: alternative price model (based on the boiler costs) and the marginal cost model. Additional simulation runs were created where all other parameters remained the same (*ceteris paribus*).

In the alternative price model, a simulation was developed where 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 the participants' simulation run with this model to show how much better or worse growers are off in a short term market.

In the marginal cost model, a simulation was developed where all offers and bids were done 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). Therefore in each of the fourteen days, the market is clear at the marginal cost level of a producer. This scenario is the best case for growers, but the worst case for producers. We compare the sales and profits of the producers in the participants' simulation run with this model. This tells us how much better or worse producers are off in a short term market. Additionally, the following three performance indicators (PI) were used to evaluate the performance of the short term market:

1. The short term market price should remain below the cost of heat production with a boiler for horticulture companies
2. 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).
3. A high amount of heat energy volume should be traded on the market
4. Stakeholder satisfaction should be high

The first 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 second 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 third 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.

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 fourth 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.

The next chapter shows the results of the simulation. First, the bidding behaviour is discussed and afterwards the market results are presented

5. Results

Bidding behaviour

It is found that the bidding behaviour of growers is very similar between them. The larger part of the demand is bid at a high price level, close to the cost of the alternative (boiler or CHP). A small part of the demand is strategically used to lower the market price by bidding lower. When the market price was high the horticulture companies considered their alternative production asset as a price reference, but when market prices are much lower all bids were done at relatively lower price points.

The offer behaviour of the producers shows that some tried to increase the market price by strategically offering part of their production capacity for higher prices. In tight market conditions (during the winter), producers do not consider their marginal cost as a price point reference and offer their production capacity for relatively higher prices. When heat energy demand decreases (during the summer) there is a production capacity surplus and competition among producers to supply the demand intensifies. Under these market conditions, producers start to offer at marginal cost levels.

In summary, the growers collectively managed to put pressure on the producers to lower their offers. 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. 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, rather than alternative or marginal costs. Also, 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.

Market outcomes

Figure 3¹ shows the market price development during the simulation, the alternative cost of heat energy production with a boiler and the market price development in a marginal cost bidding scenario.

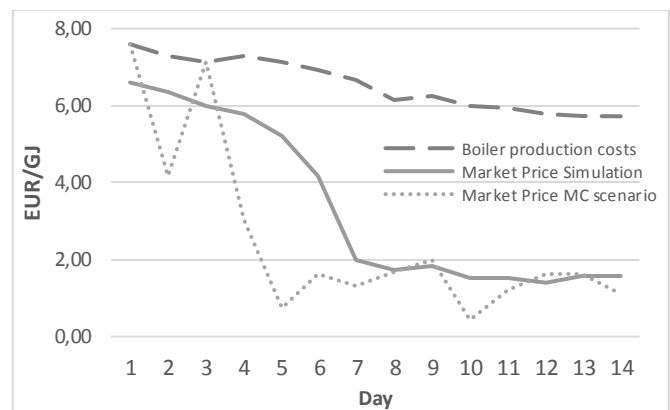


Figure 3 - Market price development per scenario

As can be seen in the graph above, the market prices during the simulation were always below the boiler cost price point. From day 7 onward the market price is very close to the marginal cost reference scenario, while prior to day 7 the market price in the simulation differs more from the marginal cost bidding scenario market price. After the first six days the market prices are equal to the marginal costs of the producers. This is shown in the following graph, where the market prices of the simulation and the marginal costs of the different producers are plotted:

¹ 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.

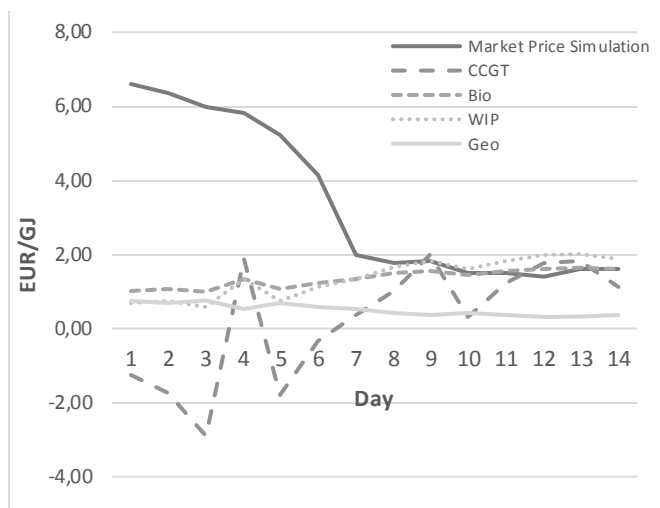


Figure 4 - Market price and marginal costs in the simulation

In the double-sided auction that was used in the simulation, growers run a risk of not purchasing their entire demand. When bids were done below the market price, these volumes would not settle. The following graph shows not all demand was settled throughout the simulation:

