The participation of greenhouses in the redispatch market for congestion management on the electricity grid

Judging the redispatch market based on greenhouse grower specific characteristics

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I hope you will enjoy the read!

Anneroos Renaud

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Executive summary

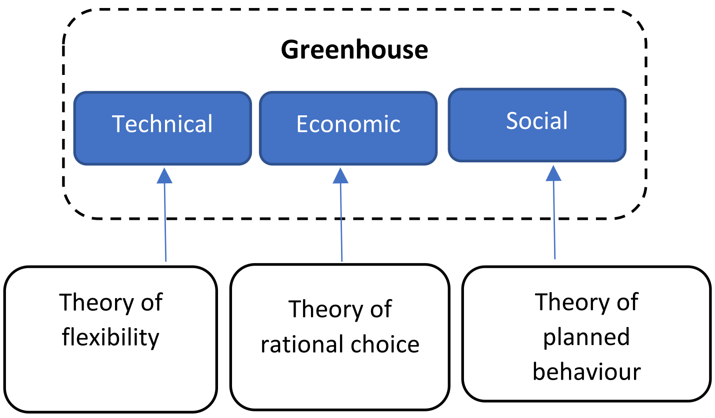
The growing share of renewable electricity generation poses a balancing challenge on the electricity grid and thus increases chances for congestion. On the supply side, flexibility can be built into the system. One option for a market to avoid congestion is the redispatch market, which is the way of solving congestion used in The Netherlands. Given the growing needs for congestion management, the redispatch market has recently been opened up to allow smaller volumes to supply to this market. The question is who can and wants to provide additional supply to the redispatch market. This research is executed for AgroEnergy, a market leader in delivering sustainable energy solutions for greenhouses. The focus of this research will be on potential flexible electricity offered to the redispatch market, by greenhouse growers.

There are still unclarities regarding the potential for an expansion of the redispatch market by using the flexible supply of greenhouse growers. These unclarities concern the technical potential of greenhouse growers in providing flexible electricity to the redispatch market, the potential profitability of the redispatch market for greenhouse growers and the factors influencing the willingness of greenhouse growers to participate in the redispatch market. The following main research question is the focus of the research:

How will the redispatch market be judged from the perspective of a greenhouse grower as electricity supplier and what may be done to change this judgement?

A market can be designed in multiple ways. There appear to be two main goals of an electricity market, being affordability and reliability. The goal of this research is to identify how greenhouses can supply to the redispatch market and how this supply can potentially be enlarged by changes in the market design of the redispatch market.

Different knowledge gaps related to this research question have been identified in a literature review. In the literature review, two viewpoints are discussed: neoclassic theory and behaviour theory. According to the neoclassic theory, an individual will rationally choose for a certain action if he can make profit from it. In order to be able to make profit from the redispatch market, first a greenhouse needs to be able to supply to the redispatch market given technical characteristics. Following from the neoclassical theory, is the rational choice theory. This theory states an individual will always choose for the best option, out of different alternatives. So following from the rational choice theory, the redispatch market needs to provide an additional revenue as compared to opportunities. Logically, if a greenhouse grower can earn more, from supplying to other markets, he will not supply to the redispatch market, according to the rational choice theory. Lastly, besides (rational) economical motivations to perform a certain action, there appear to be other behavioural aspects determining the behaviour of individuals.



The first knowledge gap is related to the technical characteristics of a greenhouse, in relation to the redispatch market. A greenhouse grower appears to have specific characteristics that influence the ability to supply flexible electricity, which restrict the hours flexible electricity can be offered to the redispatch market. Besides, the redispatch market has certain characteristics that determine the flexibility needs. The theory of flexibility is used, to investigate whether greenhouse growers would technically be able to supply to the redispatch market. Using available congestion data at TenneT and information about the redispatch market design, the flexibility needs in the redispatch market are established. Besides, using greenhouse specific data available at AgroEnergy, the flexibility to be (potentially) supplied by greenhouse growers, is established. The results are presented in the following table. From this, it appears based on technical characteristics, greenhouse growers can supply to the redispatch market.

Flexibility aspects	Present in greenhouse	Needed in redispatch market
Time specificity	Most flexibility in the transition months, mostly during the morning (before APX) or afternoon (after APX).	Most congestion occurs between 9:00 and 19:00, but congestion can occur during any hour.
Change in time: capacity	Average value of 1 CHP is 2 MW. The total capacity of the redispatch pilot greenhouses differs from 6 to 20 MW.	All congestion volumes are needed. The minimum bid-size is 0,5 MW.
Duration	Duration is at least 1 hour, at maximum (averagely) 5 hours.	The most occuring congestion had a duration of 1, 2, and 4 hours.
Lead time	A few minutes.	Most congestion management happens the day before delivery.
Location	Distributed over the whole country, but there are specific regions where greenhouses are concentraded.	Congestion management is needed in the whole country; in non-congested areas, upward regulation redispatch volume is needed.

The second knowledge gap is related to the potential profitability of the redispatch market. A deterministic model has been developed to identify for which prices on the redispatch market it would be rational for a greenhouse grower to supply to the redispatch market. Here, the valuation of opportunity plays a role in determining the needed redispatch price. Based on data about the redispatch costs of 2017, provided by TenneT, it is likely that the redispatch market can provide an additional revenue to greenhouse growers. Next to this price-calculation, a deterministic model has been developed, which can be used to calculate the average monthly revenues on the redispatch market. Since the exact congestion scenarios and pricing in the redispatch market are still unknown, this deterministic model is meant to give an indication of potential earnings under different circumstances.

The third knowledge gap is related to the willingness to participate to the redispatch market, which can be caused by multiple aspects. The theory of planned behaviour is used as an approach to structure this part of the research. The most important findings from this part of the research are that greenhouse growers are mainly motivated by monetary rewards. Besides it appears greenhouse growers can quite easily be motivated to change from current behaviour to behaviour that may increase their earnings: stickiness is not an important determinant for behaviour. However, it appears losses are valued high in the redispatch market. The potential fine that a greenhouse grower may have to pay, for not delivering a certain volume, can withold a greenhouse grower from participating in the redispatch market.

The last knowledge gap relates to the market design of the redispatch market, and tries to identify how the participation of greenhouse growers in the redispatch market can be enlarged by changing the market design, while still adhering to the goals of an electricity market: affordability and reliability. A few market design aspects can be changed, in order to increase the willingness of greenhouse growers to participate in the redispatch market.

In the redispatch market, a fine will be given to a supplier if a different volume is supplied, compared to the settled volume. There are certain market aspects that can be changed in a specific way, in order to reduce the risk for a fine. Since it has appeared a fine may withhold potential participants from participating, it is advisory to reduce the risk for a fine. One way of doing so is by allowing units to form a pool, which allows suppliers to integrate reserve units into their portfolio.

Besides, while a capacity payment appears to enlarge willingness to supply to the redispatch market, this leads to gaming incentives and is therefore not advisory. A valuable addition to the redispatch market would be to add conditional bids, where a supplier can supply multiple bids of which only an amount can be settled. This increases both the supply to the redispatch market, as the probability that a greenhouse can sell to the redispatch market. Lastly, it appears a marginal pricing rule is better for allowing new entrants to a market, as compared to a pay-as-bid pricing rule. Namely, it appears to be difficult to estimate a good price in a pay-as-bid auction, which may be a barrier. However, for the greenhouse growers who are clients of AgroEnergy, this aspect is irrelevant since AgroEnergy places the bids for its clients.

Definitions and abbreviations

These definitions may provide clarity for certain technical terms.

Greenhouse grower	A person who owns a greenhouse.
Combined heat & power plant (CHP)	A machine which is often fueled by gas, which produces both heat, CO_2 and electricity.
Congestion (on the electricity grid)	When the transport needs on a certain part of the electricity grid are larger than the transport capacity.
Flexible electricity	Electricity that can be used to match demand and supply, if demand and supply do not match at a certain time and location.
Flexmarket	A market place where flexible electricity can be sold and bought voluntarily. Flexible electricity is needed in times of congestion.
Redispatch	A mechanism where the electricity market is cleared as if there is no congestion. Then, after clearing, the TSO redivides market bids (a bid contains: a certain amount of electricity that can be delivered, at a certain time and place, for a certain price) to prevent congestion to happen.
Pilot	(Small) project to test a certain technique or design.
Grid reinforcement	Changing the physical structure in such a way that more electricity can be transported over the grid, at a certain moment in time.
TSO	Transmission system operator, responsible for the transmission grid
DSO	Distribution system operator, responsible for the distribution grid
Settlement of a (redispatch) bid	By settlement, ‘acceptance’ of a bid is meant. The offered capacity is bought by the system operator.

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Chapter 1: Introduction

In this chapter, the introduction of the problem that will be central in the research, is given in Section 1.1. More insight regarding the research scope is given in Section 1.2. Lastly, the problem statement is explained in Section 1.3.

1.1 Problem introduction

In the following years, a drastic change has to be made in the sources that are used for producing energy. Fossil energy sources contribute to climate change since CO_2 is emitted in the process of retrieving energy from fossil sources. By signing the Paris Agreement in 2015, many countries including The Nederlands have acknowledged CO_2-emissions have to decrease drastically (UN, 2015). This trend towards sustainability imposes challenges for the electricity system (TenneT, 2019).

1.1.1 Congestion on the Dutch electricity grid

To enable the increase in the share of renewables in the electricity market, the electricity system needs to adapt in order to avoid congestion on the grid. Congestion is a situation where the capacity of the electricity grid is not large enough to serve the demanded capacity (Tennet.eu, n.d.). In Figure 1, the predictions made by TenneT (2018) show an increased need for congestion management, on both the transmission and distribution grids. The transmission grid is the high voltage grid, transporting a large amount of electricity from large producers to a small amount of consumers. These consumers are mostly distribution companies, who transport the electricity over the lower voltage distribution grids to a large amount of smaller consumers. As treated in the proposed Dutch Klimaatakkoord, system operators and market parties need to develop a system for congestion management, in which local flexibility is used based on market principles (Rijksoverheid, 2018). There are certain trends increasing the likelihood of congestion. First, renewable energy supply - via wind and solar - is volatile and often differs from the expected production (Heide et al., 2010). Besides, because of a higher share of decentralized electricity supply, for instance generated using solar panels, a higher capacity of the electricity grid might be needed. Lastly, demand peaks are higher which asks for a higher capacity as well. Demand peaks can for instance be caused by people charging their electric vehicle at the same time (Stedin, 2018).

At this moment, 15% of the total electricity use is generated by renewable sources. 55% of the renewable production consists of wind power; 18% is produced from solar energy (CBS, 2019). In 2018, the largest growth in renewable energy supply was supply using solar energy. Wind and solar are both volatile renewable energy sources; the growth of these two production sources implies a growth in volatility. Different specific congestion challenges have already been predicted in the Netherlands. An example is the congestion that will likely occur when the wind farm of Borssele will start to produce electricity; on days of heavy wind, the transport capacity of the grid will not be sufficient to fullfil the transport needs (Reijn, G., 2019). Greenhouses encounter problems with congestion on the electricity grid as well, since on some locations, there is not enough transport capacity so greenhouses cannot expand (ANP, 2-3-2019).

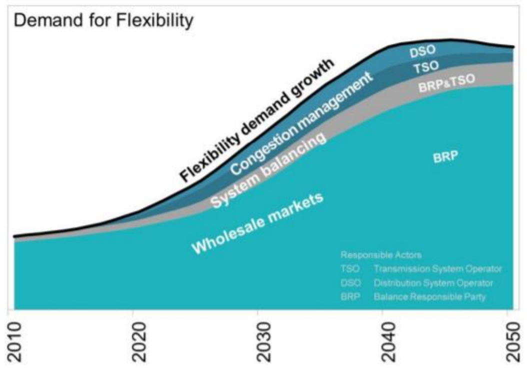


Figure 1: Demand for flexibility, future prediction. Source: TenneT Flexibility Roadmap, 2018

1.1.2 Types of congestion management

Congestion management implies the actions undertaken to avoid congestion on the electricity grid (Kumar, Srivastava & Singh, 2005). It is important to resolve congestion, since unsolved congestion can lead to a black-out, after which it may take days before the system is restored (Hirth & Glismann, 2018). There are two main types of congestion management: changing the physical structure or shifting generation and load (Hirth & Glismann, 2018).

1.1.2.1 Changing the physical structure

For short term solutions, network operators can reconfigure the network topology or cancel planned outages of network elements, if these outages seem physically impossible. The strategy for a long term solution would be to reinforce the grid. Reinforcing the grid means changing the physical structure in such a way that more electricity can be transported over the grid, at a certain moment in time. However, reinforcing the grid requires high investments and a clear business case. System operators do not want to reinforce the grid for 'a few sunny days' that cause the transport needs to be high; this would be too costly (Savelkouls, 2019). Besides, reinforcing the grid takes time, while congestion is already an issue. Research executed by Jirous et al. (2011) shows the grid capacity in The Netherlands cannot develop as fast as the increase of renewable energy supply requires to.

1.1.2.2 Shifting generation and load

Shifting generation and load implies reducing generation at one place and increasing generation at another place, in order to solve congestion. Storage of electricity could be an option to shift generation and load. This way, electricity produced when it is windy or sunny can be stored for days with less wind and sun. For instance Shell is currently working on such a method using batteries (Dijk, 2019). However, storage is very expensive and needs more investigation on the reliability (Argyrou, Christodoulides & Kalogirou, 2018). Therefore, this option will not be considered in this research.

A flexmarket for energy could be a less expensive and thus more socially desired alternative to avoid congestion, as compared to grid reinforcement and storage (OTE, 2018). A flexmarket is a certain place where flexible electricity can be sold by suppliers and bought by grid operators to balance the grid. This way, the transport capacity is being used more efficiently by motivating grid users to increase or decrease their consumption or production at certain moments (Duijnmayer, 2019a). The price of electricity is the current mechanism to change the behaviour of (possible) suppliers of flexible electricity (Stedin, 2018). It should be mentioned flexibility solutions do not prevent the grid from having to be reinforced, but can only provide a temporary solution to solve congestion (ECN, 2017).

Currently in The Netherlands, congestion on the transmission grid is solved using the market mechanism of market-based redispatch. In fact, there are three options for doing congestion management using a flexmarket, as described by Hirth & Glismann (2018). These three options are:

1) Connection management, meaning restrictions to new connections can be done, based on the available connection capacity.
2) Dispatch management (Redispatch), meaning a network operator reschedules the dispatch, from one location to another.
3) Trade management, meaning the trade between two locations is managed via for instance capacity auctions or nodal pricing.

In this thesis, it will be assumed dispatch management will remain the main mechanism to solve congestion in The Netherlands. Redispatch is a mechanism where market bids are redivided to prevent congestion to happen (TenneT, 2018). A bid contains a certain amount of electricity that can be delivered, at a certain time and place, for a certain price. For redispatch, the location of the electricity producer and consumer is important because congestion occurs on a certain location on the grid.

Grid operators can choose between two potential forms of performing redispatch. The first type of redispatch is congestion management as described in the Dutch law (Netcode Elektriciteit, art. 9, 2019). This form of congestion management is used when structural congestion is expected in a certain area. Electricity producers with a connection capacity of over 60 MW are obligued to participate in this form of congestion management. Electricity producers with a lower connection capacity, can voluntary participate in this form of congestion management. This form of redispatch is the traditional way of redispatching, where a number of generators was obligued to participate (Hirth & Schlecht, 2018).

The second type of redispatch is congestion management via a voluntary flexmarket. The difference with congestion management as described in the Dutch law, is the fact that participation is voluntary for *any* supplier in a flexmarket. Units cannot be forced to participate in a flexmarket. These two both forms are currently existing next to each other in The Netherlands. More detail regarding the specific differences between the two forms will be given in Chapter 4.

To be able to serve the increased demand for congestion management (See Figure 1), there needs to be an increased supply to the redispatch market. As stated by Stedin (2018, pp. 11)): ‘Finding enough flexible supply to avoid congestion, currently is a big challenge’. Another reason to increase the amount of suppliers, is the fact that currently, there is not much competition in the redispatch market since there is a small amount of suppliers. It appears however that competitive markets for supply and demand enlarge the system efficiency (Hermans, Van den Bosch, Jokic, Giesbertz, Boonekamp & Virgag, 2011). For these two reasons, there needs to be an increase in power plants that can provide supply-side flexibility. Supply-side flexibility refers to power plants or storages able to ramp up or down in order to attain the power balance in times of disequilibria (Cochran et al., 2014). In order to increase the supply to the redispatch market, access has been given to electricity producers with a smaller capacity. In the two different forms of redispatch, smaller capacity units (<60 MW) can *voluntarily* supply to the redispatch market. For smaller units, the two forms of redispatch do not differ heavily. For grid operators, it is useful to know whether small suppliers would actually be willing to participate in the redispatch market.

1.1.3 Research company

The research will be executed as an internship for the company AgroEnergy. AgroEnergy is a subsidiary of Eneco and is a market leader in delivering sustainable energy solutions for greenhouses. AgroEnergy tries to map the electricity sector and this way tries to, specific for each greenhouse, form a strategy concerning when and where to buy and sell its energy. Selling electricity via a flexmarket is one of the options. Because of this, the focus of this research will be on greenhouses as suppliers of flexible electricity to the redispatch market.

1.2 Research scope

There are multiple smaller parties that could participate in the redispatch market. Combined heat and power plants (CHPs) could be used as a flexible source to balance the intermittent renewable power production (Levihn, 2017). In many greenhouses, a CHP is used in the production process. Greenhouses use these CHPs to produce heat and CO_2 for their crops as well as electricity for the lights. The amount of CHPs in greenhouses has increased sharply in the past few years (See Figure 2), when the economical potential of owning a CHP became clear (Kasmire, 2015). After 2009, the CHP capacity in the Dutch horticulture sectore has remained nearly constant (Velden & Smit, 2015; CLO, 2019). Statistics provided by CBS (2015) show in 2015, 109,1 PJ electricity was produced by decentral CHPs which are often located in greenhouses. This is equal to approximately 30 TWh[1]. So when it comes to volume, CHPs could offer a significant contribution to the increased flexibility needs (See Table 1).

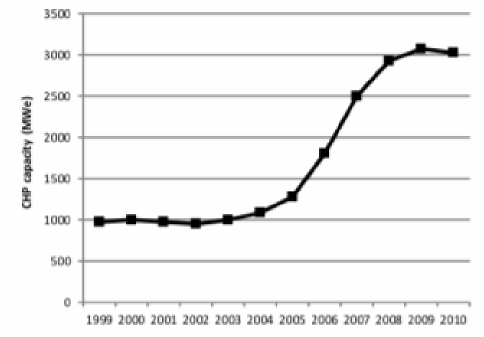


Figure 2: Development of total electrical CHP capacity in the Dutch horticulture sector. Source: Van den Velden & Smit, 2011

Remaining electricity – electricity that is not needed for the lighting – can be sold to multiple electricity markets. Since a greenhouse is a fairly complex system where the amount of light hours, heat and CO_2 are of great importance for their crops, this may pose a restriction to the amount of flexible electricity the greenhouses are able to offer (Rodrigues, Berenguel, Guzman & Ramirez-Arias, 2015). In other words: it is a question whether these small suppliers can contribute to solving congestion. This is something that has not been researched yet.

Table 1: Demand for flexibility in balancing market due to different future scenarios of renewable energy generation. Source: ECN Policy Studies (2017), Demand and supply flexibility in the power system of The Netherlands, 2015-2050.

		Reference scenarios			Alternative scenarios		
	Unit	2015	2023	2030	2023	2030	2050
Maximum hourly ramp-up	GW/h	1.1	3.9	4.7	3.9	4.7	13.7
Maximum hourly ramp-down	GW/h	1.1	3.6	4.4	3.6	4.4	12.8
Annual demand for ramp-up	TWh	0.7	2.4	3.0	2.4	3.0	8.5
Annual demand for ramp-down	TWh	0.4	1.5	1.8	1.5	1.8	5.3

Besides the technical constraints determining the *ability* to offer capacity to the redispatch market, it is important to investigate the *willingness* to offer capacity to the redispatch market. The redispatch market is an addition to the already existing places where greenhouses can offer their electricity to (AgroEnergy, 2017). The different electricity markets will be treated in Chapter 4. Greenhouses are free to choose between the different alternatives, so the question is whether they would (voluntarily) decide to offer electricity to the redispatch market and what may motivate or withold them from doing so. It still remains a question what drives greenhouse growers to adjust their behaviour in the direction of offering flexible electricity.

The exact design of the redispatch market is still under discussion (GOPACS meeting, 2019). It is important to investigate which different design changes can still be considered and how these differences influence the role of greenhouse growers in congestion management, based on the technical ability and social and economical willingness to supply to the redispatch market.

[1] Watt = Joule/second → 1 Wh = 3600 J → 1 TWh = (1/3600)*1000 = 0,28 PJ.

1.3 Problem statement

From this problem introduction, it follows the flexibility demand for both TSO and DSOs for doing congestion management will increase in the future (Figure 1). In order to deal with this, smaller volumes have been given access to the redispatch market for doing congestion management. In the redispatch market, units with a relatively low capacity (<60 MW) cannot be forced to supply to the redispatch market. The question rises whether units with a small capacity would voluntarily supply to the redispatch market.

Greenhouses with a CHP may be in the position to provide the flexibility needed to participate in the redispatch market. The real potential of greenhouses as suppliers to the redispatch market needs to be investigated, which depends on their technical potential, their social willingness and their economic characteristics. The impact of certain aspects of the market design on these characteristics is an essential part of the research. In Chapter 2, a literature review will be presented, from which the knowledge gaps follow which will serve as guidance for the research.

Chapter 2: Literature review: Theory on behaviour of suppliers in electricity markets

GOAL	METHOD	RESEARCH QUESTION
To identify how an electricity market could be designed and what the likely response to certain design (aspects) is, if participation in the electricity market is on a voluntary basis.	Literature review using existing theory.	From this literature review, specific knowledge gaps follow which will be translated into the research questions (See Chapter 3.2). Existing theory forms a framework for the research.

The goal of this literature review is to identify the state-of-the-art knowledge about the impact of the different design-options of electricity markets on the parties performing behaviour in electricity markets. The literature gives a motivation for the choice where to focus on in the further research. Two perspectives are considered in this literature review: the perspective of TSO and DSO, who are in the position to design an electricity market, and the perspective of a greenhouse grower as potential supplier to an electricity market. This will be done by first focussing on the market design in Section 2.1, by identifying the goals (Section 2.1.1) and potential inefficiencies (Secion 2.1.2) of an electricity market and the way an electricity market can be designed to reach those goals and overcome the inefficiencies (Section 2.1.3). Based on neoclassical economics literature (Section 2.2) and on behavioural economics literature (Section 2.3), it will be identified what the relationship between a certain design and the behaviour of parties in this market design is, given the theories. The knowledge gaps that follow from this literature review will be presented in the final part of this chapter, Section 2.4.

2.1 The market design of an electricity market

The goal of an electricity market design is to provide reliable electricity at low costs (Cramton, 2016). These are the targets that should be kept in mind when designing an electricity market. First, it will be explained what is needed in order to fulfill this goal and which inefficiencies might stand in the way of these goals. Then, the market design aspects that target those goals are explained. For investigating the design options, the focus is on European electricity markets. European markets are more fragmented than e.g the North-American electricity market. This fragmentation is in line with the legislative packages of the European Comission, prescribing a liberalised internal energy market (EPRS, 2016).

2.1.1 Goals of an electricity market design: Reliability and affordability

Reliability of the electricity grid is measured by three indicators by ENTSOE. These three measures are: 1) Energy not supplied to final consumers due to incidents, 2) Total loss of power, which is generation shortfall and 3) Restoration time, which is the time from disturbance until the return to the nominal system frequency. With a higher share of variable renewable energy sources in the electricity system, flexibility services should be brought into the market in order to maintain a reliable electricity system (Heylen, Deconinck, Van Hertem, 2018). So flexible supply to the redispatch market is needed to maintain a reliable Dutch electricity system. Since the flexibility needs will increase, system operators need more participation in the redispatch market to be able to solve congestion and to maintain a reliable electricity system.

In line with this, there are the two key-objectives of a market design, as described by Cramton (2016), being 1) short-run efficiency and 2) long-run efficiency. Short-run efficiency points to making use of available resources; e.g. greenhouses with a CHP to assist in congestion management. Long-run efficiency points to a market providing the right incentives for efficient, long-run investments. Since the focus of this research is on greenhouses who already own a CHP as participants in the redispatch market, the focus is on those design aspects that motivate available resources to participate in the redispatch market: short run-efficiency. In the discussion in Chapter 9, it will be discussed whether it will be likely that parties invest in production units to specifically participate in the redispatch market. In other words: whether the redispatch market adheres to the long-run efficiency objective.

Secondly, a market design should focus on providing electricity at low costs. Congestion management is the responsibility of the grid operators, meaning they have to pay for congestion management. The lower the redispatch prices, the lower the costs for the grid operators. The most common way of reducing costs, is by enlarging supply in a competitive market (Hermans et al., 2011). Namely, a larger supply will likely lead to lower prices, which reduces costs for TSO and DSOs. So enlarging the supply of generation power in an electricity market, is both advantageous for the reliability, as for the affordability of electricity. It should be noted enlarging supply is beneficial from the perspective of system operators. From the perspective of potential suppliers, lower prices will not be beneficial.

2.1.2 Market inefficiencies: Market power and gaming

There are certain risks involved with the behaviour of parties in an electricity market, that may reduce the reliability and affordability of electricity. The two main inefficiencies in electricity markets, are market power and gaming.

Market power

The definition of market power is “the ability of a seller to profitably maintain prices above competitive levels for a significant period of time” (Rahimi and Sheffrin, 2003, p. 486). Market power can exist of physical withholding, meaning a seller withholds some of its capacity in order to drive up the prices. Economic withholding means bidding way above marginal costs in order to drive up the prices. Market power cannot exist in a competitive market with abundant supply, since a party would lose market share (Rahimi and Sheffrin, 2003). However, locational market power may lead to parties with a small market share on system-level, have a significant market share on locational level. Since congestion is location-specific, this form of market power may thus rise, even in a competitive market.

Gaming

The definition of gaming is “market participants engaging in uncompetitive behaviour that takes advantage of certain market rules and system conditions by deviating from normal bidding, scheduling and operating patterns” (Rahimi and Sheffrin, 2003, p. 487). In redispatch specifically, increase/decrease gaming – inc-dec gaming – is possible. This happens when generators purposely increase congestion by scheduling a sell-bid – on e.g. the day-ahead market – in an area with high congestion probabilities. Then, they will receive a payment for not delivering this electricity (Neuhoff, Hobbs & Newbery, 2011). So in the end, congestion is not decreased and the system operator only loses money. This form of inc-dec gaming can only occur if a supplier anticipates the redispatch market when submitting bids to the spot market (Hirth & Schlecht, 2018). This means he must be able to make an accurate prediction of congestion in his area in order to adapt his day-ahead bids. In Germany, this is likely the case, where some lines are congested for 20% of the time (Hirth &

Schlecht, 2018). It needs to be investigated whether such information could be deducted from the Dutch redispatch market, making gaming possible.

Arbitraging

A legal form of gaming is arbitraging, which is defined as "an investment strategy that guarantees a positive payoff in some contigency with no possibility of a negative payoff and with no net investment" (Dybvig & Ross, 2017, p. 188). Arbitraging can occur in any market. Arbitraging can cause prices to converge, when for instance a trader who expects imbalance prices to be high buys on the day-ahead market and then sells in real-time, on the imbalance market. Rahimi and Sheffrin (2003) claim arbitraging has no negative impact on the affordability and reliability of electricity, this may be different for the redispatch market. However, the underlying assumption of this claim is that the location does not play a role, while for congestion management this is not true. As explained, congestion happens when a certain cable is congested, so congestion cannot be solved with 'any bid'. This may make arbitraging between different electricity markets a problem, if an essential bid to solve congestion is arbitraged via another market.

2.1.3 Aspects of an electricity market design

An electricity market can be designed in multiple ways. Polavskaya and De Vries (2019) developed an assessment framework of the degree of integration of distributed energy resources (DER) into the balancing market. The goal of this framework is to be able to provide recommendations for an electricity market design. This framework focusses on European regulation and can be used by any EU country. The reason this framework is used, is to ensure no market design aspects are neglected. To define distributed energy sources, the definition proposed by Ackermann, Andersson and Söder (2000) is used: 'Distributed generation is an electric power source connected directly to the distribution network or on the customer side of the meter.' (Ackermann et al., 2010, p. 201). Using this definition, greenhouses using a CHP are distributed energy sources. This justifies the use of this framework for the judgement of the market design. First, the whole framework is presented. Then, the aspects relevant for this research – greenhouses with CHPs in the redispatch market – are picked by discussing each of the aspects. The adapated framework will then be used for the research. The full framework is presented in Table 2.

Table 2: Assessment framework for judging a market design. Poplavskaya & De Vries, 2019

	Group	Variable
Market access	Formal access requirements	Explicit restrictions for certain types of service providers
		vRES acces to the balancing market
		Capacity provision
		Specific products for DER
	Administrative aspects	Pooling
		Approach to prequalification
		Explicit portfolio requirements
	Technical prequalification criteria	Activation speed and duration
		Ramp rate
Auction configuration	Bid-related requirements	Minimum bid size
		Bid symmetry
		Procurement of capacity & energy
		Energy bid adjustment

		Non-precontracted energy bids
	Time-related characteristics	Frequency of bidding - capacity
		Frequency of bidding – energy
		Frequency of market clearing – capacity
		Frequency of market clearing & activation - energy
	Remuneration	Pricing rule
		Special support schemes for balancing service provision

2.1.3.1 Market access

Market access relates to all rules for parties who want to access a particular market. In this group, formal access requirements refer to obligations or restrictions for certain parties who want to enter a market. Explicit restrictions can be based on different aspects, for instance connection level or size. This aspect is relevant for the research, since it determines whether greenhouses with a CHP can enter the redispatch market.

Variable renewable acces is not relevant for the research, since greenhouses with a CHP are no vRES.

Capacity provision relates to the obligation of power plants over a specific size to provide balancing services. This is not relevant for the research, since the redispatch market is voluntary and since greenhouses with CHPs can only offer relatively small volumes.

Specific products for DER are meant to extract additional value from a particular technology in the form of for instance demand response or immediately interruptable loads. This can play a role in the research if for instance power plants can be shut down in a congested area.

Administrative aspects relate to the way distributed energy resources are organized. Pooling of different suppliers makes it possible for suppliers to integrate reserve units into their portfolio and also allows for a bundling of capacity that can be offered. This is relevant given the small capacity of a CHP in a greenhouse and given the relatively low reliability of a CHP (Haghigam & Manbachi, 2011). The approach to prequalification points to whether each unit is prequalified or the portfolio as a whole. In this research, this points to whether a redispatch bid has to be delivered by a specific CHP in a greenhouse, or by the connection the greenhouse has to the grid. For sake of clarity, this aspect is renamed as 'verification of delivery'. Verification of delivery is important, since for solving congestion accurately, all scheduled bids need to be supplied at the right location. If a supplier in the redispatch market behaves differently than 'promised', congestion may occur. The exact delivered volume can be verified in multiple ways. Explicit portfolio requirements may oppose restrictions to the amount of units in a portfolio and can be relevant, if there are requirements.

Lastly in this group, technical prequalification criteria are relevant, since a CHP has technical restrictions; the technical prequalification criteria need to be such that a CHP can supply.

2.1.3.2 Auction configuration

The minimum bid size is relevant, since CHPs can offer relatively small volumes. The bid size can have an impact on the potential supply, too. A higher supply appears to be beneficial to an electricity market (Section 2.1.1 and 2.1.2). Corresponding to this, is the *settled* size of a bid. Namely, settlement can be partial or all-or-none, in both time and volume (Bichpuriya & Soman, 2010). If partial volume settlement is allowed, this means only a part of the volume of a bid will be bought. This may have implications for suppliers to a certain market, who may expect to sell a certain volume and in reality sell less. If partial settlement with regards to the duration of the bid is allowed, this may lead to problems with for instance minimal downtime, which is often at least 1 hour due to technical characteristics of a CHP (Vögelin, Koch, Georges & Boulouchos, 2017).

Bid symmetry means in one bid, both upward and downward volumes can be supplied. Bid symmetry is relevant for congestion management, since in a certain area, either upward or downward redispatch is needed (Hirtz & Glismann, 2018). By allowing bid symmetry, the supply of volume can double. Related to this, is the existence of conditional bids, which may allow for placing multiple bids of which one can be chosen.

Procurement of capacity and energy is relevant for this research, if congestion appears to be solved using fixed capacity payments and separate energy bids. For the balancing market for which this framework has been developed, capacity payments are an option. It needs to be investigated if capacity payments are a potential option for the redispatch-market.

Energy bid adjustment means a supplier can adjust its bid. This is relevant in the research, since being able to adjust a bid increases the opportunities of where a supplier can sell its electricity. It is important to make a distintion between adjusting a *placed* bid, or adjusting a *settled* bid.

Non-precontracted energy bids can be done by parties who did not have a capacity reservation. This is only relevant for the research, if in a redispatch market capacity reservation will occur.

The second type of characteristics in this group are the time-related characteristics. The frequency of capacity bidding only plays a role, if capacity biddings occur. The frequency of energy bidding does play a role, since it determines how many bids a certain supplier can do, in a certain time frame. The frequency of market clearing and activation of energy plays a role, since this determines when a supplier knows whether his bid will be settled. If a bid is not settled, it determines how much time a supplier has left to sell his electricity elsewhere.

Lastly, the remuneration of suppliers plays a role in the market design. The pricing rule can be pay-as-bid, where a supplier receives the bidding price if his bid gets settled. Another option is marginal pricing, where based on the total supply bids and the demand for congestion bids, one single price is established. Although Hirth and Schlecht (2018) claim marginal pricing and pay-as-bid will likely lead to the same price level, pay-as-bid remuneration has a higher probability of causing locational gaming. Namely, if a supplier knows he is one of the only suppliers in a congested region, he can add a high price to its bid which will have to be paid, if this bid is needed to solve congestion. Therefore, the remuneration plays a role and needs to be taken into account.

Special support schemes exist if a specific type of supplier gets (financial) premiums and is relevant for the research, if appears these premiums exist in the redispatch market.

From this discussion it appears some of the design aspects in the framework are irrelevant for the research. Therefore, a shorter framework remains with which will be worked during the research. See Table 3.

Table 3: Adapted assessment framework relevant for the research. Based on Poplavskaya & De Vries, 2019.

	Group	**Variable**
Market access	Formal access requirements	Explicit restrictions for certain types of service providers
		Specific products for DER
	Administrative aspects	Pooling
		Verification of delivery
		Explicit portfolio requirements

	Technical prequalification criteria	Activation speed and duration
Auction configuration	Bid-related requirements	Minimum bid size
		Bid symmetry
		Procurement of capacity & energy
		Energy bid adjustment
	Time-related characteristics	Frequency of bidding - energy
		Frequency of market clearing & activation - energy
	Remuneration	Pricing rule
		Special support schemes

2.1.4 Conclusion on market design

In this section, an overview of the goals and potential inefficiencies in an electricity market design, has been given. The main goals of an electricity market design are reliability and affordability, which can mainly be reached by obtaining a high supply volume to that specific market. In line with the short-run efficiency target of electricity markets, it is important to mostly use already existing resources. Inefficiencies can occur due to market power. For congestion management, locational market power may exist. Another inefficiency can occur due to gaming; in congestion management, inc-dec gaming can occur. This is a situation where a supplier purposely increases congestion, to later receive a payment to reduce that congestion. Lastly, arbitraging between different electricity markets is a risk in a redispatch market. This may lead to congestion not being solved since a specific bid is arbitraged via another market.

An overview of the market design options for the redispatch market has been given, based on the framework by Poplavskaya & De Vries (2019). This framework can be used in the research.

2.2 Neoclassical economics as an approach to estimate behaviour in electricity markets

In this section, the neoclassical approach to identify behaviour in a certain electricity market, is explained. First in section 2.2.1, the theory behind neoclassical economics is explained. Then, in section 2.2.2, the use of neoclassical economis in this specific research is explained.

2.2.1 Theory

This section is meant to identify the behaviour in an electricity market, if suppliers were to behave fully rational, according to the neoclassical theory. The main assumptions of neoclassical economics, as described by Weintraub (1977), are:

- People are rational in their choices
- People maximize utility or profit
- There is full information-transparency

The neoclassical theory implies, if a certain action can increase utility or profit, a person would rationally choose for this certain action. This also implies that, if a certain market (design) is profitable to an electricity supplier, he would rationally - according to neoclassical theory - supply to this market. Neoclassical theory, logically following from this, assumes preferences are equal between all suppliers (Berg, 2003).

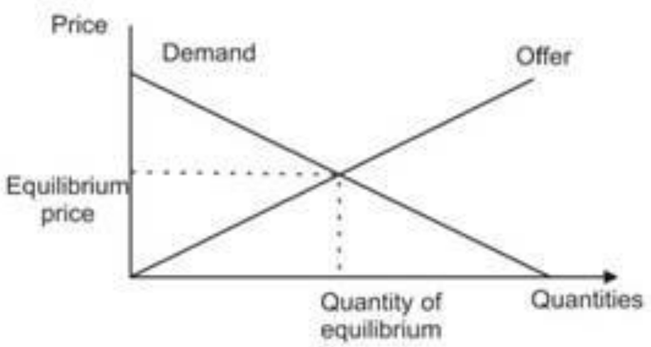


Figure 3: Neo-classical equilibrium

One of the main ‘features’ of a neoclassical market, is the equilibirum that exists when supply and demand are in equilibrium. The demand for congestion volume is not constant since congestion is not constant. The question arises, whether greenhouses can be a supplier to the redispatch at all; can greenhouses provide congestion volume at those hours where there is congestion?

From the neoclassical point of view, a market design can be judged based on the impact a certain design has, on the potential gains (revenues minus costs) of a supplier to this market. Opportunity losses play a role in neoclassical economics too. Namely, according to neoclassical theory, people rationally choose between opportunities, the one with the highest value (Harris & Holland, 1990). This is called the rational choice theory. This theory assumes people, before making a certain decision, calculate the costs and benefits of each option (Scott, 2009). (Aspects of) market designs that may affect potential gains, are from this neoclassical point of view, taken into account. Market designs that may reduce costs, lower the redispatch price (by for instance increasing supply) or affect the flexibility requirements in such a way that more parties are (technically) able to supply, are relevant. The question arises, if supplying to the redispatch market is a rational choice for greenhouses with a CHP, according to neoclassic theory. The starting point for answering this question, will be the link between the demand for congestion volume and the (potential) supply of a greenhouse.

2.2.2 Use in the research

From a neoclassical view, the economic potential of the redispatch market relates to the amount of money greenhouses can earn by supplying to this market. This depends on the relation between the technical aspects of a greenhouse and the demanded flexibility in the redispatch market. When having admitted to a certain supply bid in the redispatch market, a supplier cannot deviate from this bid anymore and will have to deliver. This implies there are opportunity costs associated with bidding in the redispatch market (Gan & Litvinov, 2003). A literature review executed by Kondziella and Bruckner (2016) on the flexibility requirements of future energy systems concludes current research mainly focusses on the *technical* potential of flexible electricity, while there is not enough research on its *market* potential. This points to the importance of considering the bigger system – including other options for selling flexible electricity – when researching the economic potential of the redispatch market. Opportunity costs are not real monetary costs, but can be used to value a certain decision over other opportunities – What could have been earned if an alternative decision had been made? This is in line with the rational choice theory which will be used for this part of the research. It needs to be investigated whether the potential earnings in the redispatch market, are higher than the potential opportunity losses on other markets.

2.2.3 Neoclassical response to a market design

As explained, the focus is on enlarging supply to the redispatch market, while still taking the goals of an electricity market – affordability and reliability – into account. Gaming, market power and arbitraging can reduce the affordability and reliability of an electricity market.

From a neoclassical point of view, any market design that reduces costs for (potential) suppliers, will likely lead to more supply to a certain market and then result in a lower market price. Namely, for a lower revenue (the price), more suppliers are able to gain from this action when the costs decrease. This is shown by a shift in the supply-curve to the right. Besides, the supply-curve can shift to the right if more parties are *able* to supply, due to less strict requirements.

Likely, any design aspect that increases costs will lead to lower supply. Namely, if the costs increase, a certain supplier will need to receive more (a higher price) in order to be willing to sell. Therefore, the supply-curve shifts to the left. See Figure 4 for an illustration.

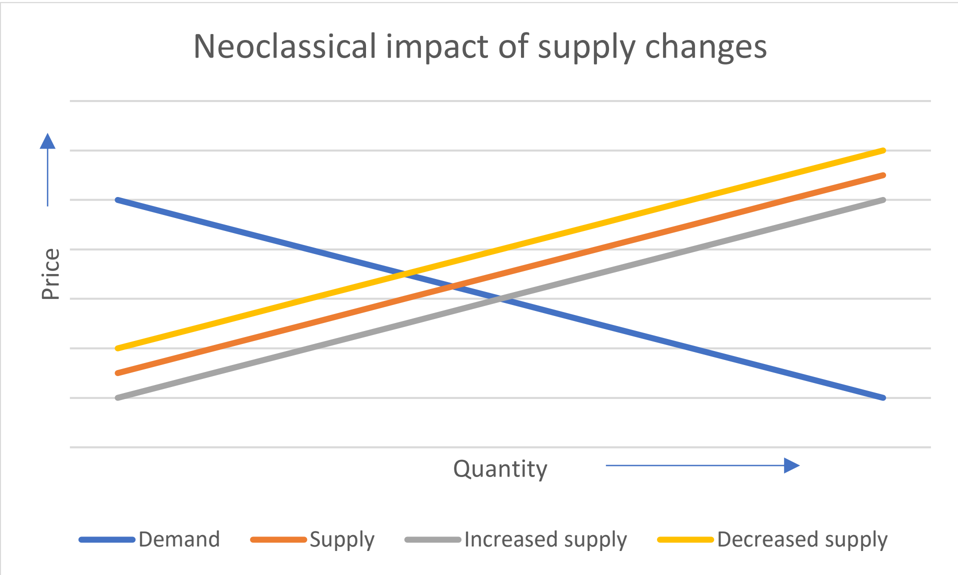


Figure 4: Neoclassical impact of an increased supply.

