

Implementing capacity subscription in the Dutch electricity market

An impact assessment using fundamental analysis

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Abstract

Keywords: Electricity market - Capacity subscription - Renewable energy - Security of supply - Demand response

The production of renewable energy is steadily going up, and as a result of the (almost) zero-marginal cost renewables, the marginal cost based electricity prices go down. While the need for backup generation increases due to the fluctuating availability of renewable energy, the generation units that supply electricity during demand peaks see their income per year drop. This trend could continue to a point where they are mothballed or shut down. As a result, different forms of capacity mechanisms are implemented all over the world, to prevent an increasing amount of blackouts. A capacity subscription market is a capacity mechanism in which consumers make monthly payments, related to the peak demand they want to consume during hours of shortage. Compared to other capacity remuneration mechanisms, this market has the advantage that consumers can choose and pay for their own security of supply. However, a capacity subscription market has not been implemented, and there has been limited scientific research into it. This study aims to give insight into the impact of implementation of a capacity subscription market.

By means of an hourly dispatch model, plant profitability of all electricity generation plants in the Netherlands was estimated. Eight scenarios were used to determine the impact of capacity subscription, varying on the amount of renewable energy production as a result of the weather and the availability of interconnection. The impact of capacity subscription on reliability is positive, meaning there are less hours in a year where the amount of electricity supply is insufficient, and the total amount of unserved energy is lower. The results show that the price for capacity subscription would be around 5-30 €/kW/year. The price per year is dependent on the under- or overinvestment at that time. Because consumers can determine their own security of supply, the risk of underinvestment, black-outs, and thus peak prices is dependent on the risk taking behavior of consumers. While the total long term effect on affordability is unclear, the market is expected to become more efficient, as more demand response decreases the need for back-up generation. The implementation would reward consumer flexibility of consumption and could improve local congestion management.

Therefore, a capacity subscription market is considered suitable to accommodate reliability in a 100% renewable market. However, if capacity subscription would be applied just in the Netherlands, the effect could leak away to neighboring countries. If there are shortages in countries with a high interconnection with the Netherlands, this could result in peak prices regardless of a capacity subscription market. It is therefore advised that either this market should be implemented in all coupled European electricity markets or other measures are taken to prevent peak prices caused by neighboring countries. Further research should look into design measures that could prevent this leaking effect.

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During my time as a student of the bachelor and master programme of TPM, I enjoyed the complex courses the most. I loved doing projects which had multiple disciplines and stakeholders involved. I am therefore very grateful for all the people around me who have allowed me to write my thesis exactly in this context, making it an enjoyable ride.

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List of abbreviations

APX	Amsterdam Power Exchange
BAU	Business as Usual
CAPEX	Capital Expenditures
CM	Capacity Mechanisms
CONE	Cost of new entry
CS	Capacity subscription
DSR	Demand side response
EEU	Expected Energy Unserved
EEX	European Energy Exchange
ENS	Energy not served
ENTSO-E	European Network of Transmission System Operators for Electricity
EOM	Energy Only Market
EPEX	European Power Exchange
ETS	Emission Trading Scheme
FA	Fundamental Analysis
GWh	Gigawatt hour
IHS CERA	Cambridge Energy Research Associates
kWh	Kilowatt hour
LOLE	Loss of Load Expectation
LRMC	Long Run Marginal Cost
MWh	Megawatt hour

NVG	Non Variable Generation
OPEX	Operating Expenses
PV	Photovoltaic
RA	Resource Adequacy
(v)RES	(variable) Renewable energy systems
SMP	System Marginal Price
SoS	Security of supply
SRMC	Short Run Marginal Cost
VG	Variable Generation
VoLL	Value of Lost Load

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1. Introduction

As some countries, like Denmark and Germany, are moving towards 100% renewable electricity production (Sensfuß, Ragwitz, & Genoese, 2008), the energy system is changing. Because of low marginal costs of renewable energy, prices of electricity are dropping (Eurostat, 2017). The question arises if the current market model is suitable to determine prices in this changing system (Cludius, Hermann, Matthes, & Graichen, 2014; Rubin & Babcock, 2013). If the price would be determined solely on the marginal costs, the electricity price could drop to zero. Examples of near zero or even negative electricity prices have occurred in Germany over the last years (Independent, 2016).

At the same time, there is a 51 gigawatts of mothballed capacity in the European Union, and an additional 110 gigawatts of combined cycle gas turbines (CCGT) (which is 60% of the total gas-fired capacity), which currently are unable to cover their fixed costs and may face closure within the next years (Caldecott & McDaniels, 2014). If (some of) these facilities would indeed close down, this could pose a serious threat to Europe's security of electricity supply. This is because there would be a big capacity of variable electricity generators, which runs on variable sources like the sun and the wind, but a small amount of firm-capacity, which can be switched on at any time. At times when the production of the variable-capacity units is low, when there is little sun and wind, this results in a larger number of blackouts.

With the increasing amount of installed renewable capacity, the need for a new pricing method becomes more and more urgent (Malik & Ravishankar, 2016). One of the proposed solutions is the introduction of a capacity subscription market (L. De Vries & Doorman, 2017; G. L. Doorman, 2000). This would privatize capacity and would allow consumers to determine their own security of supply. However, as this solution is relatively new, there has not been much research into its effects. This thesis aims to increase insights into the relevant design variables, the impact on producers and consumers in the electricity market, and implementation issues of this proposed solution.

First, in chapter 1, a literature review will be conducted to identify problems in the current electricity sector, and explore the option of capacity subscription. The chapter will end with the knowledge gap, problem statement, and research question. Chapter 2 will go over the

research question in more detail and provide the sub-questions that will be used to answer the main question. Then, the definitions of the objectives are determined in chapter 3. The model implementation is discussed in chapter 4, which will include the market design of a capacity subscription market, an explanation of the model used and the experiment design. The demonstration phase will be presented in chapter 5, which will contain the steps that will lead to the results in chapter 6. These results will be evaluated in chapter 7, after which the research question will be answered in the synthesis in chapter 8. The conclusions and recommendations, and the discussion and reflection will conclude the thesis in chapter 9.

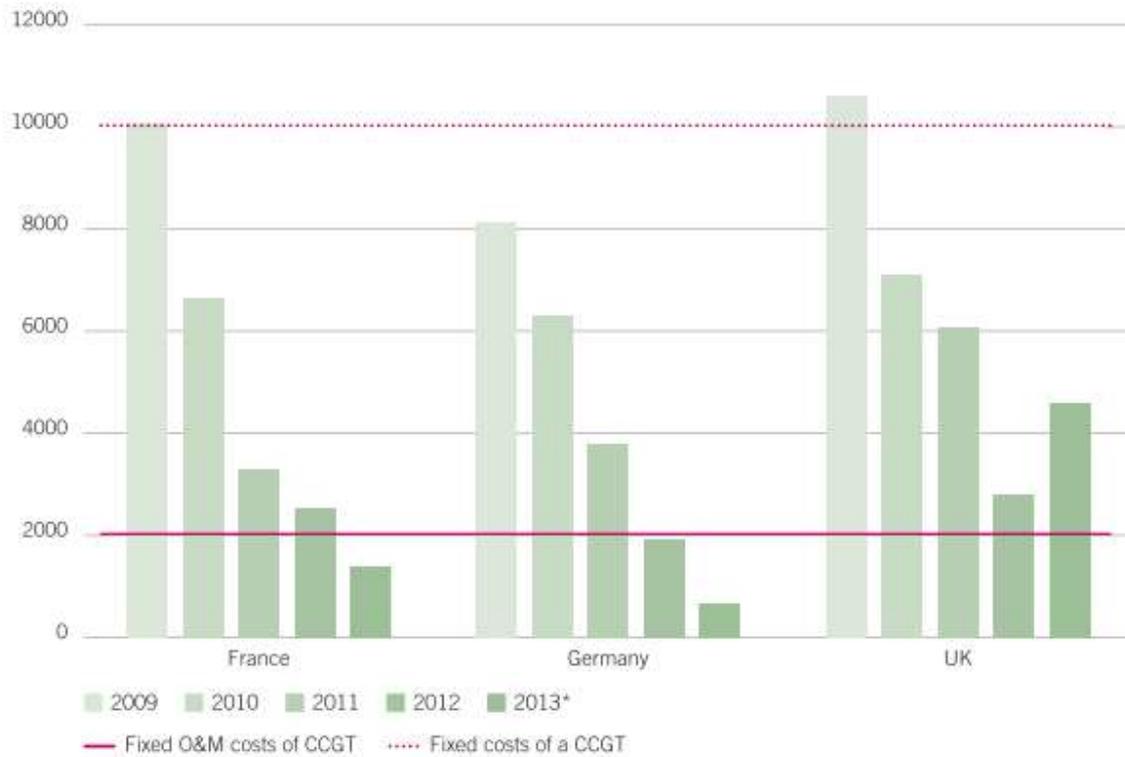
1.1. Problem definition

This section will define the problem described in the introduction. First, the impact of renewable energy is discussed. Because the impact of the weather will become larger in the future electricity system, this is considered in the second section. The last paragraph elaborates on reasons why the current electricity system might not be suitable to solve the problems that have been identified.

1.1.1. The impact of increasing renewable energy

With the introduction of large amounts of renewable energy systems, the electricity sector is evolving. Renewable energy systems like solar photovoltaics and windmills are intermittent, which means their output differs over time. During times of high supply of renewable energy, the price of electricity goes down (Green & Vasilakos, 2011; Würzburg, Labandeira, & Linares, 2013). Because the marginal costs of renewable energy generation units are very low, they are at beginning of the merit order. Therefore, they will always run if there is enough demand. If the residual demand, the demand which is left after supply of renewable energy, is low, the most expensive plants, mostly dispatchable electricity sources like gas plants, will not be needed. This results in a low price for electricity. However, this also means that these plants will make less money. This will become a problem if this plant is earning so little that it is not able to cover its operational costs. This can be seen in Figure 1: Decrease in revenue for CCGTs (in €/MW/month). Source: (*Linklaters, 2014*). If this happens often, the plant will not be profitable anymore and eventually shut down. TenneT, the Dutch Transmission System Operator (TSO), warns that the security of supply could become a problem on the

medium long term, depending on the weather. This is because the mothballed capacity will become more expensive to take back into operation, the longer the capacity has been mothballed (Tennet, 2017).



Analysis: FTI-CL Energy – Revenues calculated from wholesale spot prices excluding estimated short-run marginal costs. Excludes combined heat and power revenues and revenues from ancillary services. Figures for Germany for 2013 are based on 11 months.
Sources: EPEX, APX, IHS CERA

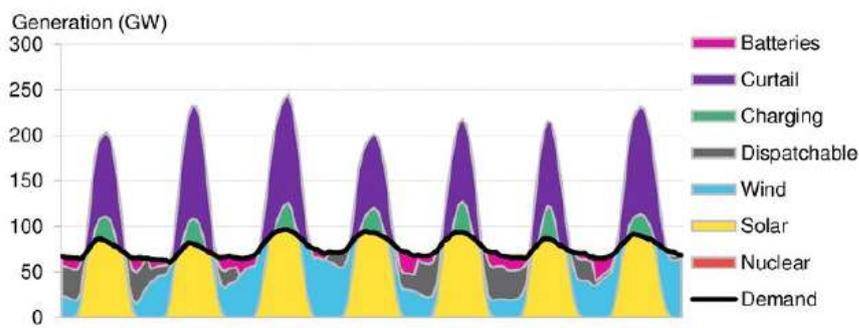
Figure 1: Decrease in revenue for CCGTs (in €/MW/month). Source: (Linklaters, 2014)

1.1.2. The impact of the weather on security of supply

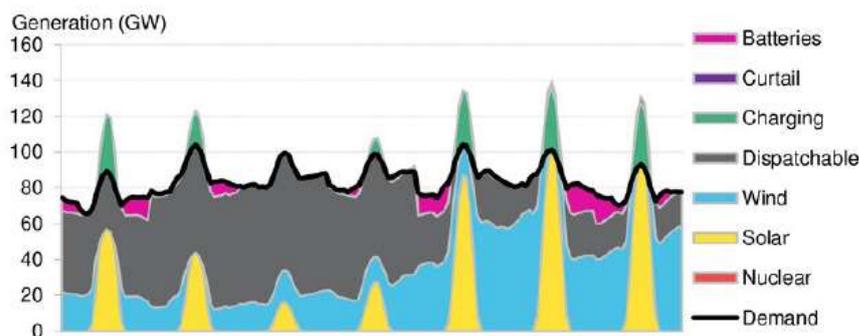
The situation described in the previous paragraph seems like a well-functioning market. However, there is a possibility that a scenario called ‘wind drought’ occurs (Diesendorf & Elliston, 2018). This scenario entails winter in Northern Europe, with high heating demand for electricity and low solar output. If in addition, it happens that there is nearly no wind for two weeks, there is a real problem. There is almost no renewable energy production, and there is not enough dispatchable generation available anymore to supply the high electricity

demand. A visualization of this problem can be seen in Figure 2: Electricity supply in a high and low RE week in Germany 2040. Interconnections would not provide a solution as the whole continent faces the same problem. In addition, large storage options like the Scandinavian dams would not be able to provide enough capacity, and small storage options like electric vehicles (EV's) would run out in a couple of days (Pelka, 2018). At this point, when all dispatchable plants would have been shut down, this would result in major power outages.

Germany 2040 high RE week in NEO 2018



Germany 2040 low RE week in NEO 2018



Source: Bloomberg NEF

Figure 2: Electricity supply in a high and low RE week in Germany 2040

1.1.3. Why the current market is unable to solve this problem

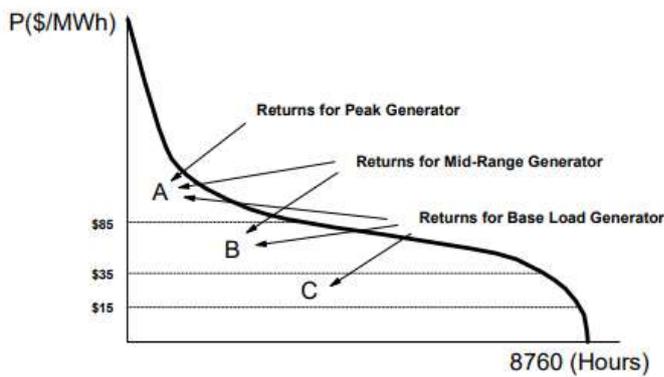
Why is the energy-only market not capable of solving this problem? The current market provides sufficient incentives for electricity producers to build additional capacity if this is demanded. However, there are some aspects of this market that are expected to become a problem when the market becomes more decentral and renewable-based. First of all, most demand is not flexible enough. If supply is scarce, the price of electricity goes up, and demand should go down. However, because consumers (mostly) pay flat prices, they do not have an incentive to lower their demand. So, when scarcity occurs, the price for electricity will become very high. So high, that it is possible for generators to earn back all operating costs for the whole year, in just a couple of days. But at the same time, consumers have no incentive to lower their demand at that specific time, and the costs are divided over all consumers. This pricing system is simple, and was designed when the price of electricity was mostly relatively stable and predictable. Although sometimes there is a differentiation in day and night tariff, this is still inadequate to ensure efficient consumption. This is already causing inefficient investment, consumption, and operational decisions, but this effect is expected to get bigger with a higher penetration of RES (Pérez Arriaga & Knittel, 2016). The disadvantages of the current system thus include a high risk for the dispatchable plants, high electricity prices for consumers, and the risk of power outages.

To illustrate this, one could look at the following example. If there is more demand than supply, the price for electricity goes up to the Value of Lost Load (VoLL), which is defined as “The value attributed by consumers to unsupplied energy” (Emissions-EUETS, 2016). Currently, this is €3.000/MWh in the day-ahead market. If it would cost €20.000/MW/year to keep a plant operational, this plant would only have to run for 7 hours during times of shortage where the price cap is applied to make a profit. But the catch is that by building this plant, the scarcity period is avoided, and the scarcity prices do not occur.