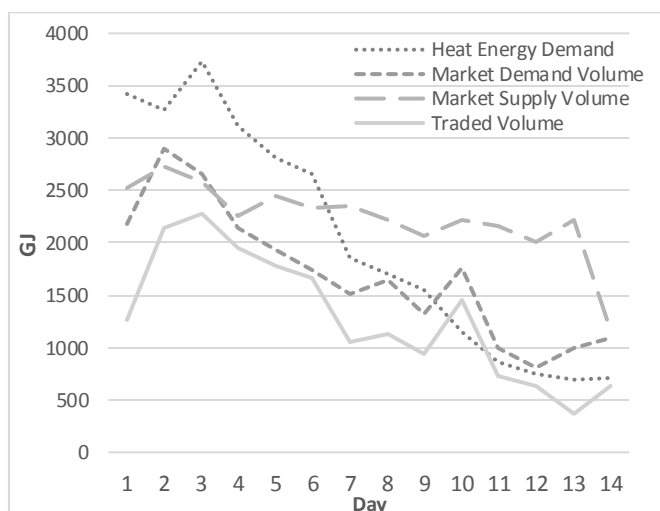


Figure 5 - Traded volume development in the simulation

The traded volume graph shows the total volume that was sold each day during the simulation. The heat energy demand is the sum of the demand of all growers. The market demand and supply volume show the total amount of heat energy that was asked by growers and offered by producers. There is quite a difference between total demand and market demand. This can be explained by the fact that all the growers with a CHP did not ask their demand on the market until day 7, because it was cheaper for them to produce with their CHP. 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), as a result of bids that were done below the market price.

When the simulation is compared to the alternative cost scenario, it is found that growers are better off buying their energy from the heat market. The positive financial results differ per group. Growers with only a boiler paid on average a lot less for heat energy, between 23%-35%. Although growers with a CHP only started buying from the market after day 7, their result is also positive. Their average cost for heat energy was reduced by 9%-23%. The prosumers sold so much energy on the market that their average costs were negative, meaning that they made more profit from sales than paid for the costs of producing heat energy for themselves.

Comparing the simulation to the marginal cost scenario the results are as follows:

Table 6 - Sold heat energy per producer in GJ

Producer	Sales simulation	Sales MC scenario	Difference
CCGT	6448	9029	- 29%
Geo	3284	5100	- 36%
Bio	4229	3985	+ 6%
WIP	2346	2173	+ 8%

Table 7 - Profits per producers

Producer	Profit simulation	Profit MC scenario	Difference
CCGT	€ 28976	€ 24923	+ 16%
Geo	€ 8948	€ 9268	- 3%
Bio	€ 11095	€ 6330	+ 75%
WIP	€ 8175	€ 4472	+ 83%

The results show that the CCGT producer and the geothermal plant sold less energy in the simulation. These producers both tried to drive up the market price with their bid blocks. This has resulted in less energy being sold, but looking at the profit difference it is clear that the strategy of the CCGT producer had a positive result. He managed to get 16% higher profits in the simulation, than what he would have earned if he used marginal cost offering (MCO) strategy. The geothermal plant gained 3% less profit.

The biomass producer mostly used an MCO strategy with some bid blocks of a higher price. WIP 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 WIP were settled, even though they were higher in the merit order than the CCGT 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. This had a large positive influence on their profit.

The results of the producers show that those who used a marginal cost bidding strategy were better off than the producers who tried to drive up the market price. However, they were only better off because the other producers used a different strategy. If all the producers used marginal cost bidding, the results of the simulation would be the same as in the marginal cost model scenario. It thus 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 MCO strategy.

6. Discussion

In the previous chapter, the bidding behaviour of the participants and market outcomes in the simulation were presented. For the analysis of the bidding behaviour, it can be concluded that the demand function for heat energy is for the most part highly elastic. This represents the high offers for the number of volume growers want to get settled. The price point is offered below the alternative cost price point. The tail of the demand function is very inelastic. It represents the biddings done to put pressure on the producers to achieve a lower market price. 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 depending on the production volume. This profit-seeking behaviour and the fact that there were days of insufficient production capacity are the reasons 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. Growers had no contact with each other, so these results 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.

The comparison with the scenarios showed that both the growers and the producers had positive results in the short term market. When the market performance is evaluated, with the five criteria that were formulated in Chapter 4, the findings are the following.

The first PI is that the market price should stay below the cost of producing heat with a boiler. Figure 3 clearly shows that this is the case. Throughout the simulation, the market price stayed under the boiler cost level.