2.2.4 Conclusion

In light of the neoclassic theory, a certain market design is judged by the potential revenues, as compared to revenues from alternative markets. This is done fully rational, where the costs and benefits of the alternatives are considered – opportunity costs are considered costs here. Therefore, it needs to be investigated which electricity markets are direct alternatives for the redispatch market. Then, the expected revenues on each of these markets needs to be investigated in order to be able to judge the markets.

One important part of the research is to investigate the exact design of the redispatch market, based on the framework proposed in section 2.1.3, and those design aspects that are not fixed yet. Then, the impacts of different design aspects in light of the neoclassical theory – so impact on costs and/or benefits – can be treated.

2.3 Deviations from neoclassical behaviour as an approach to estimate behaviour in electricity markets

As explained, neoclassical economics assumes individuals behave rational when making certain decisions. However, there is clear evidence irrational aspects play a role in decision-making, which may lead to individuals not always choosing what is best for them in the long-run (Thaler & Sunstein, 2008). Two different forms of literature regarding human behaviour will be studied, being behavioural economics literature and pro-environmental behaviour literature. For decision-makers designing a new market – like the redispatch market – behavioural transformation strategies may provide insight into why target parties behave in a certain way and how parties could be motivated to behave differently, if the behaviour does not correspond to neoclassical expectations (Pollitt, Shaorshadze, 2011). Namely, it has been recognized by policy makers and researchers, that behavioural economics plays a role in the decision making with regard to energy policy (Alcott & Mullainathan, 2010). Literature regarding pro-environmental behaviour can be relevant, since a good working redispatch market can contribute to an accelerated energy transition.

This literature review is structured according to the Theory of Planned Behaviour (TPB). The TPB is a theory developed by Ajzen (1991) to predict human behaviour in specific contexts. According to this theory, there are three aspects determining the intention to perform behaviour:

- Attitude toward the behaviour: "refers to the degree to which a person has a favorable or unfavorable evaluation or appraisal of the behaviour in question" (Ajzen, 1991, p. 188)
- Subjective norm: "refers to the perceived social pressure to perform or not perform the behaviour" (Ajzen, 1991, p. 188)
- Perceived behavioural control : "refers to the perceived ease or difficulty of performing the behaviour" (Ajzen, 1991, p. 188)

The three social factors can all provide insight into why, from a social point of view, people would or would not perform a certain action. The role a party like AgroEnergy can play, is typically to influence characteristics that might oppose a party to act by providing facilitating factors (See Figure 5). Facilitating factors can increase the extent to which certain behaviour is performed (Triandis, 1977), since it can increase the perceived behaviour control.

The next sections explain, per factor of the Theory of Planned Behaviour framework, how these social factors may be present in greenhouse growers, and how in turn the offered capacity is influenced by social characteristics. This decision-making framework is used, since offering capacity to the redispatch market is a certain decision: it it not something greenhouses are obligued to do, they are free of choice. In this research, the 'behaviour' is 'to offer capacity', given technical characteristics (See Figure 5).

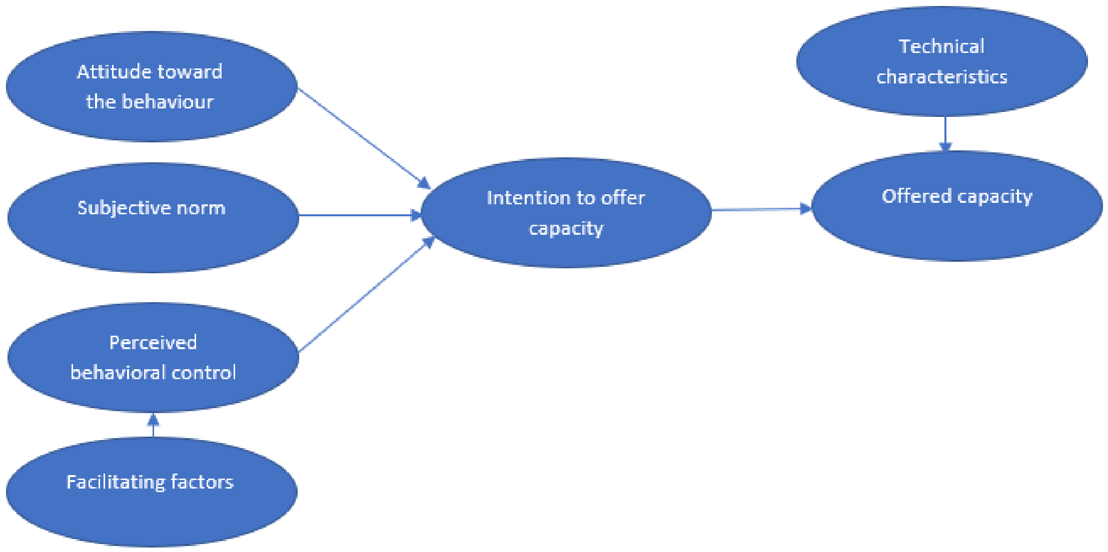


Figure 5: Theory of planned behaviour adapted to the research. Based on Ajzen (1991).

The use of the framework specific in this research, is explained in Table 4, based on the definition of the social determinants and the current knowledge of the redispatch market: a competitive market to solve congestion on the electricity grid.

Table 4: Use of the theory of planned behaviour in the research. Based on Ajzen (1991).

Social determinant	Relation to subject	Definition within the research
Attitude toward the behaviour	Greenhouses may have a positive or negative attitude toward participating in the redispatch market.	The extent to which participating in the redispatch market is (non-)favorable.
Subjective norm	Greenhouses may feel pressure to act as other greenhouses do, in order to not miss any opportunities.	The extent to which participating in the redispatch market tends to be seen as something a greenhouse has to do.
Perceived behaviour control	The redispatch market is a new market for greenhouses. Before participating in a market, greenhouses must feel like they have control over the market.	The perceived ability to be a supplier to the redispatch market and to earn money from it. This also includes the experiencing of barriers.
Facilitating factors	Some of the barriers greenhouses experience, might be taken away by AgroEnergy who can play a facilitating role.	An action which can be executed by AgroEnergy, leading to less opposition - if there is opposition - to the redispatch market.

In this section, state-of-the-art knowledge about the origin and impact of these different aspects will be presented, after which a knowledge gap can be identified.

2.3.1 Attitude toward the behaviour

As stated in Table 4, the definition for 'Attitude toward the behaviour' used in this research, is 'The extent to which participating in the redispatch market is (non-)favorable. This also includes (potential) environmental behaviour and opportunity losses.' Relevant aspects found in both pro-environmental and behavioural economics literature are presented.

2.3.1.1 Findings from behavioural economics

Opportunity loss

The impact of opportunity costs on decision making has already been researched decades ago. Thaler (1981) already decribes that opportunity costs are an important explanatory variable for choices made. However, opportunity costs are often wrongly estimated, since it appears to be hard to generate all possible alternatives (Frederick, Novemsky, Wang, Dhar & Nowlis, 2009). From research executed by Brown et al. (2019), it appears there is a negative relationship between potential opportunity losses and trust. A barrier that decreases intention for a certain action, is a lack of trust (Blake, 1999). This implies potential opportunity losses are a barrier to performing certain behaviour.

Bounded rationality

Bounded rationality is a phenomen where agents have cognitive constraints, disabling them to process all information available (Simon, 1986). Therefore, they may not always make the most rational choice, even though they would want to do so. Bounded rationality can be caused or enforced by choice overload, where too many options lead to a difficulty to pick one option (Iyngar & Lepper, 2000). This can apply to the research, where greenhouses – originally not initiated as 'electricity sellers' – suddenly have a relatively large choice as to where to sell their electricity.

Bounded rationality can also be caused by heuristics, being shortcuts in decision-making. While neoclassical economy assumes the future is known, or at least the probabilities of uncertainties can be estimated (Camerer & Loewenstein, 2004), people usually don't take the time to accurately estimate the probabilities. Different research shows people often behave differently than they would have, if they would have used a statistical rule to estimate uncertainties (Pollitt & Shaorshadze, 2011). Heuristics could be applied when a supplier decides whether he wants to supply to the redispatch market, since it is much effort to calculate the average earnings.

Prospect theory and importance of reference points
The prospect theory by Kahneman and Tversky (1979) states that changes in welfare are valued according to three reference points, being: loss aversion, the endowment effect and the status-quo bias. This is in contrast with the neoclassical theory, which states that a person is rational and will always choose for an option that enlarges its welfare.

Where neoclassical economics assumes people place equal value on losses and gains, Kahneman and Tversky argue this is not the case. Empirical evidence shows people, in general, value losses more than gains (Shogren & Taylor, 2008). A certain decision that has an equal opportunity of losing €1000 or earning €1000, would thus in general be seen as negative. When choosing between different uncertain options, people use the expected value and the degrees of uncertainty as guidance (Tobler, O'Doherty, Dolan & Schultz, 2007). Individual risk attitudes determine how this uncertainty plays a role in decisions (Tobler et al., 2007). Potential losses reduce the intention to perform certain behaviour, but it also depends on individual risk attitude how a potential loss exactly influences decision-making (Arkes, Herren & Isen, 1988). However, from literature it can be concluded in general, potential gains need to be higher than potential losses due to the value '**loss-aversion'**. Besides, it appears people do not accurately process statistical information. A very low probability of a huge loss or gain is often overstated (Pollitt & Sharshadze, 2011).

The endowment effect refers to value individuals attach to goods they already own (Politt & Shaorshadze, 2011). It appears individuals attach a significantly higher value to goods they already own, as compared to new goods (Heberlein & Bischop, 1986). This may not be relevant to the research, since greenhouses do not have to buy any extra goods in order to be able to supply to the redispatch market.

Searching for alternative options costs effort. This may lead to preferences for already discovered options, as compared to not yet discovered options (Ge, Bridgen & Haubl, 2015). A similar statement is done by Arkes, claiming 'the extra effort required to use a more sophisticated strategy is a cost that often outweighs the potential benefit of enhanced accuracy' (Arkes, 1991, pp. 486-487). The status-quo bias refers to the fact that individuals tend to stick to the default option; **stickiness** (Kahneman, 1991). People who haven't chosen an option yet, are more likely to choose new options, while those who already have chosen an option, are not likely to deviate from this. This can show in the behaviour of greenhouses with CHPs in the electricity market, where greenhouses currently sell their electricity mainly to the day-ahead and long-term market. Research claims those greenhouse growers will not likely want to deviate from this.

2.3.1.2 Empirical findings: Motivations for similar projects
Stedin executed a pilot project in the neighbourhood Hoog Dalem to test a new energy system. In this neighbourhood, locally produced electricity is mostly sold locally, in order to reduce the

transport needs of the system. As greenhouses can contribute to solving congestion by offering part of their flexibile electricity to the redispatch market, the houses in this community contributed to solving congestion by participating in this pilot. The motivations behind participating may thus have some similarities. The main findings about the motivations for participating, are that participants are mainly interested in the financial advantages of participating in the project. Besides, participants are interested in the development of the project and their contribution to it (Energieproject Hoog Dalem, Stedin, 2019). In general, participants did not participate because of environmental considerations.

2.3.2 Subjective norm

The second determinant of behaviour is the subjective norm, according to the Theory of Planned Behaviour. The definition of the subjective norm, is the extent to which participating in the redispatch market tends to be seen as something a greenhouse has to do. In Section 2.3.2.1, the subjective norm is split up into different parts, which are then translated to this particular research. In Section 2.3.2.2, relevant findings from behavioural economics literature that fit in this determinant are given. Lastly, in Section 2.3.2.3, pro-environmental literature is researched, since the presence of a subjective norm may lead to pro-environmental behaviour.

2.3.2.1 The use of the subjective norm

Research shows the impact of the subjective norm on behaviour is relatively small, as compared to the relation between attitude and behaviour, and behaviour control and behaviour (Armitage & Connor, 2001). Where the subjective norm in the theory of planned behaviour is a social injunctive norm – social pressure is central – descriptive norms appear to play a role too. Descriptive norms point to what is normal; which behaviour do others perform (White, Smith, Terry, Geenslade & McKimmie, 2011)? Social injunctive norms can be present in the greenhouse market, since supplying to the redispatch market can solve congestion and therefore help others. This relates to the evidence found for pro-social behaviour in behavioural economics.

Descriptive norms appear to have an independent impact on intentions and thus are an addition to the Theory of Planned Behaviour (e.g. Manstead, 2000; Sheeran & Orbell, 1999). **Descriptive norms** may be apparent in this case, when greenhouses copy behaviour of other's and may not want to be one of the different ones, supplying to a market where almost no other greenhouse supplies to.

Thirdly, it is argued personal injunctive norms play a role, too. **Personal injunctive norms**, 'an individual's internalized moral rules', (Parker, Manstead & Stradlin, 1995, p. 129), have an independent impact on the intentions. This relates to the feeling whether parties feel a moral obligation to engage in a certain action (White, Smith, Terry, Greenslade & McKimmie, 2011). In this specific case, this is translated to whether a greenhouse feels like he should be the one contributing to solving congestion. One of the barriers as described by Blake (1999) – lack of efficacy – may reduce this impact of moral rules on intention. This barrier means people do not see the efficacy of a certain action. Besides, a certain moral rule might lead to pro-environmental behaviour (White et al,. 2011).

2.3.2.2 Findings from behavioural economics

Pro-social behaviour and fairness

Unlike neoclassic theory assumes, people are not fully selfish in a sense that they only strive for enlarging their own welfare. People could, for instance, act out of pro-environmental considerations. Besides, it appears for some people, the well-being of other's is a reason to act (Kahneman, 1986). Congestion probabilities increase when the share of variable renewable energy resources increases, so supplying to the redispatch market could be seen as 'pro-environmental'. Besides, congestion can cause outages or can withold greenhouses to expand, so supplying to the redispatch market to reduce congestion can also be seen as **pro-social**.

2.3.1.3 Personal injunctive norms: Pro-environmental behaviour

Personal injunctive norms – a person's set of moral rules – may induce pro-environmental behaviour. Since a good working redispatch market can contribute to an accelerated energy transition, environmental psychology literature is researched. Self-transendence – values that prioritize collective benefit – and self-enhancement – values that prioritize individual benefit – values appear to be most relevant in determining environmental behaviour (Steg & De Groot, 2010). For this case, self-transendence behaviour will likely lead to a greater participation in the redispatch market. Biospheric and altruistic values have appeared to be the most influential determinants of self-transendence behaviour. These thus play an important role while deciding to engage in pro-environmental behaviour (Steg et al., 2014). Altruistic values reflect the key concern about the welfare of others, while biospheric values relate to the concern for the environment.

From literature, it appears self-transendence values lead to pro-environmental behaviour (Steg et al., 2014). The question is to what extent these values will likely be present in similar cases. Schwartz developed a model of social values, in which he describes that values that promote self-interest conflict with values of the community – for instance pro-environmental behaviour (Schwartz, 1992). Building on this model, research executed by Evans, Maio, Corner, Hogetts, Ahmed & Hahn (2013) conclude in order to activate pro-environmental behaviour, it should not be tried to stimulate people with monetary motivations.

Besides, research executed by Jensen (2010) emphasizes the importance of knowledge on pro-environmental behaviour. It is very unlikely people participate in pro-environmental actions, if they know nothing about the potential contribution of certain actions (Gifford, Nilsson, 2014). A lack of knowledge has also been established as a barrier by Blake (1999).

2.3.3 Perceived behaviour control and facilitating factors

Perceived behaviour control is an objective measure, relating to the belief that certain behaviour is under a person's control (Ajzen, 1991). Generally, if people think they are in the ability to perform certain behaviour, they are willing to put more effort into it. Facilitating factors can have an influence on the social factor 'behavioural control', since facilitating factors can decrease the barriers (Triandis, 1977). Trafimow, Sheeran, Conner & Finlay (2002) built upon the theory of planned behaviour. They claim perceived behaviour control exists of two variables: perceived control and perceived difficulty. Perceived control relates to whether a person feels certain behaviour is under his voluntary control, where perceived difficulty refers to the feeling of behaviour being easy or difficult to perform (Spark et al, 1997). Concluded from the research, is that perceived difficulty is – in general – a better predictor for intentions, than perceived control (Trafimow et al., 2002). What remains is perceived difficulty, what relates to specific factors that make behaviour difficult to perform (Trafimow et al, 2002).

2.3.4 Non-neoclassical response to a market design

As has become clear from this section, there are certain behavioural aspects that may cause individuals behaving different from the neoclassical assumption of fully rational behaviour. Expected is a market design with which a potential loss is associated, will not be seen as favorable, given that people value losses more than gains. Besides, an additional market may be seen as additional effort, which leads to people sticking to their current behaviour. Then, people need to actively be made aware of a certain market and its benefits to change their behaviour. Besides, it appears potential opportunity losses may reduce the willingness to participate in a market. However, given the variety of electricity markets, there will always be an opportunity loss.

2.3.5 Conclusion

All relevant information from the literature review, is summarized in Table 5. This information will be used in the research, to analyse potential barriers of different designs of the redispatch market and solutions to these barriers.

Table 5: Behavioural relations in literature, structured according to the Theory of Planned Behaviour (Ajzen, 1991).

Social determinant	Definition within the research	Relations found in literature
Attitude toward the behaviour	The extent to which participating in the redispatch market is (non-)favorable. This also includes (potential) environmental behaviour and opportunity losses.	Uncertainty about gains appears to negatively influence willingness to perform behaviour.
		Potential opportunity losses will likely decrease trust and will thus likely have a negative impact on the attitude.
		Bounded rationality may lead to people not always making the most rational choice, since there is too much information to process.
		People appear to value losses more than gains.
		People appear to put a higher value on goods they already own and tend to stick to a default-option.
Subjective norm	The extent to which participating in the redispatch market tends to be seen as normal	People appear to not only strive for their own welfare, but often act pro-social.
		Environmental behaviour can improve the attitude toward behaviour, but it is expected this will not play a significant role in this specific case.
		People appear to be influenced by the behaviour of others in a sense that they are likely to copy behaviour.
		People have an internal set of values, by which their behaviour is influenced.
Perceived behaviour control	The perceived ability to be a supplier to the redispatch market and to earn money from it. This also includes the experiencing of barriers.	Perceived difficulty has a significant impact on the perceived behaviour control and occurs when people think certain behaviour is difficult to perform.
Facilitating factors	An action which can be executed by AgroEnergy, leading to less opposition - if	Facilitating factors can increase perceived behaviour control and therefore leas to a higher

	there is opposition - to the redispatch market.	intention to perform certain behaviour.

2.4 Conclusion and knowledge gaps

From this literature review, different insights follow. First of all, there are two goals that should be kept in mind when designing an electricity market, being reliability and affordability. Enlarging the supply in an electricity market appears to be beneficial to reach those two goals – especially when using already existing resources. There are different inefficiencies that may rise with the redispatch market, being (locational) market power, inc-dec gaming and arbitraging. For this research, an adapted framework for the market design of a redispatch market, based on the framework developed by Poplavskaya and De Vries (2018) will be used. Using available resources can provide short-run efficiency in a market. Here, the first knowledge gap exists, because the question rises whether greenhouses with a CHP belong to those available resources able to supply to the redispatch market. In other words: Can greenhouses be suppliers to the redispatch market?

Secondly, from the neoclassical theory it appears individuals are rational, profit-maximizing beings. The rational choice theory, which follows from the neoclassical theory, states people rationally choose between opportunities. This is where the second knowledge gap arises. Greenhouses with CHPs are free to decide where to sell their electricity. There are opportunity costs involved, since electricity can only be sold once. Would it be a rational choice to expand their current electricity portfolio with the redispatch market?

From theory it appears the behaviour of individuals often differs from neoclassical behaviour. Behavioural economics is the research branch studying this phenomen and is relevant for the research, since it appears behavioural economics often plays a role in the decision making with regards to energy policy. Based on the Theory of Planned Behaviour, relations in literature between certain relevant aspects and behaviour are structured. These theorethical relations will be used as a foundation for the empirical relations between different properties of greenhouses and the redispatch market. The specific knowledge gap is how these theorethical relations play a role in the actual behaviour of greenhouses in the redispatch market. How do these socio-economical characteristics influence the willingness to participate in the redispatch market?

As appears from the review regarding the goals and market inefficiencies, and as appears from the introduction, an increase in flexible supply to the redispatch market is needed. There are different design options to do so. This is where the fourth and last knowledge gap rises. Based on the technical characteristics and motivations for behaviour, what would be the best way to enlarge participation of greenhouses in the redispatch market?

Chapter 3: Research structure

This chapter presents the structure of the research, by presenting the research approach. In Section 3.1, the objective and scope of the research are presented. In Section 3.2, the main research question is presented, together with the sub questions. The research approach and the motivation for choosing this approach is presented in Section 3.3, together with the research methods. The chapter will conclude with the presentation of a research flow diagram in Section 3.4, in which the flow of the different parts over the research will be presented.

3.1 Research objective and scope

The following core elements are used to hold a clear focus during the research:

- Subject of interest: the extent to which different types of greenhouses can and are willing to participate in the redispatch market, for different types of greenhouses under different designs.
- System of interest: congestion management in The Netherlands, being executed using market-based redispatch in which greenhouses are the (potential) suppliers.
- Implications: difficulties to predict the exact characteristics of congestion management and the development the redispatch market.

3.1.1 Research objective

The main research objective is to investigate how the redispatch market can be judged from the perspective of a greenhouse grower as electricity supplier. A greenhouse grower can judge the redispatch market based on technical characteristics, determining if and how much could be supplied to the redispatch market. Secondly, economic characteristics likely play a role, pointing to how much could be earned from the redispatch market. Social characteristics (or: non-neoclassical characteristics) could play a role too, since judgement of a certain action often appears to be non-rational. Lastly, the goal is to turn this judgement into suggestions for how to change the market design.

3.1.2 Research focus

From a neoclassical approach, the focus of this research will be on identifying those market design aspects that influence the potential of greenhouses as suppliers to the redispatch market in terms of *if* they can supply to the redispatch market, and how the added value of the redispatch market for greenhouses could be enlarged. Namely, supply to the redispatch market needs to be increased; from a neoclassical focus, the more can be earned from this market, the more likely the supply will increase.

Then, from the approach of the theory of planned behaviour, complemented with the theory of behavioural economics and pro-environmental behaviour, the focus will be on those design aspects that that may influence the willingness to supply, based on the relations found in the literature. The scope is bounded to greenhouses with a CHP installation within the Netherlands. Greenhouses can sell their electricity at any Dutch electricity market, as long as it is technologically possible. Only the currently existing Dutch electricity markets are used.

3.2 Research questions

From the literature review, it appears supply to the redispatch market needs to be enlarged. Greenhouses with CHPs may be in the position to enlarge that supply. It appears it is still unclear weather greenhouses can fulfill that position technically and are willing to fulfill that position based on economic and social motivations. There are different design options available that may affect these three aspects. The main knowledge gap is summarized in the following research question:

How will the redispatch market be judged from the perspective of a greenhouse grower as electricity supplier and what may be done to change this judgement?

The goal of this question is to find out whether the current design of the redispatch market is attractive to greenhouse growers and whether they are willing to supply to this market. The goal is to eventually be able to give an advice as to whether the redispatch market can be an addition to the portfolio of greenhouses. AgroEnergy can use this advice to determine whether it should advise its clients to supply to the redispatch market. Besides, the goal is to investigate which aspects of a market design have an impact on the willingness to supply to the redispatch market – the willingness will likely, according to literature, not only be determined by the (potential) earnings. An advice for AgroEnergy for how to motivate its clients to participate in the redispatch market, and an advice to TenneT for how to change the market according to response to certain market design aspects, will be given.

The sub-questions relate to the four knowledge gaps that follow from the literature review (See Section 2.4). The following four sub-questions can together give a coherent answer to the main research question:

1. What are the technical characteristics of a greenhouse, determining the potential of different types of greenhouses as suppliers to the redispatch market, under different circumstances?
2. Under what circumstances can the redispatch market be an added value to the portfolio of greenhouses, given their technical characteristics and behaviour in other markets?
3. How do socio-economical characteristics influence the willingness to participate in the redispatch market?
4. How can the participation of greenhouse growers in the redispatch market be enlarged, while adhering to the goals of an electricity market?

The goal of the first research question is to identify whether the flexibility available in greenhouses matches the flexibility needed in the redispatch market, in order to solve congestion. The flexibility available in greenhouses will differ per greenhouse, per day, based on the technical characteristics. Then, using the current knowledge of congestion management in the Netherlands, it will be determined whether greenhouses could be a supplier to the redispatch market.

The second research question will, corresponding to the rational choice theory, calculate the expected benefits of the redispatch market using the currently available data. These benefits will be compared to potential benefits in alternative markets that are a direct competition to the redispatch market. This way, it can be investigated whether rational greenhouse growers would supply to the redispatch market.

The third research question builds upon the theory of planned behaviour and behavioural economics, by investigating if certain theorethical relations can be found in the behaviour of greenhouses and in turn how these relations may impact the willingness to offer capacity to the redispatch market.

The fourth research question is meant to link the knowledge obtained in question 1 to 3. The goal is to link this knowledge to potential changes in the market design of the redispatch market, to enlarge the supply of greenhouses to the redispatch market. Where in the first research question, the focus is on greenhouses explicitly, this last question is meant to shift focus and consider the bigger system of an electricity market, where goals and inefficiencies play a role.

3.3 Research approach and methods

In this section, the research approach and methods will be explained with which the sub questions will be answered. The approach to fully answer the research question consists of a mixed method approach, where quantitative and qualitative research are combined. This form of research is sometimes called triangulation (Webb et al., 1966), which is defined as the combination of methods to study a certain phenomenon (Denzin, 1978). The research methods to answer each of the sub questions will be explained.

As appears from the literature review, behaviour can be explained using neoclassical theory, but neoclassical theory appears to be only part of the causes for certain behaviour. Therefore, to fully identify the characteristics of a greenhouse as electricity supplier, the social elements will be researched as well, using the theory of planned behaviour. Now, it will be explained how the different theories will be applied.

3.3.1 Use of the neoclassical approach: Data analysis and modeling

The neoclassical approach will be used to structure the first two parts of the research: the first two research questions. Here, it will be explained how aspects of the theory are applied.

The neoclassical theory will structure the first part of the research. According to the neoclassical theory, individuals will perform a certain action if this is rational. This implies suppliers able to supply to multiple markets, will choose to supply to that market from which they can earn the most. Logically, in order to be able to sell to a certain market, it must be ensured the (potential) supply matches the demand.

3.3.1.1 Use of the theory of flexibility: Data analysis

As explained, according to neoclassic theory, an individual will perform a certain action if it is rational. For answering the first research question, a framework to structure the demand for redispatch volume and the potential supply of redispatch volume will be used. Demand for electricity on the redispatch market is not constant, since congestion is not constant. Therefore, the supply to the redispatch market should be able to provide certain flexibility in order to match the demand. Greenhouses are complex technical systems, where multiple aspects may determine the flexibility potential, e.g. the (heat) buffer capacity, the amount of electricity needed for the lights, the needed amount of CO_2-production and the capacity of the CHP installed in the greenhouse.

This research section will be structured according to a flexibility framework developed by Grunewald (2016), where both the redispatch demand and the (potential) flexible supply are structured according to this same framework. Since by nature, flexibility cannot be shifted in time, it is useless to be flexible before or after an event that requires flexibility (Grunewald, 2016). Therefore, it needs to be investigated how the flexibility greenhouses can offer is distributed over the day and over a year (on average) and matches the flexibility demanded in the redispatch market. This framework is developed to identify both flexibility in demand and supply of electricity. Flexbility exhibits different aspects, as described by Grunewald (2016):

1) Time specificity: When is the flexibility needed?
2) Change in time: What is the volume of the needed flexibility?
3) Duration: What is the (average) duration of the flexibility needs?
4) Lead time: On what notice is the flexibility needed and settled?

Next to these four aspects regarding the timing of flexibility, the location of flexibility is important too if the flexibility is to be used for congestion management.

5) Location: Where is the flexibility needed?

It needs to be investigated whether the flexibility greenhouses can supply, matches the flexibility the redispatch market demands.

Based on a data analysis, it will be examined whether the flexibility needed in the redispatch market matches the flexibility which can potentially be offered by greenhouse growers. Besides, market design characteristics may influence the flexibility needs too. The two different 'forms' of flexibility – demand and potential supply – will qualitatively be compared, in order to investigate whether greenhouse growers are in the position to supply to the redispatch market. The data that is needed for performing this analysis, is congestion specific data revealing the flexibility needs in the redispatch market. Besides, data regarding the potential flexibility in greenhouses will be analyzed and structured using the framework.

3.3.1.2 Use of the rational choice theory: Deterministic modeling

As explained, according to rational choice theory, which is in line with the neoclassical theory, individuals always choose the best alternative out of a set of possible alternatives. For research question 2, a deterministic modeling approach will be used. The input to this model are the potential load profiles to the redispatch market of (different) greenhouses, which follow out of research question 1.

The Key Performance Indicators (KPIs) exist of the revenues earned by a particular greenhouse on the redispatch market, versus the potential losses on competing markets. See Figure 6.

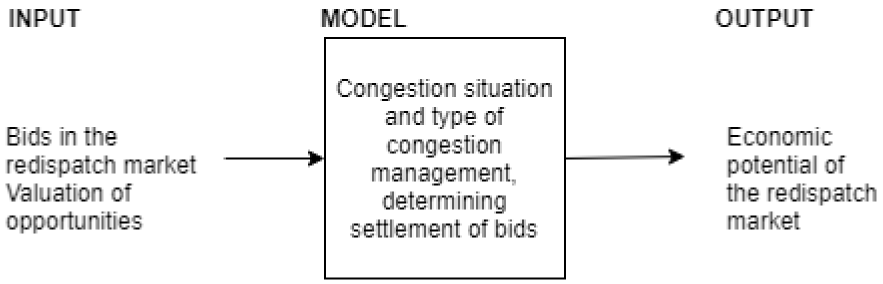


Figure 6: Visualisation of the deterministic model.

The congestion situation and following from this the probability of a settlement of a certain bid, may differ per location. In order to avoid gaming (See Section 2.1.2), exact congestion details are not revealed. This is an uncertainty that has to be dealt with. Uncertainty can be defined as the lack of knowledge, regardless of the cause of this lack (Refsgaard et al., 2007). There can be dealt with uncertainty in a deterministic model by doing a model sensitivity analysis, where the impact of (small) changes in the uncertain input variables on the output is investigated.

3.3.2 Use of the non-rational decision-making theory: Empirical data-gathering

In order to answer research question 3, the theorethical behavioural aspects found in literature (See Section 2.3), will be empirically verified using interviews. Empirical research uses data from the real world. An important use of empirical data research is theory building: why do certain phenomena occur (Flynn et al., 1990). Namely, the theorethical foundings have to be translated into 'real world factors' that are valid for the behaviour of greenhouses, in order to be able to make real world conclusions. So to answer the third research question, interviews with different greenhouse growers will be held. Because "Asking questions and getting answers is a much harder task than it may seem at first." (Fontana and Frey, 2000, p. 645), an interview protocol is set up, to assist the data collection. An interview protocol is a script of the information you give before the interview, the interview questions and how conclusions are drawn. Prompts reminding the interviewer of the to be collected information are part of an interview protocol, too (Jacob & Paige Furgerson, 2012). Qualitative interviews are in general used to explore views and beliefs of single participants (Gill, Stewart, Treasure & Chadwick, 2008).

Just like the literature review, the interviews will be structured using the theory of planned behaviour.

3.3.3 Use of the market design framework

Sub-question 4 combines the analyses made for sub questions 1 to 3 and links this to the market design of the redispatch market. The first two sub questions analyze, from the viewpoint of a greenhouse, whether they can and should supply to the redispatch market, according to neoclassical theory. The third question tries to find those behavioural aspects in greenhouse growers that may affect their willingness to offer capacity to a market like the redispatch market. Given the exact characteristics determining (potential) behaviour of greenhouses, it is the question how the market can be designed to change the judgement of the redispatch market a greenhouse grower. This will be done by qualitatively investigating the impact of a change in a market aspect and, based on the conclusions from research question 1 to 3, analyze if this change could change the judgement positively. Validation of a proposed market design lies outside the (time-limited) scope of the research. In the discussion in Section 9.3.3, it will be discussed how the a proposed market design could be validated.

The framework developed by Poplavskaya and De Vries (2019) and adapted for this specific research (See Section 2.1.3) will be used to structure the analysis executed to answer sub question 4.

3.4 Research flow diagram

In Figure 7, the research flow diagram is shown. The literature presented in Chapter 2 is an important part of the research since it will be used as a theorethical structure for each of the chapters 4 to 8.

To ultimately answer the research question, some previous knowledge is needed. Therefore, in Chapter 4, the Dutch electricity market will be explained. From this, it follows who is responsible for making changes in the redispatch market and how the redispatch market can be placed within the Dutch electricity system.

In Chapter 5, the technical characteristics of a greenhouse are explained. Based on these technical characteristics in relation to the congestion management needs, the first research question can be answered. In Chapter 6, the theorethical economic potential of different types of greenhouses in the (current design of the) redispatch market will be calculated as compared to competing alternative markets, using a deterministic model. Based on research question 1 and 2, it can be concluded whether, from a neoclassical point of view, greenhouses will logically offer capacity to the redispatch market. Besides a theorethical potential to earn money from the redispatch market, willingness to participate in the redispatch market can be caused by other aspects as well, as explained in chapter 7.

Chapter 5, 6 and 7 together form a characterisation of a greenhouse as an electricity supplier to the redispatch market. Based on this characterisation, proposed design changes can be made to enlarge the participation of greenhouses in the redispatch market. In Chapter 9, the discussion will be presented, where the impact of the assumptions and simplifications are mentioned. The conclusion of the research is presented in Chapter 10. Lastly, in Chapter 11, a reflection on the research and internship presented.

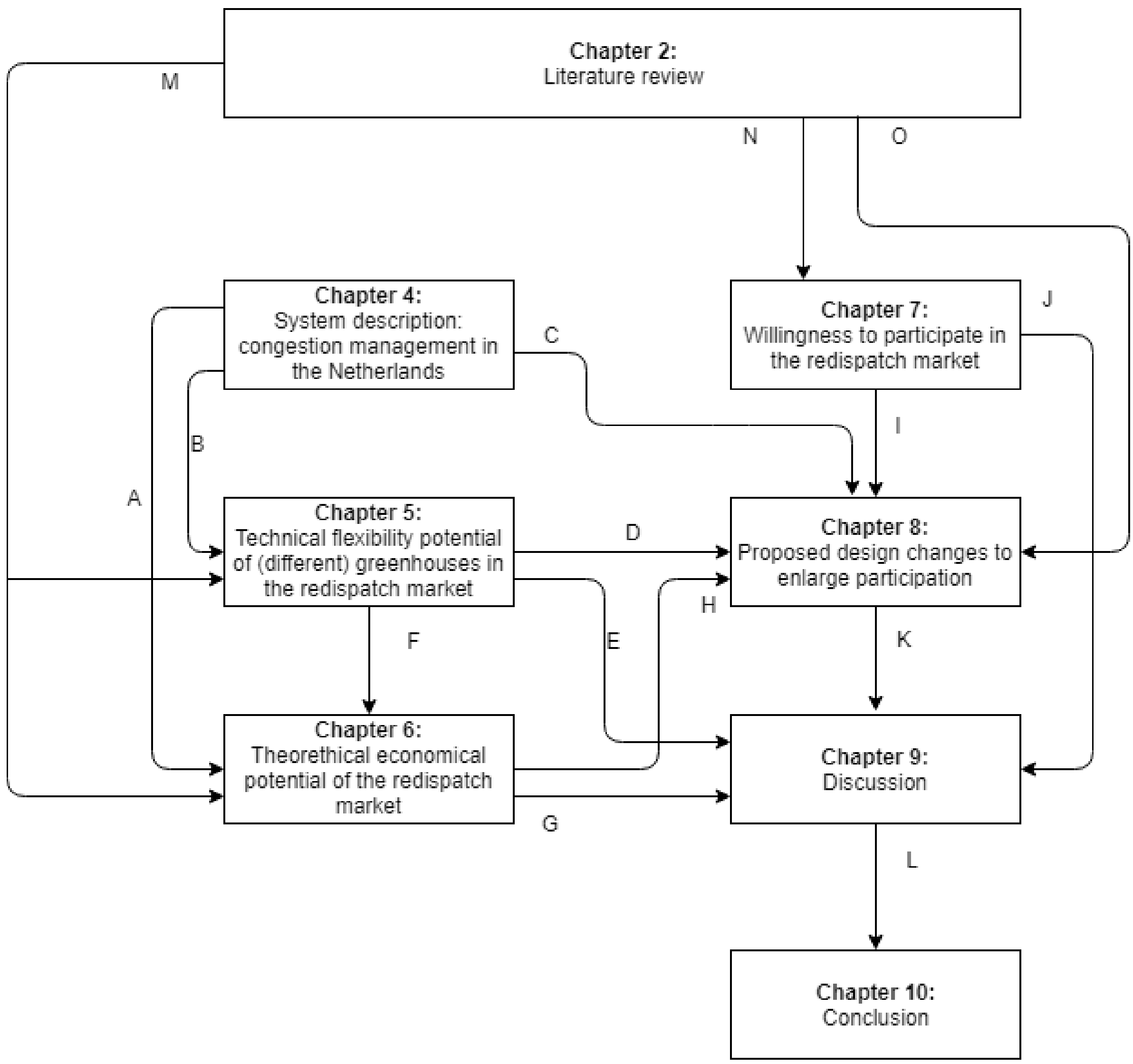


Figure 7: Research flow diagram

Legend	
A	Design aspects + opportunities other markets
B	Current design redispatch market
C	Current design redispatch market
D	Technical potential and barriers
E	Answer to RQ 1
F	Flexibility profile (bids in redispatch market) Economical potential and barriers
G	Answer to RQ 2
H	Social potential and barriers
J	Answer to RQ 3
K	Answer to RQ 4
L	Recommendations
M	Neoclassical theory of rational choice
N	Theory on planned behaviour
O	Theory on market design

Chapter 4: System description: congestion management as part of the Dutch electricity system

GOAL	METHOD	RESEARCH QUESTION
To provide background into the relations and responsibilities, and to identify the potential opportunity losses of supplying to the redispatch market.	Qualitative analysis, using literature and reports.	Used for all sub questions since for all research questions, different markets are compared. These markets are described in this chapter.

In this chapter, the Dutch electricity market is being described. To be able to fully understand the behaviour of parties in the redispatch market, it namely is important to understand the relations in the electricity market and the relation between the different markets. First in paragraph 4.1, the different parties in the electricity market are explained. The goal of this section is to investigate who is responsible for congestion management and which parties can change the design of the different electricity markets. In paragraph 4.2, the different places where electricity can be traded, together with the goal of each of these different places, is explained. The ultimate goal of section 4.2 is to identify the competition of the redispatch market – To which markets can a greenhouse grower supply its electricity, next to the redispatch market and thus, which potential opportunities does he lose when he supplies to the redispatch market?

4.1 Institutional layer

In The Netherlands, the Transmission System Operator (TSO) is TenneT. TenneT is responsible for balancing the grid, maintaining the right frequency, for the high frequency grid and for the international network connections. There are multiple Distribution System Operators (DSOs) who are responsible for the local distribution grids. As regulated by the Dutch law, electricity generation and network operation is unbundled, meaning electricity generation cannot be done by a party who also operates the grid. The reason is to avoid unfair competition. After all, Europe has implemented a liberalized electricity market. The grid operation is a natural monopoly, meaning the entry costs are so high that the barriers for new parties are too large to enter. The ACM – Authority Consumer & Market – controls the TSO and DSOs in the fully regulated electricity market. The ACM has the power to, for instance, stop a certain pilot if this is against the regulation of the electricity market Lastly, there are Balance Responsible Parties (BRPs) who have to keep supply and demand in check. BRPs send the planned demand and supply and which network they will use for transporting their electricity, to TenneT. This is called the E-programme. They also measure the realized supply and demand. The difference between the planned and realized transactions is the imbalance (TenneT, n.d.). BRPs are responsible for the financial impact the of the real-time net-imbalance of their portfolio (Hu, Harmse, Crijns-Graus, Worrel & van den Broek, 2018).

On the demand side, there are large consumers, who are directly connected to the grid. Small consumers have to buy their electricity via a retail-company. The relationships between the different players in the electricity market is given in Figure 8. Greenhouse growers able to produce and consume electricity are called prosumers, and thus play the role of both a power generator as a consumer. The two-sided arrow indicates the decentral generation.

Figure 8: Relationships between parties in the Dutch electricity market. Source: Van Amstel, M (11-12-2018). Flexibility design for electric vehicles. University of Twente.

An overview of all the active players in the energy market, is given in Table 6.

Table 6: Parties in the electricity market, together with their activities.