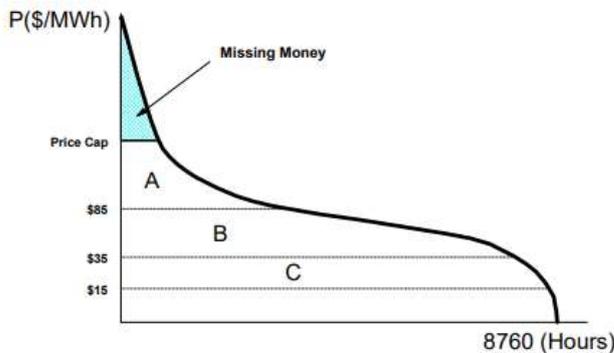
In addition, these events of scarcity are very rare and weather dependent. They could occur twice a year, but it could happen just as well that there is no scarcity for multiple years. This brings an big risk, one that investors are currently not willing to take (Linklaters, 2014). Another problem is the price cap itself. If there was no price cap, there would be a huge

benefit to these scarcity periods. But because the consumer cannot respond to these price peaks, the price is capped by regulation. This results in a lower reward for investors, as the benefits of scarcity periods are lower (Cain, Lesser, & White, 2007). A visual of this phenomenon can be found in Figure 3: The effect of a price cap. Source: (Hogan, 2005).

A Market Price Duration Curve



A Price Cap Results in "Missing Money"



Missing money reduces the payments to all types of generation.

Figure 3: The effect of a price cap. Source: (Hogan, 2005)

1.2. Demand response

As demand response is an important concept for this problem, this paragraph will elaborate on the definition. Demand response is a collective term for measures that shift demand from moment of scarcity towards moment of abundance. Examples of demand response are *demand bidding*, *curtailment*, *direct load control*, and *price based programs*. Further detail

on the first three concepts of demand response can be found in Appendix 2: Demand response. This section shall go deeper into price based programs that would accommodate demand response in the energy only market without the need for further market intervention.

Price based programs are a form of demand response where the price of electricity changes over time, to incentivize electricity use at certain times. Different forms of pricing include Time of Use (TOU), Critical Peak Pricing (CPP), Extreme Day Pricing (EDP), and Real Time Pricing (RTP).

Time of use pricing is the most common price based program, and has been used for some time. The idea is that prices are predefined for certain times. This works by installing two or more separate electricity meters for different times. Most common approach is a day and a night tariff, where the night tariff is the lower one. In the USA, Pacific Gas & Electric has used this form of pricing since 1982. More than 86,000 households participated in this pricing program, saving over \$240 dollar per year, while the company saved money by the shift to off-peak hours (Jones, 2003).

Research in California found that CPP can have a significant effect on peak consumption. Consumers with programmable communicating thermostats used 25% and 41% less energy during 5 hour and 2 hour critical events respectively, when incentivized by critical peak prices. Consumers without these automatic thermostats still reduced their consumption with 13% (Herter, McAuliffe & Rosenfeld, 2005).

Extreme day pricing is similar to CPP, but applies for a full day. This would result in a by contract determined number of days per year of high pricing, and lower pricing during the rest of the year. The disadvantage in contrast with CPP is that it is less accurate, because even these days have off-peak hours. However, the advantage is that this does not require a lot of equipment at the consumer side, measuring their electricity use.

Real time pricing can be seen as the ideal scenario for price based programs. It would result in an exactly accurate electricity price at all times. There have been multiple studies with RTP (Albadi & El-Saadany, 2008; Faria & Vale, 2011), and all consistently resulted in a

significant and constant high load response. This load response is relative to the height of the price incentive, giving higher response the larger the price volatility is (Jones, 2003). The disadvantage of RTP is that it is complicated, and consumers must be able to get significant incentives to participate. While RTP would incentivize demand shift, it could still be beneficial for both companies and electricity producers to use demand bidding (Aghaei & Alizadeh, 2013).

While price based programs can work well on the short term to reduce the peaks within a day, the literature suggests that the impact on long-term investment is limited (Jones, 2003; Yang, 2006).

1.3. Capacity mechanisms

This paragraph will reflect on the solution space for the problem described in the Problem definition. To avoid blackouts and scarcity prices, national governments or responsible institutions can use capacity mechanisms (Vázquez, Batlle, Rivier, & Pérez-Arriaga, 2003). These can be split up into two categories: targeted and comprehensive (see Figure 4: Overview Capacity mechanisms. Source: Bloomberg NEF). The targeted mechanisms and market wide payments are called strategic reserve mechanisms. The fourth and fifth mechanism fall under the category capacity markets.

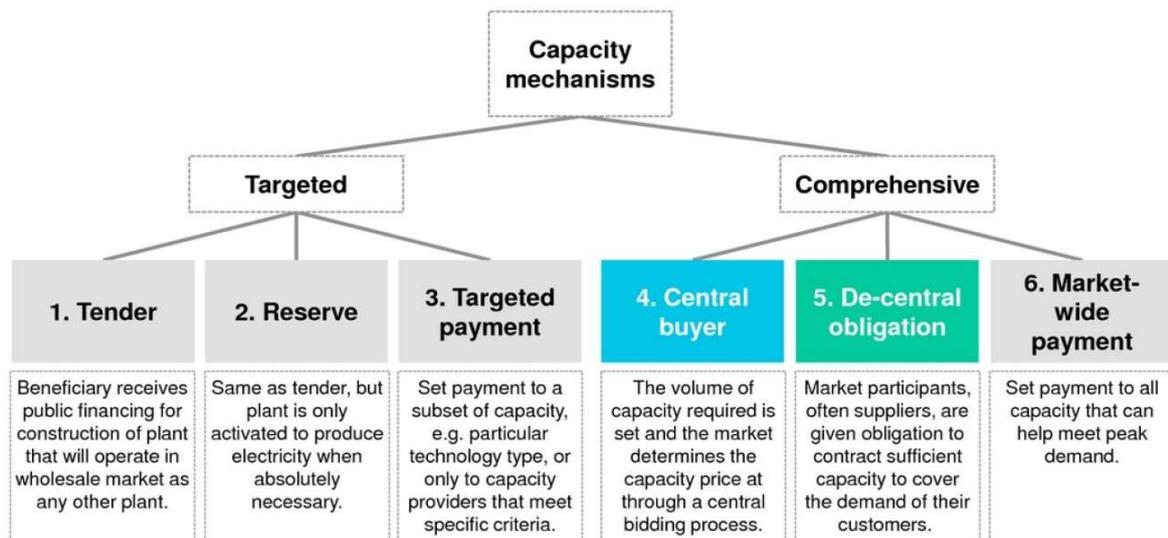
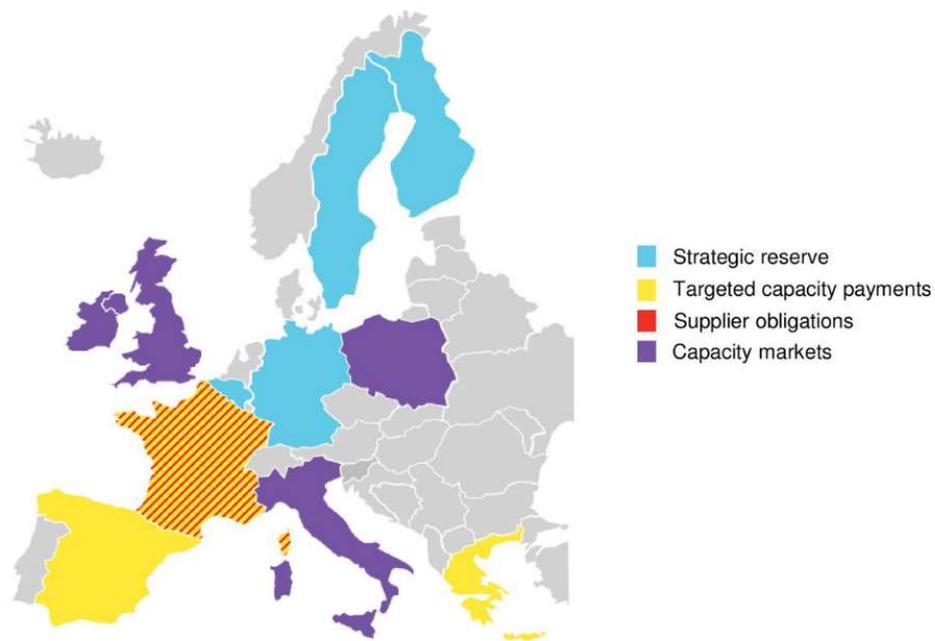


Figure 4: Overview Capacity mechanisms. Source: Bloomberg NEF

Strategic reserves are aimed at the short term and mean that the responsible institution pays the utility to remain operational, so that in case of a shortage, this plant can supply electricity. The advantage is that this is relatively cheap and has a small influence on the market. Capacity markets are aimed at the long term, are more complex, and exist in different forms. Already within Europe, many different forms of capacity mechanisms exist (see Figure 5: EU Capacity Mechanisms). This section will reflect on the most common capacity remuneration mechanisms (CRMs): the strategic reserve, the capacity market, and supplier obligations. The final paragraph will present a mechanism that has not been implemented in practice, the capacity subscription market.

EU capacity mechanisms



Source: European Commission, Bloomberg NEF. Note: striped means that there is more than one mechanism of the same type. Interruptibility mechanisms and implicit capacity guarantees are not included. The Portuguese SEN security reserve is not included as auctioning has been put on hold until it gains European state aid approval.

Figure 5: EU Capacity Mechanisms. Source: (Bloomberg New Energy Finance, 2018)

1.3.1. Strategic reserve

A strategic reserve is a mechanism in which the responsible institution (often the transmission system operator) contracts capacity to remain available when needed. An example of a strategic reserve is the German lignite reserve. The German government wanted to close down lignite plants, in order to reduce emissions. To ensure security of supply, the government agreed to keep the plants operational for four years after decommissioning. The plants that were selected for this reserve were selected on age, emission-intensity, regional effects and employment. This reserve will be phased out between 2016 and 2023. On average, it will be 1.56 GW of capacity and it costs 230 million euros per year (Bloomberg New Energy Finance, 2018). The strategic reserve cannot participate in the wholesale market as this would cause market distortion. However, the existence of a strategic reserve alone could already distort the market as it can withhold electricity producers to build new capacity.

1.3.2. Capacity markets

Capacity markets use a market system to ensure security of supply. Within this category, there are again multiple options. This part will evaluate the capacity market that has been implemented in the UK. The UK capacity market was implemented in 2014. The process of the capacity market can be found in Figure 6: UK Capacity Market process. As this capacity market and its design elements are relevant for designing any capacity mechanism, this section shall go into this market in more depth.

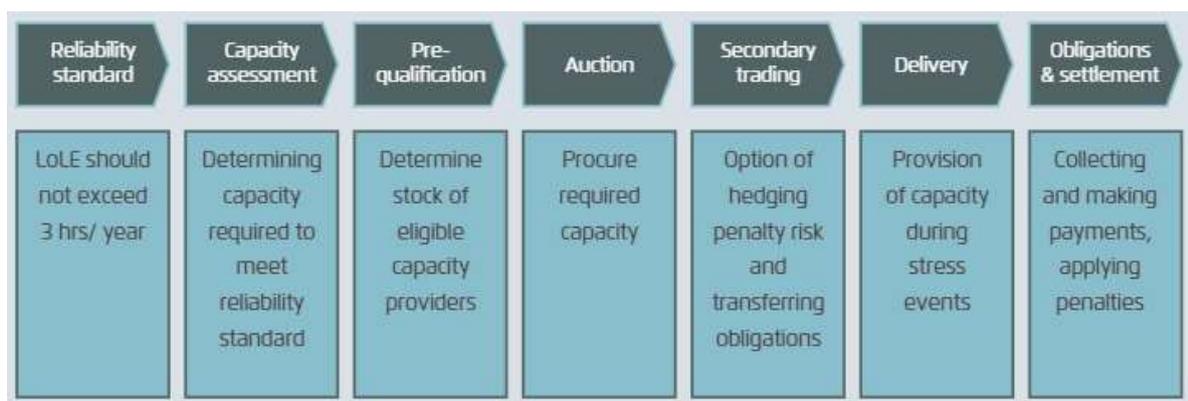


Figure 6: UK Capacity Market process

Regulation

First, a reliability standard is determined. This standard requires that the annual loss of energy expectation (LOLE) should not exceed 3 hours/year and has been determined by comparing the estimated cost of new entry (CONE), minus expected profits from the energy market. This assumes an average value that customers place on supply, i.e. the value of lost load (VOLL). Then, the required capacity can be estimated. This is done by an analysis of the system operator, National Grid. All new and existing capacity can then compete in the auction. This includes storage and demand side response. Pre-qualification is done to determine if the bidder is expected to be able to deliver the capacity for which it bids. The capacity contracted is awarded through a so-called “Dutch auction”. This works like a “descending clock”, where providers indicate in the first auction round what capacity would be provided at an initial, high price. Subsequent rounds are held at reducing prices, with offered capacity also reducing until the required capacity is just met. All capacity clearing this final round will be offered capacity contracts at the clearing price. The auction format is illustrated in Figure 7: Descending clock auction (McNamara, 2014). This means that the required capacity is based on modelling by the system operator.



Figure 7: Descending clock auction. Source: (McNamara, 2014)

Suppliers

Awarding of contracts: There is a T-4 (four year ahead) and a T-1 (one year ahead) auction. The T-4 auction is designed to contract the required capacity, and the T-1 auction takes place

to adjust for changed demand or capacity that withdrew. The T-4 auction awards contract for 1, 3 or 15 years. The 15 year contracts are only for new-build capacity, and the 3 year contracts are only for plants that need to be refurbished. Suppliers are allowed to trade their supplier obligations from 1 year ahead of the delivery year.

Payment structure and supplier obligation: Suppliers receive annual payments in return for being available during notified “stress events” in the delivery year. These events are situations where the energy balance can only be achieved by otherwise shedding demand. These events are announced by the system operator, at least four hours in advance. If the supplier fails to deliver the contracted capacity, penalties can be given, which are capped at 200% of monthly revenue, with an overarching cap of 100% of annual revenue.

Supplier participation: In the first auction, interconnection was excluded to supply capacity. However, the European Commission ruled that this was considered state-aid, and interconnection should be included in future auctions (European Parliamentary Research Service EPRS, 2017; Grubb & Newbery, 2018).

Storage

Storage is allowed to participate at the auction, but at a de-rated fraction. Equivalent Firm Capacity (EFC) can be used to normalize the security of supply contribution of non-conventional adequacy resources like storage. An EFC is defined essentially as “for an additional penetration of that resource, what is the amount of perfectly reliable firm capacity it can displace while maintaining exact risk level” (Burke, 2017). This is because storage can only provide electricity for a certain amount of time until it runs out. The de-rating factors for storage set by National Grid can be found in Table 1.

Final De-Ratings Per Duration in Hours	"2018/19"	"2021/22"
Storage Duration: 0.5h	21.34%	17.89%
Storage Duration: 1h	40.41%	36.44%
Storage Duration: 1.5h	55.95%	52.28%
Storage Duration: 2h	68.05%	64.79%
Storage Duration: 2.5h	77.27%	75.47%
Storage Duration: 3h	82.63%	82.03%
Storage Duration: 3.5h	85.74%	85.74%
Storage Duration: 4h +	96.11%	96.11%

Table 1: CM De-Rating Factors Proposed for Duration-Limited Storage Class in the 2018/19 T-1 and the 2021/22 T-4 Auctions. Source: (National Grid, 2014)

Consumers

Consumer participation: Large consumers or small embedded generators who have the ability to change their demand pattern or ‘flex their demand’ may participate in a new Demand Side Balancing Reserve (DSBR) service. This is a separate mechanism beside the capacity market. Because demand response can only participate in either the capacity market or the DSBR mechanism, most consumers chose the latter, as this would result in immediate revenue, whereas the capacity market would only pay out during the delivery year.

Evaluation

In this system, annual reverse pay-as-clear auctions take place four years ahead of time. In addition, there are auctions a year in advance to correct for changes in demand for capacity or loss of contracted supply from the first auction. Generation capacity can participate in both the wholesale, and the capacity market at the same time. In the first auction, only existing coal, gas and nuclear generators were selected to provide the 50 GW de-rated capacity. This wasn’t the outcome aimed for, and resulted in the criticism of supporting fossil fuels. In addition, interconnection was excluded from the auction, which resulted in a ruling by the European Commission that this was discriminatory and state-aid for national companies. The first round was allowed, but future auctions had to include interconnection (Grubb & Newbery, 2018). These results have to be taken into account when designing any capacity mechanism.