The second 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 4. From day 7 the market price is down to marginal cost levels. Therefore it can be stated that when there is limited 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, because producers strategically offered at higher prices. This means 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 prices are still lower than the cost of self-production with a boiler. This changes during the spring when the market price drops due to changing market conditions when approaching the summer.

The third PI is that sufficient volume should be traded. Figure 5 shows that 76% of the market demand was settled. The result of the traded volume compared to the market supply yields a much lower result, especially in the summer. However, the criterium is evaluated from the consumer's perspective, thus it is concluded that a sufficient amount of heat energy was traded. The 24% that was not settled is mainly a result of the failed strategic choices by growers to ask small volumes for very low prices.

The fourth and last PI concerns 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, ability to 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 market power of producers and security of supply. The goal of this research was to find answers to such concerns.

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 question of security of supply can be answered by a more technical analysis of the DHS, which was out of the scope of this research. Nevertheless, 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.

In tight market conditions, there is a dominant strategy for producers to offer higher prices than MC to the point of the alternative cost price point, because all producers must operate to supply the market demand. There is a limited risk of losing market share when producers offer at high prices. For the individual producer, the risk of missing a settlement gives him the incentive not to offer too high. 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, 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 (WIP and Bio) performed better than the profit-seeking producers (CCGT and Geo). The volunteer's dilemma explains why this is the case (for a summary see von der Fehr & Harbord (1998) p. 29 to p. 36).

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.

As soon as the market conditions are wider, 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 in making use of his market power. In the simulation, there was no explicit collaboration among participants, because participants did not know each other and 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 strategic offers of the CCGT 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 the CCGT producer, not for the geothermal producer.

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. The market outcome is however still 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.

7. Conclusion

The goal of this research was to find out if in a short term heat market, the degree of competition is sufficient to drive the market price to marginal cost levels or if market power from producers dominates the market price.

In summary, this research has shown that in a short term heat market of horticultures DHS prices will converge to marginal cost levels when market conditions are not tight.

Both horticulture companies collectively and producers have market power depending on the market conditions. The results of short term market will not be comparable to the case of a perfectly competitive market. However, they can still be considered desirable for both horticulture companies and producers when we look at the PI's:

- The market prices will be lower than the cost of 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.

These conclusions apply to the DHS in the B3-Hoek when it is more developed in the future, because those market conditions were tested. In tight market conditions (winter), producers will behave in a Cournot competitive way where the output level of production and offer prices are strategically used to increase profit. The degree of competition is not high enough to prevent this. However, increasing the market price through strategic behaviour is limited to the extend that horticulture companies are willing to pay.

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 lowers. This puts pressure on the producers to offer at marginal cost levels. This means that during the summer the heat prices are more likely to reflect marginal costs of production in the DHS, because the degree of competition is high enough.

Recommendations

Based on the findings in this research, recommendations can be given for the implementation of a short term market in the B3-Hoek and for future research.

For the implementation of a short term heat market, technical analysis of the system should be done to identify technical changes that have to be made to support a short term market. Throughout this research technical constraints, be it on the production side, consumer side or in the network itself were not discussed and need further investigation. How does

each of the technical characteristics of each type of producer support or limit short term trading in a heat 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 for a financial analysis into the costs that are involved for changing the system and its new operational structure.

Lastly, a market consultation in the B3-Hoek should be done to question more stakeholders about their opinion on the short term market implementation in the future. The results of the interviews and surveys are not significant for the whole B3-Hoek. This research can be used to explain the working of the short term heat market, and show that it can be a good alternative for 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 perform better.

For future research, the behavioural characteristics of the growers and producers found in this research can be used in a computer simulation of a market. Here more market conditions can be simulated to investigate the performance. Also, the effect of different cost structures can be used to develop more scenarios and see what factors determine the strategies used by agents in the short term market. Agent-based modelling could be used to develop such a model.

Moreover, more research should be done into the necessity of using intraday market in a heat market. The liquidity of a heat market can be improved by adding an intraday market. This intraday market takes care of missed settlements in the short term market, 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 redispatch. It would also be valuable to investigate how this intraday market affects behaviour in the short term market.

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 two different markets. This interdependency is not 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? Additionally, this research used a sealed double-sided uniform auction. There are other auction formats for energy trade, such as one side (only producers offer, demand is given), discriminatory or Vickrey auction. The effect of the different auction methods on the market performance is well-studied in electricity markets (Fabra et al., 2002; N. H. von der Fehr & Harbord, 1998), but not for markets such as the one studied in this research. More research could provide knowledge on what auction format results in the best market performance.

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