Party	Activities
Transmission system operator (TSO)	- Grid balancing - Frequency control - Responsible for high frequency grid (>110kV) - Responsible for international network connections
Distribution system operator (DSO)	- Responsible for medium to low frequency grid (<110 kV) - Responsible for electricity delivering
Balance Responsible Party (BRP)	- Responsible for informing grid operator about planned activities (production, consumption, transport)
Power generation	- Produces electricity and sells this to BRP
Prosumer	- Both consumes and produces electricity (Greenhouses are an example of large prosumers)
Retailers; energy suppliers	- Buys electricity (from BRP and prosumers) and sells it (to consumers)
ACM	- Controls system operators

4.2 Trade markets

A good working price mechanism that enables both short-term operation and provides long-term incentives to invest in production capacity is needed, for the well-functioning of electricity markets. Trade markets try to be such a place. There are different markets where electricity can be offered and sold – each market has its own characteristics and goals. The trade markets can be sub-divided based on the goal of the market. In section 4.2.1, the different trade markets are explained, together with the goal of each of these markets. Hereafter in chapter 4.2.2, the potential opportunity losses when supplying to the redispatch market are explained. The conclusion about trade markets is given in chapter 4.2.3.

4.2.1 Different markets

In the following paragraphs, the different trade markets are explained, together with the goals of each market. The markets are ordered based on the point in time that the electricity is bought and sold, relative to when the electricity is used. This is visualised in Table 7. For each market, the important question for this research is whether a greenhouse grower can offer flexibility on this certain market.

Table 7: Trade markets ordered to the point of electricity delivery, based on: TenneT Market Review 2017.

Time before use →	**Year**	**Month**	**Day+1 00.00**	**23:59**	**Day0 00:00 23:59**
Markets	OTC	OTC	APX	Redispatch and Intraday	Intraday and Redispatch
					Passive imbalance market
		Contracting reserve volume			Using reserve volume

4.2.1.1 Over the counter

For the long-term electricity planning, over the counter (OTC) contracts are concluded, bought on the ENDEX platform. In these OTC-markets, both price and quantity are fixed. These markets exist to provide certainty to electricity producers and consumers, since the price risk is taken away. The average OTC price is higher than the average price of electricity traded in the spot market (energiemarktinformatie.nl, n.d.). The OTC-market is also available to smaller generators, such as greenhouse growers. It is possible to trade your OTC-position.

4.2.1.2 Day-ahead market

The day-ahead planning takes place on the EPEX market (apxgroup.com, n.d.). On this market, electricity supply bids and electricity demand bids are ordered for each hour of the next day. The supply bids are ordered from low to high price, and the demand bids are ordered from high to low price. From these aggregated bids, the day-ahead price for electricity follows. This is a form of marginal pricing. There is an hourly day-ahead price; bids are provided per PTU (15 minutes). As can be seen in Figure 9, renewable energy has a depressing influence on the electricity price, since the marginal costs of wind and solar power are very low. Gas-fired CHPs, owned by greenhouse growers, can be offered on the EPEX market. AgroEnergy offers a tool to its clients, which predicts the EPEX-price of the following day. Based on the marginal costs and these predictions, the EPEX-bids are placed. It is possible to trade your position, via the balancing market.

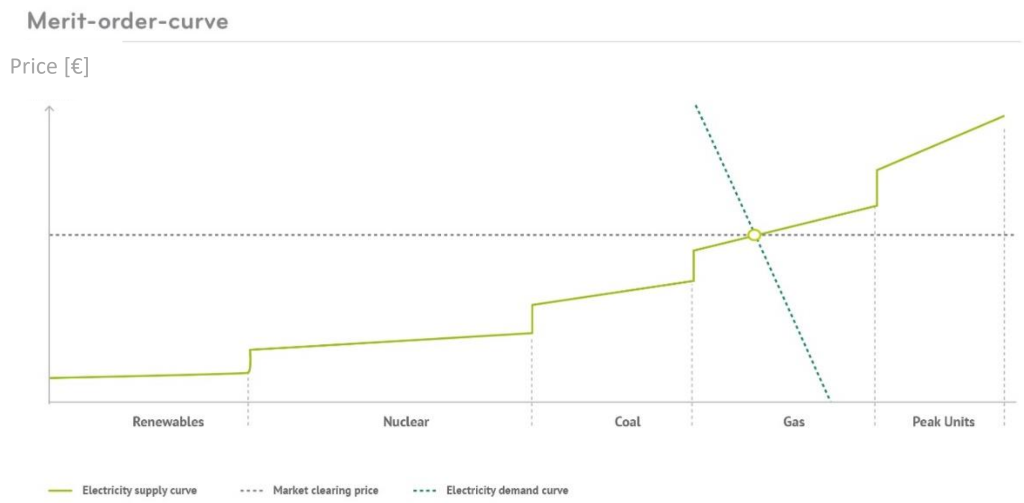


Figure 9: Day-ahead price calculation via the merit-order. Source: www.next-kraftwerke.be, n.d.

4.2.1.3 Intraday market

The intraday-market is meant to make up for the 'wrong estimations' made in the day-ahead market and allows parties to adjust their position (Hu et al., 2018). On the delivery day itself, electricity can be bought and sold until up to 15 minutes before delivery. Wrong estimations can be caused by for instance power plant outages or wrong weather predictions. The increase in renewables causes more variations between the day-ahead predictions and the real demand and supply, increasing the need for a good working intraday market. Greenhouse growers can also supply to the intraday market. A supplier can supply to both the day-ahead market and the intraday market. When for instance the day-ahead bids have not (fully) been settled, the remaining capacity can be offered to the intraday market.

Intraday volume can both be offered on EPEX SPOT and ETPA. ETPA – Energy Trading Platform Amsterdam – is a platform where volumes starting from 0,5 MW can be offered. The goal of the platform is to provide access to producers, large consumers and aggregators who can this way easily trade electricity. Communication between BRPs and the grid operator about the buyer and seller are not needed anymore, since ETPA uses Single Sided Transactions. This means ETPA nominates a certain transaction on behalf of the BRPs, and sends this to TenneT (ETPA, n.d.). It is relatively cheap to sell electricity via ETPA, theorethically making it an attractive platform for small suppliers like greenhouses. The entrance-fee is €250,-. Besides, there is an annual fee of €1800,- (ETPA fee schedule, 2018). Although ETPA sounds like an easy-to-use platform, in reality it appears ETPA is still barely used for intraday-trading. This shows a certain solution can be economically optimal, but there are other effects determining the efficacy. There could be thought of a lack of knowledge about how the new market exactly works, the presence of alternatives (EPEX) or entry barriers.

EPEX SPOT is a variant to the regular EPEX-platform for day-ahead trading, specially designed for intraday trading. The entrance fee of this market is €25.000 euros. Additionally, there is a yearly fee of €10.000 and an annual technical fee of €4000,-(epexspot.com, 2019). Besides, the variable fee is €0,07/MWh. These costs are way higher than the costs on the ETPA platform. Making a quick calculation using the 2018 average price on the Dutch EPEX SPOT - €63,08 (EPEX SPOT, 2019)– a party in the intraday market should sell at least 620 MWh to the intraday market in order to only cover the participation costs. This makes the EPEX SPOT not suitable for greenhouses, who offer relatively small volumes and will unlikely reach a large enough volume.

For AgroEnergy, intraday trading is different from the regular intraday trading. Namely, the intraday volume of the electricity offered by clients of AgroEnergy, is sold to Eneco Energy Trade (EET) who needs intraday volume to balance its portfolio. EET collects relevant market information and needed intraday-volume. Based on this information, EET makes a price-curve for which price it wants to buy or sell intraday-volume (order). This curve is adapted hourly. Intraday-trading will take place hourly, too. Intraday-trading starts at 18:00 on the day before the delivery day. For this thesis, it is assumed the intraday-trading of greenhouses will continue to have this form. In reality, greenhouses could also offer electricity directly to the intraday-market, via both the ETPA platform. For now, the certainty of the price-volume orders provided by EET are valuable to greenhouses.

	A	B	C	D	E
1	datetimestart_utc	eet_buys_maxvol_mw	eet_buys_price_eur	eet_sells_price_eur	eet_sells_maxvol_mw
2	28-3-2019 12:00	40	39.07	1000	40
3	28-3-2019 12:15	40	44.88	1000	40
4	28-3-2019 12:30	40	34.86	1000	40
5	28-3-2019 12:45	40	36.6	1000	40
6	28-3-2019 13:00	40	45.12	1000	40
7	28-3-2019 13:15	40	41.99	1000	40
8	28-3-2019 13:30	40	38.43	1000	40
9	28-3-2019 13:45	40	31.66	1000	40
10	28-3-2019 14:00	40	26.43	39.75	40
11	28-3-2019 14:15	40	26.43	46.4	40
12	28-3-2019 14:30	40	26.43	59.71	40

Figure 10: Intraday price-curve example

An example of an intraday price-curve, generated by EET, is shown in Figure 10. This curve is generated at 12:00, meaning the intraday optimization model of AgroEnergy reads this file at the optimization run of 12:00. The column 'eet_buys_price_eur' determines for how many euros/MWh, EET wants to buy intraday volume from AgroEnergy. This means if the intraday-optimization run from 12:00 has calculated that during 1 PTE, the greenhouse has to sell electricity to the intraday-market, it will pick the best price from the at that moment valid price-curve.

4.2.1.4 Redispatch market

As explained in the previous paragraph, the cheapest plants are dispatched first on the day-ahead market. Consequently, this situation leads to a lot of electricity having to be transported. If this transport capacity is not large enough, congestion could happen. In the Netherlands, TenneT uses the market-based mechanism of redispatch to solve congestion on the high frequency grid (TenneT Market Review, 2017). Currently, there are two forms of redispatch: 1) Redispatch using 'reserve power for other purposes' and 2) Redispatch using IDCONS via GOPACS. These two different forms will be explained in this paragraph.

Original redispatch using reserve power for other purposes

TenneT uses the bids provided by market parties and reallocates the bids in the most efficient way, in order to prevent congestion on the transmission grid. The bids are provided to TenneT as 'reserve power for other purposes', on a platform called Resin. Important is the fact that the location has to be added in order for the bids to be used for solving congestion. Next to congestion management, these bids are used for assistance to other countries (TenneT, System & Transmission Data, n.d.)

If not enough redispatch bids are provided, TenneT places a request for additional bids. The supply in the redispatch market mainly comes from a few large suppliers, with which TenneT concludes bilateral contracts. However, smaller bids are possible as well; the minimum bid size is 1

MW (TenneT, 8-2-2018). The compensation is based on pay-as-bid. The acquisition method is a continuous single-sided auction, where TenneT can continuously call any valid bid at any time.

Redispatch with IDCONS via GOPACS

To enlarge the number of suppliers and increase competition, a variant to the original redispatch market is developed. In the original redispatch market, suppliers submit their bids directly to TenneT. In this new form, bids are submitted to a market, which in turn sends the information to TenneT. The main difference between redispatch via Resin and redispatch via GOPACS, is the fact that redispatch via GOPACS will in the future also be used by distribution system operators (DSOs) to solve congestion on the distribution grids.

ETPA is such a market where redispatch bids can be offered to indirectly. When the location is added to a certain transaction, congestion management is possible. IDCONS – Intraday congestion spread – is an instrument which has been developed in 2018 (Stedin position paper, 2018). An IDCONS is a combination of a buy and a sell order, on two specific locations, that can together decrease congestion (See Figure 11). This instrument is a merger between the market place of two products: intraday and redispatch (Hirth & Glismann, 2018). Currently, traders supplying to the intraday market via ETPA are not obligued to add their location to the intraday bids. This type of redispatch eases access to the redispatch market for small market parties. For the redispatch pilot, AgroEnergy is not bidding to this market yet, but to Resin instead.

Once congestion is expected on a certain part of the electricity grid, the network operators registers this congestion to GOPACS – Grid Operators Platform for Congestion Solutions. GOPACS is a tool which makes use of the IDCONS-bids. GOPACS considers all feasible bids and calculates the least costly solution for solving the congestion. If not enough redispatch capacity is available for solving congestion, a bid-requests is placed on the website. The goal of this platform is to allow cooperation between TenneT and the DSOs. Namely with calculating this solution, it is made sure that when solving congestion in one part of the grid, no congestion in another part is created (Hirth & Glismann, 2018).

Market parties with a supply order to IDCONS receive the ask price, market parties with a buy order pay the bid price (Hirth & Glismann, 2018). When a redispatch bid has been accepted, a supplier cannot deviate from this bid anymore meaning he has to deliver according to the arrangement. Important for this market to develop is the condition that enough supply and buy orders are provided.

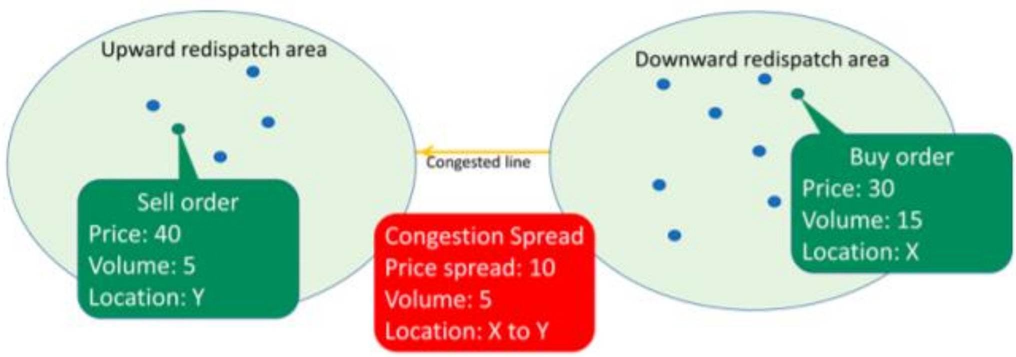


Figure 11: A congestion spread. Source: Hirth & Glismann, 2018. Congestion management. From phyisics to regulatory instruments. Leibniz information center for economics, Kiel, Hamburg.

4.2.1.5 Reserve market

Parties that provide balancing volume are called Balancing Service Providers (BSP) (TenneT, 2019). TenneT uses reserve volume for real-time managing of the power balance. TenneT also uses this reserve volume to maintain the right frequency – 50 Hz – on the grid. There are three types of reserve volume: primary, secondary and tertiary reserve volume. Primary volume – also called automatic Frequency Restoration Reserve (aFRR) - is used when there is a deviation from the right frequency, and is automatically activated within 30 seconds. Primary volume is being auctioned in a weekly auction. Based on the price, TenneT determines which primary volume order is activated first. Besides, participants receive a capacity price.

The secondary reserve volume market (R2) – manual Frequency Restoration Reserve scheduled activated (mFRRsa) - is being used when the system is imbalanced for up to 15 minutes. R2 is being contracted by TenneT in monthly auctions. Suppliers of contracted secondary reserve volume, need to be available at any time during the contract period and receive a capacity payment (AgroEnergy, 2017).

The tertiary reserve market – manual Frequency Restoration Reserve direct activated (mFRRda) - is used when the imbalance lasts more than 15 minutes (TenneT, 2019). Supply is usually offered by large parties, or by a pool of multiple smaller parties, who can together offer large amounts of emergency power (Hu et al., 2018). Tertiary reserve needs to be available at any time and thus cannot be offered at other markets. Because of this reason, tertiary reserve is mainly offered by parties who own an emergency power aggregate (Movares, n.d.). Suppliers receive a fixed capacity payment for the capacity offered + a variable payment if the supplier actually has to deliver. Greenhouses typically provide tertiary reserve volume in a pool of multiple greenhouses (AgroEnergy, 2017). They cannot provide primary reserve volume, since CHPs are not able to ramp up or down quick enough.

4.2.1.6 Passive imbalance market

Imbalance happens when the actual electricity use or production differs from the E-programme a BRP has sent to TenneT. Tennet tries to, via the imbalance price mechanism, provide an incentive to market parties to restore the balance. This does not happen with an auction or contracts, but it happens in real-time. Parties with a settled day-ahead position can for instance 'sell' that position by buying power from the imbalance market. What they (physically) do, is just not turning their CHP on. The 'fine' they pay is the imbalance price. This is an efficient way of allocating generation capacity.

The imbalance price settlement (ISP) is 15 minutes. The imbalance price settlement happens through marginal pricing. It is based on the payments TenneT had to make for balancing, using the secondary and tertiary reserve (TenneT, 2019). It is equal to the highest activated FFR bid, in a certain ISP (TenneT Market Review 2017, 2018). The incentives follow from the two aspects: 1) it is disadvantageous to enlarge the imbalance and 2) it can be advantageous to decrease the imbalance (TenneT, 2019). Parties don't need a balancing contract to be able to deliver electricity to the imbalance market. A good working intraday-market can already compensate for large fluctuations, since differences between the BRPs E-programme and the adjusted estimations of the electricity production and use can be largely covered in the intraday-market.

Greenhouse growers can deliver and consume electricity on the imbalance market against the imbalance price. However, because of the large fluctuations in the imbalance price (See Figure 12), it is hard to make a stable business model out of 'investing in the imbalance market'. Most of the time, the imbalance price is high for 1 ISP, after which it decreases rapidly since (too) many parties have started supplying.

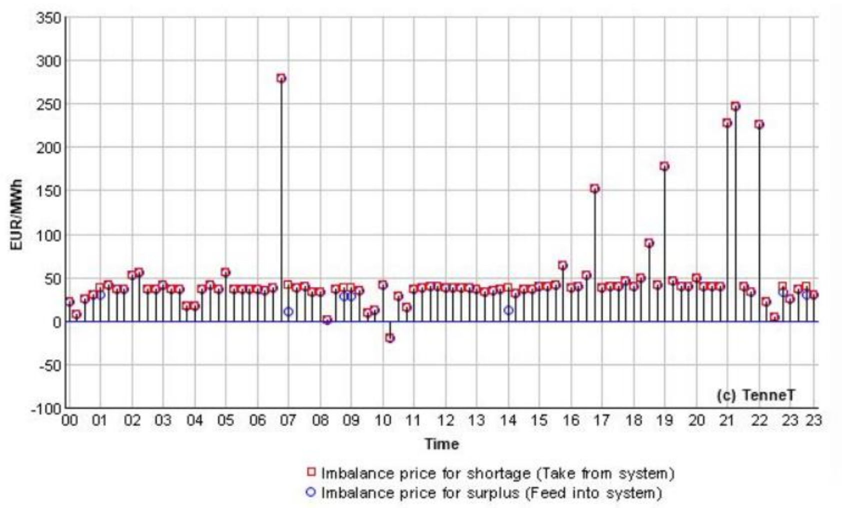


Figure 12: Example of an imbalance price settlement, date 18-02-2019. Source: Tennet.org

4.2.2 Opportunity losses

Opportunity losses occur when there is a need to choose among separately valued options (Buchahan, 1991). In the rational choice theory, competing opportunities are defined as alternatives between which has to be chosen (Harris & Holland, 1990). In this thesis, the term 'opportunity loss' will be used. Opportunity losses are defined as: a measure of the forgone profit or avoided loss of not being able to transact the entire order (The Science of Algorithmic Trading Portfolio Management, 2014). As appeared from section 4.2.1, greenhouse growers can supply their (flexible) electricity to various different markets. In this section, the commitment related to investing in a particular market, of which possible opportunity costs flow, is treated, as compared to the redispatch market. With a certain choice, a (temporary) lock-in can be created which enlarges the risk for higher opportunity costs. For each of the trade markets, it will be explained if opportunity losses may occur when investing in the redispatch market and which exact opportunities are lost.

OTC

As shown in Table 7, the OTC-market trades take place long before the day of delivery and therefore does not compete with the redispatch market. Redispatch can still be executed next to OTC-trades. The OTC-market will therefore not be used further in the research.

Day-ahead

Redispatch happens after the day-ahead settlement. Following from this it can be concluded that in principle, these two markets do not compete. Day-ahead sell-bids can be bought back via the redispatch market, which will be explained in Section 5.2. However, no opportunity losses

Intraday

Intraday-trading takes, just as congestion management, place after the day-ahead settlement. Therefore, it is a direct competition to the redispatch market. Most congestion management happens between 21:00 and 00:00 on the day before the delivery day (GOPACS meeting, 2019). As explained, the first intraday trade takes place at 18:00 on the day before the delivery day, up to an hour before delivery. For greenhouses active on both redispatch and intraday, the intraday trade will be paused between 21:00 and 00:00, because at those hours, the redispatch trade is active (See Figure 13). During the 'pause', no intraday deals can be made. This pause is inserted to avoid double settlement: when two bids are settled for the same hour, while there is only capacity to supply one of the two bids. Namely, if both redispatch and intraday run at the same time and place a bid for the same hours, this will cause problems since a certain volume at a certain hour can only be sold once.

It needs to be investigated if opportunity is lost in those hours, which can occur if the intraday deals between 21:00 and 00:00 are (in general) better than the deals before 21:00 and after 00:00.

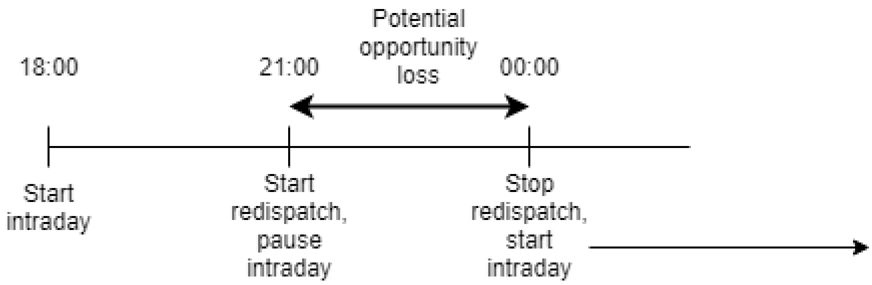


Figure 13: Opportunity losses of combining redispatch and intraday.

The second type of opportunity loss that could occur, happens because flexibility cannot be sold endlessly; a greenhouse has a certain amount of hours he can offer flexibility per day. As will be explained in section 5.3, the flexibility of a greenhouse is provided by the space in the buffer; the larger the buffer space, the larger the flexibility (a larger buffer space gives potential to turn the CHP on for more hours). If a greenhouse has 2 'flexibility hours' each day, and if these two hours are sold to the redispatch market, they cannot be sold to the intraday market. This is also an opportunity loss.

Tertiary reserve market
When a certain power plant is offered to the balancing market, it cannot be offered to the redispatch market anymore since for the balancing market, the power plant needs to be available anytime. Since the decision to offer a CHP to the balancing market takes place long before the day-ahead and redispatch market bids have to be supplied, there is no direct competition between the redispatch and balancing market.

Passive imbalance market
Redispatch is a direct competition to the passive imbalance market, in a sense that if a greenhouse offers to the redispatch market and if that bid is settled, he cannot 'offer' to the passive imbalance anymore at those hours. It needs to be investigated how a certain greenhouse grower values this opportunity loss and how large this opportunity loss is.

The opportunity loss due to less flexibility, as occurs when combining redispatch and intraday, also occurs when combining redispatch with the passive imbalance market. If there are two flexibility hours which are sold to the redispatch market from, for instance, 8.00-10.00, the greenhouse does not have any flexibility left during the rest of the day. It can occur the passive imbalance prices are very high at, for instance, 17:00. If the CHP is turned off at that time, it would usually make sense to turn it on in order to benefit from the high passive imbalance prices. However, due to the fact the buffer maximum has already been reached, the CHP cannot be turned on anymore. This is an opportunity loss.

4.2.3 Conclusion on trade-markets

Taking all the previous information together, an overview table of all the trade markets in the Dutch electricity system is given (See Table 8). As explained earlier, the location of a bid is needed when electricity is used to solve congestion.

Table 8: Different trade markets.

Trade market	Platform	Goal	Opportunity loss when combined to redispatch?
Over the counter (OTC); futures market	Bilateral contracts	Long-term electricity buying and selling, for an already known price	No
Day-ahead auction	ETPA EPEX	To match demand and supply of electricity, one day before production and use.	No. The only way the redispatch-market and day-ahead market can be combined, is when an existing day-ahead position is sold, by placing a buy-order on the redispatch market.
Intraday market	ETPA EPEX For AgroEnergy: orders from EET.	To match demand and supply of electricity when it differs from the APX position, up to 15 minutes before use.	Yes, redispatch and intraday are direct competition.
Redispatch	Reserve power for other purposes (Resin)	Congestion management	-
Redispatch	IDCONS	Congestion management, with coordination between TSO and DSO (GOPACS)	-
Reserve volume	Bilateral contracts	Used to restore the frequency on the electricity grid	If greenhouses can offer the same CHP to both the market for reserve volume **or** the day-ahead market combined with redispatch, opportunity losses may occur.
Imbalance settlement	Bilateral contracts and no contracts	Last mechanism to restore the supply- and demand balance	Yes, redispatch and passive imbalance are direct competition.

4.3 Solving congestion on different grid levels

As explained in the previous sections, congestion can occur on both transmission and distribution grid. The transmission system operator – TenneT – is responsible for solving congestion on the transmission grid, where the different distribution system operators are responsible for solving congestion on the distribution grid. Currently, there is congestion on both the transmission and distribution grid. As explained in the introduction (Section 1.1), congestion is expected to increase on both types of grids.

The redispatch market, which has been explained in Section 4.2.1.4, is a mechanism initiated by TenneT, to solve congestion on the transmission grid. Both parties connected to the transmission and distribution grid can supply bids to the redispatch market. Namely, congestion on transmission level can also be solved by actions of parties connected to the distribution grid. See Figure 14 for a simplified illustration of a possible situation. If the red transmission line is congested, greenhouse 1 could produce less electricity, such that less electricity needs to be transported over the congested transmission line. Greenhouse 2 should produce more electricity, to compensate for the reduced supply of Greenhouse 1. The implication that rises, is that the increased production of greenhouse 2 should not cause congestion on distribution line 2. This would be a shift of the problem – congestion – from the TSO to the DSO. In the original redispatch market, this situation could occur.

In the new redispatch market – IDCONS bids which are settled via GOPACS – there is an in-built mechanism which ensures solving congestion on one part of the grid can not cause congestion on another part of the grid. For doing so, the transmission operator and multiple distribution operators are connected to this platform. The (congestion)-situation on each part is used for determining potential solutions. Where the original redispatch market is used to solve congestion on the transmission grid, the redispatch market using GOPACS can also be used by distribution operators to solve congestion on the distribution grid.

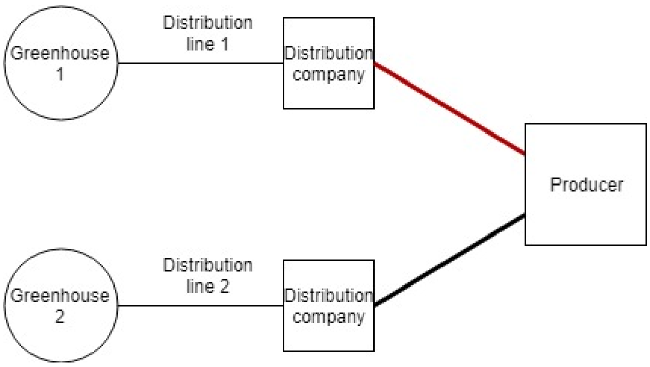


Figure 14: Simplified illustration of congestion

Since GOPACS has only recently been launced, congestion on the distribution grids has up till recently been solved via different initiatives of the distribution operators.

4.4 Current design of the redispatch market in the Netherlands

In this chapter, the current design of the redispatch market is explained. As explained in section 1.3.4, research into changing the balancing market to increase participation has been executed. Borne et al. (2018) developed a framework to identify barriers for distributed energy sources, to provide flexible reserve volume to new electricity markets. Poplavskaya & De Vries (2019) built upon this research, by investigating which market design of the balancing market facilitates the integration of distributed energy resources (DER). This research is used to investigate the design variables of electricity markets.

The adapted framework developed by Poplavskaya & De Vries (See Section 2.1) will be used to decompose the design of the redispatch market in order to identify specific inefficiencies for greenhouses. The two main aspects of this framework are 1) Market access and 2) Auction configuration. Market access relates to which parties can supply to a market and auction configuration relates to the design aspects of the specific market.

As explained in Section 4.2, there are two types of redispatch markets. Currently, it is the expectation that the GOPACS platform using IDCONS will be used more in the future (GOPACS website). However, the RESIN platform is still in use. As admitted by Tennet (GOPACS meeting), TenneT uses the cheapest solution to solve congestion and thereby does not discriminate between RESIN and GOPACS. The only relevant difference between RESIN and GOPACS for now, is the minimum bid size. As explained, where RESIN is only used by TenneT to prevent congestion on the *transmission* grids, the goal of GOPACS is to eventually be used by the TSO and DSOs together to prevent congestion on the *distribution* grids too. The potential impact of a different future situation will be discussed in the discussion (Chapter 9). For the research, the current situation and design will be used.

The aspects of the design of the redispatch market are summarized in Table 9, which is structured according to the framework that followed from Section 2.1. The specifications of the redispatch market are explained in two documents provided by TenneT: Product Specifications reserve volume (11-4-2019) and Bidding Specifications reserve volume (21-1-2019).

One remark has to be made, regarding the current design. Namely, as indicated in the product specifications, bids can be partially settled regarding *volume*. However, as indicated by Glismann (12-4-2019), the probability for partial settlement is very low: 'Given the relatively small capacity of a CHP relative to the size of congestion, the occurrence of a partial settlement of a redispatch bid by a greenhouse is almost 0. Solving congestion will not come down to a difference of e.g. 500 kW'. Therefore, for this specific research in which *greenhouses* (with a small CHP capacity) are suppliers, the probability of a partial settlement will be assumed to be 0%, which means partial settlement will not be taken into account. Possible consequences of a higher probability of partial settlement will be discussed in Chapter 9.

Another aspect also deserves some more explanation. Energy bid adjustment is not allowed if a bid is already settled. This means if a supplier places a 2 MW bid in the redispatch market and this bid is settled, he has committed to selling this bid. If he does not deliver this exact amount, the supplier has to pay a fine to the system operator. The fine will only have to be paid if a certain supplier aggrevates congestion. If a supplier has committed to *selling* 2 MW but only *sells* 1,5 MW, he aggrevates congestion and has to pay a fine. If he sells *more* than 2 MW, he will not get a fine. He will receive the passive imbalance price for the surplus. This also works the other way around, for supplying a buy bid.

Table 9: Design of the redispatch market, using the framework of Poplavskaya & De Vries (2018).

DESIGN ASPECT	**Group**	**Variable**	**Current design**
Market access	Formal access requirements	Explicit restrictions for certain types of service providers	Every party can supply, both connected to distribution and/or transmission grid.
		Specific products for DER	No specific products for distributed energy resources associated with the redispath market.
	Administrative aspects	Pooling	Pooling of different EAN codes not (yet) allowed.

		Verification of delivery	Currently, verification based on EAN code.
		Explicit portfolio requirements	No explicit porfolio requirements.
	Technical prequalification criteria	Activation speed and duration	Minimum duration: 1 hour.
Auction configuration	Bid-related requirements	Minimum bid size	Resin: 1MW GOPACS: 0,5MW Bids activated: Partially regarding bid-size (for greenhouses assumed: fully), fully regarding period
		Procurement of capacity & energy	Only procurement of energy (bids); no capacity payments will be given.
		Bid symmetry	Yes, possible to place sell and buy bids for same hour.
		Energy bid adjustment	Not allowed when bid is settled. If settled bid is not (fully) delivered, supplier has to pay a fine (level of fine still unknown)
	Time-related characteristics	Frequency of bidding - energy	Suppliers of volume larger than 4MWh (per hour) can submit as many bids as they want. Only three bids lower than 4MW are allowed per day per EAN
		Frequency of market clearing & activation - energy	Not one moment of market clearing – bids can be settled up till 3 PTU before delivery
	Remuneration	Pricing rule	Pay-as-bid auction.
		Special support schemes	Do not exist in the redispatch market.

Chapter 5: Technical potential for a greenhouse grower in the redispatch market

GOAL	METHOD	RESEARCH QUESTION
The goal of this section is to identify whether, using the current design of the redispatch market, greenhouses can supply to this market and to investigate how greenhouses can increase the settlement probability.	A data-analysis and desk research will be executed, where demand and supply are structured according to the framework of flexibility (Grunewald, 2016).	What are the technical characteristics of a greenhouse, determining the potential of different types of greenhouses as suppliers to the redispatch market, under different circumstances?

As explained in Section 2.2, according to neoclassical economics, individuals are rational and always make well-informed, profit-maximizing decisions. In neoclassical economics, a price originates at the point where demand and supply are in equilibrium. For this research specific, this means the settlement of a bid happens when the supply of a redispatch bid matches the demand for congestion volume, at that time.

This is where the first knowledge gap of the research evolves, since it needs to be investigated whether the potential flexibility supply of greenhouses could match the flexibility demand needed in the redispatch market. The research question that comprises this knowledge gap, is: ***'What are the technical characteristics of a greenhouse, determining the potential of different types of greenhouses as suppliers to the redispatch market, under different circumstances?'*** In order to answer this question, first in Section 5.1, the demand for electricity in the redispatch market is investigated. Then, in Section 5.2, the potential supply of different types of greenhouses to the redispatch market is investigated. In Section 5.3, the research question will be answered.

The framework used to structure this section is the flexibility framework, which is introduced in Section 3.1.1.1. The aspects of this framework are (Grunewald, 2016):

1) Time specificity
2) Change in time
3) Duration
4) Lead time
5) Location

5.1 Demand for flexibility: Flexibility needs in the redispatch market

In this section, the current characteristics of congestion management in the Netherlands are presented. First, the pattern of congestion over the day and over the year is presented, to determine when the need for (extra) flexible capacity is highest.

The data which has been used for determining the flexibility needs in the redispatch market, is data provided by TenneT: 'Settled reserve volume other purposes'. TenneT publishes System and transmission data, which can be exported for analyses (www.tennet.eu). As specified by TenneT, the product 'Reserve volume other purposes (ROP)', is used to solve transport issues; congestion (TenneT product specifications, 2019). Reserve volume other purposes is also used to provide assistance to other countries regarding transport issues. Still, assumed is the pattern of congestion over the day and year can be deducted from the data. Up to 2018, TenneT only used the bids provided as 'Reserve volume other purposes' for solving congestion; the GOPACS platform has only recently been launched. The data over 2017 and 2018 is used. According to the Royal Netherlands Meteorological Institute (KNMI), the weather differed between 2017 and 2018 when it comes to temperature, sunshine hours and wind power. By taking data of two years, the impact of the weather on congestion is tried to be smoothened. For this research, this data is used as 'congestion data'. The following relation is used: if ROP is settled, this means there was congestion.

5.1.1 Time specificity

In this section, the characteristics of congestion management in the Netherlands are investigated and presented. The data used, presents the settled volume per PTE (15 minutes). Based on this data, the influence of seasons and time of the day on congestion can be estimated.

In this section, first, the pattern of congestion over time is presented (Section 5.1.1.1). Then, using available data, it is investigated whether congestion can be predicted. If congestion can – to some extent – be predicted, this may enable suppliers to supply at those times when the demand for flexibility in the redispatch market is highest. For the suppliers – here: greenhouses – this may increase the potential earnings from the redispatch market. For TenneT, this may increase the supply of congestion volume and this way reduce the costs. In Section 5.1.1.2, the relation between day-ahead trade volume and congestion volume is investigated. In Section 5.1.1.3, it is investigated whether there is a predicting value in congestion (data) itself.

5.1.1.1 Pattern of congestion

This section is split up into a daily, weekly and yearly pattern of congestion.

Daily congestion pattern

As explained, for determining the daily pattern of congestion, the data provided by TenneT (2019) is used, for the years 2017 and 2018. In Figure 15, the weighted probability of congestion per PTU is shown. This is calculated by first calculating the probability of there being congestion at all, at a certain PTU on the day. Then, this is weighted for the congestion volume. This compensation for volume is done because a higher congestion volume also implies more supply of redispatch volume needed. This figure can be interpreted as, at PTU x, the average probability of there being congestion is y. No information regarding location can be deducted from this data, so it does not imply 'any' line is congested for e.g. 18% of the time at PTU 49. However, it gives a good indication of the time of the day for which settlement probability is relatively high or low.

As can be concluded from this data, the largest amount of reserve volume for other purposes settled is from PTE 37 until PTE 76 – 9:00 – 19:00. The pattern for upward and downward use of reserve volume is similar. During the evening and night, the average amount of settled congestion management volume is relatively low.

If market parties supply to the market for 'reserve volume other purposes', they should take into account that the demand is highest during these hours, suggesting the probability of a bid being settled is highest during these hours. If a supplier can only deliver flexible electricity at night, this does not directly mean he cannot supply to the redispatch market: It implies the probability of a match between supply and demand (a settlement) is lower. Assumed is the congestion pattern (which will be used for the neoclassical model presented in Chapter 6) is reflected by this pattern of settled reserve volume for other purposes, weighted for volume. If all congestion is solved using IDCONS bids via GOPACS, assumed is the demand for these IDCONS bids follows the same daily pattern.

An upward redispatch bid is a production bid where a downward redispatch bid is a consumption bid.

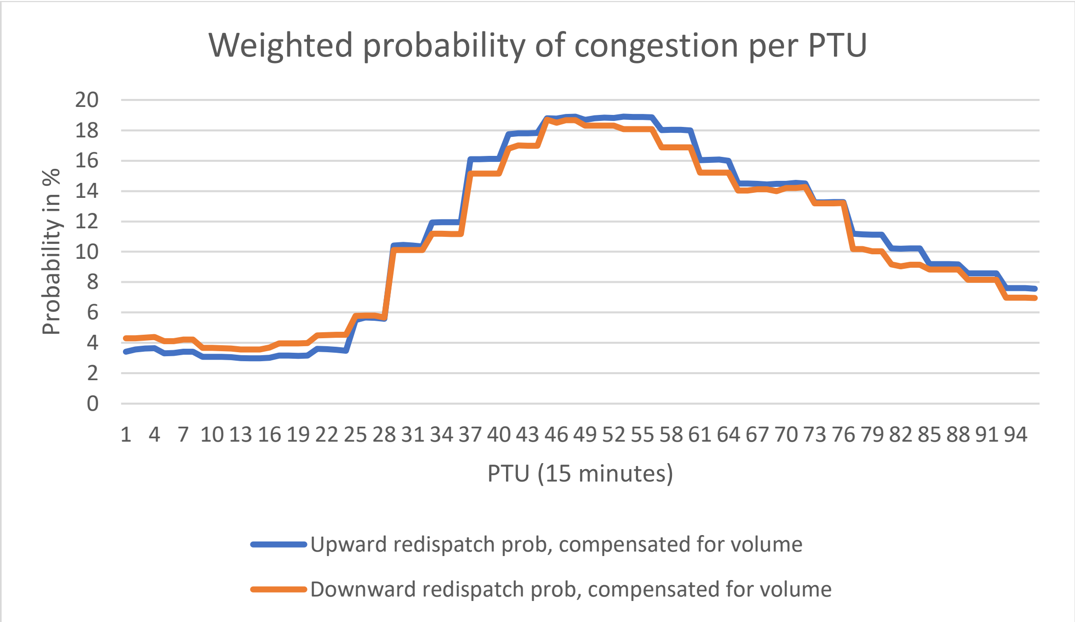


Figure 15: Probability of congestion, based on historical data of 2017 and 2018. TenneT (2019).

Weekly congestion pattern
An analysis executed by BlueTerra shows a market forecast of the Dutch electricity market for 2024, taking the growth in wind power production into account. The conclusion of that analysis is that if the trend continues, during working days, wind power will push coal plants out of the merit order. Therefore, mainly during working days, more flexible power is needed from other plants, like CHPs. The volatility that arises because of more volatile energy sources will likely increase the value of flexibility (Schlatmann, Buunk & Hoek, 2018). This is in line with the neoclassical theory. Namely, if volatility increases and therefore congestion probabilities increase, the demand for flexible electricity increases. The demand-line shifts to the right. If the supply remains unchanged, the prices will increase. This is shown in Figure 14 at the start of this chapter.

Yearly congestion pattern
In order to investigate whether there is a yearly pattern of congestion, the data published by TenneT in the yearly Market Reviews is used. In a Market Review, details regarding the Dutch and German electricity markets is given. Some information about redispatch is also given in these reviews.

Over the year of 2017 and 2018, the congestion volumes in the Netherlands fluctuated (See Figure 16). In November 2017, the redispatch volume was high due to high prices in Belgium and France, combined with some planned maintenance outages in the Dutch transmission grid (TenneT Market Review 2017, 2018). The result was congestion, which was solved using redispatch. A clear seasonal pattern of congestion can not be found, suggesting congestion is hard to predict. Where for instance in 2017, no congestion occurred in September, September appeared to have the highest redispatch volumes in 2018. Because of this information, it is assumed congestion is not influenced by yearly patterns and could happen at any time of the year.

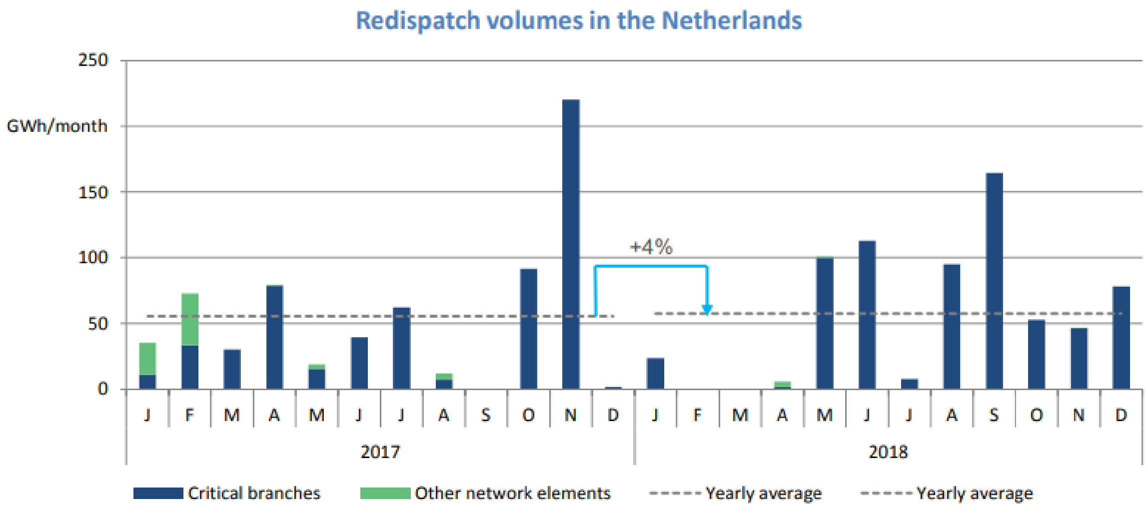


Figure 16: Redispatch volumes in the Netherlands, 2017 and 2018. Source: Tennet Annual Market Update 2018, 2019.