1.3.3. Supplier obligations

Supplier obligations are a form of comprehensive capacity mechanisms. As an example, the French supplier obligation regulation is used. In this scheme, suppliers of electricity are obligated to purchase capacity for the peak demand of their consumers. This peak demand is based on the previous year. Electricity producers receive a certificate for every 0.1 MW they produce. They can sell these certificates via centrally organized auctions or through over-the-counter (OTC) trades. These certificates can be re-sold, effectively creating a secondary trade market. In this system, suppliers have a direct financial incentive to reduce the peak demand of their customers. Also, because of the bilateral contracts, the system

works well in a decentralized market. A disadvantage of this system is that it could distort retail competition by acting as an entry barrier.

1.3.4. Capacity subscription

This section will elaborate on the system of capacity subscription. The main idea is that it will privatize the need for backup capacity. This is done by letting consumers choose the amount of electricity they want to use during system scarcity. Consumers pay for (subscribe to) a certain amount of kilowatts (kW). In case of a shortage, they have the right only to consume this much electricity for a price near the marginal cost of generation. If they consume more, they are either physically limited in their use (by Load Limiting Devices (LLDs)), or they pay a penalty. The alleged advantage of this system is that it will prevent the closure of essential backup generation, and thus black- or brownouts.

While there currently is no way for consumers to determine how much capacity they should generally subscribe to, De Vries & Doorman (2017) believe that the market will fix this, as there will be a high demand for such applications once this system is implemented. They also plead for a minimum required capacity, to avoid consumers buying zero capacity to save costs. Steven Stoft (2010) mentioned a flaw in the current electricity grid that would not allow capacity subscription at this point. As metering is still done “offline”, there is no way of metering and billing real time. However, the amount of smart meters is rising quickly, with an estimated finished roll-out in 2020 (Engerati, 2017). If smart meters are installed, the market can be designed to overcome this obstacle, by not using LLDs but by using financial penalties for fining people that consume more than their subscription during shortages.

Equity might be a problem for this system: how acceptable is limiting people in their power usage? Do poor people get struck by this harder, as they will experience being shut off more often, or is it fairer, where richer people are willing to pay more for security of supply? Important decision variables when implementing capacity subscription: minimum capacity subscription, penalty for non-compliance (both consumers and generators), allowance of real-time buying of excess supply, mandatory capacity subscription (L. De Vries & Doorman, 2017). With no real-world application of this mechanism, there is limited data available on what the impact of this mechanism would be on the electricity market.

1.4. Knowledge gap

The problem of intermittency is clear and has been researched thoroughly. With capacity mechanisms, a direction of the solution was found. But where a capacity subscription market seems to have significant advantages compared to existing capacity remuneration mechanisms, it has not been implemented yet. In addition, there is very limited literature on this measure. There is a clear knowledge gap on how this system would work in practice. Important unknown variables are the price for capacity, the impact on different technological generation units, and the impact on demand side response (DSR). In addition, there is limited literature available to support the claimed advantages including a reduced cost for electricity, increased short- and long-term reliability, and improved investment incentives.

1.5. Problem statement and research question

With increasing renewable energy systems, it seems inevitable that some form of capacity management is introduced in the Netherlands. There are already multiple forms of capacity mechanisms, but there is no clear best practice yet. The idea of capacity subscription has not been implemented, but seems promising, as it privatizes the need for backup capacity. To give insight in this potential market, this thesis aims to answer the following research question: *“How will a capacity subscription market affect the Dutch electricity market in a (near) 100% renewable system?”*

2. Research approach

As described in the first chapter, a capacity mechanism might be essential to ensure security of supply in a future electricity market with increased renewable energy. Some countries have applied forms of capacity management, but there are a lot of different forms. The solution of a capacity subscription market is relatively new and has not been researched thoroughly yet. Therefore, this thesis will aim to provide an improved understanding on how this market would perform. The definition of performance and the applicable stakeholders will be discussed further on. The following research question was defined:

“How will a capacity subscription market affect the Dutch electricity market in a (near) 100% renewable system?”

This chapter describes the research approach. The first paragraph will dissect the research question into separate concepts. These concepts will then be explained with the scope and the sub questions. Then, the research method will be presented. This chapter concludes with the scientific and societal relevance of the research.

2.1. Scope and research questions

To answer the research question, it should be evaluated if a capacity subscription market is effective under specific circumstances of production. Because the market is designed for a high penetration of renewable energy, the electricity market should be evaluated in a scenario when there is more renewable energy production than today. As current policy states clear goals for the amount of renewable energy production in 2030, this year will be used as the example year to test the impact. The thesis will focus on the Dutch electricity market, taking the interconnectedness with other European countries into account. Although the markets in NW Europe are coupled, the amount of international electricity trading is currently constrained by congestion, which influences prices in different market zones (Grimm, Schewe, Schmidt, & Zöttl, 2017). Countries that are taken into account are Belgium, Denmark, France, Germany, Luxembourg, and the United Kingdom. These countries are selected because they are either directly connected through electricity interconnection or interconnected in a second-order, which could still affect electricity prices in the Netherlands. The impact assessment is limited to the Netherlands.

The first sub question is aimed at elaborating a single concept of the main question: affection. To determine the impact of a CS market, it should be clear how this impact is measured. This leads to the first sub question:

1. How is the performance of the electricity market defined?

This research, based on literature and expert interviews, should identify *key performance indicators* (KPIs) on how to evaluate the performance of the electricity market. Important indicators that should be used, but further specified, are affordability (for both system costs as well as consumer costs), sustainability (constraints for environmental and political goals), and reliability (short term security of supply and investment climate). A distinction should be made between industrial consumers (that operate on the wholesale market), and consumers that buy their electricity on the retail market. This question will be answered in chapter 3.

The second concept from the main question is the “capacity subscription market”. If the impact of a market is evaluated, the description of how this market is defined is important. Therefore, the second sub question is formulated as:

2. What is the design of a capacity subscription market?

This research should conceptualize the design of the CS market in order to develop a model to assess the impact. First, the proposed design by Doorman (G. L. Doorman & Solem, 2005) will be discussed. Then, the elements of the design that have an impact on the configuration or input variables of the model, will be discussed in separate paragraphs. Finally, this market design will be used to create an experiment design. This is then used to evaluate the impact of the design elements. This question will be answered in chapter 4.

An important aspect of capacity subscription is the price for capacity. To determine the impact of this market, the price has to be determined. The third sub question is:

3. What will the price of capacity be in a functioning capacity subscription market?

For the impact of CS, it is important what the price of capacity will be. For this, an hourly dispatch model that Eneco has to its disposal, will be used. As the CS market is an open market, the price is determined by supply and demand. Therefore, to determine the price

for capacity, a demand and supply curve for capacity is constructed. The supply curve is based on expected plant profitability. The output of the dispatch model that will be used is the time that dispatchable generators will be used, the marginal costs of the generators, and the price they sell their electricity for. This will lead to an estimation of the “missing money” of these generators, and thereby a price they will need to receive from this capacity market to “break even”. The demand curve will be based on the residual demand, which is the total demand minus the production of energy by solar and wind generation. But, as the CS market has introduced a price for capacity, some demand elasticity would emerge. As there is no comparable market in the real world, the amount of demand elasticity is very hard to determine. Therefore, an assumption is made on how this residual demand will change as a result of the capacity market. The intersection of the supply and demand curve will give a price and quantity for the capacity subscription market. This question will be answered in chapter 5.

The last sub question combines the information from the previous sub questions. If the performance measures and the design is known, the impact of the CS market can be assessed:

4. What is the impact of capacity subscription on the electricity market?

If the price of capacity subscription is determined, the impact can be estimated. This will include the impact on KPI's as defined in the first sub question, as well as the impact on different stakeholders, for example multiple types of consumers like industries, households, energy suppliers, regulators, and energy producers. Then, both a qualitative and quantitative comparison can be drawn between the different scenarios. By comparing these scenarios, the impact of one specific variable can be assessed. The goal of this assessment will be elaborated on in the experiment design (4.3). Together, this will show which outcomes are beneficial to which stakeholders. This question will be answered in chapter 6.

Lastly, the main question will be answered in the chapter 8, the synthesis.

2.2. Research method

The research will consist of two main research approaches: a literature study and a quantitative market model. This paper will generally follow the design science research methodology (DSRM) approach, proposed by Peffers et al. (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007). This approach is chosen because it is a useful method to assess performance.

A literature study is performed to give an overview of the current state of knowledge. The overview will contain both different market mechanisms and price based programs that have been researched for regulation of the electricity sector. As Eneco has access to an hourly dispatch model, this model will be used to provide data on hourly clearing and the electricity price.

The DSRM approach is an approach to create an intervention in a current system. DSRM consists of problem identification and motivation, defining the objectives for a solution, design and development, demonstration, evaluation, and communication. In the definition of the objectives for a solution, the DSRM method states that is important to make the model consistent with prior research. Therefore, this chapter shall use a literature review to determine the key performance indicators. The design phase should include an overview of the market design variables that are relevant for model implementation. The demonstration phase will include the use of the hourly dispatch model that is able to generate electricity prices. Different scenarios will be used to determine the effect of the implementation of the capacity subscription market. The evaluation phase will include analysis of the results to answer the research questions. This method is applied by using the phases as described in the paper by Peffers. At each chapter, the introduction of the chapter shall discuss what the method prescribes for that specific phase. A visualization of this approach can be found in Figure 8: Research Flow Diagram.

The DSRM method describes the development of a “mental model” to visualize the solution. A mental model is a “*small-scale model of reality that can be constructed from perception, imagination, or the comprehension of discourse*” (Peffers et al., 2007). This thesis aims to provide this mental model by providing the design of the capacity subscription

market, reflecting on implementation issues, and giving concrete examples on what this means for specific stakeholders.

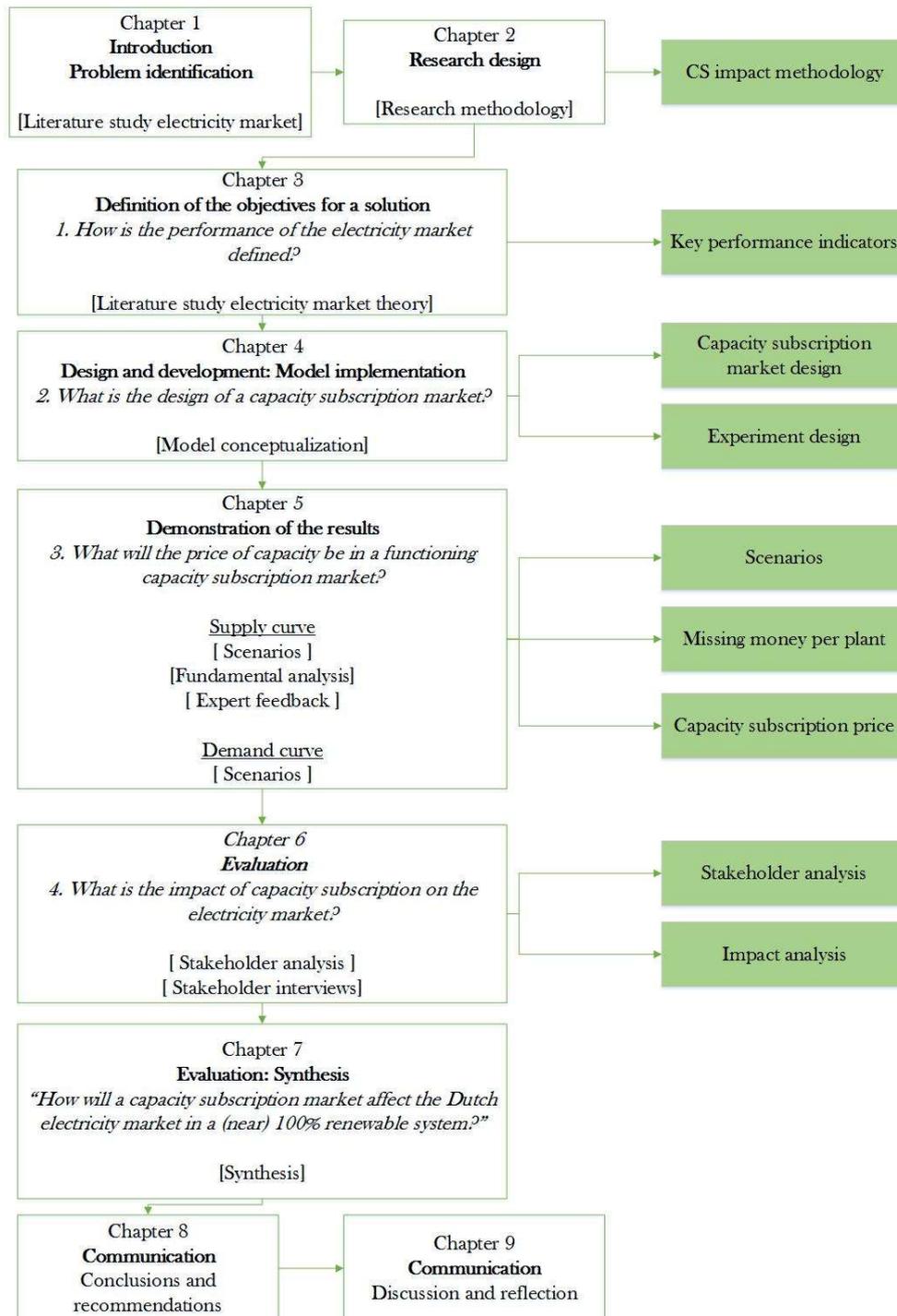


Figure 8: Research Flow Diagram

2.3. Scientific and societal relevance

This thesis aims to provide both scientific and societal added value. This thesis will provide scientific relevance by developing a method to evaluate the impact of a capacity subscription market. To do this, it will combine fundamental analysis, demand shifting, and a plant profitability model. This approach will be repeatable, and can be applied to other research into capacity mechanisms.

This thesis provides societal relevance by generating data on a new form of capacity management, capacity subscription. Intermittency of renewable energy is expected to require some form of intervention on the electricity market. At this moment, forms of capacity mechanisms are considered in the Netherlands (see Appendix 8: Workshop on reliability Energie-Nederland), and this thesis will provide a useful analysis on the expected impact of this market. Not only does it give insights in the effects on the electricity market, it also links the results to stakeholders with interests in different technologies or businesses. As a special interest, it will look at the role of energy suppliers, like Eneco. By looking at the impact on Eneco, and engaging in discussion within the company, the viability of the idea can be tested, and barriers and disadvantages can be identified.

3. Definitions of the objectives for a solution

In the DSRM method, by defining the objectives for a solution, the knowledge on what is possible and feasible is collected. This chapter aims to do so by comparing the theory of an efficient electricity market to the observations in practice. This should lead to the answer of the first sub question: “*How is the performance of the electricity market defined?*” First, the theory behind the current electricity market and general principles of an efficient market are discussed. This means to give insight into the context in which the current market was designed. Then, the market imperfections that are being observed in the literature will be summarized. This section aims to give the discrepancies between theory and practice of the electricity market. After that, the implications of these market imperfections for the design of the market will be discussed. Finally, the key performance indicators will be drafted based on these implications.

3.1. Principles of an efficient market

The theory on efficient market design on the current electricity market model dates back to 1978, where Schweppe (1978) introduced the spot pricing in the electricity sector for the first time. Caramanis et al. (1982) went further, specifying that under ideal conditions, spot prices provided efficient investments both in the short and the long term. Although this theory is still applied, the practice sometimes shows different results.

Woo et al. (Woo, Lloyd, & Tishler, 2003) identified two requirements that should be satisfied for a market to perform effectively. First, the market should be competitive. This requires low entry barriers, many players, and an absence of market power. Second, the market should function properly. For this to happen, there should be little or no information asymmetry, and transaction costs need to be minimized. If these criteria are met under least cost dispatch, this should lead to prices that are close to marginal costs.

Objective	Design variable	Goal
Competitiveness of the market	Entry barriers	Minimize
	Number of suppliers	Maximize
	Number of consumers	Maximize

	Market power	Minimize
	Information asymmetry	Minimize
	Transaction costs	Minimize

Table 2: principles of an efficient market

In this context, market power is not so much a design variable that can be adjusted or steered directly, but more an outcome of the other variables mentioned above. Generally, the following relation can be assumed: more suppliers, more consumers, less information asymmetry, means less possibilities for market power. However, there are design variables that can influence market power for suppliers. For example, when the European electricity markets were coupled, this decreased the ability of players to exercise market power (Spiridonova, 2016).

An important variable of an auction is the payment structure. In the electricity market, this is pay-as-cleared. This means that every supplier receives the same payment per unit of electricity supplied at a certain time. Another option would be to pay suppliers pay-as-bid. This means that every supplier receives the price that it bid in the market. On first glance, this might look more efficient, as suppliers that bid a lower price, receive less money, and the system becomes cheaper. However, as Khan et al. (2001) notice, a pay-as-bid system would radically change the bidding behaviour, introducing new inefficiencies, weaken competition and impede expansion in capacity. Therefore, this thesis shall not reflect further on the implications of other than pay-as-cleared bidding forms.

3.2. Market imperfections

Sometimes the theory for efficient investment does not apply completely, which seems to be the case for the electricity sector (see Problem definition). These inefficiencies are caused by market imperfections (Hobbs, Iñón, & Stoft, 2001). Because market imperfections are largely recognized in the practice of the electricity sector, they are often included in analyses and the development of policy (Skytte, 1999). Three of these market imperfections will be discussed in this section: demand uncertainty, investment cycles, and regulatory uncertainty.

These were chosen because they are considered most relevant in the context of security of supply.

3.2.1. Demand uncertainty

An important market imperfection is the demand uncertainty. The expected future electricity demand is dependent on a lot of factors. Currently, important uncertainties in the Netherlands are the pace in which gas is phased out (The Holland Times, 2018), the electrification of the industry (Moraga & Mulder, 2018), and the development of heat networks (Niessink & Rosler, 2015). All these developments are dependent on consumer behavior, political decisions, and strategic decisions of energy companies. This uncertainty brings a certain risk, which makes companies reluctant to invest in new electricity generation capacity.

3.2.2. Investment cycles

In a perfect energy-only market, there will never be a reliability issue. However, as discussed in chapter 1 and as the literature shows, practice shows that there are investment cycles, in which shortages sometimes occur (Abani, Hary, Rious, & Saguan, 2017; L. De Vries & Heijnen, 2007). These cycles are periods when there is no investment, followed by a period with a lot of investment. These cycles are caused by the delayed response on market prices. Construction for new generation capacity is generally only started after the electricity price has been going up. As all market parties wait for this moment, everyone is investing at the same time. Then, it takes a few years for this capacity to be taken into use, after which the price goes down, and investment stops. Investment cycles are generally more extreme if there is more demand uncertainty (G. Doorman et al., 2016).

At the two extremes of these cycles there is a market with underinvestment and a market with overinvestment. Both extremes have disadvantages. The disadvantage of underinvestment is that of extreme prices. When there is not enough supply, the prices will go up, and can go up to the price cap. These high prices are bad for consumers. During times of overinvestment, the opposite happens, and electricity prices go down. So far down, that generators are unable to cover their operational costs. If this happens for longer stretches of time, generators can be forced to shut down (Linklaters, 2014).

3.2.3. Regulatory uncertainty

Regulatory uncertainty is another factor that can cause underinvestment. During a transition, the government does not always know what to stimulate, what to regulate, and what to leave to the market. An example of this is the policy on renewable energy, which received different forms of stimulation over the years. An even greater impact can be seen on regulation with the phasing out of nuclear reactors in Germany (Clean Energy Wire, 2018), and the forced closing of coal plants in the Netherlands (ABB, 2016). During these periods where policy is changed often, investors are more cautious to invest in technology with a long return on investment, as future policy might make it impossible to earn back the investment (Ishii & Yan, 2004). Reinelt and Keith (2007) stated that “*interaction of regulatory uncertainty with irreversible investment raises the social cost of carbon abatement by as much as 50%*” with risk-neutral investors (Fan, Hobbs, & Norman, 2010).

3.3. Implications for design

According to classical theory from Schweppe and Caramanis, the energy-only market would provide efficient investment. However, there are clear signs that this does not always work in practice. Chapter 3.2 Market imperfections shows that some market imperfections need to be considered in the electricity market. This is because all these factors cause investment risk. Electricity producers already face a volatile market, when commodity prices, the carbon emission market, and weather impact their revenues. The market imperfections discussed add another layer of uncertainty. The capacity subscription market targets exactly this risk, as generators will receive a form of fixed income per year, and are thereby less dependent on the variable income from the electricity market.

3.4. Key performance indicators

In order to determine the performance of (interventions on) the electricity sector, it is important to identify the *key performance indicators (KPI's)*. This will be done based on the goals of the Dutch government. These goals are defined in the 2050 ambition in the energy report of 2016 (Netherlands Ministry of Economic Affairs, 2016): Low CO₂-emissions, Safe, Reliable, and Affordable. In the context of this thesis, the first two goals are straightforward. Low CO₂-emissions can be measured by the number of tons of CO₂ that are emitted by the

electricity sector as a whole. Specific goals for emissions are 20% emission reduction in 2020, 40% in 2030 and 80-95% in 2050 (compared to the 1990 emission levels). To give an indication on the difference of impact between technologies, a comparison should be made between renewable energy systems, baseload plants, and plants for peak load. Safety is more of a constraint, and is primarily named as an ambition to emphasize the importance of a good balance between fast implementation of innovations and maintaining a high level of safety. Safety is considered out of scope for this thesis. The other two goals are more complex and will be discussed in the following paragraphs.

3.4.1. Reliability

Reliability of electricity supply can be divided into two key characteristics: adequacy and security. Adequacy is defined as the ability to provide electric power at the energy requirements of the customers within component rating and voltage limits, taken into account planned and unplanned outages of system components (L. J. De Vries, 2004). Adequacy can be defined in three levels. The first one is generation adequacy level (or hierarchical level I), which is the total system generation including the effect of transmission constraints such as net transfer capacities. Second is transmission adequacy level (or hierarchical level II), which involves the generation and transmission facilities in an adequacy evaluation. The last one is the overall hierarchical level (or hierarchical level III), which includes everything in the functional zones connected at the distribution level (Entso-E, 2017). This thesis will focus only on the first level, meaning that congestion and net balancing will be left out of scope. Security measures the resilience of a power system, e.g. the ability to respond to disturbances. This thesis considers the problem of backup capacity, which applies to adequacy. Therefore, the disturbances of the system, and thus security, is considered out of scope.

A common metric to measure adequacy is Loss of Load Expectation (LOLE), which is the statistically expected hours of blackout in a year on the long-term. The Dutch government has set the standard for LOLE at 4 hours per year (CEER, 2014). Lastly, the total amount of unserved energy shows how much energy was missing during hours of shortage. Bhagwat et al. (2017) have specified two indicators for evaluating the reliability performance of capacity

markets. First, the number of shortage hours (hours/year), which measures the average number of hours per year with scarcity prices. The second one is the supply ratio (MW/MW), which is the ratio of available supply over peak demand. All generation capacity has to be de-rated to account for maintenance/outage rates. A third metric is net export. If shortages occur, the price goes up to the price cap, and it matters where the generator is actually located. It is therefore assumed that net exporting countries have a higher reliability than net importing countries (Lo Prete et al., 2012; Vázquez et al., 2003).

3.4.2. Affordability

The goal of affordability means that the supply of energy has to be economically efficient. This means that the energy bill for consumers and companies has to be as low as possible. Bhagwat et al. (2017) identified three indicators for evaluating the affordability of capacity markets. The first one is the average electricity price (€/MWh) over the considered period. The second one is the average cost to consumers in the capacity market (€/MWh), which is the cost incurred by consumers for contracting the mandated capacity credits from the capacity market, divided by the total units (MWh) of electricity consumed. And lastly, the total average cost to consumers (€/MWh): the sum of the electricity price, the cost of the capacity market and cost of renewable policy (if applicable) per unit of electricity consumed. Lastly, missing money is also considered a part of system costs, as missing money is unsustainable on the long term (Mount, Lamadrid, Maneevitjit, Thomas, & Zimmerman, 2010).

3.4.3. European constraints

European policy has a big influence on Dutch policy, and provides constraints to what is possible. For example, the EU is currently working on legislation to set a limit on emissions for power plants that receive capacity payments (Hall, 2018). The proposed limit (of 550 gCO₂/kWh) is expected to be put into effect between 2019 and 2025. In addition, the EU has set criteria to which capacity mechanism must comply. (European Parliamentary Research Service EPRS, 2017)

- Analysis of generation adequacy must correspond with the ENTSO-E forecast for generation adequacy across Europe (will it support short- or long-term capacity?)
- The necessity of the capacity mechanism must be demonstrated
- The capacity mechanism should be technology-neutral and should not discriminate between existing players and investors. The evolution of interconnections must also be taken into account
- The measure must be proportional
- The measure must have an incentive effect, that is, it should not cover costs that would normally be paid by the beneficiary, or standard commercial risks
- The mechanism should avoid undue negative effects on competition and trade

3.5. Conclusion

This chapter aimed to answer the sub question: “*How is the performance of the electricity market defined?*” The first two paragraphs showed that the electricity sector is not a perfect competing market and market imperfections distort the market. Capacity subscription could decrease the impact of some of these market imperfections. To be able to measure improvement, KPI’s of the electricity market have been identified. An overview of the selected KPI’s can be found in Table 3: Overview of KPI’s. As discussed in the section on market imperfections, uncertainty is an important factor that plays a role in long term reliability. Therefore, not only the actual results are taken into account, but also the variability of the objectives in different scenarios. In addition to these KPI’s, an analysis of impact on stakeholders should provide context on what would change for specific players on the electricity market.

Objective	Design variable	Goal
Sustainability	CO ₂ -emissions [kton CO ₂ / MWh]	Minimize
Safety	-	-

Reliability	LOLE [hours per year] Unserved energy [GWh] De-rated capacity margin [MW supply/MW demand] Net export	Minimize (<4) Minimize Maximize Maximize
Affordability	System costs [€/year] Electricity wholesale price [€/MWh]	Minimize
European constraints	Generation adequacy must correspond with the ENTSO-E forecast Technology-neutral Incentive effect Avoid undue negative effects on competition and trade	Necessity and proportionality Efficiency Efficiency Efficiency

Table 3: Overview of KPIs

4. Model implementation

This chapter discusses the model implementation. In DSRM, this is the design and development phase, which entails the creation of an artefact. It includes determining the functionality of the artefact and the creation of it. First, the model conceptualization will be discussed in paragraph 4.1. This paragraph will answer the sub question of the chapter: “*What is the design of a capacity subscription market?*” Then, the available hourly dispatch model is explained. In paragraph 4.3, the experiment design is presented, after which the concluding paragraph ends with the resulting scenarios.

In order to provide insight in the operationalization of the capacity subscription market, the demonstration phase will estimate the quantity and price of capacity in this possible future market. This will be done by using a fundamental analysis dispatch model. This model will be discussed in section 4.2. The following input variables can be adjusted to simulate a CS market: the weather assumptions, the availability of interconnection, and the amount of demand response based on the implementation of a CS market. This will be discussed in paragraph 4.3. The fundamental analysis should provide multiple outputs: it has to produce the electricity market costs and it should provide the input variables for the plant profitability model, which are the load factors, marginal costs, and the system marginal price for every hour of the year. Finally, it should give metrics for price volatility, supply ratio, unserved energy, and CO₂-emissions.

The plant profitability model will determine the profitability of every electricity generation plant in the Netherlands during the run time. This will be used to construct the supply curve for capacity and thereby the cost of the CS market. This model is discussed in 4.3.5.

This approach is constructed incrementally, starting with a basic model with assumptions (see Appendix 4: Model assumptions), and then improving the model step by step. An overview of the relation between the models and the KPI's is visualized in Figure 9: Modelling approach.

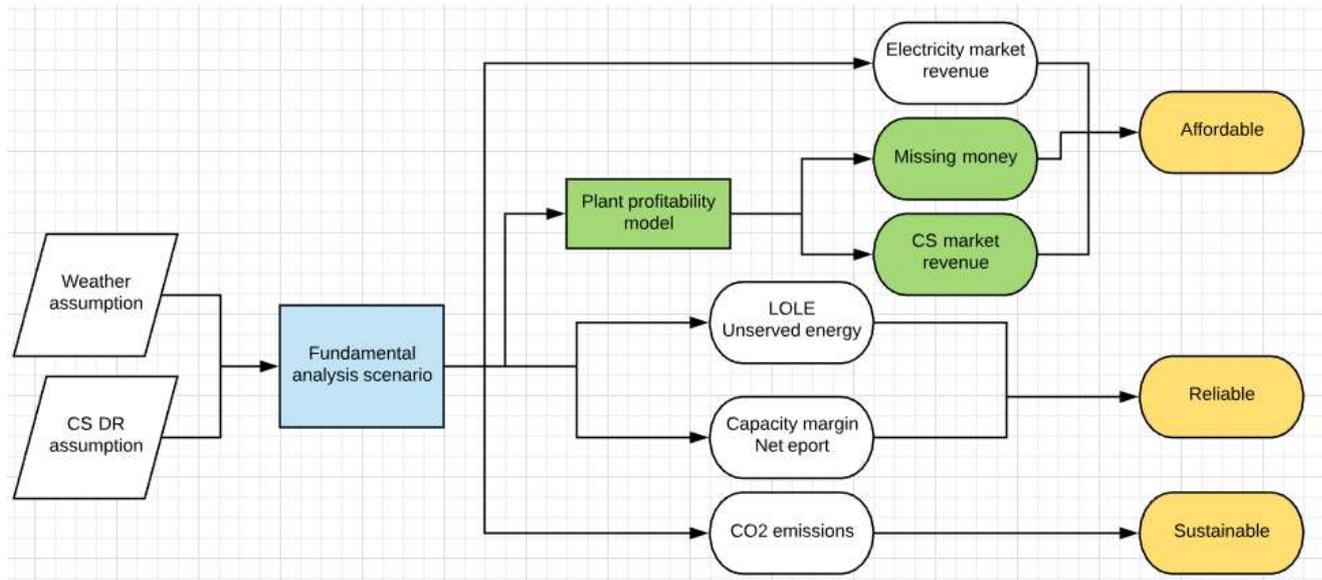


Figure 9: Modelling approach

4.1. Model conceptualization

The goal of this section is to define the design of a capacity subscription market. With this definition, the first sub question “*What is the design of a capacity subscription market?*” will be answered. First, the original design, proposed by Doorman, is presented. Then, three aspects from the design that are relevant for the model design, storage, interconnection and cross border capacity, and sustainability, are discussed further.

4.1.1. Original Capacity Subscription market design

The original design for CS was proposed by Doorman (G. L. Doorman, 2000; G. L. Doorman & Solem, 2005). He describes the market as follows. Consumers must decide beforehand how much capacity they will need. Consumers pay for this capacity per kW per year, and are limited during shortages through so-called load limiting devices (LLDs). Because not all consumers will consume their peak demand at the same time, it is proposed that either through random allocation, or through prices auctions, the excess electricity is divided. Suppliers bid their expected available capacity during shortages. Capacity is continuously tradeable.

This design is in line with the principles of an efficient market, as the entry barriers are meant to be low: all consumers participate, and all producers can participate. However, the complexity of certification could determine if small generators eventually will. The number of suppliers and consumers should be high, as the whole electricity sector is included. Market power should be minimized by making the market transparent. Finally, the system would definitely have transaction costs. The amount of transaction costs and possibilities to keep these low, will be discussed further on in this paper.

Shortage period

In this design, a regulator is appointed to oversee the market. In the context of the Dutch electricity market, the TSO would be the most probably institution to take up this role. If the regulator foresees a shortage, a warning will put out to all consumers with capacity subscription to limit their demand to the contracted amount. Consumers that do not comply with their contracted amount will be either physically limited or receive a financial penalty. Suppliers will need to supply their contracted amount of capacity. If the supplier fails to deliver the contracted capacity, penalties are given. The effect of this design element is that the model assumes that both consumers and suppliers will always have the information about how much electricity they are able to consume, and how much electricity they are required to produce at any given time. It is assumed that both the consumer and producer know when the shortage will occur and adjust their behavior based on this information.