5.1.1.2 Day-ahead trade-volume as predictor for congestion volume

For choosing when to place bids on the redispatch market and this way increasing the probability of a match between supply and demand, it needs to be estimated when the congestion probability (during that day) is highest. The hypothesis is that congestion probabilities can to some extend be determined by the day-ahead trade volume. The reasoning behind this is that when day-ahead trade volumes are high, relatively more electricity needs to be transported, leading to higher congestion probabilities. In order to test this hypothesis, the data provided by TenneT - 'Reserve volume other purposes' – is compared to the day-ahead trade-volumes on the days congestion occured. The data structure of the two files had to be arranged in order to do analyses.

From the analysis, it appears the correlation between congestion and day-ahead trade volume is very low. See Table 10. This implies the day-ahead trade volume cannot be used to accurately predict congestion.

In this table, upward redispatch means the settlement of sell-bids where downward redispatch means the settlement of buy-bids. As explained in section 4.2.1.4, downward redispatch is needed in a congested area, where upward redispatch is needed in another area in order to compensate for the lower production in the congested area.

Table 10: Correlation between congestion and day-ahead trade volume

	PTU	Upward redispatch	Downward redispatch	Day-ahead trade volume
PTU	1.000000	0.157977	0.130094	0.143199
Upward redispatch	0.157977	1.000000	0.823828	0.102147
Downward redispatch	0.130094	0.823828	1.000000	0.072148
Day-ahead trade volume	0.143199	0.102147	0.072148	1.000000

The low correlation is visualised in a scatterplot, from which it also becomes clear there seems to be hardly any relation between day-ahead trade volume and both upward and downward congestion. In Figure 17, the relation between upward redispatch and congestion is plotted.

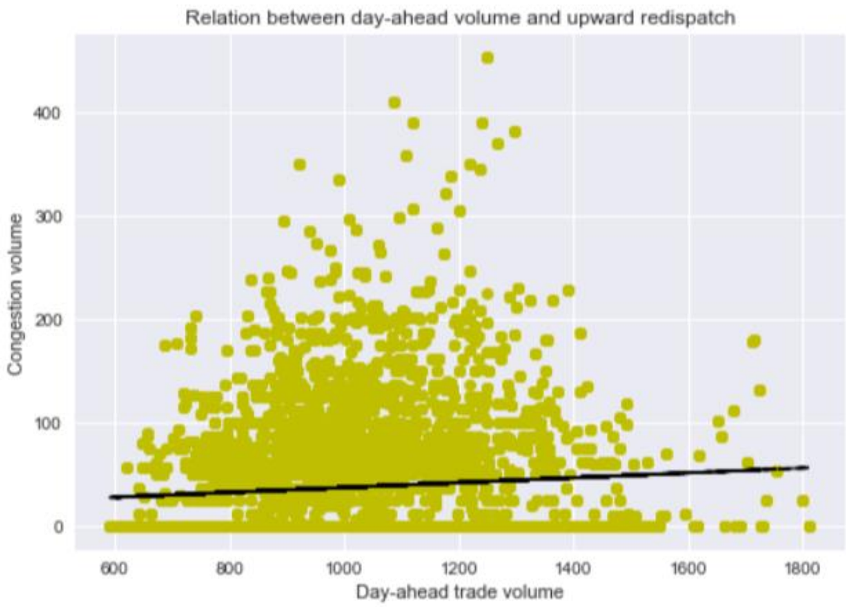


Figure 17: Scatterplot of the relation between day-ahead trade volume and upward redispatch

A similar relation is visible between day-ahead trade volume and downward redispatch. See Figure 18.

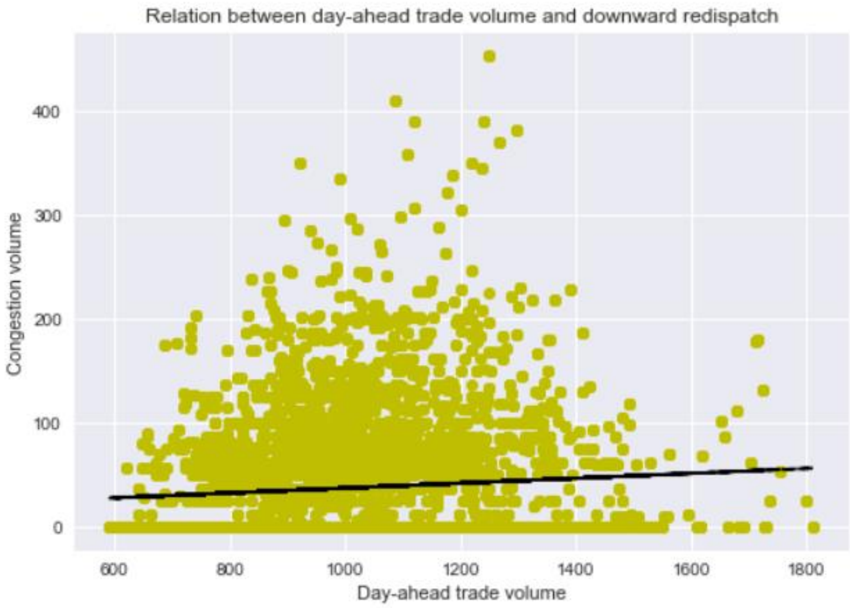


Figure 18: Scatterplot of the relation between day-ahead trade volume and downward redispatch

Concluded can be that there is the day-ahead trade volume is not a good predictor for congestion volume.

5.1.1.3 Autocorrelation in congestion

As appears from section 5.1.1.2, the congestion volume can hardly be predicted by the day-ahead trade-volume. Since the settled congestion volume of D-1 (yesterday) is known at D0 (today) (on www.tennet.eu), it makes sense to check for autocorrelation in the congestion data. Autocorrelation can check for cyclic patterns in the data and represents the dependence of a certain data point, with a previous data point (Box, Jenkins & Reinsel, 1994). The goal is to check whether current congestion can be predicted based on historical congestion data. For doing the analysis, the Reserve volume other purposes for 2017 and 2018 is used. One time-step in the data is one PTU (15 minutes), so 96 PTU is 1 day. At lag k, the autocorrelation shows the correlation between values that are k intervals apart.

From the analysis, the daily pattern becomes visible (each 96th PTU, there is a peak). This corresponds to the congestion probability during the day (Section 5.1.1.1), which is not constant. Besides, the analysis shows there is a higher correlation between Day 0 and Day -1, than between Day 0 and Day -2. The autocorrelation decreases further with a higher k. Almost the exact same pattern shows for both upward and downward redispatch.

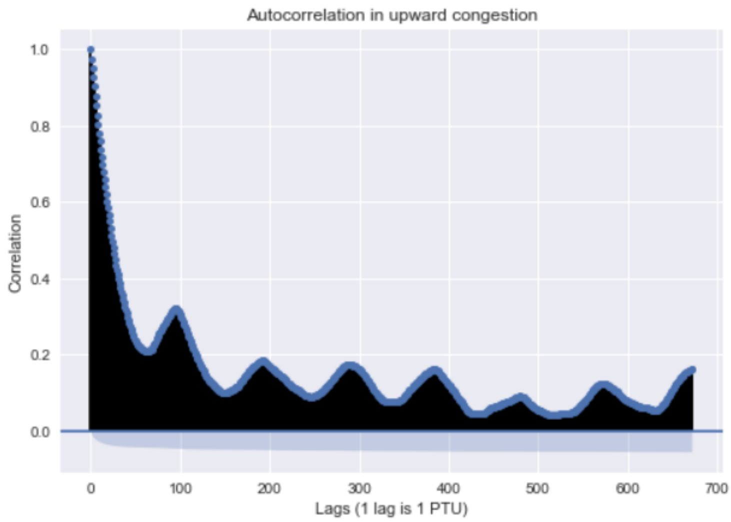


Figure 19: Autocorrelation in upward congestion

As can be seen in Figure 19, the correlation between congestion on Day0 and Day-1 is approximately 0.3. In order to investigate whether congestion on Day-1 can be used for predicting congestion and thus placing the 'right' redispatch bids, the correlation between congestion on Day0 and Day-1 is visualised in a scatterplot. See Figure 20. From this scatterplot it becomes clear there is barely any relation between congestion on Day0 and Day-1; there is not a clear (linear) pattern. Therefore, yesterday's congestion will not be used to place the redispatch bids.

A similar relation shows for downward congestion, which is why these plots haven't been shown separately.

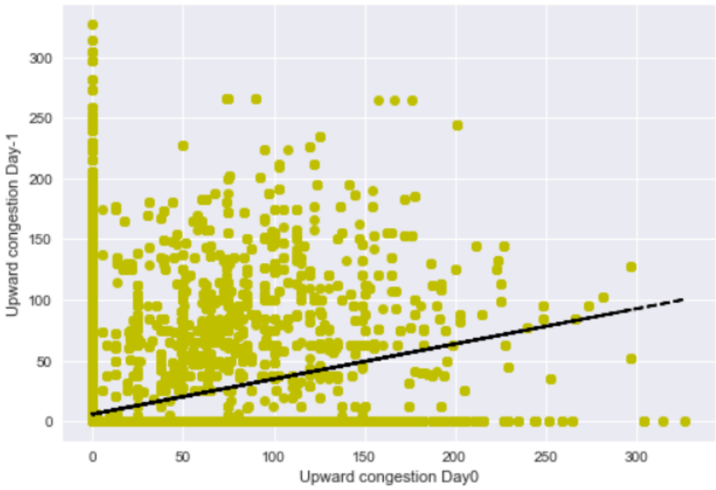


Figure 20: Correlation in upward congestion between Day-1 and Day0

5.1.1.4 Conclusion on time specificity

From the analysis executed in Section 5.1.1.1, it can be concluded there is a clear pattern in the highest occurrence of congestion during the day; most congestion occurs between 9:00 and 15:00. This can be used as a decision variable when to place redispatch bids, if there is a need to choose between different timeslots. However, from section 5.1.1.2 and 5.1.1.3, it appears it is hard to predict accurate congestion using the information available; both the correlation between day-ahead volume and congestion and the correlation between Day-1 and Day0 congestion, are weak and can thus not be used to predict congestion. This emphasizes the importance of market messages in which accurate congestion predictions are presented.

5.1.2 Change in time

The rate of change is expressed as power per unit of time. In this specific case, it is interpreted as capacity that is needed per unit of time. The congestion volumes needed differ per congestion occasion. The most occuring upward congestion-management volume is 50 MWh/PTU, meaning a capacity of 200 MW is needed at that time. The most occuring downward congestion-management volume is 75 MWh/PTU, meaning a capacity of 300 MW is needed at that time. This volume does not have to be provided by one (or a few) suppliers; different volumes can be combined to form the full needed congestion volume (GOPACS meeting, 2019).

5.1.3 Duration

To investigate the duration of the need for congestion management, the average duration (amount of PTUs) of the use of Reserve Volume for Other Purposes is determined. The data is analysed using Python (File: Duration). It appears the highest occurences (9.3% of the time) of congestion in 2017 and 2018 were 4 PTUs, or 1 hour. The longest duration of congestion was 336 consecutive PTUs, being 14 days in a row; this only happened once in 2017 and 2018 together. The shortest duration was 4 PTUs.

On the redispatch market, multiple consecutive bids can be used to solve congestion. This means a supplier to the redispatch market does not have to be available during the full duration of the congestion (GOPACS meeting, 2019).

Duration in PTE	Occurence	Average occurence (%)
4	18	9.230769
8	17	8.717949
16	16	8.205128
24	13	6.666667
20	12	6.153846
28	12	6.153846
48	11	5.641026
12	11	5.641026
36	9	4.615385
60	8	4.102564

Figure 21: Most occuring duration of congestion in 2017 and 2018.

5.1.4 Lead time

The lead time determines the notice on which flexibility is needed. Some flexibility is needed on short notice, where other flexibility needs can be forecasted. TenneT receives the day-ahead positions on the day before delivery. In principle, the aim is to solve congestion beforehand. After all, the consequences of congestion can be severe – congestion can cause outages which last for days (Hirth & Glismann, 2018). TenneT aims at solving the most congestion issues between 21:00 and 01:00, on the day before delivery day. It can occur that congestion needs to be solved during the day, too (GOPACS meeting, 2019). However, since AgroEnergy withdraws bids after 00:00 in order to start intraday-trading, the greenhouses operated by AgroEnergy will only contribute to the preventive solving of congestion.

5.1.5 Location of congestion management

As described in Chapter 1, the need for congestion management depends on the development of demand peaks, decentral generation and generation using variable renewable energy sources. Besides, loop flows from abroad appear to have an influence on the Dutch congestion management needs. Since congestion is location specific and thus congestion management needs are location specific, it is important to investigate in which regions the congestion management needs will be highest. However, since congestion can be caused by different reasons, the congestion needs per area fluctuate. Low prices in neighbouring countries (Germany and Belgium) can for instance lead to more congestion and thus redispatch needs. Planned maintenance outages in the high-voltage grid can cause congestion too (TenneT Market Review, 2017). To avoid this intransparency, TenneT is working on a mechanism where TenneT sends out a message if congestion is expected on a certain period and location.

Orders wanted on 5 Feb 2019 between 09:00 and 12:00
Buy orders (i.e. downward regulation) required in areas: Groningen, Friesland, Overijssel, Drenthe, Flevoland (ten noorden Ketelmeer), on all voltage levels
Sell orders (i.e. upward regulation) required in areas: Flevoland (ten zuiden Ketelmeer), Gelderland, Utrecht, Noord-Holland, Zuid-Holland, Zeeland, Brabant, Limburg on all voltage levels

Figure 22: Example of a congestion announcement. Retrieved from: www.gopacs.eu/marktberichten

Information as shown in Figure 23 reveals areas with high congestion probabilities. As stated by Glismann (Gopacs meeting), congestion management is needed in the whole country. Namely, in congested areas, downward regulation is needed in order to reduce the transport in that area. To compensate for the reduced electricity production, non-congested areas, upward regulation redispatch volume is needed.This way, the total electricity production remains unchanged.

Information as shown in Figure 23 can be used to determine what type of flexibility supply is needed. If a potential flexibility supplier can only provide upward redispatch bids, but is located in a congested area (inicated using the red colour), it is quite unlikely the upward redispatch bid will be settled. Producing more electricity in an already congested area likely worsens the transport problem. While this information could thus be valuable to potential suppliers, this information is not yet available for the whole country.

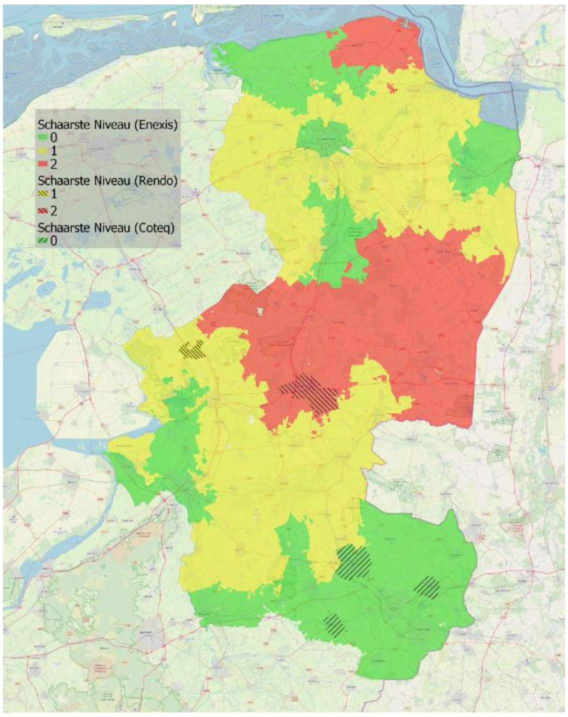


Figure 23: Areas with transport problems in the area of DSO Enexis. Enexis, 14-3-2019.

5.1.6 Conclusion on flexibility needs in the redispatch market

The flexibility needs in the redispatch market are summarized in Table 11.

Table 11: Flexibility needs in the redispatch market

Flexibility aspect	Estimated average 'value'
Time specificity	Most congestion occurs between 9:00 and 15:00, but congestion can occur during any hour.
Change in time: capacity	All congestion volumes are needed. The minimum bid-size is 0,5 MW (GOPACS) and 1 MW (Resin).
Duration	The most occuring congestion had a duration of 1, 2, and 4 hours.
Lead time	Most congestion management happens the day before delivery. With an increase in volatility, more congestion management may be needed during the day or delivery.

Location	Congestion management is needed in the whole country. Namely, in congested areas, downward regulation is needed in order to reduce the transport in that area. To compensate for the reduced electricity production, non-congested areas, upward regulation redispatch volume is needed.This way, the total electricity production remains unchanged.

5.2. Supply of flexibility: The technical potential of a greenhouse as supplier to the redispatch market

In this section, the supply of market parties to the redispatch market is investigated. The market parties central in this research are greenhouses. Greenhouses are complex systems where the main goal is producing crops; the electricity sales can provide an extra income. The goal of this chapter is to fully identify greenhouse growers' technical characteristics, to then investigate whether the (potential) flexibility supply by greenhouses matches the flexibility demands in the redispatch market.

It will first be explained how greenhouses can produce electricity and what the exact role of a CHP is, in a greenhouse (5.2.1). Herafter, the available flexibility in greenhouses is determined (5.2.2). This section is, just as section 5.1, subdivided according to the flexibility framework described by Grunewald (2016).

5.2.1 Greenhouses as electricity suppliers

To be able to estimate the flexibility in a greenhouse, it is important to first identify the technical characteristics of a greenhouse. A schematic overview of a greenhouse with a CHP, and the flows within the system, is given in Figure 24. The flexibility of a greenhouse is provided by the buffer, which can store heat for later use. If the buffer is full and the temperature of a greenhouse should not be higher than it currently is, the CHP should not produce anymore. Some heat could leave the greenhouse by opening the windows, if the outside temperature is cold enough. However, this is not a favorable solution since it is a waste of energy.

Electricity that is produced by the CHP, but not (entirely) needed for the lights, can be transported to the distribution grid; this is the electricity that is offered to the market.

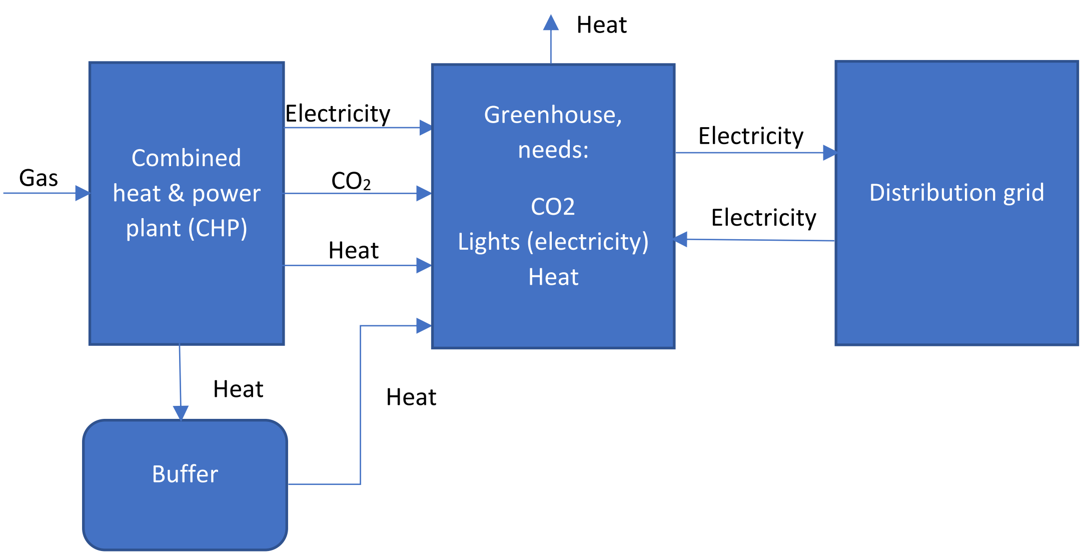


Figure 24: Schematic overview of the flows within a greenhouse.

AgroEnergy uses a tool (BiedOptimaal), where for each greenhouse, the day-ahead sell- and buy-bids are placed. For doing so, an expected day-ahead price is calculated. An optimization is executed to calculate the optimal day-ahead bids, given the lighting-profile, heat-profile and CO_2-profile, within certain technical constraints. The tool calculates an expected day-ahead price.

Next to the expected day-ahead price, other factors determine the day-ahead bids as well:

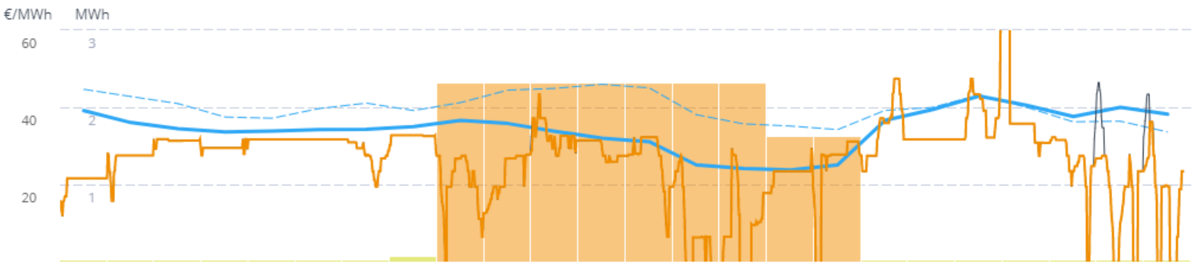
- The marginal costs (based on the gas price)
- The needed heat-profile (using the weather forecast)
- CO2-profile
- Lighting-profile (using the weather forecast)
- Operating electricity
- Buffer space

It lies outside the scope of the research to explain the whole optimization process that takes place. What *is* relevant, is the outcome of this tool, since the redispatch bids are placed after the day-ahead settlement. So while placing the redispatch bids, the day-ahead position is considered to be given. Flexibility, then, is the extent to which electricity can be traded around this day-ahead position.

Using this data, day-ahead bids are placed, for a certain volume, a certain hour of the day and a certain price. The weather forecast is relevant for doing the day-ahead bids as well, since the weather forecast determines the lighting and heating needs. The output on a randomly picked day, for a randomly picked greenhouse grower, is shown in Figure 25. Here, the orange blocks is the day-ahead position of this greenhouse. From 8.00 – 15.00, this greenhouses sells slightly more than 2 MWh per hour. From 15.00 – 17.00, this greenhouse sells 1,7 MWh per hour. This reduction in day-ahead electricity sales could have taken place because the CHP was turned from full- to partial load. Another reason could be that the lighting was switched on during those hours, increasing the greenhouse's own electricity consumption and thus reducing the to-be-sold electricity.

The imbalance price is shown by the orange line. The dotted blue line indicates the expected day-ahead price; the continuous blue line indicates the realized day-ahead price.

The message of this example is to show what a day-ahead block could look like, thus visualising what is meant with 'trading around the day-ahead position'. In this situation (Figure 25), e.g. no electricity sales can be done between 8:00 and 15:00, since the CHP is already selling its full volume to the day-ahead market.



Uur:	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24
- -	44,7	42,8	41,0	37,5	37,2	39,7	41,1	39,2	41,2	44,5	44,9	46,0	45,0	38,1	35,7	35,2	34,2	39,2	40,0	43,2	40,0	36,2	36,4	33,6
—	39,2	36,1	34,5	33,6	33,9	34,2	34,3	35,0	36,6	35,8	33,8	32,0	31,1	25,1	24,1	23,8	25,1	36,6	39,4	42,9	40,6	37,6	40,0	38,2

Figure 25: Day-ahead positions of a random greenhouse, calculated using BiedOptimaal (a product of AgroEnergy).

5.2.2 Flexibility available in greenhouses

For the redispatch pilot, an optimization model has been developed to calculate during which hours of the day, bids can be supplied to the redispatch market. In this section, the technical details of a greenhouse, determining this flexible supply to the redispatch market, are explained. Each greenhouse is different in terms of buffer size, CHP, CO_2-profile, lighting-profile and heat-profile. It is important to investigate how each of these aspects influences the flexibility a greenhouse can deliver.

The distinction between upward and downward flexibility is important. Upward bids are production or sell-bids: relative to your position, you have to produce more. Downward bids are consumption or buy-bids: relative to your position, you have to consume/produce less. If a greenhouse grower has a certain day-ahead position and has to produce, he can place a downward bid. If the bid is settled, he receives money (day-ahead price minus the price of the downward bid) while not turning the CHP on.

5.2.2.1 Time specificity

On average, CHPs in greenhouses are producing electricity during the daily hours on working days (Schlatmann, Buunk & Hoek, 2018). Since the redispatch bids are placed after the day-ahead settlement, the (average) day-ahead position is an important determinant for the time specificity of the flexibility that can be provided to the redispatch market. During the day, the timing of bids depends on a few factors, being:

- Day-ahead bids: redispatch bids need to be placed around the day-ahead bids
- CO_2-block: if the CHP is used for producing CO_2, it will not be turned off, so during that period, no buy-bids will be done.
- Lighting-block: if the CHP is used for producing electricity for the lighting, it will not be turned off. During that period, no buy-bids will be done.
- Minimum up- and downtime: indicate the minimum time a CHP needs to be turned up or down. This restricts the potential bid slots.

These four factors are specific per greenhouse. Redispatch buy-bids will only be provided outside the lighting and CO_2-blocks. The reason for this is that the day-ahead bids are placed in such a way, that the greenhouse has the optimal lighting and CO_2-production to grow the crops. Since the main objective of a greenhouse is to grow crops, redispatch may not stand in the way of this objective.

Daily distribution of flexibility

The average day-ahead trade over the year 2018 of a tomato-grower with a total CHP-volume of 6 MW is shown. A tomato-grower needs a lot of light. The impact of lighting needs on the electricity position is clearly visible in the graph of the day-ahead trade. From PTU 73 (18:00 hr), the average day-ahead trade starts to become negative meaning the greenhouse sells electricity. In the lighting-data of this specific greenhouse, it shows at most days, the greenhouse turns off the lights at 18:00. This is indicated with an arrow in the figure. So for this specific greenhouse, most flexibility can be offered during the evening hours; during the day, the produced electricity is needed by the greenhouse itself.

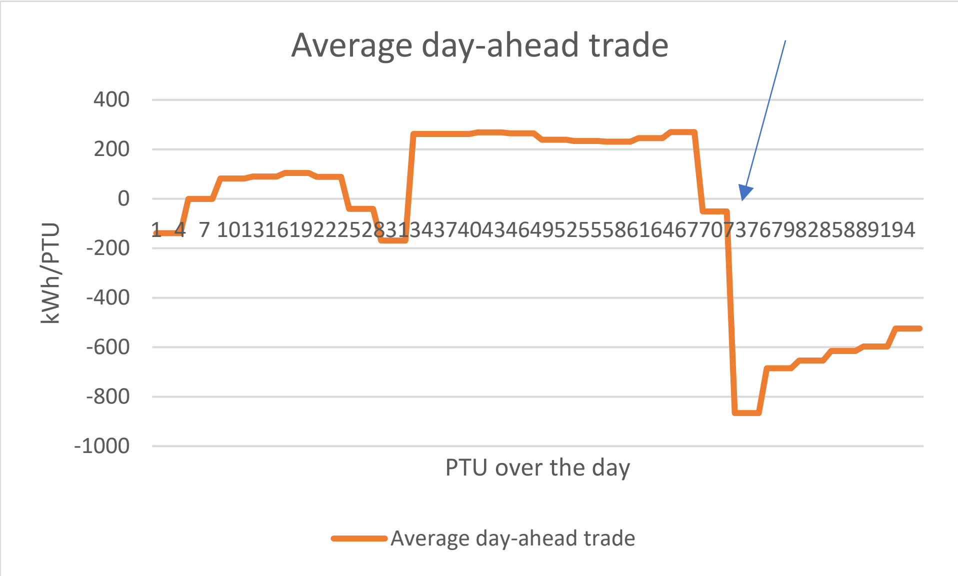


Figure 26: Average day-ahead trades of a tomato grower, over the day.

Yearly distribution of flexibility

A greenhouse has a specific energy use which is influenced by the seasons. As explained, a CHP can deliver electricity if it produces electricity which is not needed in the greenhouse. In winter, it is colder and darker, meaning a relatively large part of the power and heat the CHP produces is needed in the greenhouse. In summer on the contrary, less heat and lighting is needed. The CHP cannot be turned on very often in summer, since a the heating-needs of a greenhouse are relatively low and the buffer does not have an endless capacity. This implies electricity production is low.

In the transition months – February to April and September to October – it is generally still cold, but the days are getting longer. Therefore, the CHP is (often) still needed for the production of heat, but not all produced electricity is needed for the lights. During those months, the potential electricity delivery is highest. This can also be seen in Figure 27, which shows the day-ahead trade volume over 2018 of tomato grower. A negative trade volume means the greenhouse sells electricity, a positive trade volume means the greenhouse buys electricity.

As visible in Figure 27, from around day 50 until day 150 (end of February until the end of May) and from around day 275 until day 325 (September until mid-October), the day-ahead trade volume is positive on most days. This means the greenhouse produces and sells electricity. Flexibility will likely be highest in those months, too.

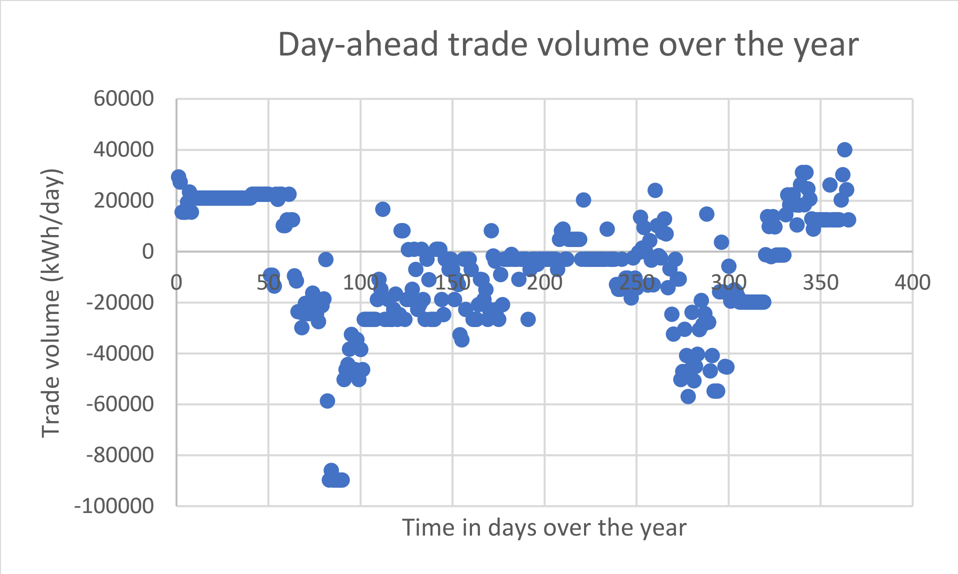


Figure 27: Day-ahead trade volumes of a tomato grower, over the year.

5.2.2.2 Change in time: Capacity

Due to technical restrictions, a greenhouse can produce on only two loads: full-load or partial load (about 70%).

The rate of change is expressed as power per unit of time. In this specific case, it is interpreted as capacity that can be delivered per unit of time. For greenhouses as suppliers or buyers of flexible electricity, this depends on the power of the CHP, the maximum off-take of electricity and the sell- and buy-capacity of the connection between the electricity grid and the greenhouse.

If the connection capacity is sufficient, a greenhouse can provide sell-bids maximally as large as the maximum power of the CHP(s). If the greenhouse has multiple CHPs, the EAN-code of the CHPs needs to be similar in order to be able to sum the capacity in one redispatch bid. After all, congestion management is EAN-specific since the EAN is the only indication of the location of a greenhouse (Chapter 4). The greenhouses participating in the redispatch pilot have a total CHP-capacity ranging from 4000 kW up to 20.000 kW. On average, a single CHP has a capacity of 2000 kW.

If the connection capacity is sufficient and if the greenhouse has a day-ahead position, the greenhouse can place buy-bids maximally as large as the volume sold on the day-ahead market at a certain time slot, plus the amount of electricity which can be used by the lights (if the lights are still turned off). Namely, the position can be bought back and extra electricity could be used by turning on the lights. If the lights are already turned on with a certain position, the maximum buy-bid is as large as the position, which can then be bought back. Noted should be that, if the lights do not have to be turned on for the crops, a greenhouse will never pay for this electricity since it is worthless to the greenhouse. According to neoclassical theory, an individual will always rationally calculate costs and benefits of a certain decision; he will not make a decision which is in his own disadvantage. Only in times of a severe shortage of transport capacity and if the buy-prices get negative – meaning you earn money for buying electricity – this behaviour can happen since then, it would be rational to do so.

Figure 28: Illustration of a maximum buy-bid

For some greenhouses, the connection capacity is a constraint to what can be sold. For sell-bids, a constraint can occur if the sell-connection capacity is smaller than the total capacity of the CHPs. An example is one of the greenhouses in the redispatch pilot, who has a maximum sell-connection capacity of 3950 kW, while the capacity of the CHPs is 6000 kW. Not all this capacity can be fully sold. For buy-bids, a similar situation can occur.

5.2.2.3 Duration

The amount of hours flexibility can be provided, depends on the buffer space and on the minimum uptime.

Duration of a sell-bid

With calculating the day-ahead position, the heating needs are taken into account (Section 5.1.1). Namely, the day-ahead position is the outcome of the planning. Therefore, the heat produced by the CHP when it delivers 'extra electricity' on the redispatch market is, assuming the day-ahead position calculates the heating needs correctly, not directly needed and needs to be stored in the buffer. For calculating the maximum duration of the sell-bids in the redispatch market, the buffer space therefore forms a constraint; the buffer level needs to stay within the boundaries (See Figure 29). The daily buffer levels are used for determining the maximum amount of sellable hours at a certain day. The duration can be calculated, by calculating how many heat is produced by turning on the CHP for one hour. When the buffer is expected to reach the maximum-level with the regular day-ahead bids, no sell-bids can be placed anymore. If there is still space in the buffer, bids can be placed for that amount of hours until the buffer reaches its maximum. This is often not much more than 5 hours.

The minimal uptime of a CHP determines for how many hours the CHP minimally needs to be turned on, in order to lower the probability of failures of a CHP. If the redispatch bids are not directly linked to the day-ahead settlement block, the duration of the redispatch bid needs to be at least as long as the minimal uptime. It can happen that the buffer space allows two more flexible sell-hours, while the minimal uptime is three hours. Then, no bid disconnected from the day-ahead position can be done.

The minimal downtime adds a restriction to the potential bids, too. This could for instance happen if there is a day ahead position from 9:00 – 12:00, and from 15:00 – 18:00. If the minimal downtime is 3 hours, it is not possible to, for instance, place a redispatch bid from 12:00 – 13:00, since then the CHP will be turned off for two hours.

The reason why there is a minimal uptime and minimal downtime, is the fact that the failure probability increases when the up- and downtime are too low. Therefore, it is often contracted what is the minimal up and downtime.

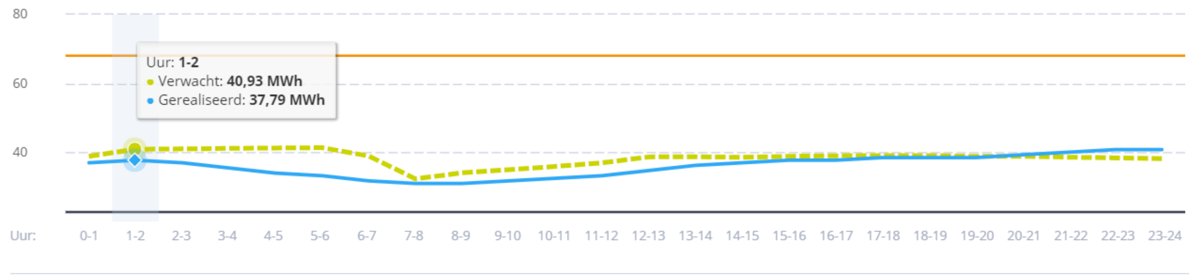


Figure 29: Example of a plotted buffer line, with minimum (black), maximum (orange), expected (green) and realized (red) levels.

Duration of a buy-bid

With calculating a buy-bid, it is the other way around. If a day-ahead position is sold, less heat is produced than expected only based on the day-ahead position. If the use of heat (out of the buffer) remains unchanged, and assuming the boiler does not compensate for the lower heat production of the CHP, the buffer level will drop as compared to the expected buffer level. The maximum buyable hours are calculated based on the space between the expected buffer level and the minimum buffer level.

5.2.2.4 Lead time

The lead time points to the amount of time it takes before a certain generator can start up from a cold state (Grunewald, 2016). The start-up time of a CHP can be up to 20 minutes. This is not relevant for the redispatch market, since the bids will be withdrawn at 00:00 if they are not settled. If this changes in the future, greenhouses can always withdraw the redispatch bids in time to not risk a too long lead time may cause a fine. After all, a fine will be given if a settled bid is not fully delivered (Section 4.3).

5.2.2.5 Location

Greenhouses are distributed over the whole country (Boerenbusiness, 2015). There are specific regions where greenhouses are concentrated, being Westland, Wieringermeer, Venlo and the Noordoostpolder. These locations are spread over The Netherlands. If more details about the congestion areas as presented in Section 5.1.6 are given, it can be determined whether a greenhouse should mainly supply buy-bids or sell-bids.

5.2.2.6 Conclusion on flexibility in greenhouses

Based on the different technical characteristics, a flexibility pattern is calculated. This flexibility pattern will be used to calculate the theorethical economical potential of a greenhouse in the redispatch market (Chapter 6 and 7).

Table 12: Flexibility aspects in a greenhouse with CHP

Flexibility aspect	Influenced by	Estimated average 'value'
Time specificity	Heating needs, lighting needs, CO_2-needs, day-ahead positions	Most flexibility in the transition months, mostly during the

		morning (before APX) or afternoon (after APX).
Change in time: capacity	The capacity of a CHP and the amount of CHPs on one EAN.	Average value of 1 CHP is 2 MW. The total capacity of the redispatch pilot greenhouses differs from 6 to 20 MW.
Duration	Buffer size, heat use, day-ahead position	Duration is at least 1 hour, at maximum (averagely) 5 hours.
Lead time	Start-up time of a CHP	A few minutes.
Location	EAN-code	Distributed over the whole country.

For the further analysis, 3 types of greenhouses are selected. These are presented in Table 13. The first type of greenhouse is a greenhouse producing cherry tomatoes, which have lighting needs. The second type of greenhouse is a greenhouse producing pot plants, which have intensive lighting needs. The third type of greenhouse is a tomato-grower, having no lighting needs.

Table 13: Selection of greenhouses

	Crops	Specifics
Greenhouse 1	Cherry tomatoes	Lighting needs
Greenhouse 2	Pot plants	Intensive lighting needs
Greenhouse 3	Tomatoes	No lighting needs

5.3 Conclusion on technical potential of greenhouses as market party in the redispatch market

The available flexibility in greenhouses is linked to the flexibility needs on the redispatch market, also classified based on the different aspects of flexibility. The exact characteristics of the redispatch market are opaque. The reason for this is to avoid gaming; if congestion on a certain part of the grid is expected, large parties could adjust their biddings to even further increase congestion and this way drive up the redispatch prices. Based on previous redispatch needs using historical data, the flexibility needs in the redispatch market are tried to be established.

The research question central in this part, was: **What are the technical characteristics of a greenhouse, determining the potential of different types of greenhouses as suppliers to the redispatch market, under different circumstances?** The specifics regarding flexible supply available in greenhouses and needed in the redispatch market, are presented in Table 14. From this, it follows, with the current characteristics and knowledge of the greenhouse market and given the technical characteristics, greenhouses do have a potential as supplier of congestion management volume to the redispatch market. There are no technical characteristics witholding greenhouses from the possibility to supply to the redispatch market.

Table 14: Flexibility present in greenhouse versus needed in the redispatch market.

Flexibility aspects	Present in greenhouse	Needed in redispatch market
Time specificity	Most flexibility in the transition months, mostly during the morning (before APX) or afternoon (after APX).	Most congestion occurs between 9:00 and 19:00, but congestion can occur during any hour.

Change in time: capacity	Average value of 1 CHP is 2 MW. The total capacity of the redispatch pilot greenhouses differs from 6 to 20 MW.	All congestion volumes are needed. The minimum bid-size is 0,5 MW.
Duration	Duration is at least 1 hour, at maximum (averagely) 5 hours.	The most occuring congestion had a duration of 1, 2, and 4 hours.
Lead time	A few minutes.	Most congestion management happens the day before delivery.
Location	Distributed over the whole country, but there are specific regions where greenhouses are concentraded.	Congestion management is needed in the whole country; in non-congested areas, upward regulation redispatch volume is needed.

Chapter 6: Theorethic economical potential of greenhouses in the current redispatch market

GOAL	METHOD	RESEARCH QUESTION
To calculate under which circumstances the redispatch market is profitable for a specific greenhouse, as compared to (direct) opportunities (intraday, passive imbalance)	Deterministic modelling, using sensitivity analysis to test the impact of uncertain input variables.	Under what circumstances can the redispatch market be an added value to the portfolio of greenhouses, given their technical characteristics and behaviour in other markets?