Excess load relief

During a shortage period, all consumers are expected to reduce their demand to their subscribed capacity. However, not all consumer would be consuming their peak capacity at that time. Therefore, if all consumers would limit their consumption, there would be some load left. Doorman provides two possible solutions for this problem. The first one is random allocation of load. This means that random consumers will get the option to consume more than their subscribed amount. They would not receive a penalty for this, but they would of course pay for the electricity supplied. The other option is price based allocation. This means that all consumers that want to consume more than their subscribed amount, can bid for extra capacity. The highest bidder will receive the extra capacity. However, if later on, the

other consumer increases their demand to their subscribed level, and the excess load disappears, the consumer that bought the extra load will have to restrict his load again. An example can be found in the figure below. The shortage period starts at time (\hat{t}). If consumer 1, with demand q_1 and CS c_1 , will limit its demand to c_1 , there is some extra load left ($q_1+q_2 < Q$). The effect of this design element is that during shortage, electricity demand is “capped” at the assumed subscribed demand, and does not go down, as would happen if all consumers are physically limited to their subscribed demand.

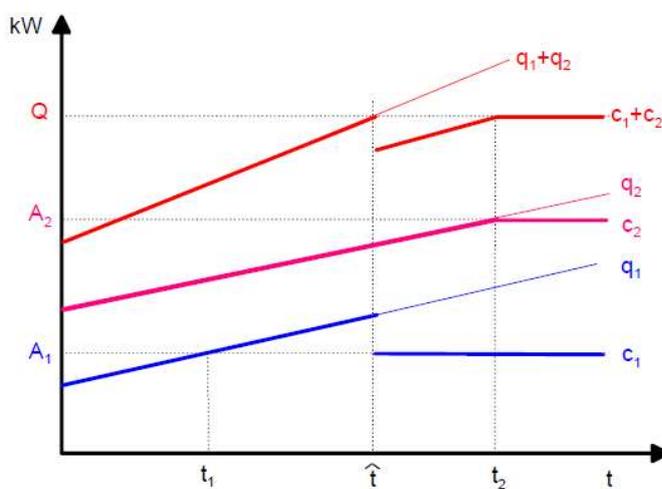


Figure 10: Excess load relief in a two consumer case (G. L. Doorman & Solem, 2005)

4.1.2. Storage

Because electricity demand and supply have to be balanced at all time, storage is an important component of the electricity market. Storage currently plays a small role in the electricity market, because most generation is still dispatchable. However, as this thesis shows, renewable energy systems provide an intermittent supply. Therefore, storage will become more important in the future market. Storage is also a difficult design variable, as storage can only provide electricity for a certain period. In this design, it is assumed storage is used to lower consumer demand peaks. Because it is included in the demand response assumption, storage is excluded from bidding as supply of capacity. When storage is connected to demand of a consumer, this consumer can then lower its subscribed peak demand, and save costs. This way, the consumer will select the type of storage that fits best with its own demand

pattern. Including storage at the supply or demand side does not matter for the equilibrium, as the price for storage does not change, but it does matter when determining the amount of demand response. This includes both small scale storage as well as big industrial storage units.

4.1.3. Interconnection and cross border capacity

While Doorman does not provide a design on interconnection and cross border capacity, the principles of an efficient market (see paragraph 3.1) state that any market should have as many suppliers and many consumers as possible. In addition, there is a big chance that interconnection and cross border capacity will have to be included in any CRM design, as it seems the EU Commission will make this mandatory for capacity mechanisms (European Parliamentary Research Service EPRS, 2017). In a rapport by CIGRE (G. Doorman et al., 2016), the need for integration of European capacity mechanisms is emphasized. Although the market for capacity subscription could be integrated in a larger European market for capacity, this thesis assumes a national implementation of the model. Because interconnection has such a big influence, it is considered as a variable in all scenarios. Cross border capacity will not be taken into account. This is because this thesis assumes a shortage in the whole of Northwest Europe, with the result that abroad capacity could provide little help. In addition, including all capacity of generators in NW Europe would increase the complexity of the model too much. The result of this choice is that the price for capacity is higher than when abroad capacity would be used. This is because the inclusion of more suppliers will lower the price at the equilibrium.

4.1.4. Sustainability

Doorman states that there are possibilities to include sustainability constraints to the capacity subscription market. Recent developments show that, in line with European legislation, it is possible to only allow suppliers with a carbon footprint of $<550 \text{ gCO}_2/\text{kWh}$ (European Parliamentary Research Service EPRS, 2017). This is to avoid polluting technologies gaining profits. In practice, this would mean that all coal plants and the least carbon efficient gas plants couldn't participate. This would result in an increase of the capacity price (as some capacity is excluded), but it would also secure payment for less polluting plants. In this model,

no constraints based on CO₂-emissions are considered. This is because it would add more complexity to the model. Also, because of the Dutch policy ban on coal from 2030, coal plants are already assumed to be closed, so the impact of this rule would be small. Excluding plants from participating in a capacity market has a price increasing effect, as more expensive plants would be needed to supply the same peak demand.

4.2. Fundamental analysis dispatch model

As discussed in chapter 2, a dispatch model will be used to simulate the electricity market. This section will provide an explanation of this model, as well as the data sources it uses. A more detailed description of the model can be found in Appendix 3: Dispatch model - Confidential. This is a fundamental analysis hourly dispatch model that can be used to provide data on plant profitability, future electricity prices, and electricity demand. Fundamental analysis is the study of the physical factors that make up the price-setting mechanism of a given commodity. For the energy market, this specifically means that the model is primarily based upon the physical aspects electricity supply, demand, transportation, and storage. This is combined with relevant variables such as (expected) fuel costs, weather forecasts, and regulatory constraints. Basic fundamental analysis assumes that all market participants will behave rationally, according to market economics.

4.2.1. The model

The scenario simulation engine simulates the supply/demand equilibrium in order to determine the set of market outcomes: plant dispatch, prices, fuel consumption, profitability, etc. This simulation engine has a classic Linear Programming (LP) core, with heuristics to simulate integer (binary) elements such as plant on-off decisions. The LP-based supply/demand equilibrium approach has a long history in power market analysis. It is well-understood, fully transparent and auditable, and it has a solid foundation in economic theory. Outside of optional heuristic elements, it is an "objective" approach. For a more detailed description of the model, see Appendix 3: Dispatch model.

4.2.2. Data sources

The dispatch model uses all public data available. This primarily consists of annual reports, environmental reports, company websites, websites for TSOs / regulators / industry bodies /

equipment manufacturers etc. Data sources include *Eurostat* for historic prices, *ICE futures Europe* for fuel prices, *EnergyMarketPrice* for exchange rates, *European Wind Energy Association* for wind capacity, as well as their own research. The output will be the electricity supplied and system marginal price per hour for a target year. The sum of these outputs is the system cost of the electricity market.

4.3. Experiment design

In order to evaluate the impact of design variables, an experiment design is defined for a CS market. Because it is not possible to run the dispatch model with a capacity subscription market as described in the first part of this chapter, an approach is used to simulate the CS market as good as possible. Ideally, the model would be dynamic, with a feedback between investment in the electricity market and the capacity subscription market. However, as the model does not allow this, a static model is proposed, where certain years are compared with and without a CS market. This is done by using scenarios. The scenarios will vary on 3 input variables: the implementation of a CS market, weather input, and an open/closed market. This approach with scenarios means that the model can only be run for a limited number of times, as each run requires manual input and processing of the output variables. For example, for the weather input this means the input cannot be a range of possible weather data, and run the model 100 times to get a bandwidth of results. Instead, only two specific weather years are used as input, as will be discussed in section 4.3.1.

The outcomes of the scenarios will be interpreted to determine the effect of a CS market. By comparing certain scenarios, the impact will be estimated. First of all, the difference between scenario 1 and 3, and 2 and 4 will be discussed. What is the impact of CS on the affordability, reliability and sustainability of the electricity market? This is visualized by Figure 11: Impact of CS 1. The next step is to compare the differences between both years. This is to determine what the impact of weather is on plant profitability. This is visualized by Figure 12: Impact of CS 2. Lastly, it is important to look at the *difference of differences*. In relation to the first comparison: How is the impact of CS different in different weather years? Looking at the second comparison: What is the difference between variability of plant profitability in

an EOM and a CS market? The variables will be discussed in the first paragraphs, after which the construction of the scenarios is discussed in detail.



Figure 11: Impact of CS 1

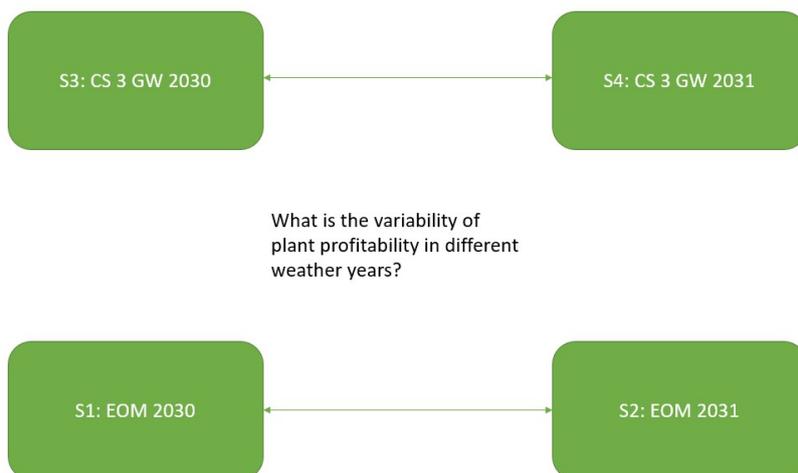


Figure 12: Impact of CS 2

4.3.1. Weather input

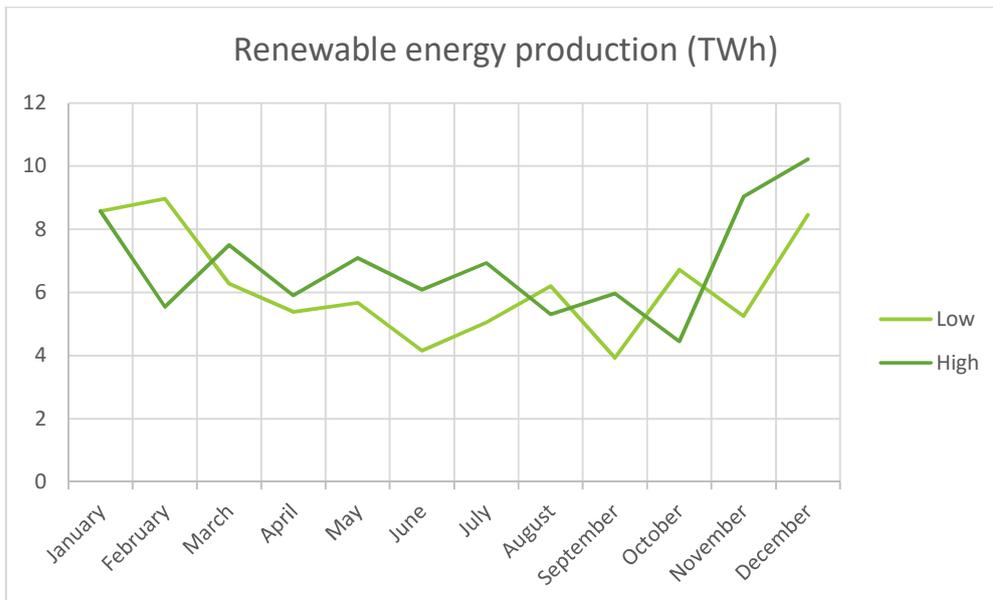
The weather can differ greatly over the years. With the penetration of more renewable energy systems like solar photovoltaics and windmills, the supply of electricity will change with the variable weather. This can have significant impact on plant profitability, electricity prices, and system reliability. Therefore, two different weather years are considered, one year has relatively low renewable output, and the second year has a relatively high renewable energy

production. The weather years are based on historic data from 2014 and 2015 (NASA, 2019). In the scenarios, this weather data is combined with the expected installed capacity of renewable energy systems in 2030, resulting in total RES production. As discussed before, this year is used because the installed capacity of renewable energy production is a lot higher in 2030, with as a consequence that the effects can be shown more clearly. To account for correlation between weather and demand, the demand curves from the same two years are applied to the scenarios.

One year has relatively low, and the other has a relatively high renewable energy production. The load factor and total energy production by renewables can be found in Table 4: Load Factors RES ‘Low’ and ‘High’ and Graph 1: Renewable energy production ‘Low’ and ‘High’ respectively.

	Wind offshore	Wind onshore	Solar
Units	%	%	%
Low	40	32	12
High	44	36	12

Table 4: Load Factors RES ‘Low’ and ‘High’



Graph 1: Renewable energy production ‘Low’ and ‘High’

4.3.2. Open/closed market

The Netherlands has a lot of interconnecting electricity cables with neighbouring countries. The electricity markets of the north western European markets are therefore coupled, with electricity flowing back and forth all the time. When policy is applied just on the Dutch market, this can lead to some impact “leaking” away to neighbouring countries. A well-known example of such a leaking effect is carbon leakage, where closure of Dutch coal plants, without additional intervention, can lead to more generation by coal plants in Germany (ABB, 2016). This thesis aims to quantify this leaking effect. By looking at both the interconnected market (as it is), and a closed system, where there is no interconnection, the impact of this interconnection can be displayed. In the scenario overview ‘business as usual’ (BAU) a scenario is considered with interconnection as expected in the target year. No interconnection (NI) means that all interconnections to other countries has been disabled.

4.3.3. Establishing a base case scenario

In order to evaluate the impact of the design variables, a base case scenario needs to be established. This is necessary to be able to compare the system with and without a CS market. Because the necessity of a capacity mechanism is greater when there is a high penetration of renewable energy generation units, 2030 will be taken as target year.

For the base case, assumptions are needed. These assumptions are made based on the latest insights by the Eneco Fundamental Analysis team, and in line with projections of the countries included. For example, the current policy of the Netherlands is that all coal plants are closed before 2030, and therefore this is included in the model. However, an important assumption has been changed compared to the reference scenario. These assumptions are discussed below. Additional assumptions are shown in Appendix 4: Model assumptions.

The dispatch model allows for assumptions on the amount of new build capacity. In the reference scenario, the amount of new build capacity is increased, to prevent energy shortages. This is because the model assumes that politics will intervene before the lights might go out. However, this is exactly the problem that the market for CS is trying to solve. Therefore, this assumption will be changed. Because the results showed that most generators cannot cover their OPEX, let alone CAPEX, the assumption has been made that there will

be no newly build generation capacity apart from renewables. This is excluding already approved generators or generators that are being built at this time.

4.3.4. Applying the CS market

In order to simulate a CS market, electricity demand is changed for the hours that demand is higher than the assumed level of subscription. The demand response (DR) is based on the residual demand peak, so when the need for dispatchable generation is highest. So, for example, when the peak residual demand in the base scenario was 20 GW, and the assumed DR is 3 GW, the new maximum residual demand peak will be 17 GW. The demand for the whole year will be adjusted so that the residual demand will remain below 17 GW. All demand during shortage hours will be shifted towards another hour after the shortage, when the residual demand is below 17 GW again. This way, the system will use the same amount of energy during the whole year, only at a different time. The chosen level of DR is 3 GW in 'Low', which is higher than DR in other capacity mechanisms (+/- 2 in the UK and FR). The Dutch market is of course a lot smaller, but there are two key differences. First, all consumers will be included instead of only large consumers that participate in capacity mechanisms. Second, storage is considered a form of demand response. This means that consumers do not necessarily have to turn down their consumption, as long as they have electricity storage options. A second reason to choose a relatively high amount of DR is to see the effects of the market more clearly.

So, for example, when the peak residual demand in the base scenario was 20 GW, and the assumed DR is 3 GW, the new maximum residual demand peak will be 17 GW. An example how demand is adjusted can be found in Table 5: Demand adjustment for CS. Demand shifting always happens towards a later point in time, when the residual demand is below the peak.