In this section, it will be calculated for different greenhouses, whether it would be rational to offer (flexible) electricity to the redispatch market. Offering flexible electricity has opportunity costs (Grunewald, 2016); if (flexible) electricity is used for one purpose, it cannot be used for a competing purpose at the same time. According to the rational choice theory, as explained in Section 2.2, suppliers always choose rationally between different options. Before making a decision, the expected value of each of the possible decisions is calculated. The option with the highest expected value, will be preferred over a competing option with a lower value. The research question that will be central in this section, is:

‘**Under what circumstances can the redispatch market be an added value to the portfolio of greenhouses, given their technical characteristics and behaviour in other markets?**’

The current design of the redispatch market (Section 4.3) is used for this question, in which a fine will be given to the greenhouse grower, if he does not supply a settled bid.

In order to give a complete answer to this second research question, the question is split up into two research questions. The results of the answer to the first research question, will be used as input to the second research question. These two (partial) research questions will be answered separately, after which a joint conclusion will be given.

RQ 2.i) What should the redispatch bid price be, in order to beat the competing markets?
RQ 2.ii) What is the average additional monthly revenue on the redispatch market, under different price- and congestion scenarios, for different months?

The goal of answering the first part of this research question is to calculate per category of greenhouse growers (See Section 5.2.2.6), for what bid price it would be rational to supply to the redispatch market, by calculating the value of opportunities and potential monetary losses. The model used for answering this partial question is shown in Section 6.1. A note should be made here; when supplying *sell* bids to the redispatch market, the price should be *higher* than a certain level. After all, when supplying to the redispatch market, money is paid by the TSO to the supplier. When supplying *buy* bids to the redispatch market, the price should be *lower* than a certain level. Namely when buying from the redispatch market, money is paid by the supplier of the bid to the TSO. This is explained in more detail in part 4.2.1.4. Buying electricity often happens when the buffer is fuller than expected, so the CHP can be turned off (See Section 5.2.2.2). As explained in 4.2.2, the intraday, passive imbalance and redispatch market take place after the day-ahead settlement, and allow for an adjustment of the day-ahead position. Therefore, these three markets are also competing for buy-bids.

The goal of answering the second part of the research question is to give an indication of the potential additional revenues when a certain type of supplier starts selling his electricity to the redispatch market. Additional monthly revenues are calculated based on current congestion probabilities and the current indication of the (average) redispatch price. While according to the theory of rational choice, an individual would always choose for the better option, for AgroEnergy it is valuable to have an idea of the magnitude of the additional profit. Namely, while for the greenhouses, the redispatch market may be a good bonus, AgroEnergy needs to invest time in further developing the redispatch product. The potential profits play a role in the decision to (not) continue.

These both questions will be answered for the three specified types of greenhouses: a tomato-grower, a cherrytomato-grower and a lilly-grower. The neoclassical assumptions account for the deterministic model, being:

- People are rational in their choices
- People maximize utility or profit
- There is full information-transparency

This implies people know the value of their opportunities. It also implies people know the value of the redispatch market. Besides, it implies people know the probability a certain event occurs (Harris & Holland, 1990). They rationally choose the best valued alternative.

The approach for answering these two research question is a deterministic approach. A deterministic approach studies the behaviour of certain system in which the relationships within the system are known. A certain set of input variables will always lead to the same set of output variables. The disadvantages of this approach are that input variables are assumed to be known, while in reality they may be uncertain. In order to show the impact of a variance in the input variables, a sensitivity analysis will be executed. The advantages of a deterministic approach are that future developments or a change in input variables can easily be adopted (Mucalo, Zentner & Mataga, 2012).

The objective of this chapter is not to give a precize answer to the level of earnings a greenhouse grower may exactly expect when he starts supplying to the redispatch market. The goal is to, based on current data, investigate whether it is likely there may be an economic benefit of the supplying to the redispatch market. In order to do so, the bid-price for which the redispatch market would provide economic benefit will be compared to the currently available information regarding redispatch prices. Then, based on the flexibility available for supplying to the redispatch market, using the current knowledge, an indication of potential additional monthly earnings will be given. The answers to part 1 of sub question 2 will be used for answering part 2 of sub question 2. Namely, in order to calculate **additional** revenues, it needs to be clear what could have been earned by supplying this volume to another competing market, which is calculated in Section 6.1.

6.1 Judging the redispatch price from the rational choice theory

In the first part, RQ 2.i will be central. First, the model introduction and method to answer this research question, will be explained in Section 6.1.1. In Section 6.1.2, the data-collection and implementation are explained. Verification and validation are explained in Section 6.1.3 and lastly, the results are explained in Section 6.1.4.

6.1.1 Model introduction and method

The goal of this model is to calculate for the specified three different types of greenhouses, with a different flexibility pattern (Chapter 5.2), the needed redispatch price to gain from the redispatch market, relative to the earnings on either the passive imbalance or the intraday-market. For each of the three types of greenhouse growers, the average valuation of the intraday-market and passive imbalance market will be calculated. This is in line with the rational choice theory explained in Section 2.2.1, assuming people rationally choose the highest valued alternative. Purely calculating redispatch gains without comparing it to alternatives would - according to this theory - not make sense.

Only the revenues are compared, since assumed is the costs are the same; the (gas)-input is equal and maintenance costs are equal per hour. Start-up costs are not taken into account, since assumed is differences between start-up costs will even out.

6.1.1.1 Scope and model build-up

The model consists of two parts. In the first part of the model, it is calculated what the minimum gain, per average bid on the redispatch market has to be, in order to compensate for (opportunity) losses. Opportunity losses consist of direct opportunity losses, caused by the inability to offer a certain capacity twice. Besides, indirect opportunity losses may result from the pausing of the intraday-trades. Lastly, there is a monetary risk involved with supplying sell-bids to the redispatch market, being the risk of a fine. This risk of the fine multiplied by the fine (in euros) should be added to the price. See Figure 30. When supplying buy-bids to the redispatch market, the risk of a fine does not occur. Namely, as explained in Chapter 1, with a buy-bid a CHP needs to turned off. Turning off a CHP is not failure sensitive. The variable 'gains on the redispatch market' are while supplying buy bids *relative gains*, namely reduced costs (if the price is lower than its alternatives).

Since the intraday-bids and imbalance-sales can still take place *after* the settlement of redispatch-bids is known (yes/no), this gives an opportunity to still sell flexible capacity to other markets, if redispatch bids are not settled. By calculating the opportunity losses of only *participating* in the redispatch market, it can be determined how high (for sell-bids) of low (for buy-bids) the redispatch price should be in order for the redispatch market to provide added value.

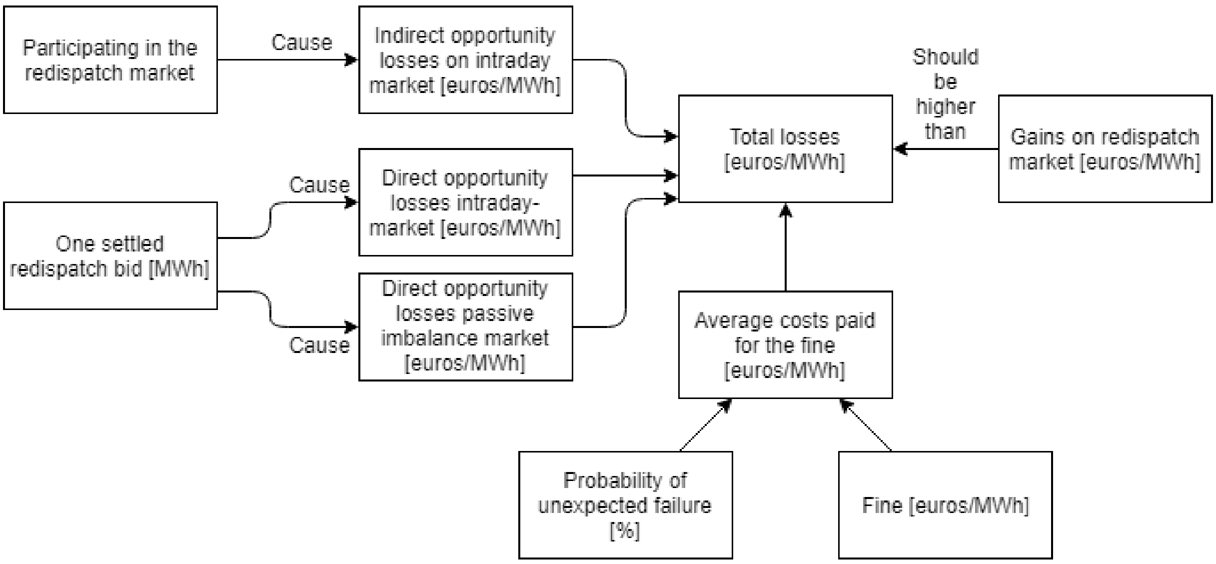


Figure 30: Conceptual model to answer question 2.i.

6.1.1.2 In- and output variables

The in- and output variables are shown in Table 15.

Table 15: In- and output variables, deterministic model research question 3.i.

Variable	Type	Description
Passive imbalance market prices, of the deals made. Specific per greenhouses.	Input	The prices of the made deals on the passive imbalance market, determine the average valuation of the passive imbalance market for a certain greenhouse.
Intraday market prices, of the deals made. Specific per greenhouse.	Input	The prices of the made deals on the intraday market, determine the average valuation of the intraday market for a certain greenhouse.
Intraday price curve	Input	The prices of intraday, over the day, for the specific month which has been modeled (See Section 4.2.2). Used to determine the passive opportunity loss on the ID market.
Fine [€/MWh]	Input	The fine that has to be paid when a certain redispatch volume has not been delivered.
Unexpected failure probability	Input	The probability that, after the settlement of a redispatch bid, the CHP has a failure.
Direct opportunity loss intraday [€/MWh)	Output	Calculates how much could have been earned on the intraday market, if no redispatch bids had been done and settled.
Opportunity loss (passive) imbalance market [€/MWh]	Output	Calculates how much could have been earned on the passive imbalance market, if no redispatch bids had been settled.
Average costs paid for fine [€/MWh]	Output	Calculates per MWh the average costs for a fine, so this should be added to the price of a bid.
Needed redispatch price to beat the alternatives [€/MWh]	Output	The price on the redispatch market, for which the redispatch market would be a rational choice for greenhouses.

6.1.1.3 Assumptions

- The fine has the same level as the fine for tertiary reserve volume. This assumption is based on an interview with Samuel Glismann (2019) (See Appendix C), who acknowledged the fine will very likely be similar.
- If a greenhouse decides to supply to the redispatch market, he will do this for a longer period of time. This allows for the use of average opportunity costs, while determining the needed redispatch price.
- For calculating the direct opportunity losses on the intraday market, the value of the intraday trades of a specific group of greenhouse growers is used. The intraday trades are done by AgroEnergy, for each greenhouse grower specific. AgroEnergy uses an optimization model to determine when to do a certain trade. Assumed is this calculation model calculates the optimal intraday trades.
- Additional start-up costs occur when a certain bid is placed in such a way, an extra start and stop of the CHP are needed. This happens when a bid is placed separate from an already existing day-ahead block. See Figure 30 for an illustration. However, both imbalance and intraday trades can also cause an extra start and stop. Assumed is potential additional start and stop costs even out.

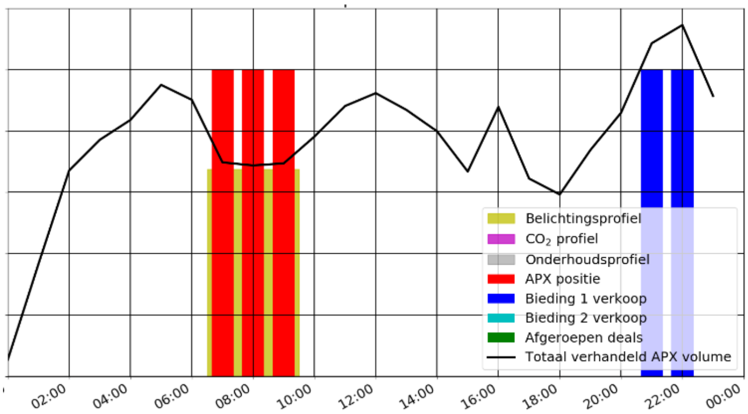


Figure 31: Illustration of an additional start and stop

6.1.2 Data-collection and implementation

In this section, it is explained how the input-variables needed for answering RQ 3.i are collected and used. In Section 6.1.3.1, it is explained how direct opportunity losses from the intraday-market are calculated, using the intraday prices of the deals made for a specific greenhouse. In Section 6.1.3.2, it is explained how indirect opportunity losses – due to pausing – are calculated and if there are any opportunity losses, how these are taken into account in the price. The direct opportunity losses on the imbalance market are calculated using the prices of the deals made on the imbalance market, specific for each of the three types of greenhouses, explained in Section 6.1.3.3. Lastly, the calculation of the average costs paid for the fine, based on the level of the fine and the probability of a fine, is explained in Section 6.1.3.4.

6.1.2.1 Direct opportunity losses intraday

Selling electricity to the intraday market

To be able to calculate an opportunity loss due to lost flexibility, when supplying to the redispatch market, the valuation of 'buffer space' on the intraday market needs to be determined. The idea is to estimate the flex capacity lost due to redispatch trades, and to calculate how much you would have earned for this flex capacity on intraday. This is done based on the intraday-trades that have been done and the price of these trades, for the greenhouses of AgroEnergy where intraday-trading is activated. The intraday-trading has only started in January 2019, which is why the intraday trade data of four months has been used. From Section 5.2, different types of greenhouses followed. For these types, the intraday-trades are analyzed.

The average valuation (= the average price) of the intraday-trades, is used as opportunity loss due to lost flexibility. The data that is used, are the intraday-trades done for different types of greenhouse growers at AgroEnergy. These trades are done by AgroEnergy for the specific greenhouse growers. Since AgroEnergy uses an optimization model for when to do intraday-trades, it is assumed these trades are done on logical moments in time, thus accurately reflecting the opportunity of selling a certain volume to the intraday-market. This average valuation is determined for the three types of greenhouses. For the type 'Tomato grower', the average valuation of sell volume is €41,23/MWh. In Figure 31, the boxplot of the different prices is shown. 50% of the values is inside the box, so approximately between 30 and 50 €/MWh. 95% of the values lies within the upper and lower whisker, so approximately between 20 and 73 €/MWh.

While, as appears from Figure 32, the valuation of the intraday sell-volume fluctuates, still an average value of the intraday-valuation is used. However, assumed is a supplier supplies to the redispatch market for a longer period of time. The fluctuations in the valuation will then even out, which justifies for the use of an average valuation.

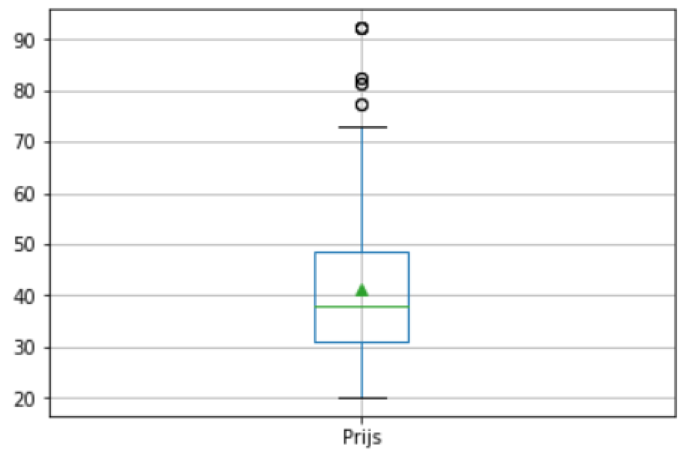


Figure 32: Boxplot of intraday-valuation of sell-volume, greenhouse 3: tomato grower

Buying electricity from the intraday market

To be able to calculate an opportunity loss due to lost flexibility, when buying from the redispatch market, the average price of an alternative buy-bid needs to be determined. Equal as for determining the opportunity loss of selling to the redispatch market, the opportunity loss of buying from the redispatch market is calculated by calculating the average value of all intraday buy-bids.

The average valuation of buying from the intraday-market, is €39,56. Just as for selling to the intraday-market, the valuation of intraday buy-bids flucturates. Since assumed is a supplier supplies to the redispatch market for a longer period of time, the fluctuations will even out.

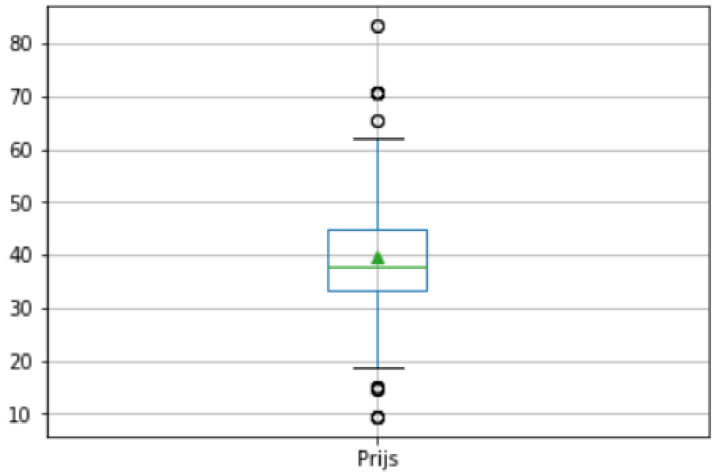


Figure 33: Boxpot of intraday-valuation of buy-volume, greenhouse 3: tomato grower

6.1.2.2 Indirect opportunity losses intraday

As explained in section 4.2.2, intraday opportunity losses can occur due to the pause in the intraday trading. For analyzing if this pausing causes a structural opportunity loss, the data from the intraday price-curve files for a period of 5 months (October 2018 – March 2019) is analyzed. For doing so, the curves generated between 21:00 and 00:00 are compared to all curves generated (so including the timeframe 21:00 – 00:00). The average buy and sell prices and the most often occurring buy and sell prices are used, to determine whether a structural opportunity loss occurs by pausing the intraday trades. Namely, this could happen if for instance the sell-prices in the period 21:00 till 00:00 are structurally higher than outside this period, implying the best sell opportunities occur in this period.

EET (Eneco Energy Trading) buy prices below €0 are excluded from the data, because negative EET buy prices mean negative sell prices for AgroEnergy. This will not be accepted: A greenhouse grower will never accept paying for selling electricity. EET sell prices higher than €100,- are excluded from the data, because if the buffer is too full, buying back needs to be cheaper than heat destruction or the heat cost price. Therefore, prices higher than €100 will never be accepted.

The results are presented in Table 16. Note: The EET buy price is the AgroEnergy sell price and the other way around. This is because the EET buy price is the price for which EET wants to buy intraday volume, from AgroEnergy.

Table 16: Determining the existence of opportunity loss due to intraday-trade pausing

	Average EET sell price (€/MWh)	**Average EET buy price (€/MWh)**	**Median EET sell price (€/MWh)**	**Median EET buy price (€/MWh)**
All PTU curves	50.22	45.40	54.02	39.92
PTU curves excluding curves generated between 21:00 – 00:00	50.57	45.66	54.02	39.92

From the data, it appears the most occurring values (median) are equal, for the curves generated between 21:00 – 00:00, the curves excluding the pause hours and for all PTU-curves. The average EET buy prices in the timeframe between 21:00 and 00:00 is (slightly) lower than the average buy price for all price curves, of which can be concluded there is no structural opportunity loss regarding selling on the intraday-market, due to the pause in trading. The average EET sell prices are slightly lower for the curves generated between 21:00 - 00:00, as compared to all curves, meaning the 21:00 – 00:00 period is (on average) slightly cheaper for buying back a position.

To analyze whether the pause in intraday trading causes opportunity losses, a t-test is executed to check whether the average EET sell price difference between all PTU-curves and the PTU-curves excluding the pause hours is statistically significant. This t-test is executed using Python. A confidence interval of 5% (alfa = 0.05) is used, which means the conclusion of the test is valid with 95% confidence. The null hypothesis of the test is: there is no significant difference between the EET sell prices of the curves including the pause hours (Group 2), and the EET sell prices of the curves excluding the pause hours (Group 1).

The formula for calculating the t-value is:

$$t = \frac{M1 - M2}{\sqrt{\frac{S1^2}{n1} + \frac{S2^2}{n2}}}$$

Equation 1: T-test

With:

M1 = Mean value of Group 1
M2 = Mean value of Group 2
S1 = Standard deviation of group 1
S2 = Standard deviation of group 2
n1= Sample space of group 1
n2 = Sample space of group 2

The calculated t-value will be compared to the critical t-value. The critical t-value is calculated using the Python package sciPy. If the calculated t-value is greater than the critical t-value, it means there is a statistically significant difference between the two datasets.

The t-test produces the following results:
Calculated t-value = 6.70825048984
Critical t-value = 6.72283377146

From the t-test, it appears the critical t-value is greater than calculated t-value, meaning the null-hypothesis cannot be rejected. This means there is no significant difference between the EET sell-prices generated during all hours and the EET sell-prices where the pause hours are excluded. This means there is no statistical significant opportunity loss due to the pause in intraday-trades. Therefore, this form of opportunity loss (indirect opportunity loss) is not considered anymore. This conclusion is valid for any of the greenhouses, since these price-curves are general and valid for any of the greenhouses.

6.1.2.3 Direct opportunity losses passive imbalance market

Selling to the passive imbalance market

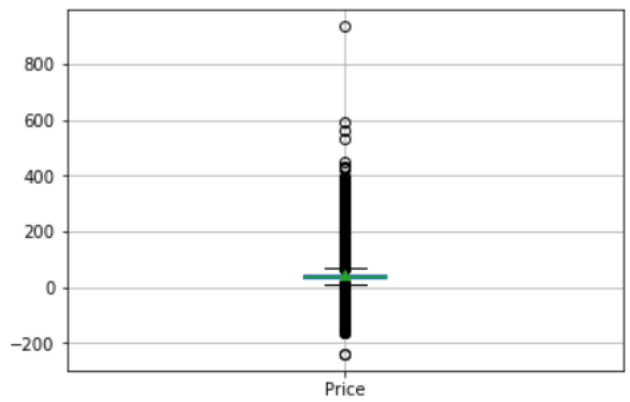
For being able to determine the opportunity costs on the passive imbalance market, the average valuation of 'buffer space' on the imbalance market needs to be determined. The data which has been used, is the data of the trades on the passive imbalance market, by each of the three categories of greenhouse growers separately.

The principle which is used, is the same as the valuation of buffer space for the intraday-market. However, there is one difference. A large part of the passive imbalance trades happen 'unintentionally', while for determining the opportunity costs, only the conscious trades count. It is possible to unintentionally supply to the passive imbalance market since, as explained in Section 4.2.1, no bids have to be supplied to the passive imbalance market. If a certain greenhouse had a net position of selling 2000 kW, but actually sold 1950 kW, he basically bought 50 kW from the passive imbalance market.

Only conscious trades determine the opportunity costs: the valuation of the trades that would have been made – consciously – which is not possible anymore due to lost flexibility space. After all, the neoclassical theory assumes each player is rational and rationally chooses between alternatives. Making rational choices without being aware of the rationality is impossible (Scott, 2000).

To determine whether a certain action could have been conscious, the partial and full load capacity have been used. For each of the target greenhouses, the partial load capacity of the CHP is 1250 kWh, the full load capacity is 1750 kWh (per hour). So the smallest conscious action could have been to adjust the CHP, from partial to full load, which makes an increased production of 500 kWh (per hour). Therefore, all values below this number are assumed to be unconscious actions, due to a change in the processes in the greenhouse. 500 kWh per hour corresponds to 125 kWh per PTU (500/4).

The results of the valuation of sell prices (the greenhouse sells to the market), is shown in Figure 34. Here, only the conscious actions (volumes higher than 125 kWh per PTU) are taken into account. While 95% of the values fits within prices from 5 to 75 €/MWh, there are many outliers far outside this range. This also shows it is very hard to make a business case out of supplying to the passive imbalance market; while prices can get very high, almost all prices fall in a 'normal' category comparable to the day-ahead prices.



The average imbalance sell price for this greenhouse is 44.79484098040897 euros/MWh

Figure 34: Boxplot of imbalance market-valuation of sell-volume, greenhouse 1: cherry-tomato grower

If the outliers are removed, the average passive imbalance valuation is very similar to the average intraday valuation, for this greenhouse. See Figure 35. The average value (44,95 €/MWh) is used as valuation for the passive imbalance opportunity loss, with the same motivation as for using the average valuation of the intraday-market.

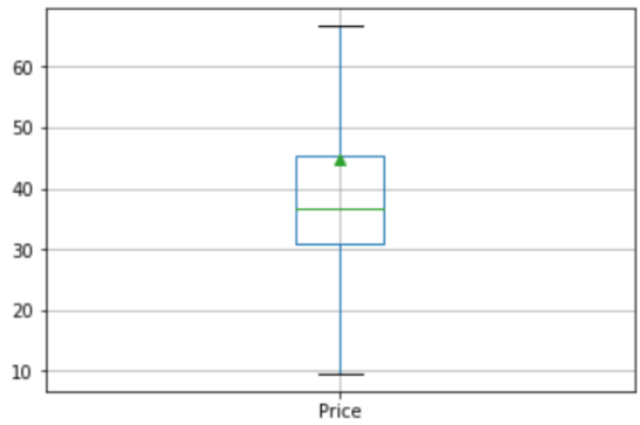


Figure 35: Boxplot of imbalance market-valuation of sell-volume without outliers, greenhouse 1: cherry-tomato grower

Buying electricity from the passive imbalance market

For determining the opportunity costs of buying electricity from the redispatch market as compared to the imbalance market, the average imbalance price is determined based on previous bids on the imbalance market. Just as for sell-bids, the unconscious trades are removed from the data.

As appears from Figure 36, the average value of buying electricity from the imbalance market is €39,47/MWh. This means, the redispatch buy-price needs to be lower in order to beat the passive imbalance market.

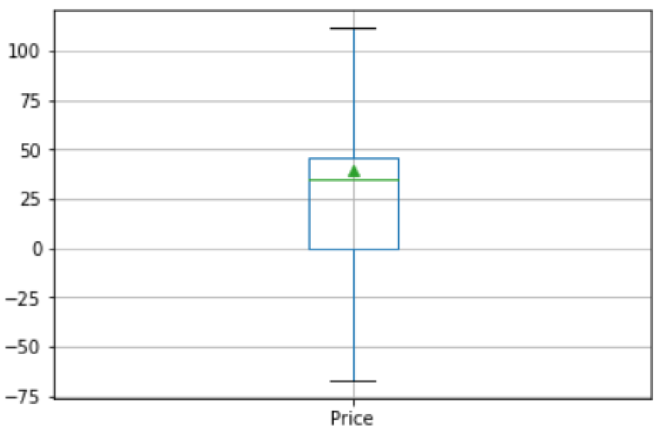


Figure 36: Boxplot of imbalance market-valuation of buy-volume without outliers, greenhouse 1: cherry-tomato grower

6.1.2.4 Average costs for the fine

If a certain settled redispatch bid is not delivered, TenneT will give a fine to the certain producer. Currently, this fine will not be given yet, which enables AgroEnergy and its clients to participate in the pilot without significant financial risks. However, this fine will likely be introduced from 2020 onwards, in order to avoid arbitraging and other inefficiencies (TenneT, 12-4-2019), which will be explained in Chapter 8.

A fine happens when a CHP is failing, while it actually has to deliver. CHPs have a relatively low reliability; a failure once a month is most common, as an expert within AgroEnergy acknowledges (Expert 1, 2019). This corresponds to a failure rate of about 3,3%. A similar failure rate is acknowledged in research by the Energy Department (2015), which claims CHPs are available 96,6% of the time. For this research, 3,3% will be used as failure rate. The level of the fine is not determined yet, but a good estimation of the (future) redispatch fine is the fine for tertiary reserve volume

(Glismann, interview). The level of this fine is determined by the following formula (TenneT, 17-4-2018):

Fine = 4 * price [€/MW/hour] * capacity [MW]

This means, if the price is e.g. €40/MWh and the planned sell-bid lasts 1 hour, the fine would be:

Fine = 4 * 40 * 1 = €160,-

TenneT states, the risk of a fine needs to be priced in the redispatch price. If the redispatch market stays as it is currently designed, this pricing of the risk can be done by multiplying the probability of a fine by the level of the fine.

6.1.3 Implementation

Selling

For calculating the needed redispatch sell-price, assumed is it needs to beat the highest of its alternatives. If the imbalance valuation is highest, this valuation will be used for determining the price. If on the other hand the intraday-valuation is highest, this will be used for determining the redispatch sell price. As appers from part 6.1.2.2, there are no indirect opportunity losses, which means only the average costs for the fine (in €/MWh) have to be added to the minimum sell price. Since the fine uses the (needed) redispatch price, a formula needs to be established where this is taken into account. The following formula is established:

min. sell-price > highest of the alternatives + min. sell-price * 4 * failure probability

The minimum sell-price and the highest of the alternatives are in €/MWh. The failure probability is in %. In the deterministic model, the highest of the alternatives will be taken, which are calculated as explained in part 6.1.2.1 and 6.1.2.3.

Buying

For calculating the maximum redispatch buy-price, assumed is it needs to be lower than both of the alternatives. In the deterministic model, the valuation of the alternatives is calculated as explained in Part 6.1.1.1 and Part 6.1.1.3. Since there are no indirect opportunity losses and no risk for a fine, the maximum redispatch buy-price can be calculated by:

max. buy-price < lowest of the alternatives

6.1.4 Verification and validation

To check whether the model produces accurate outcomes, to predict real-world behaviour that the model represents, verification and validation are needed (Carson & John, 2002). Verification points to checking whether the model is correct and behaving as it is supposed to do. For verification, multiple techniques exist, of which two have been picked: debugging and sensitivity analysis. Validation is meant to substantiate that the model possesses enough accuracy to be consistent with the intended application of the model (Sargent, 1983) – are the results valid? Two techniques have been picked for analysing this, being the use of expert opinions and a comparison to real system. In the next two paragraphs, the verification and validation will be explained.

6.1.4.1 Verification: Debugging

Debugging of the deterministic model happened throughout the process of modelling. The most import debugging steps included:

- Verifying whether the intraday-prices loaded into Python match the intraday-prices on the AgroEnergy database.

- Verifying whether the imbalance-prices loaded into Python match the intraday-prices on the AgroEnergy database.
- Checking if only *unconscious* trades are removed from the imbalance trades.
- Checking if, for calculating indirect opportunity losses on the intraday-market, the right intraday price-curves are compared (All curves, versus curves excluding curves generated between 21:00 and 00:00.

Debugging happenened during the whole modelling process.

6.1.4.2 Verification: Sensitivity analysis

A sensitivity analysis can be used to test how the output of the model is changed, by a certain change in inputs (Pianosi et al,. 2016). The verification of the two main input variables is executed, being on imbalance and intraday prices, and the failure probability.

Prices of opportunities

To verifiy whether the prices are calculated correctly, it is investigated what the impact of a 10% increase or decrease of the average intraday-and imbalance prices, on the model output is. With an increase in the valuation of alternatives, the minimum sell-price should increase and the maximum buy-price should increase. The results are shown in Table 17. Concluded can be that the valuation of the alternatives is rightly modelled.

Table 17: Sensitivity analysis: impact of a change in valuation on prices. Greenhouse 1: Cherry-tomato.

	Regular model output	Imbalance and intraday + 10%	Imbalance and intraday – 10%
Minimum sell-price	51,00	56,75	46,43
Maximum buy-price	37,47	41,22	33,72

Failure probability

To verify whether the failure probability and following from this, the level of the fine, is accurately taken into account, a sensitivity analysis on the failure probability is executed. Here, the failure probability is reduced to 0%, which should reduce needed sell prices, and increased to 5%, which should increase needed sell prices. The results are shown in Table 18. From this, it can be concluded that the impact of the failure probability is modelled correctly.

Table 18: Sensitivity analysis: impact of a change in failure probability of prices. Greenhouse 1: Cherry-tomato.

	Regular model output	Failure probability 0%	Failure probability 5%
Minimum sell-price	51,59	44,78	55,98

6.1.4.3 Validation on assumptions: Expert opinion

Multiple assumptions have been done to develop the model. These assumptions have been validated by discussing the assumptions with two different experts. For the assumption regarding the level of the fine, one question has been asked during the interview with Glismann (2019), see Appendix C. He has acknowledged this way of taking the fine into account, is valid.

The assumption that greenhouses will supply for a longer period of time to a certain market, which justifies for using average values and ignoring start and stop costs, has been validated with an expert in AgroEnergy. This person acknowledged greenhouse growers often stick to supplying to a certain market, once this has been added to their portfolio.

6.1.4.4 Validation on results: Comparison to real system measurements

In order to validate whether these results are likely to occur in reality and whether the model produces reasonable output, the 'needed' redispatch prices in order for the redispatch-market to be an addition to the portfolio of greenhouses, are compared to the 2017 redispatch costs as published by TenneT (TenneT Market Review 2017, 2018). This is the only year for which some data is published about the costs of redispatch, in relation to the volume. No exact numbers are available about the redispatch volume and costs in the Netherlands. However, TenneT has published a Market Review of 2017 in which the volumes and costs are presented in a graph. The results are published in Table 19. From this table, it appears the average redispatch costs greatly vary over the year. Assumed is the redispatch costs per MWh are equal to the spread price per MWh (See Figure 11 Section 3.2.1.4), meaning this is the net amount TenneT has to pay.

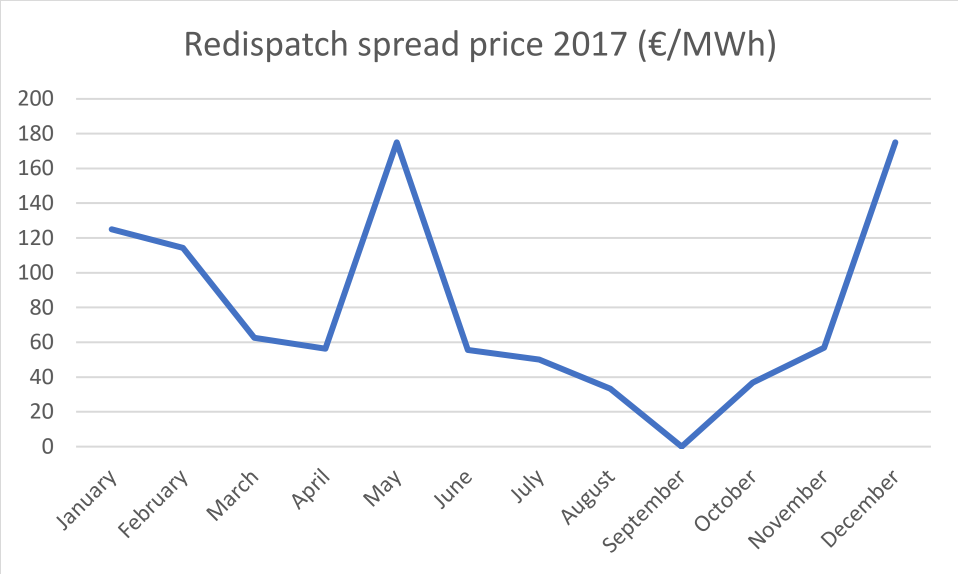
To validate the prices that are the outcome of the model, the costs for congestion of TenneT are used. If for instance a price of 1000 €/MWh appears to be profitable, but if TenneT pays way lower prices for congestion management, a certain outcome is not feasible/logical. The pricing on the redispatch market is still unclear; it is not yet certain which prices will rise.

The average costs for redispatch are €78,38 (See Table 17). The costs for redispatch is the difference between the redispatch price spread. For a redispatch sell-bid, the system operator pays, for a redispatch buy-bid, the system operator receives money.

For Greenhouse grower 1, the maximum buy-price appears to be €37,47/MWh and the minimum sell-price appears to be €51,00/MWh. The netto costs for TennT would then be 51 – 37,47 = €12,13/MWh. Since the average redispatch costs for 2017 are €78,38/MWh, it means the average sell-prices were higher, and the average buy-prices were likely lower. A conclusion that can be drawn, is that based on the redispatch costs for 2017, greenhouse growers can clearly earn money from the redispatch market.

Table 19: Average redispatch costs for TenneT per MWH, 2017. Source: based on TenneT Market Review 2017, 2018

Month	Redispatch volume [GWh]	Redispatch costs [Million €]	Average costs [€/MWh]
January	40	5	125
February	70	8	114
March	40	2.5	62,5
April	80	4.5	56
May	20	3.5	175
June	45	2.5	55,5
July	60	3	50
August	15	0.5	33
September	0	0	0
October	95	3.5	37
November	220	12.5	57
December	20	3.5	175
Average over 2017			**€78,38**



6.1.4 Results

In the first part of this chapter, the following research question was central:

What should the minimum redispatch price be, in order to beat the competing markets?

From the analysis it appears there is no significant opportunity loss associated with the pausing of intraday-trading. On average, 3,3% of the time, a CHP is failing. This means there is a 3,3% chance a certain settled bid cannot be delivered. Rationally reasoning according to neoclassical theory, this probability of a fine times the level of the fine, needs to be added to the redispatch bid-price.

The results of the deterministic calculation model are shown in Table 20. In Table 21, the maximum redispatch buy-price is shown. Based on the validation of the results, it is likely the sell-price will be higher than the minimum needed sell-price, and the buy-price will be lower than the maximum buy-price. This would imply the redispatch market could provide an additional gain.

Table 20: Minimum needed redispatch sell-price, as compared to opportunity losses and additional costs.

Type	Intraday valuation [€/MWh]	Imbalance valuation [€/MWh]	Average costs for fine (3,3% reliability) [€/MWh]	Minimum needed (average) redispatch price [€/MWh]
Cherry-tomato	44,27	44,78	6,81	51,60
Pot plants	35,03	43,66	6,64	50,31
Tomato	41,23	44,95		51,79

Table 21: Maximum redispatch buy-price, as compared to opportunities.

Type	Intraday valuation	Imbalance valuation	Maximum redispatch buy-price
Cherry-tomato	42,08	41,37	41,36
Pot plants	38,26	48,77	35,02
Tomato	39,56	39,47	39,46

6.2 Estimating potential additional monthly revenues of the redispatch market

In order to give an idea of the potential additional revenues when a certain type of greenhouse grower starts selling electricity to the redispatch market, the additional monthly revenues will be calculated. The currently available congestion probabilities are used, together with the currently available information regarding potential prices. If there is more information regarding the congestion probability in a certain area and the redispatch prices, this model can be used as a tool to estimate the additional monthly revenues for a specific greenhouse grower.

6.2.1 Model introduction and method

Goal and main idea of the model

The goal of this model is to calculate for the specified three different types of greenhouses, with a different flexibility pattern (Chapter 5.2), what could **on average** be earned from *selling* to the redispatch market in one month, relative to the earnings on either the passive imbalance or the intraday-market. This builds on to part 1 of this section, where the value of the passive imbalance market and intraday market are calculated. This is in line with the rational choice theory explained in Section 2.2.1, assuming people rationally choose the highest valued alternative. Purely calculating redispatch gains without comparing it to alternatives would - according to this theory - not make sense. Only the revenues are compared, since assumed is the costs are the same; the (gas)-input is equal and maintenance costs are equal per hour. Start-up costs are not taken into account, since assumed is differences between start-up costs will even out.

As appears from Part 1, next to direct opportunity losses, there are no indirect opportunity losses. There are additional costs associated with the redispatch market, namely the (risk for a) fine.

Modelling approach: Deterministic modeling

The model that will be developed, is a deterministic model. In the deterministic approach, the underlying assumption is that a given input leads to one unique output. This implies all system relations are known (Uusitalo, Lehikoinen, Helle & Myrberg, 2015). In order to deal with uncertain input variables – the settlement probability – a sensitivity analysis will be executed for the verification of the model (Section 6.2.3). Namely, a sensitivity analysis explains the change in the output, when input variables are changed.

The reason why there has been chosen for a deterministic model, is because all relations within the system are known. The only uncertainties in this case, are the input-variables.

First, the concepts in the model will be explained. This will be done by first presenting a schematic overview and a narrative of the model. This basically means, explaining in words what happens in the model. Then, in section 6.2.1.2, an overview of the needed input variables and the to be calculated output variables will be given. The most important assumptions regarding the relations in the model, will be given in section 6.2.1.3.

6.2.1.1 Scope of the model and model build-up

The scope of the model is bounded to the average earnings of one greenhouse in one month, for the three competing markets a greenhouse has to choose between: intraday, imbalance and redispatch. According to the rational choice theory, the most valuable of competing opportunities will be chosen. The earnings on other markets, for instance the day-ahead market or the OTC-market, are not relevant here since these markets are not directly competing with the redispatch market.

A conceptual overview is shown in Figure 37. This can be read as follows. In the model, a pattern of supplied bids over a month is loaded. These supplied bids are calculated by the optimization model developed by AgroEnergy, in which potential bids are calculated based on the technical characteristics (See Section 5.2). Based on a settlement probability, it is calculated which part of these bids will *on average* be settled. This is determined based on the congestion probability of 2017 and 2018 (See Section 5.1.1). The settlement probability is assumed to be equal to the congestion probability. As explained, it does not mean that at any location the congestion probability will be equal to the average congestion probability as calculated in Section 5.1.1. However, assumed is this congestion probability gives a realistic indication of a *potential* congestion probability in a certain area. Note that by calculating which part of the bids will on average be settled, a bid can be settled for e.g. 10%, while in reality, a bid will only be settled fully or partially. However, the goal of the model is to calculate *average* earnings, which justifies for this calculation.

If a bid is settled, opportunity losses occur as large as the valuation of the highest alternative (See Part 1). Besides, a fine may occur. The average level of the fine can be determined by using the failure probability.

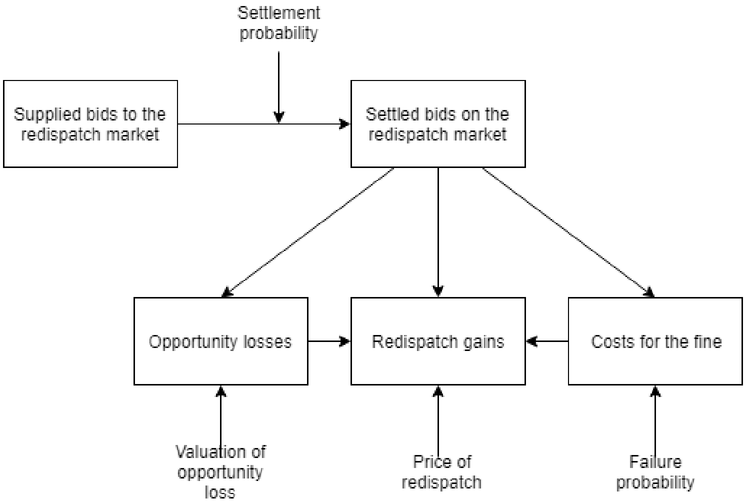


Figure 37: Conceptual model to answer research question 2.ii.

6.2.1.2 In- and output variables

The in- and output variables needed for building and using the model, are presented in Table 22.

Table 22: In- and output variables for the determinstic model answering research question 2.ii.

Variable	Type (input/internal/output)	Description
Flex profile, specific per greenhouse per month = redispatch bids	Input	The hours a greenhouse can supply to the redispatch market per day. (# hours and which hours)
Opportunity loss intraday [€/MWh	Input	Calculates how much could have been earned on the redispatch market, if no redispatch bids had been done and settled.
Opportunity loss passive imbalance market [€/MWh]	Input	Calculates how much could have been earned on the redispatch market, if no redispatch bids had been settled.
Congestion probability, see Section 5.1.1	Input	For each PTU of the day, the probability that there is congestion.
Settlement probability, assumed equal to the congestion probability	Input	For each hour of the day, the probability that a bid is settled. Uncertainty

Price redispatch market [€/MWh]	Input	Based on the redispatch costs of TenneT, a likely redispatch price is determined. After all, TenneT pays for the redispatch market. Uncertainty
Fine [€/MWh]	Input	The fine that has to be paid when a certain redispatch volume has not been delivered.
Unexpected failure probability	Input	The probability that, after the settlement of a redispatch bid, the CHP has a failure.
Gains redispatch market [€/month]	Output = KPI	Based on the #settlement/month and price.

6.2.2.3 Assumptions

Different assumptions have been made in order to be able to develop the model. These assumptions are listed below. The impact of the assumptions on the results produced by the model is discussed later.

- Steering box is working properly. This means, if a bid is settled, the steering box accurately sends a signal to the CHP to fulfill this bid (by turning either off or on). The steering box is the connection between the position calculated by AgroEnergy and the execution of these calculations by the CHP
- The congestion probability is is equal for each day. The settlement probability follows the probability of congestion.
- The optimization model developed by AgroEnergy to calculate redispatch bids calculates the optimal bids for a specific greenhouse.
- Only greenhouse growers selling electricity using the AgroEnergy tool BiedOptimaal (See 5.3.1) will be considered. It will be assumed the CHP of a greenhouse is used as proposed by the BiedOptimaal tool; so assumed is the greenhouse grower does not adjust the position.
- For placing buy-bids, assumed is the boiler will not be used to compensate for lower production of CO_2 and heat.

6.2.2.4 Model use

This model can be used to calculate, for a specific greenhouse in a specific month, what additional revenue could have been earned by supplying to the redispatch market. When redispatch prices and region-specific congestion probabilities become clearer – information that will likely follow when the redispatch pilot starts – a more specific calculation of monthly earnings can be made. For now, different scenarios are modelled to give an indication of potential earnings.

6.2.2 Data collection and implementation

Every hour of the day, EET sends an intraday price curve to AgroEnergy, with the sell- and buy-prices per hour of the following day (6.2.3). This process started in October 2018. Since these prices are needed as input for the model, only months starting from October 2018 can be considered. For the original model, one greenhouse grower will be considered. Different greenhouses and different months will be varied in the experiments (Chapter 7).

For the BiedOptimaal tool, the data is read directly from an online data-platform. For this thesis, this live-connection is not needed, since historical data will be used.

6.2.2.1 Flexibility pattern greenhouse

For the flexibility pattern of a greenhouse, the output of the developed optimization model where the potential redispatch bids based on the technical constraints (See Chapter 5) are calculated, is used. Assumed is this optimization model calculates the optimal bids, given the technical constraints.

From this optimization model, a dataset with bids is generated. See Figure 38.

	DateTimeStart	BuyBid	SellBid	EANcode	BidID	BuyCap	CallDuration	CallTime	ObjectID	SellCap	DatePos	PTU
7138	2019-02-01 00:00:00	NaN	58.71	871688520000169319	1	NaN	12	24	1	4.0	2019-02-01	1
7139	2019-02-01 03:00:00	NaN	58.71	871688520000169319	1	NaN	12	36	1	4.0	2019-02-01	13
7140	2019-02-01 04:00:00	NaN	58.71	871688520000169319	1	NaN	12	40	1	4.0	2019-02-01	17
7141	2019-02-01 10:00:00	NaN	58.71	871688520000169319	2	NaN	12	64	1	4.0	2019-02-01	41
7142	2019-02-01 13:00:00	NaN	58.71	871688520000169319	2	NaN	12	76	1	4.0	2019-02-01	53
7143	2019-02-01 16:00:00	NaN	58.71	871688520000169319	2	NaN	12	88	1	4.0	2019-02-01	65

Figure 38: Flexibility pattern greenhouse

6.2.2.2 Settlement probability

In Section 5.1.1, the average use of Reserve Volume for Other Purposes over 2017 and 2018 is shown. This data is provided by TenneT, who uses Reserve Volume for Other Purposes for solving congestion on the transmission grids. In the discussion in Chapter 9, there is reflected upon using this data for determining the settlement probability. In 2017 and 2018 together, on 175 days reserve volume has been used, which is 24% of the days. During 10% of the PTEs, reserve volume has been used. The analysis resulted in a probability of congestion per PTU, weighted for the volume of congestion. This figure is shown in Section 5.1.1 (Figure 14). This graph can be interpreted as the exact settlement probability, if the demand for congestion volume and the supply of congestion volume exactly match. Since no location specific congestion-data is available, it is assumed at any location (so for any greenhouse) the congestion probability is equal to the calculated probability of congestion. Currently, there is not much supply yet, but the exact amount is not made publically available (Glismann, interview 2019).

The settlement probability will likely not be equal to the congestion probability, since on some locations, there is more congestion than on other locations. Therefore, a variable is added: 'congestion region'. This number will be multiplied by the congestion probability, in order to create a settlement probability with an equal pattern as the congestion pattern. This will be used for the sensitivity analysis.

Based on the settlement probability (Figure 39), bids are or are not settled. Assumed is, the congestion probability at the start of the bid (start PTU) determines the settlement of the whole bid.

PTE-range	Percentage of PTUs upward redispatch	Percentage of PTUs downward redispatch
1	4.109589	4.520548
2	4.109589	4.520548
3	4.109589	4.520548
4	4.109589	4.520548
5	3.835616	4.246575

Figure 39: Implementation congestion probabilities

6.2.2.3 Opportunity loss

For the intraday opportunity loss, the results calculated in part 1 of the model (See Section 6.1) are used. This opportunity loss is assumed to be specific per type of greenhouse, but equal over the year. Also for the imbalance market opportunity loss, the results calculated in part 1 of the model (See Section 6.1) are used. This opportunity loss is assumed to be specific per type of greenhouse, but equal over the year.

To calculate the average opportunity loss, 50% of the valuation of the imbalance sell-price is used, and 50% of the valuation of the intraday sell-price is used, since the volume sold to either of these markets is almost equal.

6.2.2.5 Costs for fine

The costs for the fine are determined by multiplying the level of the fine, by the failure probability of a CHP. As explained in Section 6.1.3.4, the average failure probability of 3,3% is used. The level of the fine is calculated using the formula explained in Section 6.1.2.4:

Fine = 4 * price [€/MW/hour] * capacity [MW]

6.2.2.6 Redispatch price

As appears from Section 6.1.3, the average redispatch costs for TenneT over 2017 were €78,38/MWh. Assumed is this is equal to the spread price, meaning TenneT only makes redispatch costs by paying suppliers to the redispatch market. Assumed is the redispatch buy-price will be lower than €35,-/MWh, since for a higher price, assumed is buyers would prefer the certainty of buying from the intraday or imbalance market, for slightly higher prices (Results part 1).

Three different price-divisions are established, based on the average redispatch costs of 2017. These price scenarios are shown in Table 23.

Table 23: Price-scenarios used as input for the deterministic model.

	Sell-price [€/MWh]	Buy-price [€/MWh]
Scenario 1	103,38	35
Scenario 2	93,38	25
Scenario 3	83,38	15

6.2.3 Implementation

The input variables, which have been explained in the previous section, are all added into one dataframe See Figure 40. For each of the rows, the average costs (Column: Loss) and average profit (Column: Profit) are calculated. The average gains per bid, are calculated using the following formula:

Gains = Upward redispatch probability / 100 * Price * SellCap * CallDuration / 4

Losses = Upward redispatch probability / 100 * intraday-valuation * 50% * SellCap * CallDuration / 4
+
Upward redispatch probability/100 * imbalance-valuation * 50% * SellCap * CallDuration/4
+
Upward redispatch probability / 100 * Fine level * Failure prob * SellCap * CallDuration / 4

The multiplication with SellCap – sell capacity – is done, because the sell capacity indicates the amount of MW sold. By multiplying this amount by 'CallDuration / 4', the amount of MWh sold is calculated. Namely, the call duration indicates how many PTU the bid lasts; an hour has 4 PTUs. All prices are in MWh, so by multiplying by the sell capacity, a total gain or loss can be calculated.

Then, the gains per bid can be calculated. The total gains over the modelled month, are calculated by summing over the column 'Gains'.

	PTU	Upward redispatch probability	Downward redispatch probability	BidID	CallDuration	SellCap	DatePos	Intraday sell valuation	Imbalance sell valuation	Fine level	Price	Failure prob	Gains	Loss	Profit
0	1	3.425690	4.302329	1	12	4.0	2019-02-01	44.266403	44.794841	413.52	103.38	0.1	10.624434	3.971128	6.653306
87	41	17.742127	16.795365	2	12	4.0	2019-02-01	44.266403	44.794841	413.52	103.38	0.1	55.025432	20.567027	34.458404
19	5	3.316591	4.122491	2	12	4.0	2019-02-02	44.266403	44.794841	413.52	103.38	0.1	10.286076	3.844659	6.441417
90	65	14.497359	14.040287	1	12	4.0	2019-02-02	44.266403	44.794841	413.52	103.38	0.1	44.962108	16.805627	28.156480
20	5	3.316591	4.122491	2	12	4.0	2019-02-05	44.266403	44.794841	413.52	103.38	0.1	10.286076	3.844659	6.441417
91	69	14.485540	13.989252	1	12	4.0	2019-02-05	44.266403	44.794841	413.52	103.38	0.1	44.925452	16.791926	28.133526

Figure 40: Implementation of deterministic model to answer RQ 2.ii.

6.2.4 Verification and validation

To check whether the model produces accurate outcomes, to predict real-world behaviour that the model represents, verification and validation are needed (Carson & John, 2002). Verification points to checking whether the model is correct and behaving as it is supposed to do. Validation is meant to substantiate that the model possesses enough accuracy to be consistent with the intended application of the model (Sargent, 1983) – are the results valid? In the next two paragraphs, the verification and validation will be explained.

6.2.3.1 Verification: Debugging

For verification, Different methods available: (1) debugging. Debugging happened throughout the process of modelling. The main debugging involved:

- Checking whether the redispatch bids loaded into Python, match the redispatch bids as generated by the calculation model developed by AgroEnergy.
- Checking whether the congestion probability loaded into Python, matches the congestion probability calculated using the raw data provided by TenneT.

6.2.3.2 Verification: Sensitivity analysis

Uncertainty can be defined as the lack of knowledge, regardless of the cause of this lack (Refsgaard et al., 2007). There can be dealt with uncertainty in a deterministic model by doing a model sensitivity analysis, where the impact of (small) changes in the uncertain input variables on the output is investigated. Sensitivity analysis can be defined as the response of output variables, to the variation of input parameters.

Variation of congestion regions

In order to verify whether the the settlement probability is used rightly, a sensitivity analysis on the settlement probability is executed. Here, three different regions are used, being: a region with settlement probability equal to the average Dutch congestion probability (Section 5.1.1). A region with settlement probability being twice as high as the average Dutch congestion probability, and a region where the settlement probability is twice as low as the average Dutch congestion probability.

Table 24: Sensitivity analysis on congestion regions. Greenhouse 1: Tomato

	Reference: Settlement probability equal to	**Settlement probability twice as**	**Settlement probability twice as**

	congestion probability	high as congestion probability	low as congestion probability
Average montly revenue	497,25	994,51	248,63

Variation of redispatch prices
In order to verify whether the redispatch prices are accurately taken into account, a sensitivity analysis on the redispatch prices is executed, using the three scenarios as specified in Section 6.2.2.6. Expected is, that with a higher redispatch price, the average monthly revenues will be higher. From the sensitivity analysis, it appears this is true. Therefore, concluded is the redispatch prices are accurately taken into account.

Table 25: Sensitivity analysis on redispatch prices.Greenhouse 3: Tomato

	Reference: Scenario 1: sell-price = 103,38	Scenario 2: sell-price = 93,38	Scenario 3: sell-price = 83,38
Average monthly revenue	497,25	404,73	312,20

Variation of failure probability
Lastly, a sensitivity analysis is executed on the failure probability. The failure probability determines the average costs for a fine. Therefore, with a higher failure probability, a lower average monthly revenue should be reached. In Table 25, it is shown that changing the failure probability slightly affects the average monthly revenue. As expected, a higher failure probability leads to a lower monthly revenue. Even a small difference in the failure probability leads to a signiciant change in the average monthly revenue.

Table 26: Sensitivity analysis on failure probability. Greenhouse 3: Tomato

	Reference: failure probability 3.3%	Failure probability 0%	Failure probability 5%
Average monthly revenue	497,25	642,72	422,31

6.2.3.3 Validation: Expert opinion
In order to validate the assumptions in the model, an expert has been asked for his opinion about the deterministic model. The expert is an employee of AgroEnergy, working on the redispatch pilot.

The expert agrees upon the use of average imbalance and intraday valuation, to determine the additional added value of the redispatch market, since (as was the case for part 1), a supplier likely supplies for a longer period of time. This justifies for the use of average values.

The fact that an average additional revenue has been calculated using the congestion probability, is assumed to be valid by the expert. Even though using this method, partial earnings per bid are calculated – while in reality a bid is fully settled, or not – this way of modelling gives a good indication of average earnings. Given the research question that was central in this part, the expert agrees upon this calculation.

6.2.5 Results
In this second part of calculating the theorethic economical potential of a greenhouse as supplier to the redispatch market, the following question was central:

What is the average additional monthly revenue on the redispatch market, under different price- and congestion scenarios?

For each of the three types of greenhouses, the profitability of the redispatch market as compared to intraday and the imbalance market, is calculated for the month February. Here, the default values for the input-variables are used, being the settlement-probability equal to the congestion-probability, the opportunity losses on intraday (per MWh) equal to the average intraday-valuation, the opportunity losses on the imbalance market (per MWh) equal to the average imbalance-valuation and the failure probability equal to 3,3%. The results are shown below.

The differences between greenhouses are, logically, mainly determined by the crops grown in the greenhouse; lighting, heat and CO_2 are crop-specific, after all. Therefore, three different greenhouses are selected, based on the crops.

Tomato grower

When using the default settings and modeling the month February, the average additional earnings earnings by placing these bids, will be €497,25. For the tomato grower, the most bids were placed during hours with a relatively low congestion probability, since most flexibility was available during the night. For April, the estimated additional revenues were significantly lower, namely €81,30 in that month. This is caused by the fact that all bids were placed during hours with low congestion probabilities. Besides, there appeared to be less flexibility in April since less bids were placed.

Pot plant grower

When using the default settings and modelling the month February, the average additional earnings by placing the bids as followed from the redispatch optimization model (See Section 6.2.2.1), are €1367,26. In February, the pot plant grower had many flexibility hours. Besides, the bids were mostly placed during hours with a high (expected) congestion probability, and therefore a higher settlement probability. For April, the estimated additional revenues were €814,09. The lower value is caused by less flexibility and thus less bids placed.

Cherry-tomato grower

For the cherry-tomato grower in the redispatch pilot, no bids have been placed in the month, since there was no flexibility space in February; therefore, there are no earnings for this month. The same holds for April.

Two different months are picked, to identify monthly differences between the profitability of the redispatch market. As explained in Section 5.2.1.1, the flexibility in a greenhouses differs per month. To identify the impact of the different seasons on the economic profitability of the redispatch market, different months are modeled. February 2019 is a winter month, with lower temperatures and less sun hours than in April 2019. As appears from the results to this part, the earnings in February were higher than the earnings in April. A likely cause of this is the fact that the temperatures are lower in February, meaning more heat from the buffer is needed to heat the greenhouse. Since the buffer provides flexibility, more buffer space available means more flexibility available.

6.3 Conclusion

The goal of this section was to give an answer to the following research question: '**Under what circumstances can the redispatch market be an added value to the portfolio of greenhouses, given their technical characteristics and behaviour in other markets?'** In order to answer this question fully, the question has been split up into two parts. In Section 6.1, the minimum needed redispatch price is calculated, based on the valuation of opportunities and the risk of a fine. As can be concluded from this first part, given the redispatch costs of TenneT over 2017, the redispatch market can be an added value to each of the three types of greenhouses. Another conclusion that can be drawn from this section, is the fact that adding the risk of a fine to the price, significantly increases the redispatch price.

In the second part of the question, a model is presented to calculate the average additional gains on the redispatch market, for a specific greenhouse in a specific month. To get an indication of the potential revenues of selling electricity to the redispatch market, the average gains over the month February, are calculated for the specified 3 greenhouses – Tomato, Cherry tomato and pot plant. The gains on the redispatch market have appeared to be significantly high, suggesting for AgroEnergy it would be worth it to invest time in adding the redispatch market to the portfolio of the greenhouse grower. For the greenhouse grower growing cherry tomatoes, no flexibility was left to sell electricity to the redispatch market.

Since there are different uncertainties in the redispatch market, mainly regarding the (exact) congestion probability on a certain location and regarding the pricing that will arise in the redispatch market and therefore the *settlement* of a certain bid, a certain gain on the redispatch market cannot be assured on this deterministic model. An indication of the gain, using plausible input values for the redispatch price and the settlement probability, is calculated in Part 2. When redispatch prices and region-specific congestion probabilities become clearer – information that will likely follow when the redispatch pilot starts – a more specific calculation of monthly earnings can be made.

In Chapter 9, the impact of these uncertainties on the potential interpretation of these outcomes is discussed.

Chapter 7: Willingness to participate in the redispatch market

GOAL	METHOD	RESEARCH QUESTION
To identify the willingness to participate in the redispatch market, subdivided into economical and social motivations and barriers.	Qualitative analysis, existing of a theorethical literature review. The theorethical foundings are tested in empirical research, via interviews with greenhouse growers.	How do socio-economical characteristics influence the willingness to participate in the redispatch market?

From Chapter 6, it appears the redispatch market can – under different circumstances – be an added value to the portfolio of greenhouses, from an economic perspective. So while there may be a theorethical advantage of supplying to the redispatch market, which according to the neoclassical theory leads to supply to the redispatch market, the question rises whether there are other factors motivating or withholding greenhouses from supplying to the redispatch market. The research question central in this part, is:

How do socio-economical characteristics influence the willingness to participate in the redispatch market?

The starting point for answering this research question, are the relations between relevant aspects and behaviour found in literature (See Section 2.3). These relations are tested for this specific case by performing an empirical research, by doing interviews with multiple greenhouse growers and specialists within AgroEnergy. Eventually, the impact of the behaviour of greenhouses on the willingness to supply to the redispatch market can be determined.

In Section 7.1, the result of the literature review is linked to the current knowledge of the redispatch market and greenhouses. Now the planned design of the redispatch market is examined (Section 4.3), the technical characteristics of a greenhouse as electricity suppliers are explained (Chapter 5) and given there is an economical potential (Chapter 6), the implications of the theorethical relations on behaviour in the redispatch market are determined. Hypotheses are formed based on the theorethical relations. These can in turn be verified using the empirical research via interviews (Section 7.2). In Section 7.3, the research question will be answered.

7.1 Theorethical relations

In this section, the impact of human characteristics on the behaviour of a greenhouse grower in the redispatch market is given, based on the literature review presented in Chapter 2. The results of Chapter 2 are presented in Table 5 in Section 2.3.4. Per determinant of the Theory of Planned Behaviour, the expectations for a certain aspect on behaviour in the redispatch market is described.

All theory described in this section, is a conclusion of the literature review section. Therefore, no specific references are given in this section; the conclusions are a combination of different sources. If interested in the references, see Section 2.3. The interview questions belonging to each of the sub-parts are shown in Appendix A.

7.1.1 Attitude toward the behaviour

Just like the literature review, this section is split up into the four core findings determining the attitude toward the behaviour, being: opportunity loss, bounded rationality and the prospect theory.

Opportunity losses
As appears from literature, (potential) opportunity losses may negatively affect the attitude toward certain behaviour. Besides, it appears losses are valued higher than gains. Supplying bids to the redispatch market may cause opportunity losses on both the imbalance and intraday-market. If for instance the last hour of buffer space has been sold to the redispatch market, but during the day a high imbalance price occurred, the greenhouse cannot supply to the imbalance market anymore. For this specific situation, an opportunity loss occurs if the imbalance price at that time is higher than the redispatch price. While, as appears from Chapter 6, there may be an average economic advantage of supplying to the redispatch market, greenhouse growers may value this potential opportunity loss higher. This will be investigated in the interviews, by asking what the vision of a certain greenhouse grower upon potential monetary risks is. Besides, for greenhouse growers who have already supplied to the tertiary reserve market – where a greenhouse grower also receives a fine for not supplying a settled bid – there will be asked for the experiences with this fine.

Bounded rationality
From the literature review, it appears bounded rationality mainly occurs when there is a choice overload, or when the results from a certain action are difficult to estimate. Both these options are likely to be relevant for determining the behaviour of greenhouse growers in the redispatch market. Namely, as appears from Section 4.2, there are six trade-markets to which greenhouse growers can offer their electricity. Besides, as appears from Section 5.1, congestion probabilities are relatively small. Since the pricing in the redispatch market is still unknown too, it is difficult to make a quick estimation of profits on the redispatch market. It will be investigated by asking upon the feeling of the emergence of all new markets. Besides it will be asked how a greenhouse grower estimates the potential benefits of the redispatch market.

Prospect theory
The redispatch market has only recently been opened up for smaller volumes, so for each of the greenhouse growers, the redispatch market is not the default option. In the interviews, it will be investigated whether this stickiness may withold greenhouse growers from participating in the redispatch market by asking whether they would be willing to change their behaviour into participating in the redispatch market.

7.1.2 Subjective norm

The subjective norm points to whether greenhouse growers feel pressure to participate in the redispatch market. As explained in the literature review, the term 'subjective norm' can be split up into three different determinants that all have an individual impact, being descriptive norms, social injunctive norms and personal injunctive norms. This section is split up according to these three determinants.

Descriptive norms
Descriptive norms relate to the feeling that individuals may copy behaviour of other's, since an individual does not want to be the odd one out. Descriptive norms appear to have a significant impact on behaviour. Greenhouse companies are often concentraded in an area with multiple greenhouses (RVO, 2018), which allows for easy direct contact between different greenhouse growers. Besides, as an expert within AgroEnergy acknowledges, some groups of greenhouse growers have regulary meetings to discuss their strategy (Expert AgroEnergy, 2019). Since currently, only 5 greenhouses are supplying to the redispatch market (in the pilot), it may be likely that greenhouse growers do not want to supply to the redispatch market since the majority doesn't. It will be investigated by asking how much value a certain greenhouse grower attaches to the strategy of its competitors.

Social injunctive norms
Social injunctive norms relate to social pressure to perform certain behaviour and appear to have a minor impact on the behaviour. By supplying to the redispatch market, a greenhouse can reduce congestion. In an area with congestion-issues, it may be likely that greenhouse growers negatively affected by congestion try to push others to contribute to reducing that congestion. This specific characteristic will be investigated by asking whether greenhouse growers feel any pressure they should be the ones responsible for solving congestion.

Personal injunctive norms
Lastly, as explained, personal injunctive norms relate to a person's set of moral rules that may induce certain behaviour. As appears, in general people do not only value their own welfare; if a certain decision may enlarge the welfare of other's, this can also play a role.

First of all, supplying to the redispatch market can contribute to an accelerated energy transition. However, as appears, pro-environmental behaviour should not be tried to be stimulated with monetary motivations. Besides, knowledge seems to be an important aspect in performing pro-environmental behaviour. Since the redispatch market is primarily meant to solve congestion – which can be increased by a higher penetration of renewable sources – it may be unclear to greenhouses that supplying to the redispatch market can be seen as pro-environmental.

In order to investigate this, first it will be asked whether greenhouse growers would supply to the redispatch market from environmental considerations.

7.1.3 Perceived behaviour control and facilitating factors
Perceived behavioural control – the belief that certain behaviour is under a person's control – appears to influence behaviour, too. It can be split up into perceived control and perceived difficulty.

Perceived control
Perceived control relates to the feeling of behaviour being under an individual's voluntary control. For this case specific, perceived control issues (Am I able to to supply to the redispatch market?) can be taken away by AgroEnergy. After all, AgroEnergy can determine, using its tools, whether a certain greenhouse has space (or: is able) to supply to the redispatch market. Expected is there are no perceived control issues that cannot be taken away by AgroEnergy.

In order to investigate this, it will be asked whether greenhouse growers perceive they have flexibility left to supply to the redispatch market.

Perceived difficulty
Perceived difficulty relates to individuals experiencing behaviour difficult to perform. Part of the perceived difficulty can be taken away by AgroEnergy, who for instance calculates the optimal bidding strategy and also places bids for the redispatch market. Since it appears perceived difficulty is an important barrier for performing behaviour, it needs to be investigated if there are any (unforeseen) perceived difficulties experienced by greenhouses, as suppliers to the redispatch market.

This potential aspect will be investigated by asking about the perceived (technical) barriers a greenhouse grower foresees when supplying to the redispatch market.

7.2 Empirical research
In order to test investigate whether certain (non-rational) behavioural aspects show in the decision of greenhouse growers to participate in the redispatch market, interviews are executed. These interviews are executed with greenhouse growers at AgroEnergy. Additionally, experts at AgroEnergy have been interviewed for some additional information. Just like Section 7.1, this section is also

subdivided according to the theory of planned behaviour. An interview protocol (Appendix A) is set up for the interviews. See Appendix B for the outcome of the interviews.

7.2.1 Attitude toward the behaviour

Refers to the extent to which a person finds certain behaviour favorable or non-favorable. In this specific case, this relates to whether greenhouse growers think the redispatch market is a market where they should supply to.

Opportunity losses

From the literature review, it appears potential opportunity losses can be a barrier towards performing certain behaviour. Opportunity losses may occur, when supplying to the redispatch market. In the interviews, it is researched whether this is also true for greenhouse growers.

An interview with an energy specialist from AgroEnergy has provided insight in the valuation of opportunity loss by greenhouse growers. From this interview it appears the feeling of missed opportunities also exists in the intraday market. The intraday-market has currently been added to the 'portfolio' of different clients of AgroEnergy. For a greenhouse grower and AgroEnergy, the intraday market is an opportunity to compensate for wrong estimations done when placing the day-ahead bids. This can for instance happen when it is colder than expected. The BiedOptimaal-tool (see 5.1.1) sets a buffer target for four days from the current day. Based on this buffer target, the day-ahead bids are placed. The intraday-model determines, based on the 'four-day target', a daily target. If, due to for instance wrong weather predictions, more heat is needed and the buffer will be lower than the target, an intraday-order buy order (from the EET intraday price-curves) is bought, meaning a greenhouse sells electricity via the intraday market to EET (See Section 4.2.1.3). The intraday-model seeks for the best moment to buy the intraday-order, with the price-curve that is valid at that certain moment. Prices only slightly higher than marginal costs of a CHP (around €25,-) are accepted, since the sell-bids are needed to solve a problem: a too low buffer-level. Two feelings of opportunity losses are noticed with greenhouses. The first opportunity loss happens in combination with the day-ahead market. When the day-ahead price is €50,- on the day after the intraday-trade, greenhouses have questioned 'why the CHP didn't just sell one more hour on the day-ahead market the next day for a higher price' (Expert 1, AgroEnergy, 2019). Secondly, greenhouses have noticed high prices on the passive imbalance market, during hours at which there is sold to the intraday market. This causes feelings of missed opportunities, too (Expert 1, AgroEnergy, 2019).

As noticed in the intraday-project of AgroEnergy, greenhouses mainly experience feelings of opportunity loss when the passive imbalance price is high at times they could have sold to the passive imbalance market, if they hadn't sold to the intraday market. One feeling of opportunity loss could already lead to a negative feeling towards a certain market. This is in line with the literature review, from which it appears losses are valued higher than gains.

As appeared from an interview with Greenhouse grower 3, it however appears the impact of this aspect may be somewhat reduced by AgroEnergy. During this interview, the greenhouse grower expressed negative feelings toward the intraday-market, because of the missed opportunities regarding high passive imbalance prices, the greenhouse grower's attitude clearly changed into positive when the total earnings on the intraday-market were shown in a calculation model. The greenhouse grower acknowledged such a calculation, as the model for calculating the economic potential of the redispatch market for greenhouses, could contribute to a more positive feeling toward the market.

Bounded rationality

It appeared in general, greenhouse growers want to supply to the redispatch market if they can earn money from it. However, the information of congestion probabilities and following from this, money to be earned from the redispatch market, are not yet clear. One of the greenhouse growers gave this as the reason he participated in the redispatch pilot: 'I participated to see what I can earn from it.'. However, a greenhouse grower who does not participate yet, stated he first wanted to have a clearer overview of the potential value of supplying to the redispatch market. This also became clear from an interview with a greenhouse grower, who stated that, given the uncertain revenues from the redispatch market, he was happy with his current electricity portfolio. However, he acknowledged if the revenues became clearer, he was willing to supply to the redispatch market.

Choice overload may lead to bounded rationality, too. This factor is clearly visible in the behaviour of greenhouses. During two interviews with greenhouse growers not supplying to the redispatch market yet, it became clear they didn't know about the possibilty to supply to the redispatch market. They only knew about the already existing markets.

Prospect theory

From the interviews held with greenhouse growers, it appears each of the greenhouse growers would be willing to supply to the redispatch market, if they would certainly earn money from it. However, the monetary gains from the redispatch market are not certain. Mainly the risk of getting a fine when a settled bid is not supplied, seems to be a barrier for greenhouse growers to supply to the redispatch market. As a greenhouse grower stated: 'I got the fine for reserve capacity twice, when I forgot to turn on the CHP in time. After I got the second fine, I have never provided upward regulation reserve volume anymore.' So the potential loss associated with bidding in the redispatch market, plays a significant role in the decision to offer to the redispatch market.

The status-quo bias appears not to play a role for greenhouses. During each of the interviews, it became clear that a greenhouse would supply to a certain market if that market could provide additional revenues.

7.2.2 Subjective norm

Congestion management is a local and regional problem. Greenhouses with a CHP are in the position to reduce this problem. The question is whether the greenhouse growers feel they are responsible for solving congestion issues. As appears from the literature review, the term subjective norm exists of three values: social injunctive norm (social pressure), descriptive norm (do not want to behave differently) and personal injunctive norms (morally feel they should perform a certain action).

Descriptive norms

Descriptive norms appear to play a role in determining the intention for behaviour. During the interviews, a greenhouse grower admitted to communicate with other greenhouse growers, about to which market they should supply their electricity. An energy specialist at AgroEnergy confirmed this; he often meets with multiple clients at the same time, so they can exchange strategies. However, it also appeared from the interviews that greenhouse growers trust AgroEnergy in making the right decisions. For the greenhouse growers interviewed, the proposed strategy of AgroEnergy is more important than the strategy of fellow greenhouse growers. Therefore, this determinant appears to be irrelevant for determining behaviour in the redispatch market.

Social injunctive norm

For finding out whether social pressure plays a role, the question is asked whether greenhouse growers experience pressure from others to supply to the redispatch market. From the interviews, it becomes clear this is not the case. When asking greenhouse growers whether they feel like *they* should be the ones solving congestion, they unanimously state the TSO and DSO is responsible for solving the problem.

Personal injuctive norms

Pro-environmental behaviour: As explained in section 1.3.2.1, supplying to the redispatch market can be seen as pro-environmental behaviour. As appears, greenhouse growers do not seem to see the environmental contribution of the redispatch market. As one greenhouse grower stated in the interview: 'I didn't know congestion management may speed up the energy transition.'. While TenneT (GOPACS meeting, 2019) states one of the advantages of supplying to the redispatch market, is contributing to stability in the electricity grid and this way making the energy transition possible, this does not seem to be seen as an advantage according to the greenhouse growers who are interviewed. So far, pro-environmental behaviour does not apply to this specific case. When greenhouse growers are made more aware of the fact congestion management contributes to the energy transition, it remains question whether this will have impact. In the interviews namely, it became clear greenhouse growers mainly care about the potential to earn from the redispatch market.

Solving congestion: As appears, greenhouses do not feel like they should be the ones solving congestion. Therefore, personal injunctive norms appear to play no role in this case. Concluded can be, no moral values increase the intention of supplying to the redispatch market.

7.2.3 Perceived behaviour control and facilitating factors

If the perceived ability to perform certain behaviour is low, meaning people experiencing barriers, the intention to perform certain behaviour will be lower. Perceived control issues can completely be taken away by AgroEnergy. Each of the greenhouse growers acknowledged they trust the expertise of AgroEnergy, for taking away issues related to perceived control.

Secondly, in the interviews, the perceived difficulty of supplying to the redispatch market is investigated. One of the issues that was mentioned by greenhouse growers, was related to the fine. Namely, it had occurred that the steering box – the connection between the position calculated by AgroEnergy and the execution of these calculations by the CHP – was set on the wrong programme. This can lead to the CHP not fulfilling a redispatch position, which will result in a fine. A second issue related to this, is that a greenhouse grower mentioned he forgot to turn on the CHP in time. However, if the CHP is steered by the steering box, and if this is set on the correct programme, this issue cannot arise anymore.

7.3 Conclusion on socio-economical impact on willingness to participate

In this section, the research question '**How do socio-economical characteristics influence the willingness to participate in the redispatch market?**' is addressed, by first providing a theorethical foundation and by then testing this for the specific case, using interviews. See Table 27 for the outcomes of the research.

Concluded can be, that greenhouse growers are mainly motivated by monetary rewards. The less uncertainty about the monetary rewards, the more willingness to participate in the redispatch pilot. A potential loss, as is present in the form of the fine in the redispatch market, has in similar cases led to no supply to a certain market at all. As initially suggested by TenneT - Help speed up the energy transition – (GOPACS meeting, 2019), greenhouses would not supply to the redispatch market following environmental considerations.

Although social pressure – a feeling you have to contribute to the redispatch market to help others – and personal injunctive norms – greenhouse growers could be the ones who (partially) solve congestion issues – play a role in increasing the intention for certain behaviour in other cases, these two values appear to play no role in the decisions of greenhouse growers to offer capacity to the redispatch market. Namely, greenhouse growers feel the system operator needs to solve congestion. Descriptive norms – a feeling your actions should not differ too much from the actions of other greenhouses – do play a role; greenhouses sometimes meet with other greenhouses to discuss (electricity-related) strategies. However, AgroEnergy can play a role in advising to change a strategy. It appears greenhouses trust AgroEnergy regarding this issue.

Lastly, the potential barriers mentioned by greenhouses (forgetting to turn on the CHP or putting the steering box on the wrong programme) are not specifically related to the redispatch market; these mistakes can occur when supplying to other markets as well. However, the fact that these mistakes can lead to a fine when supplying to the redispatch market, can withold parties from participating.

Table 27: Outcomes of the research into socio-economical characteristics

Social determinant	Relations found in literature	Conclusions from empirical research
Attitude toward the behaviour	Uncertainty about gains appears to negatively influence willingness to perform behaviour.	For some of the greenhouses, this is relevant.
	Potential opportunity losses will likely decrease trust and will thus likely have a negative impact on the attitude.	This appears to be relevant, also if a high opportunity loss only occurred once.
	Bounded rationality may lead to people not always making the most rational choice, since there is too much information to process.	It is clear there is bounded rationality due to choice overload; multiple greenhouses did not know about the existance of the redispatch market.
	People appear to value losses more than gains.	This value appears to be true. The potential fine appears to be an important barrier, even when rationally, earnings can be higher than costs.
	People appear to put a higher value on goods they already own and tend to stick to a default-option.	This value appears to be not so relevant; greenhouse growers are willing to change behaviour, if they can earn money from this.
Subjective norm	People appear to not only strive for their own welfare, but often act pro-social.	This is not true for greenhouse growers supplying to the redispatch market; they feel the system operator should solve congestion.
	Environmental behaviour can improve the attitude toward behaviour, but it is expected this will not play a significant role in this specific case.	For all of the interviewed greenhouses, there were no pro-environmental motivations for participating in the redispatch market.
	People appear to be influenced by the behaviour of others in a sense that they are likely to copy behaviour.	This appears to be true; greenhouses discuss the strategy with each other and in general, do not want to be the odd one out.
Perceived behaviour control	Perceived difficulty has a significant impact on the perceived behaviour control and occurs when people think certain behaviour is difficult to perform.	Supplying to the redispatch market is not more difficult than supplying to another market, if AgroEnergy calculates and places the bids, so this aspect is not relevant.
Facilitating factors	Facilitating factors can increase perceived behaviour control and	This appears to be relevant for greenhouse growers; greenhouse

	therefore leas to a higher intention to perform certain behaviour.	growers trust AgroEnergy in making the right decisions for them.

Chapter 8. Enlarging the participation of greenhouse growers in the redispatch market by improving the benefits

GOAL	METHOD	RESEARCH QUESTION
To identify which aspects of the redispatch market could be changed, in order to enlarge supply of greenhouse growers to the redispatch market.	Using chapter 4 (current design), chapter 5 (technical barriers of current design) and chapter 7 (social barriers of current design) to propose changes in design, based on interviews and literature review.	How can the participation of greenhouse growers in the redispatch market be enlarged, while adhering to the goals of an electricity market?

Now the technical characteristics of a greenhouse in relation to the redispatch market and the social-economical attitude of greenhouse growers towards (aspects of) the redispatch market have been made clear, the question arises:

How can the participation of greenhouse growers in the redispatch market be enlarged, while adhering to the goals of an electricity market?

It is a challenge to create the right incentives for market parties to increase participation in a certain market, given the large market access and auction configuration variables (Poplavskaya & De Vries, 2019). In other words: a market can be designed in many different ways; it is task to design it in such a way to create the largest participation. The goal of this section is to investigate the impact of the current design of the redispatch market and to propose changes to this design, while adhering to the goals of an electricity market.

In the literature review presented in Chapter 2, different aspects of an electricity market design have been explained. The current design of the redispatch market is explained, using this framework, in Chapter 4.3. In this chapter, design aspects of the redispatch market are put in light of the knowledge obtained by answering the previous three research questions. Aspects that may enlarge the technical ability of greenhouses to offer capacity are explained, in line with the technical characteristics explained in Chapter 5. Besides, aspects that may increase profitability of the redispatch market, as calculated in Chapter 6 according to the rational choice theory, are treated. After all, the more profitable a market is, the more (rational) suppliers would be willing to supply. Lastly, the willingness to participate in the redispatch market based on behavioural aspects, as treated in Chapter 7, will be used as an indicator to propose a certain change in a design aspect. The propositions are then judged based on the consequence this proposition may have, using the literature review and an interview with Samuel Glismann, policy advisor working at TenneT (See Appendix C.1).

The framework with the relevant design aspects, that followed from Chapter 2.1, will be used to structure this section. Only those design aspects that influence the supply of flexible electricity by greenhouse growers in the redispatch market and may be changed to enlarge supply, are used. As appears from the current design in Chapter 4.3, there are for instance no explicit restrictions for certain types of service providers, meaning there are no restrictions that may disable certain greenhouses, based on technologies or connection levels, from supplying to the redispatch market.

AgroEnergy has a good relation with TenneT. After all, TenneT needs electricity suppliers to behave according to their strategy. AgroEnergy knows how greenhouses can do so. This section is thus meant to give advice to AgroEnergy as to how they can influence/advise TenneT.

8.1 Impact per design aspect and proposed changes

Per design aspect, divided according to the framework of Poplavskaya & De Vries (2018), the impact of this design on greenhouses is explained. Besides, the impact of changing the design in a current direction on the goals and potential inefficiencies in an electricity market, is explained, based on the literature review in Chapter 2.

8.1.1 Market access

The goal of this section, is to investigate which design aspects related to the category of 'market access', can be changed, in order to enlarge the participation of greenhouses in the redispatch market. Per relevant aspect, it is explained why this aspect is relevant and how it could contribute to a larger supply; more specific, via which of the characteristics treated in the previous chapters (Technology, profitability or willingness). Besides, impact of the change of a design aspect on goals and inefficiencies in the redispatch market is explained.