	CS level: 16.48				
	Residual demand	Shortage	Shortage	Demand adjustment	Residual Demand (new)
Unit	GW	GW	GWh	GW	
	16.14	0.00	0.00	0.00	16.14
	17.31	0.83	0.83	-0.83	16.48
	17.15	0.67	1.51	-0.67	16.48
	16.56	0.09	1.59	-0.09	16.48
	15.99	0.00	1.11	0.49	16.48
	15.22	0.00	0.00	1.11	16.33

Table 5: Demand adjustment for CS

Table 6: Demand adjustment ‘Low’ and Table 7: Demand adjustment ‘High’ will provide context on the amount of demand response that is assumed in the scenarios with a CS market. The DR max peak is 3 GW compared to the residual demand peak in ‘Low’. Because consumers would not be able to predict the residual demand peak beforehand, it is assumed that the residual demand peak, the total amount of subscribed capacity, is the same in ‘High’. Because the peak residual demand is bigger in ‘High’, the total amount of demand response is also bigger. The biggest shortage is the maximum aggregated amount of electricity that is missing at a certain hour. If demand is larger than the new residual demand peak for consecutive hours, the shortages are added up. This happens until an hour occurs where demand is lower than the residual demand peak, at which time the shortage decreases. The DR whole year is the sum of all shortages over the whole year. In the scenario overview, the abbreviations EOM and CS 3 are used, meaning the energy-only market and capacity subscription market with a residual demand peak that is 3 GW lower than without a CS market. It should be noted that this thesis assumes that all demand is shifted towards a later moment. In reality, it is possible that demand is not shifted, but shed, meaning the demand disappears all together. This form of demand response is therefore considered conservative. If demand shedding would be included, the total electricity demand in scenarios with a capacity subscription market would be lower than that in the energy-only market, thus further decreasing cost.

	EOM	CS 3
DR max piek (GW)	0	3.0
DR whole year (GWh)	0	67
Biggest shortage (GWh)	0	13
Residual peak demand (GW)	19.5	16.5

Table 6: Demand adjustment 'Low'

	EOM	CS 3
Peak DR (GW)	0	4.2
DR whole year (GWh)	0	114
Biggest shortage (GWh)	0	31
Residual peak demand (GW)	20.7	16.5

Table 7: Demand adjustment 'High'

4.3.5. Market impact

To determine market impact, the model is run for the same target years. Because the input variables are changed, it will lead to different demand and different marginal prices per hour. The system costs are calculated again by looking at three main elements of the system costs: the cost for buying electricity (per MWh), the cost of the capacity market, and the cost of missing money. The cost of the capacity market will be calculated in an Excel model by matching supply and demand for capacity in the plant profitability model. A visual of the processes for this model can be found in Figure 13: Plant profitability model.

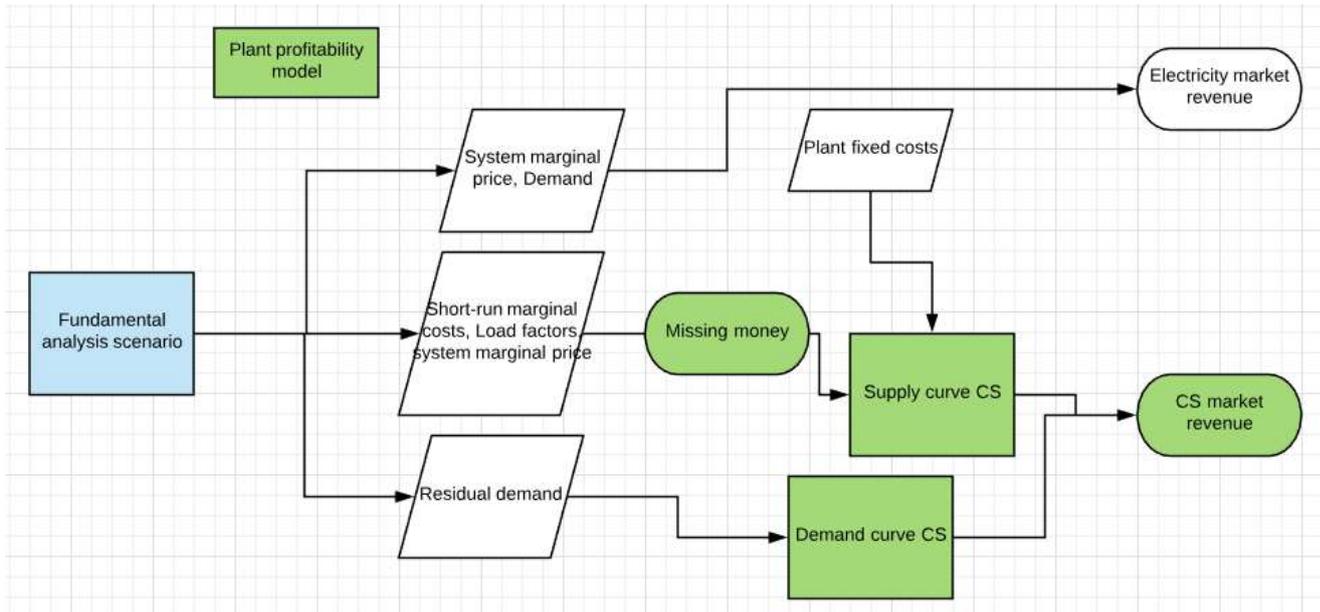


Figure 13: Plant profitability model

The supply curve will be constructed by looking at expected profits of dispatchable generation. The model will estimate the amount of missing money for dispatchable generation. This data is based on output from the dispatch model, which models the electricity market in the Netherlands. The output required will be the run time of each dispatchable generation plant, and the electricity price during that run time. This will result in a total revenue per plant. This will then be compared to the average yearly cost of this plant. If the total profit is negative, the amount of missing money will be the amount that this plant will bid in the capacity subscription market. For plants that have some form of combined heat and power (CHP), the bidding price is set to 0, as these plants have other income streams and obligations to deliver this heat, they are expected to take whatever they can get, and thus bid 0 in the capacity market. Combining the bids from all generators will result in the supply curve (see Figure 14). The method to calculate profit is described below.

$$R^* = \sum_{t=1}^{8760} SMP(t) - SRMC(t) * \frac{LF(t)}{100}$$

**Applied when $LF > 0$*

$R = \text{Revenue (in } \text{€}/\text{kW)}$

$SRMC(t) = \text{Short-run Marginal Cost (at time } t)$

$SMP(t) = \text{System marginal Price (at time } t)$

$LF(t) = \text{Load factor (at time } t)$

$$P = R - S - FC$$

$R = \text{Revenue (in } \text{€}/\text{kW)}$

$P = \text{Profit (in } \text{€}/\text{kW)}$

$S = \text{Start-up Cost (in } \text{€}/\text{kW)}$

$FC = \text{Fixed Cost (in } \text{€}/\text{kW)}$

Now, the total amount of missing money can be calculated. This is done by multiplying the (negative) Profit (P) by the capacity from the generator. The sum of all generators that are needed to generate the peak residual demand is considered the total amount of missing money. This is done only for the scenarios without a capacity subscription market, which by definition does not have missing money.

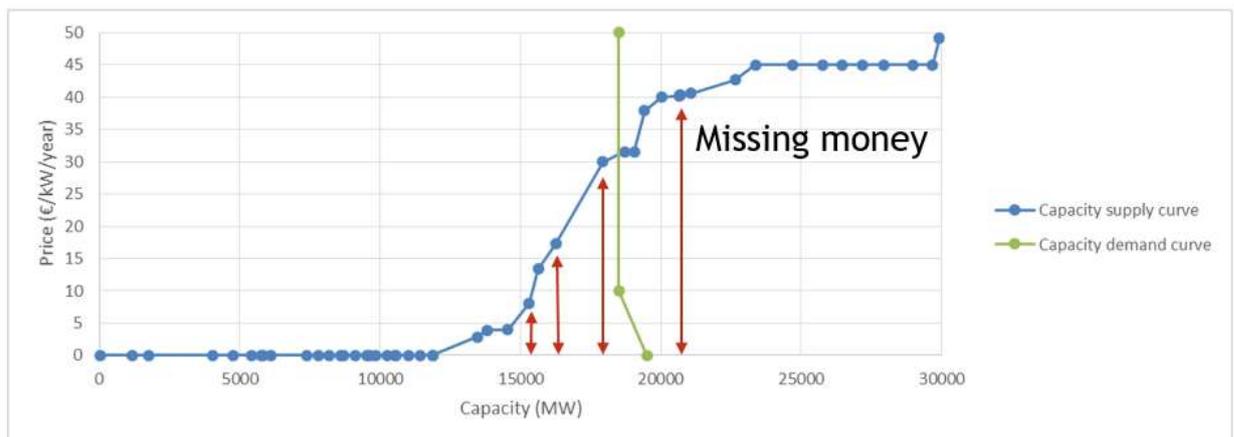


Figure 14: Missing money based on plant profitability. The blue points represent generation units, with the height of the unit is the missing money of the generator and the width the capacity of the unit. The green line represents the peak residual demand of consumption.

Lastly, the supply curve will be matched with the assumed peak residual demand, to find a price for capacity subscription. Together, this would lead to an expected quantity and price

for capacity. The total cost can then be calculated (see Figure 15). In formula, this would look as follows:

$$TC(CS) = RDP * MM(MP)$$

$TC(CS)$ = Total Costs of Capacity Subscription market (€)

RDP = Residual Demand Peak (MW)

$MM(MP)$ is the Missing Money (of the Marginal Plant needed to produce the residual demand peak). (€/kW/year)

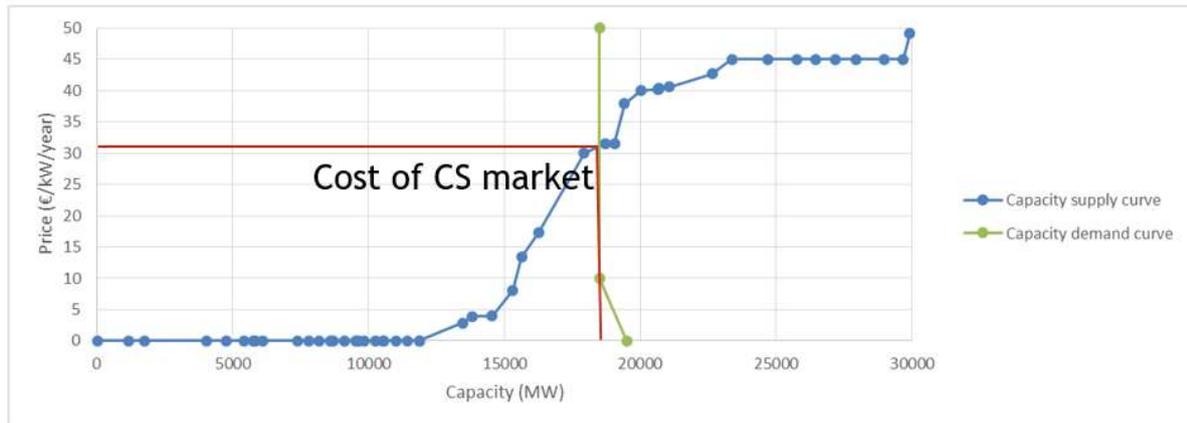


Figure 15: Cost of the CS market

4.4. Validation

To confirm that the model is designed right, a validation is performed. The model is validated by two approaches. First, the model will be validated with expert face validation. This will be done by Eneco fundamental analysis department. Experts will review the steps taken in the modelling approach to estimate its validity. Second, the outcomes of the model will be compared to other capacity mechanisms in similar electricity markets. The markets used will be the French supplier obligation mechanism, and the UK capacity market. Prices for capacity should be in the same order of magnitude as the prices in these other mechanisms.

As a result of the expert feedback, the additional scenarios without interconnection were added to the experiment design. These scenarios helped identify the impact of interconnection on reliability in the electricity sector. In addition, the results were validated in a workshop organized with employees from different business units within Eneco. A recap of that workshop can be found in Appendix 7: Workshop Capacity Subscription Eneco. Comparing the clearing prices for CS with the French and UK capacity market suggests that the clearing price could turn out lower than the results now show. In France, the price has decreased from 10 euro/kW/year to 9.30 euro/kW/year. In the UK, the price for capacity started at around 20 GBP/kW/year in 2014 and cleared last year for 8.40 GBP/kW/year, which is approximately 9.40 euro/kW/year. These prices were lower than expected in the UK, and were explained by backup private backup capacity which wasn't known by the grid operator. If the same effects apply to the Netherlands, this could mean a lower price for capacity than this thesis implies, but also a lower need for additional installed capacity.

4.5. Verification

A verification of the model is meant to show that the model works the way it should. Because the hourly dispatch model is already verified, only the plant profitability model is discussed in this section. Verification of the model will be done by doing an extreme value analysis. Scenario 8 (no interconnection, 'High') will be run with a maximum demand response of 8 GW instead of 3. The plant profitability model shows results that are consistent with expectations. Apart from the generators that use some form of combined heat and power, the amount of missing money per plant increased. Because the demand per hour is lowered, and there is no interconnection to sell electricity abroad, electricity prices stay low. This results in almost all generation units bidding their operational costs (as capacity bids cannot exceed those). As these are the results that are expected with this configuration, the model works in an extreme value scenario.

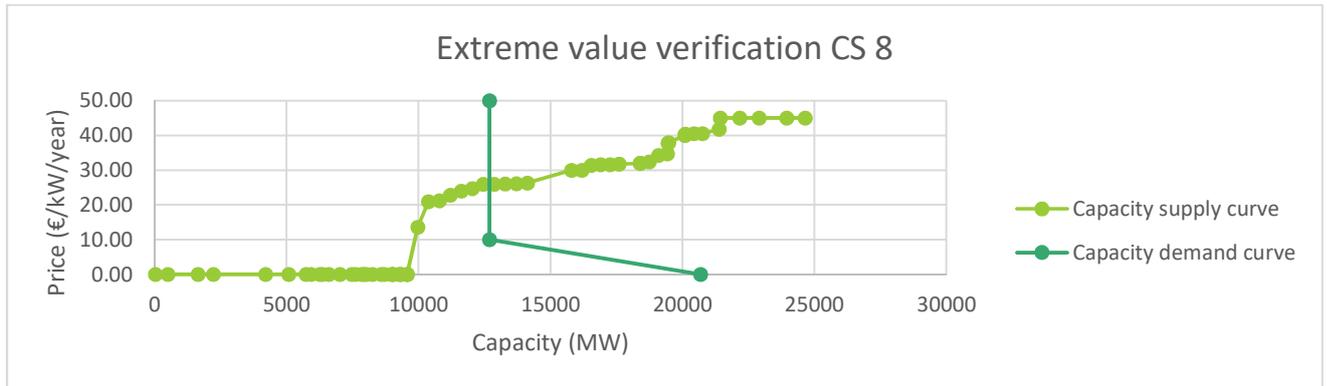


Figure 16: Missing money in extreme value scenario

4.6. Conclusion

This sections aims to summarize the most important conclusions from this chapter, after which an overview of the experiment design will be shown. In the model conceptualization, the original design of a CS market is considered. Because the hourly dispatch model is used to create data, some assumptions were made to make the design compatible in this model. This model assumes that the implementation of a capacity subscription market will change the electricity demand over time. Which design choices are most effective to reach this effect are considered out of scope for the model, but will be discussed in the discussion chapter of this thesis. This thesis aims to give insight in the impact of the CS market, and uses two additional variables: interconnectedness and the weather. The weather variable was chosen based on the literature review, which showed weather could be increasingly important in the electricity market. The variable of interconnectedness was chosen as preliminary results showed a big impact of interconnection. Expert feedback then suggested to add this variable to see the impact of the market in a more clinical scenario, without the ‘disturbance’ of interconnection.

In order to see the impact of the variables identified, being the implementation of the capacity subscription market, the weather, and interconnection, different scenarios are defined. An overview of the scenarios can be found in Table 8: Scenario overview and Figure 17: Scenario overview. The design variables used are the weather (Low = low RES output,

High = high RES output), the market (Energy-Only Market (EOM) or Capacity Subscription market (CS)), and interconnection (Business As Usual (BAU) or No Interconnection (NI)).