8.1.1.1 Administrative aspects

Pooling

Pooling may contribute to an enlarged supply, since too small units can pool and together supply a large enough bid. Pooling is for instance allowed in the secondary reserve market, to allow for smaller suppliers to participate (Borne et al., 2018). This motivation for pooling does not seem to be relevant for enlarging participation of greenhouses in the redispatch market, since it appears the capacity of a CHP in a greenhouse is large enough to meet the minimum bid size (See Chapter 5).

The second reason to allow for pooling, is the fact that pooling allows for the implementation of reserve units in a portfolio (Poplavskaya & De Vries, 2019). Pooling of units belonging to one EAN-code is allowed, since a bid is EAN-specific. This allows for greenhouses with multiple CHPs, to aggregate the capacity of these CHPs in one bid.

Pooling between different suppliers is not allowed in the current design of the redispatch market – a bid is EAN-specific. This sounds logical, since the EAN-code is a designation of the location and congestion management is location specific. The consequence of not being able to pool, is if a bid of Greenhouse x is settled but the CHP of greenhouse x is failing, neighbour Y cannot compensate for this maintenance. Since for some greenhouses, the CHP has a failure almost every month, the risk for a fine can this way be high. This also appears from Chapter 6: the fine can considerably reduce the profitability of the redispatch market for a certain greenhouse. Besides, from the interviews with greenhouse growers, it appeared the fear of a fine can withold greenhouse growers from investing in a certain market. If the fine risk cannot be reduced, this may be a serious barrier that, for some greenhouse growers, may be large enough to decide to not participate in the reserve market.

For the tertiary reserve market, AgroEnergy has created a pool of different greenhouses to reduce the risk of a fine if a CHP that has to supply is failing. To reduce the probability of non-delivery for TenneT, and the probability of a fine for a greenhouse, the allowance of a back-up CHP – on a different EAN – which can be turned on if a CHP that has to deliver electricity is in failure. This specific aspect is seriously considered by TenneT, as appears from an interview (TenneT, 12-4-2019). The impact of allowing a back-up CHP, however, is that the total supply to the redispatch market may be reduced because of this measure (Poplavskaya & De Vries, 2019). Given the currently low supply to the redispatch market, as Glismann (2019) stated in the interview, other options to reduce the risk for a fine may be considered.

Verification of delivery
As explained, verification of delivery can take place based on a unit- or pool-level. Here, with a pool, a group of CHPs belonging to one EAN or connection is meant. Currently, the idea is to have a pool-level based validation of delivery. This means a greenhouse has to make a deterministic forecast of the amount of electricity that will pass the connection from the greenhouse to the grid, without eventual redispatch sales. If this is for instance a flow of 2 MWh from the greenhouse to the grid and there is a redispatch buy bid of 1,5 MWh at that hour, the remaining flow over the connection has to be exactly 0,5 MWh in order to satisfy the settlement. However, verifying the delivery of a certain bid on the connection-level brings problems for greenhouses. Namely, as appears from Chapter 6.1, the operating electricity use often differs from expected and then is compensated via the passive imbalance market. This implies greenhouses would often diverge from the forecast. This way of verifying would therefore lead to significant probabilities of a (partial) fine and as explained, this fine likely reduces supply of greenhouse growers to the redispatch market.

Verification of delivery on a unit-level would logically take away this risk for greenhouses. If a bid is placed for a specific CHP, the operating electricity use does not influence the increased or decreased production of this CHP (with respectively: a sell and a buy bid). However, there is another risk involved with this type of verification. As followed from the literature review, a legal form is gaming is arbitraging. Although legal, this form is a problem for congestion management, since it can cause essential bids not being delivered (Section 2.1.2). If verification of delivery happens on CHP level and a greenhouse has multiple CHPs, the greenhouse can arbitrage with the different CHPs. Imagine the greenhouse has two CHPs. For the first, he did not have a position yet and places a 2 MWh sell-bid on the redispatch market. For the second, he had a 2 MWh sell-position on the day-ahead market at the same hour. If the redispatch bid is settled, the greenhouse could buy 2 MWh at the same hour on the intraday-market for the second CHP. Then, the greenhouse receives money for the redispatch sell-bid, but does not (on a connection-level) deliver electricity. See Table 28 for an illustration of the problem.

Table 28: Illustration of arbitrage possibility, by having a unit based verification of delivery.

	Position on D-1	**Actions on D0**
CHP 1	2 MWh – intraday, sell	Buys 2 MWh from intraday, netto postion: 0 MWh
CHP 2	2 MWh – redispatch, sell	2 MWh, redispatch, sell
Net delivery on connection level	Expectation of TenneT: 4 MWh, sell	Realisation: 2 MWh, sell

In order to prevent a wrong estimation of the company's production use from happening, verification of delivery should take place on each of the units (CHPs) in a certain pool (EAN). To avoid the possibility of arbitraging, should be verified that the CHP not supplying to the redispatch market, does not change its position, or at least not in the wrong direction. This intensifies the administration for TenneT, but is the only way to prevent both issues from happening.

8.1.1.2 Technical prequalification requirements
The technical requirements - activation speed and duration – are no barrier to greenhouse growers. Bids are ultimately settled 3 PTUs before activation, which allows for a timely activation, given the activation speed of a CHP of maximum 15 minutes (See Chapter 5). Besides, the minimum duration of a bid is 1 hour, which is not a problem given technical characteristics of greenhouses (See Chapter 5). TenneT is not planning on changing the technical prequalificatio requirements in the future, so there is no risk for greenhouses regarding this design aspect (Glismann, 2019, Appendix C.1).

8.1.2 Auction configuration

The goal of this section, is to investigate which design aspects related to the category of 'auction configuration', can be changed, in order to enlarge the participation of greenhouses in the redispatch market. Per relevant aspect, it is explained why this aspect is relevant and how it could contribute to a larger supply. Besides, impact of the change of a design aspect on goals and inefficiencies in the redispatch market is explained.

8.1.2.1 Bid-related requirements

Minimum bid-size

The minimum bid-size on the redispatch market is 1 MW, on GOPACS the minum-size is 0,5 MW. This does not give problems for greenhouses, since the CHPs' capacity is on average 2 MW. However, if the minimum bid-size is smaller, this gives CHPs the possibility to bid partial load (70%) on the day-ahead market and full load (30%) on the redispatch market. However, production costs of a CHP are determined per hour, regardless if it is producing partial or full load, a CHP often produces on full load. Therefore, the impact of a smaller bid size on an enlarged supply will likely be limited. Besides, a smaller bid-size intensifies the transaction costs for the system operator, who has to deal with more bids (Borne et al., 2018). As stated in the GOPACS information session (8-3-2019), a reduction of the minimum bid-size is not considered.

Procurement of energy and capacity

In the current design of the redispatch market, only procurement of energy and capacity will be done jointly. This means, no specific capacity payments will be given. As appears from the interviews, the uncertainty of gains in the redispatch market may withold some greenhouse growers from participating in the redispatch market. A capacity payment would take away this uncertainty.This may enlarge supply to the redispatch market, which could therefore be an instrument to use if congestion probabilities are high in a certain area. Capacity payments are involved with the balancing market for the same reasons: to provide some certainty to suppliers to the market.

However, there is an important difference between the nature of a redispatch market and a balancing market influencing the potential (mis)use of a capacity payment: balancing happens in real-time, congestion management happens based on forecasts. One important property of congestion management, is that it is about avoiding congestion, rather than solving congestion. Here, it clearly differs from the balancing market, which is reactive. This may cause wrong incentives. An example can illustrate this. If there is an area where downward regulation is often needed, in order to avoid congestion, you might think of contracting a few parties (e.g. greenhouses) for downward regulating, by giving them a capacity fee and a certain variable fee if the party actually has to regulate. The greenhouse knows he earns money anyway, but might earn more when he really has to act. This creates an incentive to produce 'as much as possible', in order to enlarge the probability of congestion. The system operator then has to pay the capacity fee + the production fee to the greenhouse, while there might not have been a problem to start with. The greenhouse grower can purposely have created a problem.

This is a typical example of locational inc-dec gaming (Hirth & Schlecht, 2018), which is explained in Section 2.1.2, and is one of the market inefficiencies a market design must prevent. In order to prevent locational gaming, no detailed information about the location of congestion can be given. Capacity payments reveal congestion information and are therefore not suitable for such a market. Because of these wrong incentives, a capacity payment will not be an option to add in the design of the redispatch market. This is also verified by TenneT (interview Glismann, 2019).

Energy bid adjustment

If a redispatch position cannot be fulfilled, this will be punished with a certain fine. As indicated by different greenhouse growers, a (potential) fine might hold back their decision to invest in a particular market. To avoid this, the fine could be lowered or even remitted. However, as indicated by Samuel Glismann (20-3-2019), a too low fine could provide possibilities for arbitrage. Arbitrage means trading and selling a certain position. Since for the redispatch market, it is important a settled bid really is delivered, arbitrage possibilities should be avoided. So although the fine may withold some producers from supplying to the redispatch market, it is needed for the well-functioning of the market.

Bid symmetry

By bid symmetry, a simultaneous buy and sell bid are meant, for the same period. This form of bid symmetry is allowed in the redispatch market, since it may enlarge supply to the redispatch market. Besides, given the uncertain characteristics of congestion, placing two bids at the same time increases the probability of settlement (Glismann, 24-4-2019). For a greenhouse specific, bid symmetry is only possible if the greenhouse has (at least) two CHPs. With one CHP, he needs to have a day-ahead sell position, which he can buy back via a redispatch buy-bid. With the other CHP, he needs to have no position yet, for which he can then provide a sell-bid to the redispatch market. In theory, this sounds fair. However, such a situation has not occurred yet in the redispatch pilot, where the optimal bids are calculated in the boundaries of the technical specifics (Chapter 5).

A different form of bid symmetry may be valuable, being conditional bids– placing for multiple bids of which only a part can be selected. From the redispatch pilot it appears it often happens that a certain greenhouse grower can offer a total of e.g. 2 hours, based on the buffer, but has many options as to when to offer those exact hours, based on the day-ahead position, lighting and CO_2-needs (Chapter 5.2). As appears from Chapter 5.1.1, accurate congestion is very hard to predict, so there is no good indication for how to choose between the different options. Besides, it appears revealing congestion specific information, increases the probability of (inc-dec)-gaming. By allowing for conditional bids, this increased gaming probability is also not present. So conditional bids would be beneficial to both greenhouses and TSO and DSOs. For a greenhouse, a conditional bid increases the probability of settlement of the bid, since it is offered at more hours. For the TSO and DSOs, the supply to the redispatch market is enlarged when conditional bids are used.

8.1.2.2 Time-related characteristics

Bids can be provided from D-1 15:00, until 3 PTUs before delivery (45 minutes). Bids can be adjusted anytime, if the bid has not been settled yet. Bids can also be settled anytime. The fact that bids can be adjusted and withdrawn, makes it possible for one greenhouse to supply to both redispatch and intraday, after which a not settled redispatch-bid can be sold to either the imbalance market or the intraday market. This has been used for determining the theorethic potential in Chapter 6.

8.1.2.3 Remuneration

The current pricing rule in the redispatch market is a pay-as-bid auction, where the remuneration is equal to the price of the bid. Next to a pay-as-bid auction, the pricing rule could also be marginal pricing. This is the pricing rule which is for instance valid in the day-ahead market (See Section 4.1.2.2). However, as stated by Hirth and Schlecht, pay-as-bid market actors would try to price close to the marginal price in order to increase the settlement probability. Therefore, they claim pricing in the redispatch market will not differ heavily with the two different auctions (Hirth and Schlecht, 2018). Research executed by Ren and Galiana (2004) into the market behaviour in a pay-as-bid auction versus a marginal pricing auction, where the generators are profit maximizing, shows the expected value of both a generator as the consumer payment is the same under both auction forms. According to neoclassical theory, both pricing rules will therefore lead to the same market behaviour.

Although research suggests a market with a pay-as-bid auction is hard to enter since the difficulty to estimate a good price withholds parties from participating (Krah et al., 2001), it appears for clients of AgroEnergy, the type of pricing rule does not play a significant role in the decision to (not) contribute in a particular market. Namely, as explained in Section 5.2.1, AgroEnergy calculates the optimal bids for its clients using an optimization model which takes costs and if possible price estimations into account. The barrier of estimating a good price is completely taken away by AgroEnergy.

8.3 Conclusion on market design

When TenneT designed the redispatch market, they did not see any barriers for **not** supplying to the redispatch market. However, as appears from the previous sections, there certainly are barriers – both on socio-economic and technical level. TenneT should therefore consider some changes.

Certain changes in the design of the redispatch market might overcome these barriers. In order to reduce the risk of a failing CHP and thus a settled bid which will not be delivered, TenneT can consider to change the administrative aspects, to allow for a back-up CHP that can provide electricity if a certain CHP is failing while it has to deliver. This will likely increase the willingness supply to the redispatch market, since it has appeared fines may withold some greenhouses from supplying to a certain market.

The minimum bid-size could be reconsidered and be made smaller. This way, greenhouses can deliver partially to one market and partially to another market, which may increase the total supply to the redispatch market. However, given the hourly maintenance costs, greenhouse growers prefer not to turn their CHP on partial load.

Lastly, it appears the greenhouse growers of AgroEnergy are indifferent about the pricing mechanis, since AgroEnergy will place the redispatch bids for its clients. However, it still is advisory to change the current pricing mechanism – pay-as-bid – into a marginal pricing auction. From research, it appeared this form of pricing is easier for new entrants. With a pay-as-bid auction, it is hard to estimate a good price in a market like the redispatch market, with low price transparency.

Table 29: Conclusion on market design.

DESIGN ASPECT	Group	Variable	Proposition for change
Market access	Administrative aspects	Pooling	Pooling by allowing a backup CHP, may reduce the fine risk, but also reduces supply.
		Verification of delivery	Should happen on CHP level, where it should be checked that the other CHPs in the pool do not change their behaviour (arbitraging).
	Technical prequalification criteria	Activation speed and duration	No change proposed.
Auction configuration	Bid-related requirements	Minimum bid size	No change proposed.
		Procurement of capacity & energy	A capacity payment would take away uncertainty and likely increase supply, but can lead to gaming and will therefore not be considered.
		Bid symmetry	Adding conditional bids seem beneficial to both system operators and suppliers, given the high

			uncertainties in the redispatch market.
		Energy bid adjustment	Energy bid adjustment is not allowed after settlement; this will be punished with a fine. The fine is needed to avoid arbitraging.
	Time-related characteristics	Frequency of bidding - energy	No change proposed.
		Frequency of market clearing & activation - energy	No change proposed.
	Remuneration	Pricing rule	Change to marginal pricing rule, since this enables the entrance of new parties. Marginal pricing and pay-as bid pricing will likely result in the same welfare, so the goals of a market design are not affected.

Chapter 9: Discussion

The goal of this chapter is to discuss the potential interpretation and useability of the results obtained from the research. A discussion of the implications and limitations is necessary to be able to draw just conclusions from the research. The overarching perspective of this research, is the perspective of the Dutch TSO and DSOs, who need to attract more supply to the redispatch market in order to serve the future needs for congestion management. This implies parties need to be motivated to start supplying to the redispatch market. In order to reach an increased supply, the redispatch market has been opened up for smaller capacity units. From the bigger focus, it is the question whether small producers will supply to the redispatch market and which potential barriers they may observe. In this research, there has been zoomed in on the clients of AgroEnergy: greenhouse growers for who the redispatch market is one of the many alternatives where they can sell the electricity their CHP produces. In this discussion, both the perspective of clients of AgroEnergy as the bigger perspective will be discussed.

This discussion has a clear structure which leads to a suggestion of how to use the results and concludes into a suggestion for future research. In order to reach this point, first in Section 9.1, the major findings which followed from the research up to this point are shortly repeated. These findings are considered within the focus of the research: from the perspective of a client of AgroEnergy.

In Section 9.2, the implications of the research are explained. This section is split up into two parts: theorethical and practical implications. The goal of explaining the theorethical implications is to evaluate how the theory as described in the literature review has contributed to answering the research questions and on which points the theory fell short. Secondly, the goal of explaining the practical implications is to explain which parties benefit from the research and how. A broader focus on the research will be taken, where the implications will be placed in a broader context, while also considering potential future developments.

In Section 9.3, the reliability and validity of the research will be explained. This section discusses how the results can or cannot be interpreted, based on multiple limitations: limitations on the project scope (Section 9.3.1), limitations on data (Section 9.3.2), limitations on methodological choices (Section 9.3.3) and lastly impact of assumptions (Section 9.3.4).

9.1 Major findings

At the end of each of the chapters, a conclusion of that chapter has been given. These conclusions are literal answers to the research questions. The major findings in the (narrow) research context will shortly be repeated in this section. In the conclusion chapter in Chapter 10, these findings will be put in light of the discussion. The major findings per research part are summed up below. First, the knowledge gap is repeated in order to show which knowledge gap the findings fill.

Knowledge gap 1: The redispatch market has only recently been opened up to smaller suppliers like greenhouses with a CHP. It is the question whether the flexibility needed in the redispatch market, matches the flexibility that can (technically) be supplied by greenhouses with a CHP.

- Based on the characteristics of greenhouses as electricity suppliers and the redispatch market as flexibility demand, greenhouse growers can supply to the redispatch market.

Knowledge gap 2: Given the fact that the redispatch market is a market where parties can voluntary supply to and given there are alternative markets where electricity can be sold, it is the question whether it would be rational to supply to the redispatch market.

- For clients of AgroEnergy, there are potential opportunity losses involved with participating in the redispatch market. The higher the redispatch prices, the more rational it would be to supply to the redispatch market. Given the currently available data regarding redispatch prices, it will be likely that the redispatch market can be an added value to the portfolio of greenhouse growers.
- There appears to be a significant potential for the redispatch market to provide added value to the portfolio of greenhouse growers, if they have the potential to offer electricity to the redispatch market.

Knowledge gap 3: It is clear that individuals often behave differently than rational. There are certain behavioural aspects that may lead to non-rational behaviour. It is yet unknown how certain behavioural aspects are influencing the behaviour of greenhouse growers as potential suppliers to the redispatch market.

- The most important aspect determining the behaviour of greenhouse growers, is the aspect 'loss aversion'. This aspect appears to be difficult to influence; even if the probability of a certain loss is low (the probability a greenhouse grower has to pay a fine to the TSO), the potential for the loss appears to withhold some greenhouse growers from participating.

Knowledge gap 4: TSO and DSOs want to enlarge supply to the redispatch market. There are certain aspects of the market design that may be changed in order to reach a higher potential participation of greenhouse growers. Based on the technical characteristics of a greenhouse grower (knowledge gap 1), based on the potential earnings of a greenhouse grower in the redispatch market (knowledge gap 2) and based on the barriers greenhouse growers experience with the redispatch market (knowledge gap 3), it needs to be investigated which aspects of the design can be changed.

- There appear to be some aspects that might be changed, in order to enlarge the potential participation of greenhouse growers in the redispatch market. Mainly those aspects decreasing the risks for a fine are relevant, since it has appeared greenhouse growers may be withheld by a fine. The aspects suggested to be changed are to allow for pooling and to allow for conditional bidding. Besides, verification of delivery should be on unit level.

9.2 Implications

Research implications refer to suggestions that can be done based on the research, which are not explicitly stated. First of all, theorethical implications of the theory used for this research will be given in Section 9.2.1. This section is meant to discuss how the scientific literature has contributed to answering the research questions and on which points the scientific literature could not support or explain the findings. Based on this discussion, a potential contribution to scientific literature can be given. Secondly, practical implications of the research for relevant stakeholders will be given in Section 9.2.2. These will be explained in the form of the lessons learned for the relevant stakeholders. The goal of the practical implications is to look beyond the research results, to explain what the results imply in a broader context.

9.2.1 Theorethical implications

The goal of explaining the theorethical implication is to discuss how the theory that has been used, has contributed to answering the research questions central in the research. On some points, existing literature appeared to not be able to give a full explanation of a certain observation. For each of the theories used, it will be explained how this theory has contributed. Eventually, it will be summarized how the findings of this research fit with existing knowledge and what new insights they can contribute.

The theories will be discussed in the same order as they have been used in the research. Therefore, first the use of the flexibility framework will be discussed in Section 9.2.1.1. Hereafter in Section 9.2.1.2, the use of the neoclassical theory will be discussed. The use of a combination of behavioural concepts will be discussed in Section 9.2.1.3 and a discussion of the use of the market design will be given in Section 9.2.1.4. A conclusion upon the discussion of the theorethical implications will be given in Section 9.2.1.5.

9.2.1.1 Use of the flexibility framework

The flexibility framework established by Grunewald (2016) has been used to investigate the potential link between demand of flexibility in the redispatch market and (potential) supply of flexibility. The research by Grunewald (2016) reviews flexibility as a property on the demand and supply side of the electricity market. All aspects of the framework appeared to be useable for determining the flexibility needs in the redispatch market, and the potential flexibility supply by greenhouse growers with a CHP.

One addition has been made to the flexibility framework, which appears to be relevant for this research: the location of flexibility. Where Grunewald investigates flexibility in a more abstract notion, for redispatch the exact location of the provided flexibility is important. If all flexibility can be provided in an area *without* congestion issues and no flexibility in an area *with* congestion issues, there is no relevant flexibility for the redispatch market.

In conclusion, the framework has appeared to be relevant for the research, if the location of flexibility is added.

9.2.1.2 Use of the neoclassical theory

The neoclassical theory and the theory of rational choice, which follows from the neoclassical theory, have been used to evaluate under which circumstances it would be rational to supply to the redispatch market, given opportunity losses. The theory of rational choice, as can be concluded from the name, assumes people act rational. It appears people usually do not make fully rational choices, which is why using the neoclassical theory may seem slightly naïve. Multiple researchers have claimed why the neoclassical theory does not correspond to actual human behaviour. For example Kahneman et al. (1986) prove that decision makers do not maximize (rational) utility. Besides, Thaler and Sunstein (2008) provide clear evidence that irrational aspects in decision-making may lead to individuals not always choosing the most rational option.

However, these findings do not make using the neoclassical theory completely irrelevant. Thaler (1991) accepts neoclassical aspects of individual preferences as the normative ideal, as he writes: “It goes without saying that the existence of an optical illusion that causes us to see one of two equal lines longer than the other should not reduce the value we place on accurate measurement. On the contrary, illusions demonstrate the need for rulers!” This implies individual beings need to be supported in making rational decisions. A similar ideal is built into the optimization models of AgroEnergy. AgroEnergy incorporates all possible market information and all accurate technical information of the specific greenhouse grower into an optimization model, to this way calculate the bids with the highest value.

What can be concluded is that the neoclassical theory has been able to contribute to answering the research question, since the optimization models for AgroEnergy rationally ‘choose’ between the alternative markets. Within the boundaries of the research, this theory has justly been used. Outside the research boundaries, the neoclassical theory may not be relevant. Namely, considering the complexity of the technical aspects of a greenhouse and the complexity of the Dutch electricity sector, it will likely be too difficult for a (potential) supplier to behave rational. Multiple aspects have to be taken into account when estimating when to place bids and for what price, which has been explained in Chapters 5 and 6. For instance the buffer level, lighting needs, failure probability of the CHP and level of the fine need to be taken into account when placing redispatch bids. Besides, an accurate valuation of the intraday- and passive imbalance trades is needed to determine whether the redispatch market is an addition to the current portfolio. Therefore, for a 'single supplier' not connected to AgroEnergy, it will be nearly impossible to act fully rational and in line with the neoclassical theory.

Since for answering the second research question, the assumption is a certain greenhouse grower already supplies to the redispatch market. Therefore, the use of the neoclassical theory and the theory of rational choice is justified for this research. For determining behaviour of (potential) new entrants, the neoclassical theory appears not to be sufficient, which follows from the answers to research question 3.

9.2.1.3 Combination of behavioural concepts

The theory of planned behaviour as proposed by Ajzen (1991) has been complemented with literature on behavioural economics and pro-environmental behaviour literature, in order to fully identify the potential causes of the behaviour of greenhouse growers in the redispatch market. Here, the theory of planned behaviour has been used as a framework to which behavioural economics and pro-environmental behaviour literature have been linked. The theory of planned behaviour focusses on an individual's intention to perform certain behaviour, where 'performing behaviour' is in this research 'participating in the redispatch market'. The theory of planned behaviour has three determinants for the intention to perform behaviour, being 'Attitude toward the behaviour', 'Subjective norm' and 'Perceived behavioural control'. Based on behavioural economics and pro-environmental literature, there has been tried to better substantiate the determinants. For instance, what causes a certain attitude toward certain behaviour? The theory of planned behaviour can be seen as a more rational choice model, where pro-environmental literature incorporates personal norms into its measures (Turaga, Howarth & Borsuk, 2010). Behavioural economics does not have one specific definition, but most definitions emphasize the combination of economics and psychology (Pete, 2014).

From this research, one important insight regarding the use of pro-environmental behaviour for determining behaviour in the redispatch market can be drawn, namely that currently parties do not act out of pro-environmental considerations. The redispatch market *indirectly* helps accelerating the energy transition. The greenhouse growers which have been interviewed, acknowledged to be unaware of potential environmental benefits of the redispatch market. This emphasizes the importance of knowledge in performing pro-environmental behaviour; a relation which has been confirmed by Jensen (2010) and Gifford and Nilsson (2014). However still, the greenhouse growers did not see environmental benefits as potential reason to supply to the redispatch market.

According to the theory of planned behaviour, perceived behavioural control can be increased by facilitating factors. AgroEnergy is considered to be the facilitating factor for its clients, since AgroEnergy facilitates the energy trades of each of its clients. From this research it appears not only those aspects belonging to perceived behavioural control can be influenced by AgroEnergy. For instance the aspect 'descriptive norms', belonging to the determinant 'subjective norm', appear to be for a large part made irrelevant by AgroEnergy. Where the aspect 'descriptive norms' implies an individual does not want to deviate from the norm, it appears each of the greenhouse growers which has been interviewed chooses the advice of AgroEnergy over the behaviour of its competitors. Another aspect that can be influenced by a facilitator appears to be the aspect of 'bounded rationality', which points to the disability to process all available information and which thus disables an individual from acting completely rational. Besides, potential opportunity often seem to be overstated. A facilitator could take this barrier away, since it can give an overview of potential choices, together with the consequences of each choice.

In conclusion, the research implies that a facilitator can influence not only the determinant 'perceived behavioural control', but also the other two determinants of the theory of planned behaviour. While for clients of AgroEnergy, the main barrier appears to be the potential loss (in the form of paying a fine), the behaviour of other potential suppliers may be influenced by aspects like bounded rationality or descriptive norms. It would be interesting to investigate the difference in the intention to participate in the redispatch market between greenhouse growers who are influenced by a facilitator as compared to those who are not influenced by a facilitator.

Next to the theory of planned behaviour, there are other potential explanatory concepts to identify (intention for) behaviour in a certain socio-technical system like an electricity market. An example is the Technology Acceptance Model (TAM), which states intention to perform behaviour is influenced by the perceived ease of use, the perceived usefulness and the attitude (Taylor & Todd, 1995). There is no role for a potential facilitator. The research results imply the role of a facilitator can not be neglected when explaining behaviour in a socio-technical system, implying the TAM is incomplete.

Another explanatory theory is the Unified Theory of the Acceptance and Use of Technology (UTAUT), which also reasons intention is a good indicator for behaviour (Im, Hong & Kang, 2011). This model states there is a strong correlation between facilitating conditions and user behaviour. This enforces the implication.

9.2.1.4 Use of the market design framework

The market design framework by Polavskaya and De Vries (2018) has been used to judge the design of the redispatch market from the perspective of a greenhouse grower. This framework has actually been developed to judge the design of a regulated balancing market from the perspective of Distributed Energy Resources (DERs). Therefore, it is relevant to discuss how this specific theory has contributed to answering the fourth research question and on which points it fell short.

Some of the aspects in the framework have appeared to be irrelevant for the redispatch market from the perspective of a greenhouse grower, while one aspect was added to the framework (See Section 2.1.3). The aspect that was added from the research perspective, is verification of delivery. Namely, for the redispatch market, a fine will be given if a certain settled bid is not (fully) delivered. It is important to accurately verify the delivered amount of electricity, in order to avoid unfair fines. Using the framework was useful since it forces a researcher to walk through all potential market design aspects. For markets where it is important a specific settled bid is supplied – where for this reason a fine is introduced if this not happens – the aspect 'verification of delivery' should be added.

9.2.1.5 Conclusion: new theorethical insights

Based on the discussion of the theorethical implications, multiple theorethical insights follow. First, it appears the flexibility framework by Grunewald (2016) has been relevant for answering the first research question. One addition to this framework should be made when using the framework for judging flexibility in a redispatch market: location.

Secondly, it appears before greenhouse growers have decided to participate in the redispatch market, some behavioural aspects play a role in the decision to participate. Not all aspects have appeared to be relevant. For instance environmental aspects appear to have no influence on the decision to participate. It appears the role of the facilitator may be more influential than suggested by the Theory of Planned Behaviour. When greenhouse growers at AgroEnergy start participating in the redispatch market, they behave (nearly) rational according to the neoclassical theory. The only irrational aspect that may still be relevant, is loss aversion. From the research it appears a certain (monetary) loss can lead to an individual quitting behaviour: it has appeared some greenhouse growers stopped participating in a particular market once a fine was received.

The market design framework developed by Poplavskaya and De Vries has appeared to be useful to judge the full design of the redispatch market. One aspect, verification of delivery, appears to be relevant to add in a market where non-delivery of a settled bid is punished with a fine.

9.2.2 Practical implications: Lessons learned for stakeholders

The goal of this section is to look beyond the results that directly follow from answering the research questions. Practical implications refer to the value of the research for relevant stakeholders. First, the practical implications for AgroEnergy and its clients will be discussed in Section 9.2.2.1. Then, the research will be placed into a broader context in Section 9.2.2.2, where the research will be discussed in light of the broader goals of a market design as explained in Chapter 2.1. Lastly, interesting insights regarding potential conflicts between the different perspectives will be discussed in Section 9.2.2.3.

9.2.2.1 Practical implications for AgroEnergy and its clients

For AgroEnergy, this research can be used as a motivation for continuing and further developing the redispatch market. Namely, it appears it is likely greenhouse growers can get additional value from supplying to the redispatch market.

If a certain volume which has been supplied to the redispatch market is not settled, this volume can still be sold to the intraday market or on the passive imbalance market. This implies there is no reason to not supply to the redispatch market. However, there are some further implications to take into account.

From the calculation of the potential additional benefits of the redispatch market (Chapter 6.2), it appears these benefits are highly dependent on the settlement probability. This is visible in the calculation of the additional benefits for the type 'tomato grower' in the month April, where the additional benefits are significantly lower than in February. The bids in April are placed in hours with a lower congestion probability. This implies AgroEnergy should try to incorporate market messages – if these become available – into the optimization model of calculating the redispatch bids. Placing bids at the right moments significantly increases potential additional revenues.

Another practical implication that follows from Chapter 6.2, is the fact that a higher failure probability can significantly decrease average additional potential revenues. This implies the redispatch market may be less or not suitable for greenhouse growers owning a CHP with a high failure probability. Besides, an assumption has been done that the steering box is working properly. However, if the failure probability of the steering box is larger than 0%, this may also have a significant impact on the potential revenues of the redispatch market.

9.2.2.2 Practical implications in a broader context

Where in this thesis, the redispatch market is judged from the focus of a greenhouse grower, it is also valuable for TenneT and DSOs to judge whether the redispatch market is a good mechanism for congestion management. It is important to include future developments in these considerations. To be able to judge the redispatch market, different implications will be discussed. First of all, the redispatch market and its potential barriers will be judged from the view of other (potential) participants in Section 9.2.2.2.1. Then, it will be explained how the redispatch market can be changed

9.2.2.2.1 Broader context: Other potential participants

In this research, the focus was on the clients of AgroEnergy as suppliers to the redispatch market. During the research, some potential barriers have been noticed that do not play a large role for the clients of AgroEnergy, but may withhold other parties from participating.

One example of such a potential barrier, is the pricing rule in the redispatch market. While for clients of AgroEnergy, the pricing rule appears to not play a significant role in the decision to participate in the redispatch market, from literature it appears a pay-as-bid pricing rule may withhold parties from participating in a market. For potential suppliers **not** using the pricing tools of

AgroEnergy, it may be hard to estimate a good price. Only a part of the greenhouse growers with a CHP is client at AgroEnergy, so this implies there is a significant group of potential suppliers who may be withheld by the pay-as-bid pricing rule. Since it appears the long-run market price will not differ significantly in a pay-as-bid auction or a marginal pricing auction (Hirth and Schlecht, 2018), this implies there could better be chosen for a marginal pricing auction.

Another potential barrier that may rise for suppliers other than clients of AgroEnergy, is caused by two essential differences between clients of AgroEnergy and other potential suppliers. The first difference is the way in which intraday-trading takes place. For clients of AgroEnergy, intraday is an order, meaning a certain intraday 'bid' will always be settled (See Section 4.2.1.3). For regular suppliers, intraday bids have to be supplier to either EPEX SPOT or ETPA. There is no certainty the bids will be settled. Given the fact that bids can be settled throughout the day, this implies the later a bid will be supplied to the intraday market, the lower the settlement probability since there is less time for settlement. An easy illustration of this way of thinking: imagine there is only 1 MW volume needed between 15:00 and 16:00 on D0, this is known at 18:00 on D-1. Then already from 18:00 on D-1 onwards, the available bids will be evaluated. The earlier a bid is supplied to the intraday-market, the earlier it will get into the 'evaluation process', thus the higher the settlement probability.

The second difference is related to the time frame of the settlement of redispatch bids. The largest part of the settlement of redispatch bids happens between 21:00 (pm) and 1:00 am on the day before use (GOPACS meeting, 2019). If a bid has not been settled, a certain supplier could supply that bid to another market – intraday trading and passive imbalance trading can take placer shorter before time of use. Where AgroEnergy has built in an automisation where bids that have not been supplied to the redispatch market, will be supplied to the intraday market, suppliers who are not a client of AgroEnergy will unlikely want to wait until 1:00 am to resell unsettled bids. Imagine they resell their bids at 9:00 am when they start working again, there is less time for intraday-trading implying a lower settlement probability on the intraday-market. This may lead to higher opportunity losses.

This barrier is already noticed by TenneT, since on ETPA, there now is the possibility to offer a bid to the redispatch market and intraday-market simultaneously where the bid can only be settled once. Currently there does not take much trading place on ETPA yet; most redispatch trading happens via the original redispatch market (Resin) and most intraday-trading happens via EPEX Spot. With this combination of trading, this type of barrier may show.

9.2.2.2.2 Broader context: Congestion management by TSO and DSOs

In this section, the broader context with regards to congestion management using redispatch will be discussed. Besides the fact that there have appeared to be some barriers that TenneT did not foresee, there may also be other practical implications related to the redispatch market, which will be discussed.

The difficulty of starting a new market – redispatch via GOPACS – where other quite similar markets exist, is the fact that no potential participant sees a need to participate in the redispatch market. Suppliers can already sell their electricity to a variety of different markets. Besides, since there currently is not much supply to the redispatch, it is hard to make a business case. The redispatch prices are still uncertain (Duijnmayer, 2019c), congestion probabilities differ per location and there are other uncertain dynamics in the market. For instance the probability of a partial settlement is not entirely certain; even though TenneT expects this probability to be low, this cannot be stated with certainty. Many potential suppliers are waiting for something to happen in order to see how the market dynamics will be. The wait-and-see approach is even scientifically prescribed to investors, if there is too much uncertainty regarding potential benefits (Stokey, 2016). TenneT should try to break this cycle by reducing uncertainty.

The fact that a fine will be given if a settled bid is not delivered, appears to withhold participants. TenneT may therefore consider to abolish the fine for the following months in order to attract more supply to the redispatch market, to break the 'wait-and-see' cycle.

A thought that may come to mind is why TenneT and DSOs would not invest in balancing units to start supplying to the redispatch market themselves. However, this has been made impossible due to the unbundling of generation companies from the system operators. This has been arranged via the Third Energy Package of the European Union (2009).

Besides looking at the current situation, it is also interesting to discuss the impact of (potential) future developments. Sources that can deliver flexibility are CHPs, power-to-heat plants, heat boilers or batteries (storage). The fuel for CHPs, heat boilers and power to heat plants is gas. The Netherlands have set a target to reduce CO_2-emissions by 80% in 2050, as compared to 1990 (Rijksoverheid, 2018). In order to reach this target, less gas will be used or regular gas will be replaced for biogas. As explained, currently a large part of the greenhouses use a CHP to produce the electricity, heat and CO_2 needed for their crops. This will in the future likely be exchanged for a heat production using thermal heat. Greenhouse growers will then buy electricity and CO_2 from external sources (Hotse Smit, 2018). The question that rises is how useful it is to invest in a properly working redispatch market, while a significant part of the currently potential sources will disappear. However, in a future of a higher penetration of variable renewable energy sources, there will always be some mechanisms needed to balance demand and supply. Otherwise there would be no electricity on days without wind and sun. These balancing mechanisms could be storage units or production units fuelled with biomass or biogas. The question is whether there would remain enough units that can provide flexibility to reach a properly working redispatch market for congestion management.

One may think, why can't TenneT motivate parties to invest in a storage unit that can be used to supply to the redispatch market? As explained in the literature review in Chapter 2, there are two efficiency goals of an electricity market, being short-run efficiency and long-run efficiency. Short-run efficiency means using those resources that are already available. Long-run efficiency on the other hand points to a market providing the right incentives to invest in units to participate in that market. Since the focus of the research is on greenhouse growers who already own a CHP, only short-run efficiency was relevant. However, for judging whether the redispatch market will attract enough supply, it may be valuable to investigate whether the redispatch market adheres to the long-run efficiency target. In other words; does the redispatch market provide incentives to invest in new production units?

Long-run efficiency appears to be the most difficult target to reach in an electricity market (Cramton, 2017). A common way to motivate long-run efficiency in an electricity market is to provide a capacity mechanism for investing in that particular market (De Vries, 2007). However, as appears from the research, a capacity mechanism may increase the probability of inc-dec gaming. Namely by providing capacity to invest in a redispatch unit on a certain location, some location-specific congestion information is revealed. Besides, uncertainty appears to be a barrier that withholds potential investors from investing (Stokey, 2016). Given the fact there always needs to remain a certain level of uncertainty in order, this implies long-run efficiency is hard to reach in the redispatch market.

Another option for managing congestion issues, is by managing the connection capacity. This could mean that some potential electricity users or producers cannot be connected to the grid on a certain location. Another form of managing the connection capacity, would be to restrict the electricity consumption or production of some parties or to forbid parties from expanding. While this could reduce congestion issues and while TenneT also sees this as an option to reduce congestion (See Appendix C), it appears the Dutch law claims this is unfair. Recently, a greenhouse grower who could not expand his connection capacity due to congestion issues went to court, after which the lawyer decided the DSO could not discriminate between greenhouse growers. The result: the connection capacity had to be increased (Van Der Lugt, 2019). This form of congestion management thus appears not to be suitable for The Netherlands.

9.2.2.3 Conflicts between perspectives

From the perspective of a TSO and DSO, the participation in the redispatch market should be enlarged. In general, it can be stated that the larger the participation, the higher the ability to solve congestion with the redispatch market. The only requirements are the flexibility fits the flexibility demanded in the redispatch market (See Section 5.1) and that it can be provided at the right location.

From the perspective of a (potential) participant in a certain market however, a higher supply may not be desirable. Namely, a higher supply will likely suppress prices in a market. The price development on the redispatch market is still uncertain (Duijmayer, 2019), but a larger supply will likely suppress prices. This has an impact on the conclusions of the first part of Chapter 6. Where based on the redispatch costs of 2017, redispatch prices will likely be high enough to 'beat' the opportunity costs and potential monetary losses, the redispatch prices may decrease in the future.

9.3 Reliability and validity of the research

Before presenting the conclusions of the research in Chapter 10, it is important to discuss the reliability and validity of the research. This means, how much value can be put on the conclusions and in which context can they be interpreted? There are certain limitations to the research, that may have influence on the potential interpretation of the results. The limitations of the research scope, data use and methodological choices and the impact of these limitations on the conclusions are explained in this section. The goal of discussing the limitations is to provide an accurate picture about what can or cannot be concluded from this research.

It is decided to discuss the limitations of each of the parts – project scope, data use, methodological choices and uncertainties and assumptions – per limitation, while mentioning which research questions the limitation influences. This way it is clear which results are exactly affected by certain limitations. First, the limitations of the relatively narrow project scope are described in Section 9.3.1. Then, the limitations of the availibility and use of data is discussed in Section 9.3.2. The limitations of methodological choices – if these choices had limitations – are explained in Section 9.3.3. Lastly, a discussion of the impact of certain assumptions will be presented in Section 9.3.4.

9.3.1 Limitations of the project scope

As explained in the previous section (Section 9.2.2), some implications that lie outside the exact research scope can be done based on the research. The exact results of the research can only be interpreted in a limited way. In order to avoid unjust conclusions, the impact of the limitations of the project scope on the results will be given. Namely, this research has been executed for AgroEnergy and its clients, specific. This has multiple consequences for the interpretation of the conclusions.

The specific scope does have an implication for the interpretation of the economic potential of the redispatch market. Namely, the specific way in which the intraday-market is organised for AgroEnergy, leads to greenhouse growers always being certain they can sell of buy from the intraday-market. For greenhouses who are trading on the regular intraday-market, this certainty cannot be given. This may affect the results.

The scope has a slight implication for the interpretation of the conclusions to the third research question. While greenhouse growers will likely have the same values and behavioural motivations, the fact that AgroEnergy calculates and supplies the bids to the redispatch market makes a difference. Namely, as appears from the answer to research question 1, there are technical boundaries which complicate the redispatch bids. If bids are placed wrongly and cannot be delivered, the greenhouse risks a fine. For greenhouse growers who estimate the bids themselves, this may be a large complication – this has not been researched.

Lastly, from Section 9.2.2.2 it follows there may be some potential barriers that are not observed by clients of AgroEnergy, but may be observed by other potential suppliers. It has appeared the behaviour of greenhouse growers can largely be influenced by AgroEnergy. Therefore, greenhouse growers not connected to AgroEnergy may behave differently from the greenhouse growers which have been interviewed.

9.3.2 Limitations on data use

For some research questions, a limited amount of data has been used. The cause and consequences of this limited data use will be explained per data source.

Congestion data

For the congestion data, there is a limitation. The only congestion data available, is the settled 'Reserve volume for other purposes' supplied to Resin, which is the volume TenneT uses for preventing congestion. While this data gives an accurate representation of the congestion on the transmission grids, which has in 2017 and 2018 only been prevented using bids supplied to Resin, this does not include congestion on *distribution* grids. Congestion on distribution grids has been solved with local initiatives, as for instance the 'Smart grid Westland" pilot initiated by Dutch DSO WestlandInfra (Duijnmayer, 2019b). The goal of the GOPACS platform is to be **the** platform for congestion management, both for TSO as for DSOs. Currently, this platform is hardly used, as appears from the trades done on ETPA. TenneT still uses Resin-volume and DSOs still prevent congestion using local initiatives, which implies for now, the use of 'Reserve volume for other purposes' to determine congestion characteristics is suitable.

Even though distribution grids have a lower transport capacity than transmission grids, meaning a lower volume can already cause congestion, no significant impact on the results of research question 1 are expected. Namely, the consequence of this lower capacity is that there will be more redispatch bid settlements of a lower volume. This does not have implications for the results of research question 1. The characteristics of the redispatch market do not change. The minimum bid-size does not change and congestion can be solved using multiple bids. Therefore, a lower average settlement volume does not necessarily imply smaller units (like CHPs) have a higher settlement probability.

There are implications for the second research question. Namely, once DSOs start to actively use redispatch (via GOPACS) as mechanism for congestion management, more congestion will be solved via redispatch. Therefore, the total settlement probability (See Section 5.1.1) will be higher since the accumulated congestion probability (on both distribution and transmission grids) will be higher.

Limited data available for intraday-trades

The second data-limitation consisted of limited data for the intraday-trades. As explained in Chapter 6, the data which has been used for calculating the valuation of the opportunity losses on the intraday-market, was limited to the months in which intraday-trading has been done by AgroEnergy, starting from January 2019 up to the time of use of the data - April 2019. The impact of only having data for four months, on the results of Chapter 6 will be discussed by using the data about the intraday trades on the Dutch EPEX SPOT trading platform. See Figure 41. Even though AgroEnergy does not trade via this platform, but rather trades with Eneco Energy Trade (Section 4.2.1.3), the prices that EET generates will likely be close to the EPEX SPOT prices. The buy prices would not be much higher since then, EET could better use this platform instead of the deals with AgroEnergy. Besides, the buy prices would not be much lower, since that would put off AgroEnergy in this way of intraday trading. Therefore, these prices can be used as comparison.

From Figure 41 it appears the prices from February 2019 to May 2019 are significantly lower than the other months. This implies the average valuation of the selling volume to the intraday-market may be higher than the value which has been found.

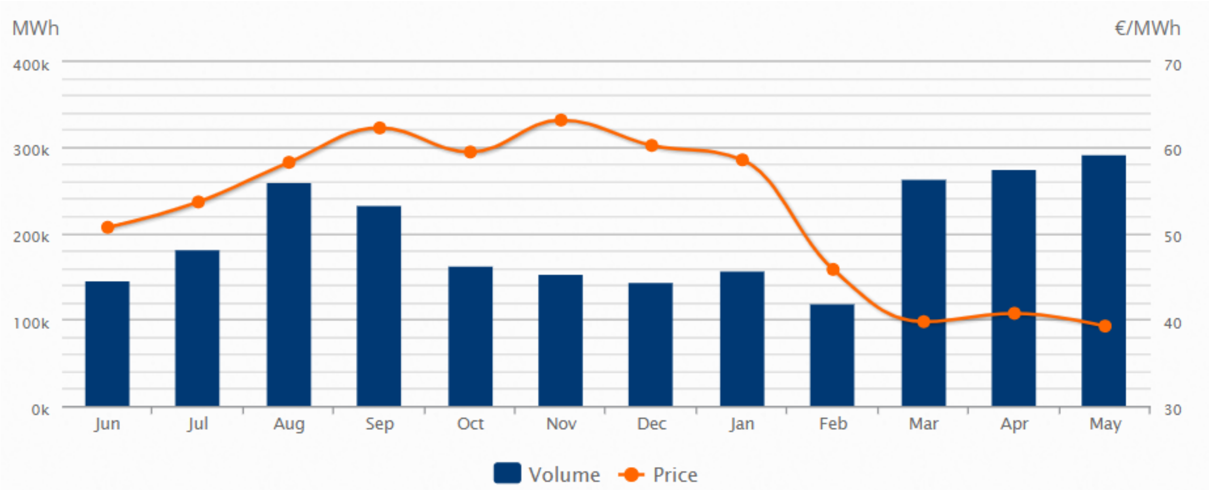


Figure 41: Intraday prices in The Neterlands of the trades on the EPEX SPOT trading platform, starting from June 2018. Source: https://www.apxgroup.com/market-results/apx-power-nl/dashboard/

9.3.3 Limitations on methodological choices

Limitations on the deterministic model for calculating additional monthly revenues

A deterministic model has been developed to calculate the benefits of the redispatch market. This deterministic model was valid for answering the research question. However, a deterministic model implies underlying system relations and input variables are known, while in reality there are often some uncertainties which have a range of possible values, instead of one value. The goal of the research question was to investigate, for the three different types of greenhouse growers, what the potential additional revenues of the redispatch market could be with reasonable input variables.

Since the input variables are uncertain, the outcomes of this deterministic calculation model cannot be literally interpreted. On the other hand, these outcomes give an indication of the potential size of the additional revenues.

Empirical research via interviews

In the current research, a few greenhouse growers have been interviewed. However, since the greenhouses are widely distributed over the country and not easily reachable, not many interviews could have been executed within the given time frame. A way to overcome this, is by sending suveys to greenhouse growers, since this is an easier way to gather more information. However, like people within AgroEnergy acknowledged, greenhouse growers generally prefer talking face to face over writing. Besides, by talking face to face, more information can be gathered. Therefore, there is chosen for quality over quantity.

Another way to overcome this, was by interviewing more greenhouse growers and putting less focus on other aspects in the research. However, since the greenhouse growers had quite similar opinions, it felt more valuable to add more aspects to the research rather than to interview more greenhouse growers.

Validating the proposed market design

In Chapter 8, those market design aspects that influence the potential supply of electricity by greenhouse growers to the redispatch market, are explained. These changes in the market design are proposed based on a qualitative comparison between characteristics of greenhouse growers and characteristics of the redispatch market. Due to the limited time for this research, the proposed changes in the market design have not yet been validated. There are multiple ways in which this could be done. Some of the potential ways will be discussed.

When proposing a certain design, it is expected for the design artefacts to be tested in the environment (Hevner, 2007). One way to do this is by testing the design in a real world case. This could be done in a pilot project, where multiple suppliers participate in a pilot testing a certain market design. The objective of a pilot study is usually to explore behaviour to eventually achieve a certain objective (Saele & Grande, 2011). Potential participants need to be contacted, which could be done with for instance a news letter or a personal visit. Besides, a certain area where the pilot will be executed needs to be picked. Since this research is not executed at a TSO or DSO, first a cooperation with TenneT or one of the DSOs needs to be established. Usually, a pilot lasts a few months to a year (Saele & Grande, 2011). So this option is very time intensive.

A different method to validate a certain design artefact is by developing a simulation model, in which the behaviour of parties in a certain environment can be simulated. Since an electricity market is fairly complex, a flexible modelling technique is needed in which market dynamics can be shown. Traders often supply to multiple markets at the simultaneously, which complicates their strategies. These dynamics need to be captured in the simulation model. One example of a simulation model that can capture these dynamics and can thus be used to validate a market design is an agent-based simulation model (Weidlich & Veit, 2008). An example of a language in which an agent-based simulation model can be developed is Netlogo (Tisue & Wilensky, 2004). In an agent-based simulation model, agents' actions in a certain market should be made clear. A large variety of agents with different actions can be added to an agent-based model, which allows for taking different strategies into account. The model can be run over time, in which a certain behaviour pattern may evolve. By comparing the expected behaviour as described in Chapter 8 to the behaviour visible in the simulation model, a certain expectation can be validated. Since modelling the electricity market is very complex, this would probably be a graduation thesis in itself. Therefore, this has not been done.

9.3.4 Assumptions

Multiple assumptions have been done to be able to answer the research question within the given time frame. The most important assumptions will be explained, together with the impact on the potential interpretability of the results.

Partial settlement

In the current redispatch market, partial settlement of a redispatch bid (with regards to volume) is theorethically possible. However, it is assumed this probability is 0% since the to be solved congestion typically has significantly higher volume than the volume a CHP can deliver. This assumption is explained in Section 4.4. This fact is acknowledged in an interview with Glismann (2019). As explained in Section 9.3.2, distribution grids have a lower capacity meaning a lower volume can already cause congestion. This implies there will be more settlements of a lower volume, which increases the probability of partial settlement for a CHP. Therefore, assuming this probability is 0% may not be valid in the future. If e.g. the partial-load volume of a CHP is 1,7 MW, while the size of the settled bid is 1 MW, the CHP owner has to sell 700 kW on either intraday of the passive imbalance market, where prices can be lower than on the redispatch market. Future research can focus on investigating the impact of a (potential) partial settlement.

Grouping of greenhouse growers

In order to calculate the opportunity losses on the competing markets– the intraday market and the passive imbalance market – for answering research question 2, greenhouse growers have been grouped based on the crops they grow. Since currently no greenhouse growers at AgroEnergy supply to both the intraday-market and the redispatch market, a tomato grower in the redispatch pilot has been 'matched' to a tomato grower participating in the intraday-market. These together form the group 'tomato growers'.

A distinction of three types of greenhouse growers has been made, where one group has no lighting needs, one group has lighting needs and the third has intensive lighting needs. Besides, heating needs are crop specific. As appears from Chapter 5, the flexibility a greenhouse can offer is mainly influenced by lighting and heating needs, which are crop-specific. For these reasons, this grouping has been done. However by doing this, the underlying assumption is each greenhouse grower within a certain group follows the same strategy. In reality, each person is to some extent risk-avers or risk-loving, which can show in their behaviour in the electricity market. A more risk-loving greenhouse grower could for instance be more active on the passive imbalance market (with highly fluctuating prices), where a more risk-averse greenhouse grower may prefer the more stable intraday-market. In order to even out the impact of a potential strategy, more greenhouse growers should be grouped. This would make the differences between the groups more based on technical aspects, rather than (potentially) on strategy, too. Due to limited data – a limited amount of participants in the redispatch pilot and in the intraday-market – this was not possible.

Chapter 10: Conclusion and recommendations

The goal of this research was to give an answer to the main research question:

How will the redispatch market be judged from the perspective of a greenhouse grower as electricity supplier and what may be done to change this judgement?

This research question is subdivided into four sub-questions, which are established based on the knowledge gaps that followed from the literature review. The answer to each of these questions will be given separately in Section 10.1, after which these separate answers will be bundled to give an answer to the main question presented in Section 10.2. At the end of each of the chapters 5 to 8, the research sub question central in that particular chapter has been answered. In the discussion it has been explained how these results can or cannot be interpreted, based on a comparison of the results to literature, limitations of the scope, used data, methods and uncertainties. The relevant aspects of the discussion will be taken into account when answering the research questions.

This chapter concludes with a recommendations section, Section 10.3, in which the findings together with the implications - taking the reliability and validity of the research into account - will be translated in an advice as to how to use the research and which actions should be undertaken, based on the research. These recommendations will be given for AgroEnergy and its clients (Section 10.3.1) and the TSO and DSOs (Section 10.3.2) separately. Lastly, recommendations for further research will be given in Section 10.3.3 Further research can be done to increase the reliability or validity of the research or to investigate identified relevant areas.

10.1 Answer to the research sub questions

1. **What are the technical characteristics of a greenhouse, determining the potential of different types of greenhouses in the redispatch market, under different circumstances?**

First, the technical potential to supply to the redispatch market, under the current design of the redispatch market is investigated. This part of the research has addressed the knowledge gap 1: *The redispatch market has only recently been opened up to smaller suppliers like greenhouses with a CHP. It is the question whether the flexibility needed in the redispatch market, matches the flexibility that can (technically) be supplied by greenhouses with a CHP.* Based on data-analysis and by identifying relevant characteristics of the redispatch market, the flexibility demanded in the redispatch market is qualitatively compared to the potential flexibility that can be supplied by greenhouse growers.

From the analysis it follows, with the current characteristics and knowledge of the greenhouse market and given the technical characteristics, greenhouses do have a potential as supplier of congestion management volume to the redispatch market. There are no technical characteristics witholding greenhouses from the possibility to supply to the redispatch market.

Flexibility aspects	Present in greenhouse	Needed in redispatch market
Time specificity	Most flexibility in the transition months, mostly during the morning (before APX) or afternoon (after APX).	Most congestion occurs between 9:00 and 19:00, but congestion can occur during any hour.
Change in time: capacity	Average value of 1 CHP is 2 MW. The total capacity of the redispatch pilot greenhouses differs from 6 to 20 MW.	All congestion volumes are needed. The minimum bid-size is 0,5 MW.
Duration	Duration is at least 1 hour, at maximum (averagely) 5 hours.	The most occuring congestion had a duration of 1, 2, and 4 hours.

Lead time	A few minutes.	Most congestion management happens the day before delivery.
Location	Distributed over the whole country, but there are specific regions where greenhouses are concentraded.	Congestion management is needed in the whole country; in non-congested areas, upward regulation redispatch volume is needed.

2. **Under what circumstances can the redispatch market be an added value to the portfolio of greenhouses, given their technical characteristics and behaviour in other markets?**

The second research question focussed on the value of the redispatch market as compared to opportunities. Namely, in order for greenhouse growers to supply to the redispatch market, there must be a financial potential to earn an additional revenue from the redispatch market. This second part of the research addressed knowledge gap 2: *Given the fact that the redispatch market is a market where parties can voluntary supply to and given there are alternative markets where electricity can be sold, it is the question whether it would be rational to supply to the redispatch market.* In order to fill this knowledge gap, a deterministic model has been developed. In order to completely answer this research question, it is split up into two parts. In the first part, it is calculated what the average redispatch market price should be, in order to add value to the current portfolio of electricity markets. The intraday-market and the passive imbalance market have appeared to be the two directly competing markets. Based on the potential opportunity losses on these markets, the needed redispatch price has been calculated. Using the data provided by TenneT about the redispatch costs in 2017, it appears these needed prices will likely be reached. This implies the redispatch market can be an added value to greenhouse growers.

For the second part of the research question, a deterministic model has been developed to calculate the potential (average) additional earnings of a certain greenhouse in a certain month. As explained in the discussion, these results cannot be interpreted literally, but can rather be used to give an indication of the potential additional monthly earnings. From the analysis it appears these potential earnings can be reasonably high. Even though the pricing and the exact congestion scenarios are an uncertainty, it is likely the additional earnings will be reasonable, as appears from the sensitivity analysis.

It appears the potential additional revenues of the redispatch market are dependent on the settlement probability. If market messages as shown in Section 5.1.1 are being updated more regularly by the system operators, it is advisory to implement these market messages into the optimization model of the redispatch bids. Secondly, it appears a higher failure probability of a CHP significantly decreases additional revenues.

3. **How do socio-economical characteristics influence the willingness to participate in the redispatch market?**

The third research question focussed on the socio-economical (or: behavioural) willingness to participate in the redispatch market. Namely, while neoclassical theory suggests individuals will always do an action if this action (rationally) provides additional profits, it appears there are underlying factors influencing behaviour. Knowledge gap 3 is addressed in this section: *It is clear that individuals often behave differently than rational. There are certain behavioural aspects that may lead to non-rational behaviour. It is yet unknown how certain behavioural aspects are influencing the behaviour of greenhouse growers as potential suppliers to the redispatch market.*

As appears from the research, *before* greenhouse growers participate in the redispatch market, certain behavioural aspects play a role in this decision to participate. Greenhouses are mainly motivated by monetary rewards. The less uncertainty about the monetary rewards, the more willingness to participate in the redispatch pilot; the uncertain revenues in the redispatch market are for some greenhouse growers a reason to not supply to the redispatch market. A potential loss, as is present in the form of the fine in the redispatch market, has in similar cases led to no supply to a certain market at all. Besides, pro-environmental behaviour does not appear to play a role in the decision to participate in the redispatch market. As initially suggested by TenneT - Help speed up the energy transition – (GOPACS meeting, 2019), greenhouse growers would not supply to the redispatch market following environmental considerations.

Greenhouse growers feel the system operator needs to solve congestion and therefore do not feel personally responsible for solving congestion. Descriptive norms – a feeling your actions should not differ too much from the actions of other greenhouses – do play a role; greenhouses sometimes meet with other greenhouses to discuss (electricity-related) strategies. This can both be a disadvantage as an advantage. Now the supply to the redispatch market is still low, greenhouse growers might not want to be the one following a different strategy. However, if more parties start to supply to the redispatch market and indeed earn from it, other parties will likely copy this behaviour. Besides it appears, AgroEnergy can play a role in advising to change a strategy, which has appeared to be more influential than the strategy of colleagues. It appears greenhouse growers trust AgroEnergy regarding this issue.

When greenhouse growers are already participating in the redispatch market, they behave nearly rational. Namely, AgroEnergy uses an optimization model in which, given all information available, optimal bids are calculated. Within certain uncertain boundaries, this behaviour is rational. The only more irrational aspect appears to be the risk for a fine. During an interview it appeared a supplier was participating in a certain electricity market, but stopped doing so after he got a fine.

4. **How can the participation of greenhouse growers in the redispatch market be enlarged?**

The last research question is related to the market design of the redispatch market, given the technical characteristics, economic profitability and willingness to supply to the redispatch market. The knowledge gap that was central in this part is: *TSO and DSOs want to enlarge supply to the redispatch market. There are certain aspects of the market design that may be changed in order to reach a higher potential participation of greenhouse growers. Based on the technical characteristics of a greenhouse grower (knowledge gap 1), based on the potential earnings of a greenhouse grower in the redispatch market (knowledge gap 2) and based on the barriers greenhouse growers experience with the redispatch market (knowledge gap 3), it needs to be investigated which aspects of the design can be changed.*

From the previous sections, it appears there are certain aspects of the redispatch market that may oppose parties from being able to, or wanting to supply. Certain changes in the design of the redispatch market might overcome these barriers. In order to reduce the risk of a failing CHP and thus a settled bid which will not be delivered, TenneT can consider to change the administrative aspects, to allow for a back-up CHP that can provide electricity if a certain CHP is failing while it has to deliver. This will likely increase the willingness supply to the redispatch market, since it has appeared fines may withold some greenhouses from supplying to a certain market.

The minimum bid-size could be reconsidered and be made smaller. This way, greenhouses can deliver partially to one market and partially to another market, which may increase the total supply to the redispatch market. Another valuable addition would be to add the opportunity of conditional bids to the redispatch market. This enlarges supply as wel as increases probability a single supplier can sell to the redispatch market, thus making the redispatch market more profitable for a single supplier.

In a broader context, it is advisory to change the current pricing mechanism – pay-as-bid – into a marginal pricing auction. From research, it appeared this form of pricing is easier for new entrants. With a pay-as-bid auction, it is hard to estimate a good price in a market like the redispatch market, with low price transparency. For greenhouse growers connected to AgroEnergy, this barrier does not occur, since AgroEnergy places the bids for its clients.

10.2 Answer to the main research question

The sub-questions together give an answer to the main research question:

How will the redispatch market be judged from the perspective of a greenhouse grower as electricity supplier and what may be done to change this judgement?

From the research, it appears greenhouses currently are in the ability to supply electricity to the redispatch market. Besides, it appears the redispatch market can be an added value to the electricity portfolio of greenhouse growers. Therefore, for AgroEnergy, it is advisory to focus on the redispatch market: money can be earned from supplying to the redispatch market. However, greenhouse growers need to be motivated to participate, too. Greenhouse growers appear to be mainly motivated by monetary rewards and tend to be very careful when a potential fine can be gotten, like in the redispatch market. The proposed changes in the redispatch market, can increase the willingness of greenhouse growers to supply to the redispatch market. AgroEnergy needs to propose these changes to TenneT, in order for the redispatch market to be more profitable for greenhouse growers. For TenneT, this increases supply to the redispatch market. For AgroEnergy, this is an additional revenue they can generate for greenhouse growers.

10.3 Recommendations

Based on this discussion and the results, multiple recommendations can be done. The most important recommandations that follow from this research, are given in a set of three: recommendations for AgroEnergy and greenhouse growers (Section 10.3.1), recommendations for DSOs and TSO (Section 10.3.2) and lastly, recommendations for future research (Section 10.3.3). These final recommendations for future research are meant to explain how the conclusions can be stated with more certainty.

10.3.1 Recommendations for AgroEnergy and greenhouse growers

For AgroEnergy and the greenhouse growers, it appears the redispatch market may likely provide a significant additional revenue. It is important to keep an eye on the development of the redispatch market. The development of the pricing in the redispatch market is yet uncertain, but it is expected redispatch prices will decrease if a larger amount of suppliers starts to participate.

In general, it is recommended to before entering a new market, carefully investigate the potential risks. From this analysis it appeared there are some risks which are not so clearly visible. In order to avoid unpleasant surprises and a reduced trustworthiness, the risks need to be investigated beforehand. If changes in the market design seem possible, as is the case in the redispatch market, it is important to discuss these potential changes with the system operators.

10.3.2 Recommendations for DSOs and TSO

The overarching question of this research is whether redispatch should be the mechanism to solve congestion, now and in the future. As described in the introduction, the congestion management needs will increase in the future – from today until 2050, the flexibility needs increase significantly.

Even though today's flexibility sources are mostly fuelled with gas, there will always be balancing sources needed. This suggests that also in the future, there will be a potential supply to the redispatch market.

DSOs and TSO will need to actively increase supply to the redispatch market. An important finding of this research and discussion, is the fact that potential participants in the redispatch market may see barriers that are not noticed by TenneT. Therefore, it is recommended to map the potential sources of flexibility to investigate if there are certain specific barriers withholding them from participating. Since the market design is not entirely fixed yet, some of those aspects may be changed if this enlarges supply. Besides it appeared that some potential suppliers are not even aware of the existence of the redispatch market. It is recommended to try to more actively attract potential suppliers. Besides, since the fine may be a significant barrier to start participating, it is advisory to not give a fine for a while, until a higher supply is reached.

10.3.3 Recommendations for future research

In this section, the recommendations for future research will be given. These recommendations follow from two sections in the discussion. First, from the discussion of the theorethical implications, a few interesting research suggestions follow. Besides, as appears from Section 9.3, there are multiple limitations of the research which reduce the reliability and validity. Based on these two elements of the discussion, there are multiple recommendations for future research, which are explained below.

Future research 1: Role of facilitator

As appears from the research and the discussion of the theorethical implications, a facilitator seems to influence more factors than only the perceived difficulty. It may be interesting to investigate which aspects can be influenced by a facilitator and to what extent these aspects then lead to a higher intention to perform behaviour. This could form a substantiated addition to the theory of planned behaviour.

Future research 2: Focus on the intraday-market

A more precise intraday-valuation combined with the redispatch market trades could be calculated. In this research, an average intraday-valuation has been used. It can be investigated whether the intraday-valuation can be estimated more precisely, based on different aspects (e.g. time on the day, month, weather). Then, a more specific advise could be given, as to when supplying to the redispatch market is better than supplying to the intraday-market.

Future research 3: Focus on the imbalance market

A more precise valuation of the passive imbalance market combined with the redispatch market trades could be calculated. In this research, an average passive imabalance market-valuation has been used. It can be investigated whether the imbalance-valuation can be estimated more precisely, based on different aspects (e.g. time on the day, month, weather) a more specific advise could be given, as to when supplying to the redispatch market is better than supplying to the imbalance-market.

Future research 4: Focus on multiple possible designs and validating these

While in this thesis, the design of the redispatch market in its current form has been used to calculate neoclassical benefits, the benefits of different designs can be investigated. For instance, the monetary benefits of a design where pooling is allowed, can be investigated as compared to the current design. As explained, in such a 'pooling' design, risks of a fine are lower, but total supply to the redispatch market is lower, too. Those market designs may be validated as described in Section 9.3.3, by for instance doing a pilot study or developing a simulation model.

Future research 5: Investigate impact of partial settlement

As indicated by TenneT (2019), the probability of a partial settlement is very low. Therefore, the (monetary) impact of partial settlement is not taken into account in this research. Since a CHP offers a (relatively) low volume, the probability that only part of that already low volume will be used, is very low, is the expectation. However, since the market has only just been opened up to small suppliers, there is no experience yet with this (probability) of partial settlement; it is possible this probability is larger than expected. Besides, when DSOs start to actively use GOPACS for solving congestion, the congestion volumes are smaller since DSO congestion problems are smaller. This may increase the probability of partial settlement. A further research could focus on different scenarios of partial settlement, and the impact of different scenarios.

Chapter 11: Reflection

In this final chapter, a reflection on the research and the research process will be given. First in Section 11.1, a reflection on the societal relevance will be given. Namely, it is important the research adds value to society and can also practically be used. Secondly in Section 11.2, there is reflected upon the academic relevance of the research. Since this research has been executed to finish the master programme of Engineering and Policy Analysis (EPA), a reflection of the link between the research and the master programme is presented in Section 11.3. Lastly, a personal reflection on the graduation process in combination with the internship at AgroEnergy will be given in Section 11.4.

11.1 Societal relevance

Namely, electrification in the Dutch process industry could significantly contribute to reaching the set climate goals (Afman, Croezen, Jaspers & van Lieshout, 2017), since as explained in the introduction, climate change is amongst others caused by CO_2-emissions that occur when fossil fuels are burned. If the electricity is generated via renewable sources, a full electrification of the Dutch process industry could lead to almost zero CO_2-emissions.

There are multiple electrification movements leading to challenges for the electricity grid. For example, the Dutch government has decided that by 2030, all new cars should not emit any pollutants like CO_2 (Regeerakkoord, section 3.2, 2019). This means cars fuelled with fossil energy sources will be replaced by electric cars in the near future, intensifying the electricity demand and the demand peaks. Another example is the increase in decentral generation using solar panels, which also puts pressure on the electricity grid. So in order to enable the energy transition to tackle the grand challenge 'climate change', the electricity system needs to change drastically. A properly functioning market for congestion management is needed to tackle the increased issues with transport capacity.

Congestion on the electricity grid is, as explained, expected to increase significantly with an increased share of renewable energy production. As acknowledged by TenneT (2019), the capacity of the electricity grid cannot increase fast enough to deal with the planned increase of renewables, confirming the needed increase of supply to the redispatch market. Delaying the energy transition is not an option: in order to reach the climate targets, The Netherlands need to start reducing CO_2-emissions now. However, it appears some solar energy parks cannot be connected to the grid due to congestion issues. Congestion management needs to improve as fast as possible.

As appears from the research, greenhouses have a technical potential to supply to the redispatch market. Besides, since greenhouses are distributed over the country and can (together) offer quite a large volume, they may considerably contribute to solving congestion. For the system operator, it is important to know what may withhold greenhouse growers from participating in the redispatch market and how to overcome potential barriers. The goals of an electricity market need to be taken into account, in order to ensure that a certain design aspect cannot cause inefficiencies to happen.

11.2 Academic relevance

This research is mainly due to the fact that the research is executed as an internship, practically relevant. Since the thesis is an academic research to graduate from university, it is important to reflect on the academical relevance. What is the contribution of this research, to already existing research?

The redispatch market as it is developed in The Netherlands is unique. Besides, since the redispatch market has only recently been opened up to smaller suppliers, it is a new research domain to investigate the technical potential of these smaller suppliers. While the potential of a CHP to provide flexibility had already been investigated, this has not been linked to the redispatch market yet. This research tried to observe the redispatch market through multiple lenses, where technical and economical aspects of the redispatch market are considered. Next to this, potential participants may observe a market from a less rational perspective, which has also been taken into account. This has allowed for getting a full picture of the redispatch market from the view point of a greenhouse grower. A large part of the research is dedicated to the impact of the redispatch market being 'one of many' choices, while mostly research only focusses on one market as if it exists in a vacuum. A synthesis of qualitative (using existing theories and empirical research) and quantitative research (data-analysis and modelling) was needed to obtain this full picture.

New insights regarding different theories have been found (Section 9.2.1), insights regarding potential causes for behaviour of parties in electricity markets have been obtained and based on this, multiple potential improvements for the design of a market like the redispatch market have been found, when considering this design in the bigger picture of the whole Dutch electricity market.

11.3 Link to master programme of EPA

This thesis has been written to complete the Master of Science Engineering & Policy Analysis. The goal of the master programme is to use multiple modelling and analytical techniques to support decision-making. In this research, a variety of these techniques has been used to get a deeper understanding of the situation in order to give a scientifically relevant answer to the research questions. Qualitative research by doing interviews with multiple stakeholders based on multiple theories has been complemented with quantitative research: data analysis and modeling. The research supports decision-making for greenhouse growers and AgroEnergy, as to whether the redispatch market deserves the attention and should be a market to participate in. Moreover, this knowledge is useful for TSO and DSO in the decision-making process of how to shape congestion management in the future.

The overarching focus of the EPA programme is on processes where technology and society meet. These complex processes can be described using the term 'international grand challenges'. This is an umbrella term for challenges in the world, that are complex and require great knowledge to be solved (Cagnin, Amantatidou & Keenan, 2012). Examples of grand challenges are terrorism, famine, floods or climate change. This research tackles an important aspect of one of those grand challenges: climate change. As explained, a good functioning market for congestion management can contribute to speeding up the energy transition and tackle climate change.

11.4 Personal reflection on the thesis and internship at AgroEnergy

Now you have finally made it to the end of this Master thesis, I would like to speak some personal words with regards to the process of writing the thesis. I feel very lucky to have been able to carry out my graduation process as an internship at AgroEnergy. I have executed my BSc graduation with a company and when I started my Master, I knew I preferred to do my MSc graduation process at a company as well. My main interest during my bachelor was in the direction of energy & industry so I was very lucky to find a corresponding internship.

It was very interesting to work in a very innovative company for a few months. I am intrigued by the speed with which new products are developed and decisions are made. Here, I noticed a quite clear contrast to university, where it's more about doing research and less about implementing the results of the research. I feel privileged to have been one of the 'redispatch-pilot' team-members. This was also one of the main reasons to have a preference for an intership, as compared to performing an own research: the practical aspects of an internship.

The intership allowed me to learn a lot of things I hadn't learned yet on university. As an employee of AgroEnergy, I could participate in 'real' meetings in which 'real' decisions were taken. Being present at for instance the GOPACS information session, or the meeting with TenneT about the (potential) contribution of greenhouses in the redispatch market, were very interesting. Accurate knowledge was shared in these meetings – knowledge which I otherwise hadn't gathered.

Each person at AgroEnergy is very good at its own job. Luckily, the open culture in AgroEnergy made every person approachable for a meeting or for a quick brainstorm. In the beginning, I sometimes felt a bit embarrased to ask questions because I was afraid to ask a stupid question. After a while I found everyone was very helpful and that most of the time, my questions weren't that stupid. This is something I have definitely learned from the internship; do not waste too much time on something that someone else can tell you in one minute.

I am very glad I got the opportunity to work in AgroEnergy for a few months. The internship has definitely confirmed the fact that I want to continue working in the energy sector!

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Appendix

Appendix A: Interview design - interviews with greenhouses

Interviews with different greenhouse growers are performed. The results of these interviews are presented in Chapter 5. As explained in section 2.5, interview protocols can help an interviewer to structure the interviews and to this way ensure getting the most out of the interviews.

Appendix A.1: Introduction

In the introduction, the goal of the research and the use of the interview in the research will be explained. I will introduce myself and my study direction. Important is to explain the current design of the redispatch market, to ensure the greenhouse grower knows what the interview exactly is about. The development of the redispatch pilot which will be performed by AgroEnergy will be explained to the greenhouse growers participating in the pilot. The weekly data report the greenhouse growers will receive will be shown.

Appendix A.2: Interview questions

The type of interview that will be held is a semi-structured interview. The main goal of a semi-structured interview is to explore similarities and differences between different interviewees (McLaughlin, 2006). The questions are mainly open-ended or partially closed-ended. The interviews are subdivided into the social and economical part.

1) Subjective norm
2) Attitude toward behaviour
3) Perceived behaviour control
4) Facilitating factors

Attitude toward behaviour

- What would be your consideration to offer capacity to the redispatch market?

- What is your feeling with all the newly emerging markets, like redispatch, intraday, tertiary reserve volume? Do you feel like you have an overview of all the markets and the potential benefits of each?

- If you were certain the redispatch market could only provide revenues, would you be willing to supply to it?

- What is your vision upon the possible monetary risks (associated with the redispatch market)?

- What would enlarge your willingness to offer capacity to the redispatch market?

Subjective norm

- Do you feel like you should contribute to the bigger problem of congestion? And do you feel *greenhouse growers* should be the ones solving congestion?

- Would you be more willing to contribute to a local congestion issue as compared to a national congestion issue?

- Do you feel like you should consider the strategy of other greenhouse growers for determining your own strategy?

- Do you feel any environmental considerations for participating in the redispatch market?

Perceived behaviour control

- Behaviour of people is strongly influenced by their perceived ability to perform it – do they think they are able to change something in their current electricity pattern?

- Do they feel like they know the electricity market well enough to earn more money from it, by supplying to the market for congestion management?

- Which technical barriers do you see that may oppose you from participating in the redispatch market for congestion management?

- Are you willing to invest time in changing their habits when there are new/upcoming markets?

Facilitating factors

- Do you trust AgroEnergy in making the right decisions concerning your electricity supply?

- Would you be willing to supply to the market for congestion management, if it doesn't cost any time and effort and if AgroEnergy can assure a positive payoff?

Appendix A.3: Conclusion

The interview will be concluded by thanking the interviewee for his/her time. After the interview, a summary of the interview will be written, which will be sent to the interviewee. Only if he/she has given permission this information is correct, the information will be used.

Appendix B. Interviews with greenhouse growers

During the interviews, the questions as given in Appendix A were asked. A summary of the interviews is given in this appendix.

Appendix B.1 Summary of interview with greenhouse grower 1

Crops: Tomatoes

This greenhouse grower is located in an area where multiple large greenhouse companies are connected via one connection (EAN) to the electricity grid. Since their own grid network has a limited capacity, this allows for pooling. However, it appears the greenhouse growers in the network do not always 'help each other' if a CHP is failing. Namely, this greenhouse grower also participates in the market for tertiary reserve volume. Here, he already got a fine twice. The greenhouse grower stated 'After I got this fine twice, I decided to not participate in the market for upward tertiary reserve volume'. Once, he forgot to turn on the CHP in time and once, the CHP had an unexpected failure. When asking if neighbours would back-up for each other if a CHP is failing, he answered they didn't.

Energy is just a 'by-product' of his business. His business is growing crops. He states that his crops are very sensitive to the just lighting, CO2 and heating, which is why he is reluctant with changing his energy strategy. This greenhouse grower also acknowledges he sometimes anticipates on the passive imbalance prices – when supplying to the redispatch market, there will be less freedom to do so.

This greenhouse grower claims not to be influenced by his colleages. Once there is a potentially interesting market, he is willing to invest time in it. What became clear however is the fact that this greenhouse grower did not know there was an ability to supply to the redispatch market at all.

This greenhouse grower would be willing to participate in the redispatch market, but he prefers to supply buy-bids instead of sell-bids, since then there is no risk for a fine. Namely, a buy-bid means an offtake of electricity, for which this greenhouse grower can just put on additional lighting or turn off a CHP (as also explained in Section 5.2.2). Lastly, this greenhouse grower states he needs a monetary stimulance for turning off a CHP (with supplying a buy-bid) since he needs CO_2; a CO_2-tank is not free.

Appendix B.2 Summary of interview with greenhouse grower 2

Crops: Lillies

For this greenhouse grower, it was not enitrely clear how the redispatch market is exactly organized since it is such a new market. He for instance did not realize the redispatch market could contribute to the energy transition. This greenhouse grower does not feel like it's his responsibility to solve congestion; the system operators need to do that.

The greenhouse grower does, when supplying to the redispatch market, only considers his own potential earnings. Environmental considerations do not play a role. Also if there was congestion in the greenhouse growers own region, he would not be more willing or feel any pressure of neighbours to contribute to solving this congestion. Besides, this greenhouse grower acknowledges he trusts AgroEnergy in making the right decisions with regards to the redispatch bids. He says he is indifferent about the type of pricing mechanism, mainly because he does not think there would be much differences for his earnings.

This greenhouse grower already decided to participate in the redispatch pilot. His motivations for this were mainly to get more experience with the potential of the redispatch market. He does see some risks though. He mainly points to the risk for a fine, due to failure of the CHP, failure of the steering box or a fine due to one of his employees forgot to turn on the CHP. This last issue sometimes happens in the company of this greenhouse grower. This would be a larger issue if there could be a fine involved. However, despite those risks, this greenhouse grower still wants to see the potential of the redispatch market.

Appendix B.3: Summary of interview with greenhouse grower 3

Crops: peppers

This greenhouse grower did not have any experience with congestion (management). Besides, he did not know about the existence of the redispatch market. This points to bounded rationality due to choice overload.

This greenhouse grower, like the other two, also ackowledges the fact that the considerations to (not) participate in a market are purely financial. He does not have any other motivations, such as environmental motivations or the personal feeling to contribute to solving congestion. As he states ‘you don’t buy a CHP to help others, you buy a CHP because you want to earn from it’. Given the fact that the failure rate of the CHP of this greenhouse grower is relatively large, the greenhouse grower is reluctant about participating in the redispatch market, after I told about the existence of the fine for non-delivery.

This greenhouse grower claims to not be influenced by behaviour of others; he follows the advice of AgroEnergy regarding which markets would be an addition to his portfolio. After the interview, the greenhouse grower still had some questions about the intraday market (in which he participates). This greenhouse grower had negative feelings about the intraday market, since he had observed high passive imbalance prices on some moments, where he now supplied to the intraday market. He felt like he had missed an opportunity to supply to the passive imbalance market. While for those moments, this feeling was true (the passive imbalance price was indeed higher than the intraday price at that time), a calculation made by AgroEnergy could show the particular greenhouse grower had gained a lot of money from participating in the intraday market. When the greenhouse grower was made aware of this fact, he suddenly had a positive feeling about the intraday market again.

Appendix C: Interview with TSO

To judge the probability of a certain proposed design (as shown in 5.4), interviews with a responsible person working at TenneT are executed.

C.1 Interview with Samuel Glismann – TenneT 20-3-2019

This interview was executed via the telephone with Samuel Glismann. Samuel Glismann is a policy advisor of TenneT and is involved with congestion management and the development of the new market for redispatch, using IDCONS.

Translation of the relevant aspects

1. Why are you going this way with redispatch? Do you also consider other mechanisms for congestion management?

Redispatch is not the only mechanism. Capacity allocation, or using international systems where we use the international market to prevent congestion. European legislation states we need to be independent in the future, which is why a properly function national congestion management system is needed.

Besides, capacity management is possible. However, currently there is the freedom of dispatch; every unit needs to get the ability to be connected to the grid. Lastly, Glismann ackowledge TenneT does not discriminate between the suppliers; any unit could participate in the redispatch market. Whether it's a storage unit or a greenhouse grower with CHP.

From the vision of TenneT, the redispatch market is an additional earning opportunity for greenhouse growers. For AgroEnergy, this is not entirely true; there are opportunity losses and monetary losses involved with supplying to the redispatch market. While for AgroEnergy, there is no significant difference between Resin and GOPACS, Glismann suggests TenneT prefers to see parties bidding to GOPACS.

2. In which circumstances would you consider a capacity market?

TenneT does not consider a capacity market, since this would lead to wrong incentives. Namely, providing capacity payments leads to location specific information regarding congestion. This enables inc-dec gaming or locational market power.

3. Can parties connected to the distribution grid also supply to Resin? (the market for solving congestion on the transmission grid)

No, congestion on the transmission grid can be solved using bids from parties connected to the distribution grid. However, in the future, this may change. Namely, GOPACS is meant to ensure congestion management by the TSO does not cause congestion on the distribution grids. If parties connected to the distribution grid supply to Resin, this cannot be monitored.

4. Is GOPACS already in use?

Yes, but there is not much supply yet.

5. What is your vision upon the information provision using market messages?

Market messages will always be sent only *after* the day-ahead settlement has taken place, in order to avoid changing day-ahead positions based on congestion predictions. However, the market messages are not automated yet; development in these messages will likely take two years.

At this moment, market messages are sent out only when there is a problem; if TenneT does not have enough volume available to solve predicted congestion.

6. Will partial volume settlement remain?

Yes, this will probably remain due to the optimizations built into the system of congestion management. Besides, balancing an illiquid market with all-or-none orders is almost impossible. There are many blocks needed in order to solve congestion and to not create imbalance on the other hand. However, the probability for a partial settlement will be low. This may be larger if DSOs start to actively use GOPACS, since then the congestion problems are smaller in volume. There is a price risk, but the market has to incorporate this risk into its bid-prices.

7. Is there something known about the level of the fine?

Yes, this will likely be equal to the level of the fine for not delivering balancing volume (on e.g. the tertiary reserve market).