	Year	Market	Interconnection	Abbreviation
Scenario 1	Low	EOM	BAU	Low.BAU.EOM
Scenario 2	High	EOM	BAU	High.BAU.EOM
Scenario 3	Low	CS	BAU	Low.BAU.CS
Scenario 4	High	CS	BAU	High.BAU.CS
Scenario 5	Low	EOM	NI	Low.NI.EOM
Scenario 6	High	EOM	NI	High.NI.EOM
Scenario 7	Low	CS	NI	Low.NI.CS
Scenario 8	High	CS	NI	High.NI.CS

Table 8: Scenario overview

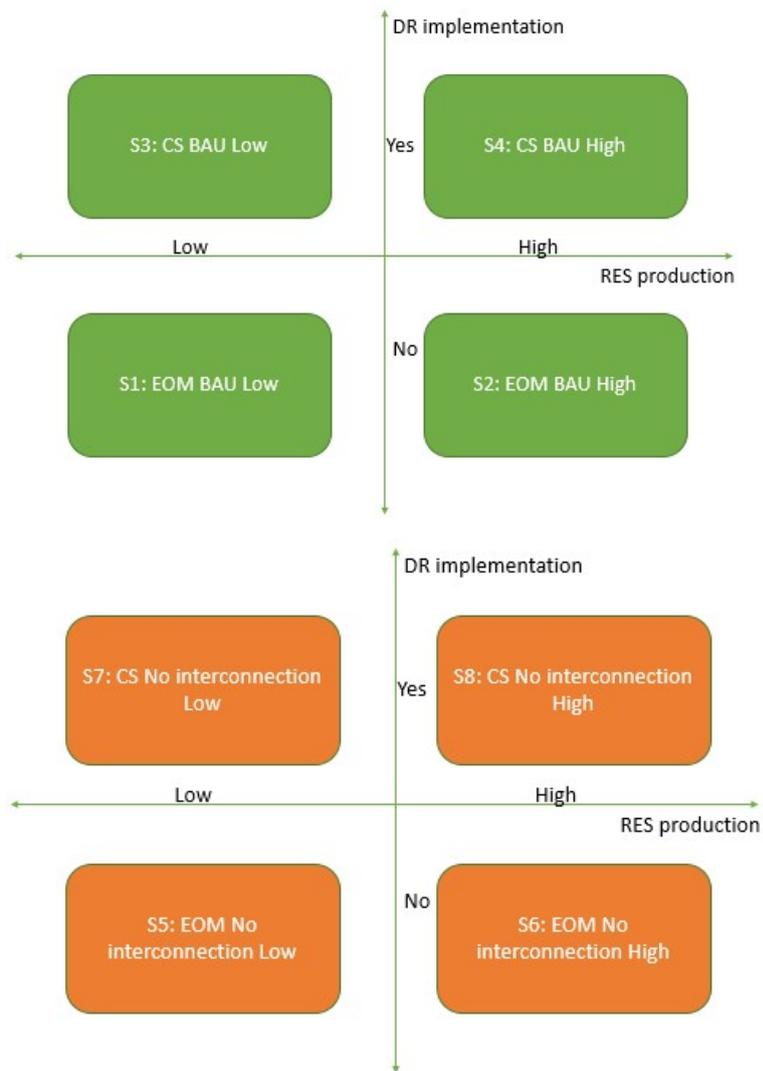


Figure 17: Scenario overview

5. Demonstration of the results

Based on the method discussed in chapter 4, this chapter presents the results. In the DSRM method, the demonstration phase is the execution of the artefact constructed in the design and development phase. Based on these results, the sub question “*What will the price of capacity be in a functioning capacity subscription market?*” will be answered. First, the four scenarios with interconnection (business as usual or BAU) will be presented. Second, the four scenarios without interconnection (no interconnection or NI) will be presented. After this, the verification and validation of the model and the results will be discussed. The last section will conclude by answering the sub question.

5.1. Results – BAU scenarios

An overview of the results from the BAU scenarios can be found in Table 9: BAU scenario results. The results will be discussed below. The plant profitability is based on the plants that can be found in Appendix 5: Model results.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Year	Low	High	Low	High
Market	EOM	EOM	CS	CS
Interconnection	BAU	BAU	BAU	BAU
Name	Low.BAU.EOM	High.BAU.EOM	Low.BAU.CS	High.BAU.CS
Variable Revenue EEX (M€)	€ 5.999	€ 6.501	€ 5.969	€ 6.435
Electricity price (€/MWh)	€ 47	€ 51	€ 46	€ 50
CS price (€/kw/year)	€ -	€ -	€ 17	€ 5
Fixed Revenue CS (M€)	€ -	€ -	€ 282	€ 82
CS Cost (€/MWh)	€ -	€ -	€ 2	€ 1
Missing money (M€)	€ 112	€ 125	€ -	€ -
Total (M€)	€ 6.110	€ 6.626	€ 6.251	€ 6.517
Total Cost (€/MWh)	€ 48	€ 52	€ 49	€ 51

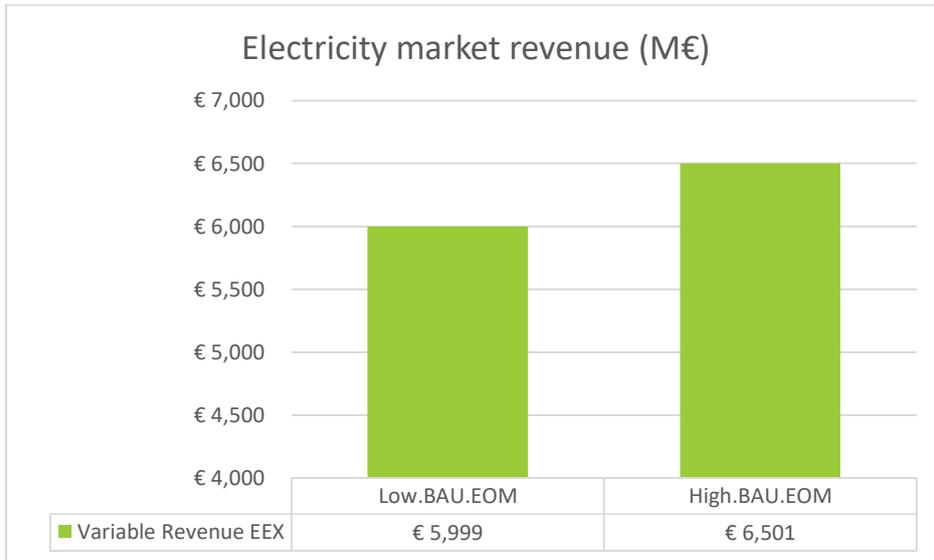
Table 9: BAU scenario results

5.1.1. The impact of the weather

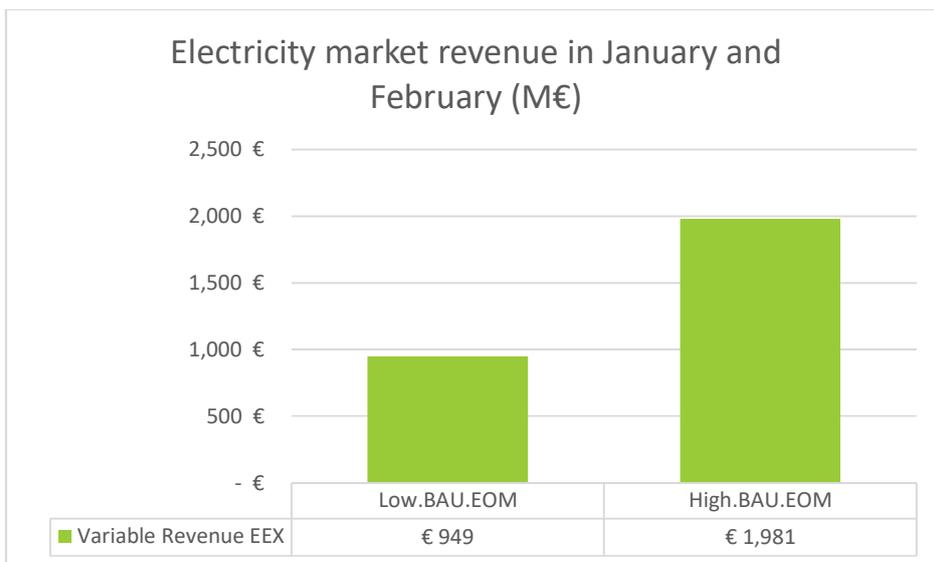
To estimate the impact of the weather, the difference on variable revenue on the EEX between the first two scenarios will be discussed. As can be seen, there is a difference of about ~500 million euros (Graph 2: Electricity market revenue Low.BAU.EOM &

High.BAU.EOMGraph 2: Electricity market revenue). This is a risk of approximately 8% of the total revenue. The outcome seems counterintuitive to the expectation. 'High' was a year with more renewable production. As renewables have lower marginal costs, this should push down the electricity price. Zooming in learns that this is mostly caused by the first two months of the year. During these months, the electricity price spikes up to the price cap (of €1000¹ euro) a total of 48 times in 'High', while this was only 3 times in 'Low'. The result of this many hours with a price cap is a result of an assumption that there will be a lack of investment in new capacity until 2030 at least. However, the difference between both years is most interesting, because this shows what a lack of investment can do to the difference in revenue over multiple years. The effect on total revenue can be found in Graph 3: Electricity market revenue Low and High in January and February. This shows how volatile and weather dependent electricity prices can become, especially in a tight market where shortages occur. This outcome is in line with the analysis from Green and Vasilakos (2011), who argue that there will be an increased amount of hours with extremely low prices, as well as an increased amount of hours with high prices.

¹ The €1000 is an EPSI model assumption, the price cap in the Netherlands is currently at €3000. The actual gains of less hours with a price cap would therefore be higher



Graph 2: Electricity market revenue Low.BAU.EOM & High.BAU.EOM



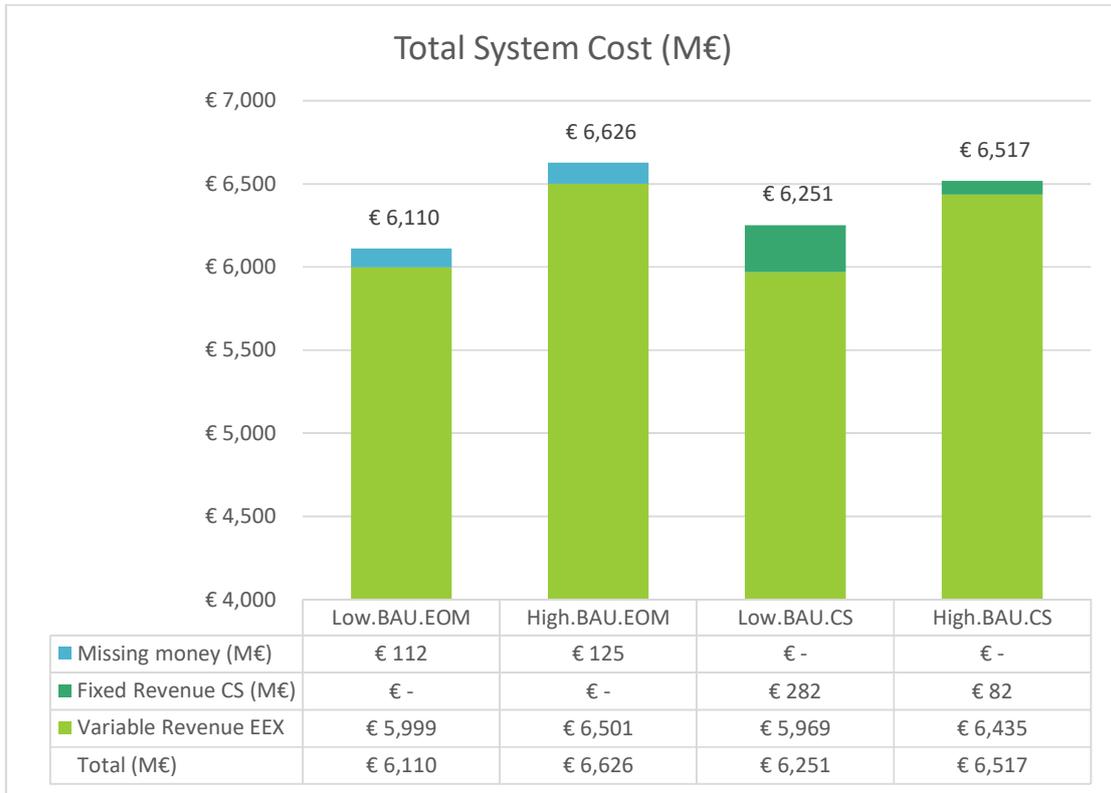
Graph 3: Electricity market revenue Low and High in January and February

5.1.2. The impact of capacity subscription

As can be seen in the table, the impact on revenues from the electricity market in both cases is slightly negative. Comparing the first and third scenario will show the difference that capacity subscription is expected to make in 'Low'. As can be seen, the price per MWh on the electricity market will be lower in a market with capacity subscription. This can be

explained by the increased demand response and the more efficient allocation of electricity during shortages. When including missing money and the cost of the capacity subscription market in the system cost, the scenario with a capacity market is slightly more expensive. However, an important difference between these scenarios is that in the market with capacity subscription, all generators that are needed for generation recover their operational costs, which would be sustainable on the long term. In the scenario with the energy-only market, the sum of missing money of generators that are needed is over 100 million euros. If these generators have similar results over multiple years, they are expected to shut down in the long term.

The total revenue from the electricity market is bigger in 'High'. In the energy-only market, the sum of missing money in 'High' is 125 million euros. In the scenario with capacity subscription, the cost for this market is lower than in 'Low', and combined with the lower revenue from the electricity market, this results in lower total system cost. This can be explained by the demand response that is triggered in the capacity subscription market. In this market, the residual demand peak is lower, which means a lower number of dispatchable generation units is needed. In addition, the units that are needed, are able to run for more hours, as the electricity demand is shifted to other moments in time. This results in a lower amount of missing money. The effect on affordability on short- and long-term will be further discussed in the next chapter. An overview of the system cost can be found in Graph 4: Electricity market revenue S1-S4.



Graph 4: Electricity market revenue S1-S4

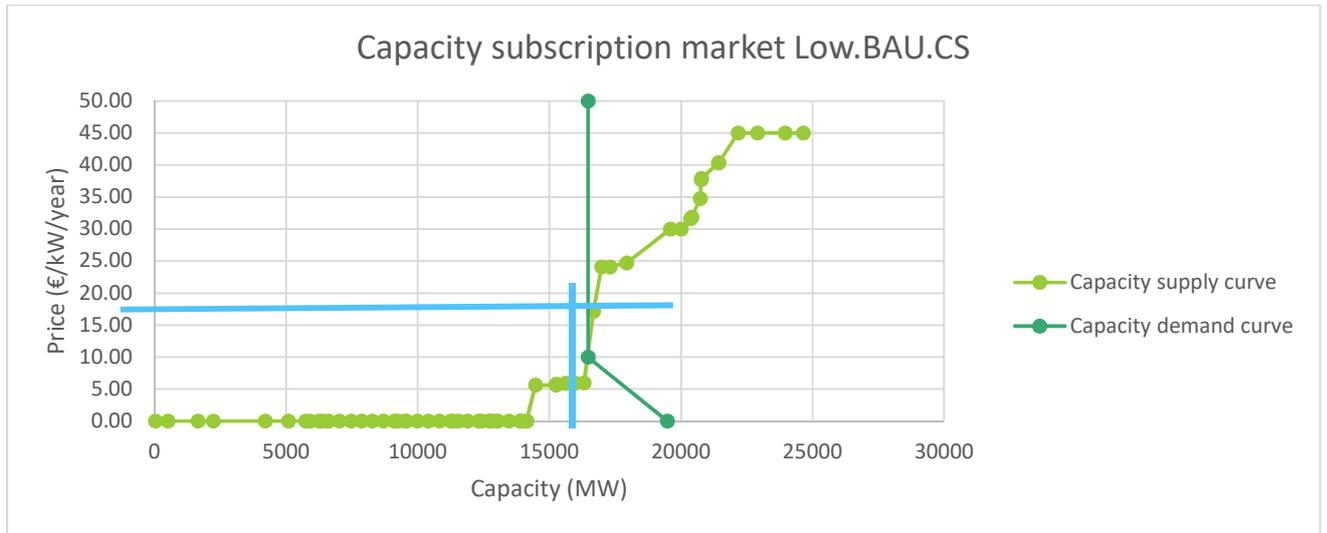
5.1.3. The difference on the CS market in different weather years

This section shall reflect on the difference of the CS market in different weather years. As can be seen in Graph 4: Electricity market revenue S1-S4, the cost of the CS market is more expensive in ‘Low’. This can be explained by the formula by which the costs for the CS market are calculated:

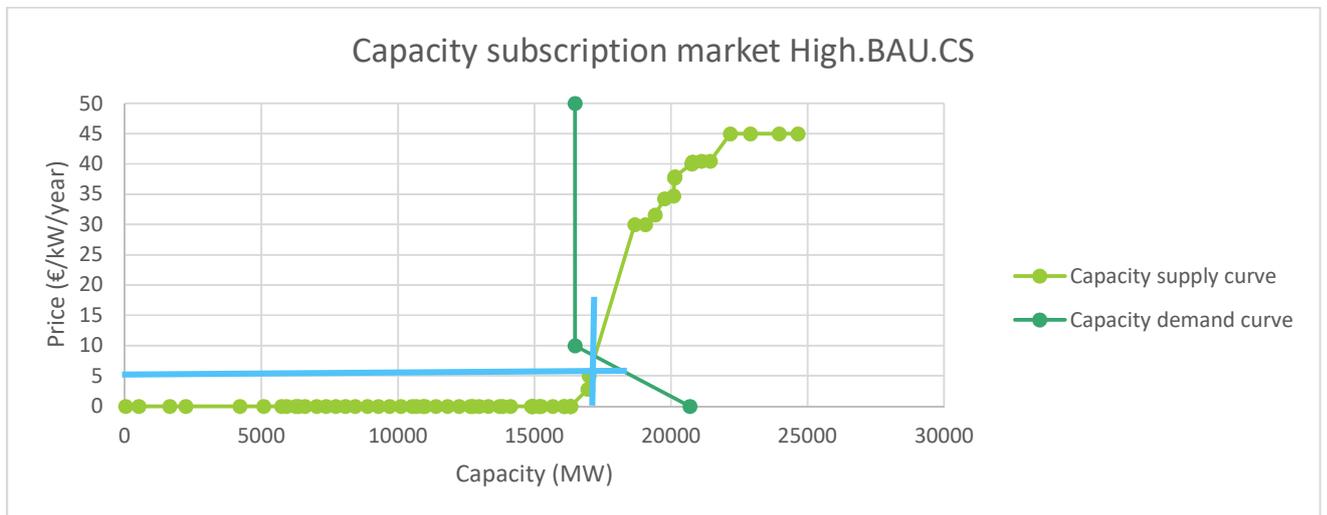
$$TC(CS) = RDP * MM(MP)$$

Because generators gain more revenue from the electricity market, the missing money from the marginal plant that is needed to produce the residual demand peak is lower (5 €/kW compared to 17 €/kW). Because the supply of capacity is so cheap, the graph intersects in the flexible part of the demand curve. Therefore, the residual demand peak is higher than the inflexible part of the demand peak. However, this higher peak is not big enough to compensate for the lower price (Graph 5: Capacity subscription market Low.BAU.CS,

Graph 6: Capacity subscription market High.BAU.CS). Comparing these results to literature, these results are realistic. The capacity market in the UK cleared at prices between 25 and 8 £/kW/year. The French supplier obligation market has had prices around 10 €/kW/year (Bloomberg New Energy Finance, 2018; Grubb & Newbery, 2018).



Graph 5: Capacity subscription market Low.BAU.CS



Graph 6: Capacity subscription market High.BAU.CS

5.2. Results – No interconnection scenarios

To determine the impact of interconnection, all scenarios are compared. First, the difference between a base case scenario (S1) and the same scenario without interconnection (S5) will be discussed. Then, the impact of the weather and the capacity subscription market will be reviewed, and compared to the situation with interconnection. The results of the NI scenarios can be found in Table 10: NI scenario results.

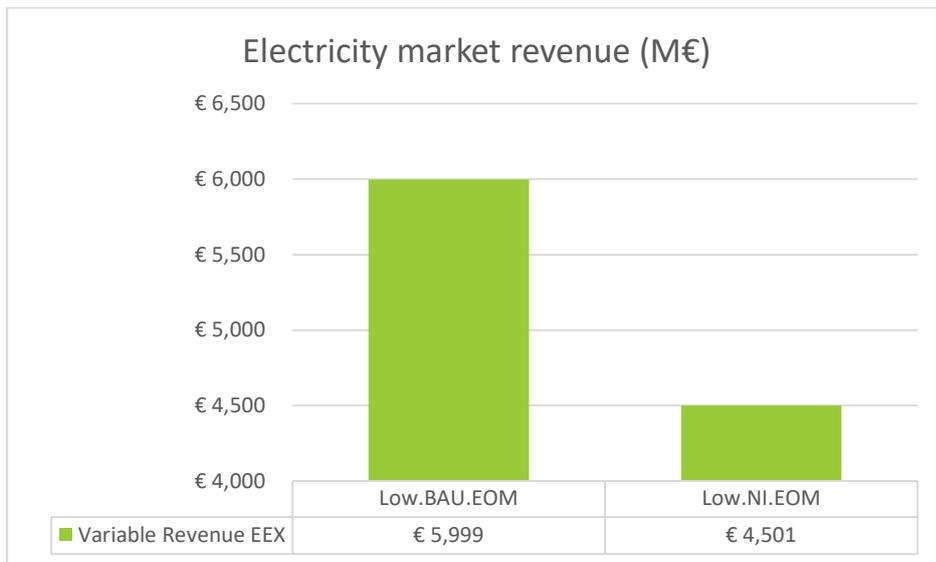
	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Year	Low	High	Low	High
Market	EOM	EOM	CS	CS
Interconnection	NI	NI	NI	NI
Name	Low.NI.EOM	High.NI.EOM	Low.NI.CS	High.NI.CS
Variable Revenue EEX (M€)	€ 4,501	€ 4,724	€ 4,464	€ 4,384
Electricity price (€/MWh)	€ 35	€ 37	€ 35	€ 34
CS price (€/kw/year)	€ -	€ -	€ 30	€ 30
Fixed Revenue CS (M€)	€ -	€ -	€ 494	€ 494
CS Cost (€/MWh)	€ -	€ -	€ 4	€ 4
Missing money (M€)	€ 257	€ 290	€ -	€ -
Total (M€)	€ 4,758	€ 5,015	€ 4,958	€ 4,878
Total Cost (€/MWh)	€ 37	€ 39	€ 39	€ 38

Table 10: NI scenario results

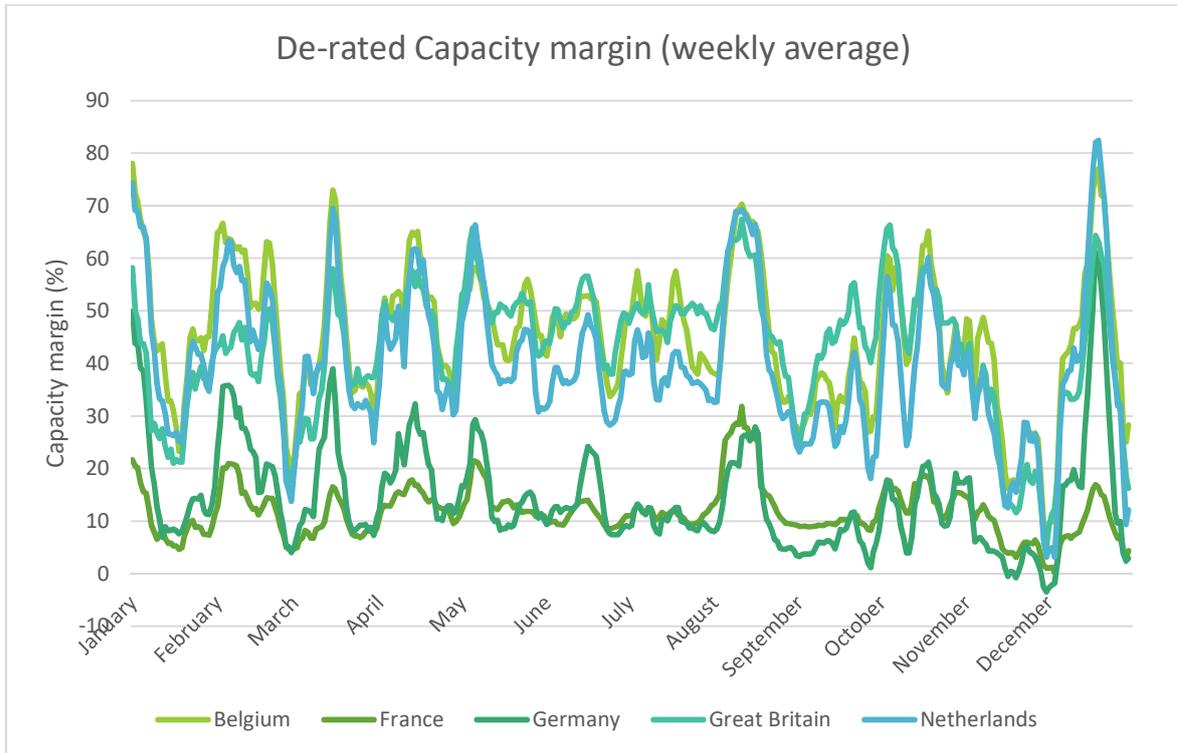
5.2.1. The impact of interconnection

The first thing that occurs, is that revenue is a lot lower in a scenario without interconnection (Graph 7: Electricity market revenue Low.BAU.EOM & Low.NI.EOM). This can be explained by the overcapacity in the Netherlands. The capacity of the Netherlands is mostly above 100%, meaning it produces more electricity than it consumes (Graph 8: Capacity margins in ‘Low’). Therefore, the Netherlands generally exports electricity, which raises the electricity price. If interconnection is taken away, this is no longer possible, keeping the electricity price lower. This also means that more shortages would occur in neighboring countries when interconnection would be taken away. This is in line with the economic theory on market coupling, and with results from literature. Lise, Hobbs & Hers (2008) show that increasing interconnection will result

in lower prices overall, but higher prices in the countries that have relatively low prices before interconnection was added. Lastly, the effect of interconnection is that the sum of missing money is a lot higher. Because generators are unable to sell their electricity abroad, their production, and thus profits, are lower. In the scenarios with a capacity market, the cost of this market are considerably higher than the scenarios with interconnection. This is a direct result of the increased missing money per plant.



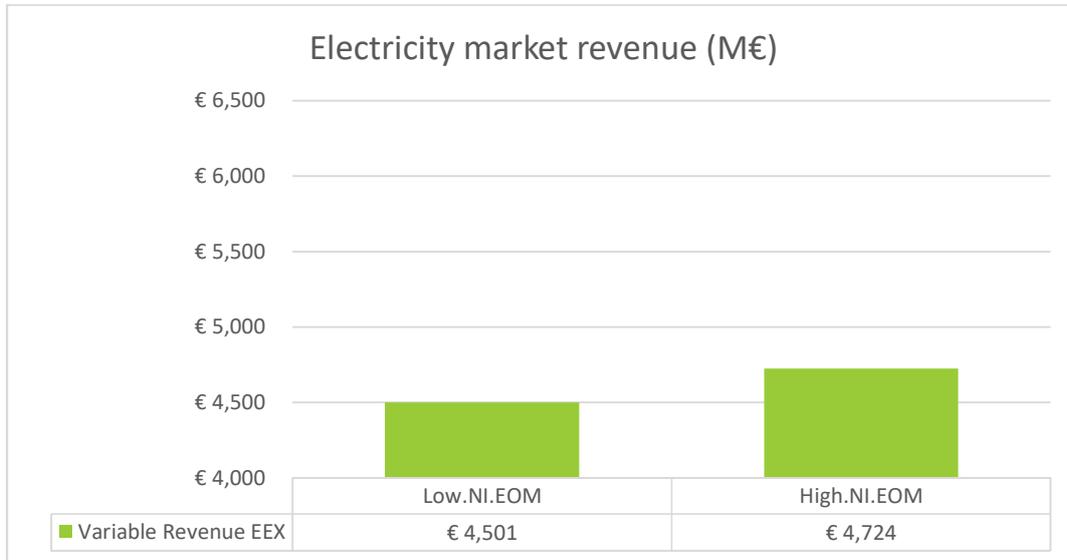
Graph 7: Electricity market revenue *Low.BAU.EOM* & *Low.NI.EOM*



Graph 8: Capacity margins in 'Low'

5.2.2. The impact of the weather

In the scenarios with no interconnection, a similar outcome emerges between the different weather years. The revenue from the electricity market is higher in 'High', with a difference compared to 'Low' of approximately 220 million euros (Graph 9: Electricity market revenue Low.NI.EOM & High.NI.EOM). These results are contrary to those of Cutler et al. (2011), who found an inverse relationship between wind generation and price. However, this again can be explained by the low wind generation during the winter months, causing many hours of shortage, and thereby skewing the total revenue of the 'High' scenario over the 'Low' revenue (see Graph 3: Electricity market revenue Low and High in January and February).

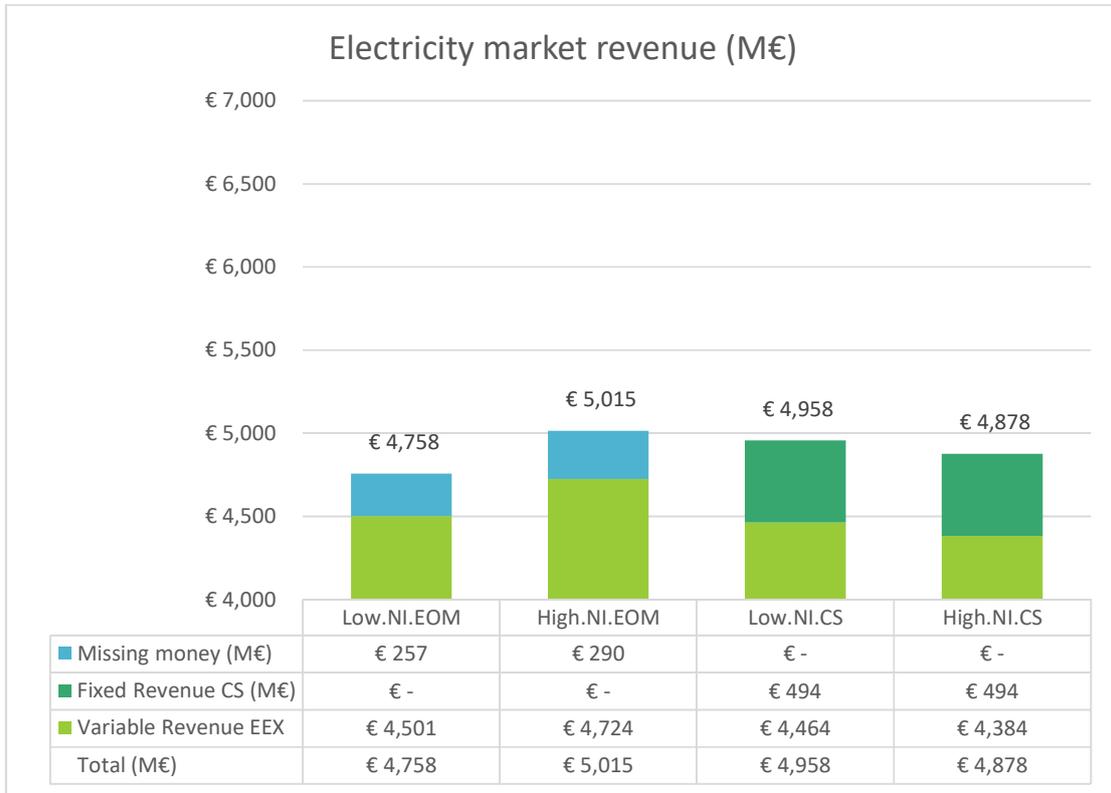


Graph 9: Electricity market revenue *Low.NI.EOM* & *High.NI.EOM*

5.2.3. The impact of capacity subscription

The impact of the CS market is quite different in a market with no interconnection. First of all, the revenue from the electricity market goes down for both years (Graph 10: Electricity market revenue S5-S8). This is because the effect of the capacity market now does not leak away to neighboring countries. By shaving the demand peak, there is less consumption of electricity during expensive hours, and the occurrence of shortages decreases (Table 11: Number of shortage hours S5-S8).

Second, the total revenue is more stable in the scenarios with a capacity subscription market. Where the difference between the two EOM scenarios is more than 250 million euros, the revenues from the CS scenarios are almost equal. This is because that in general a higher revenue from the energy market results in lower missing money, and thus a cheaper price for capacity. Also, the revenue from the CS market provides less overall risk, as this will be determined beforehand, while revenues from the electricity market cannot be predicted very well.



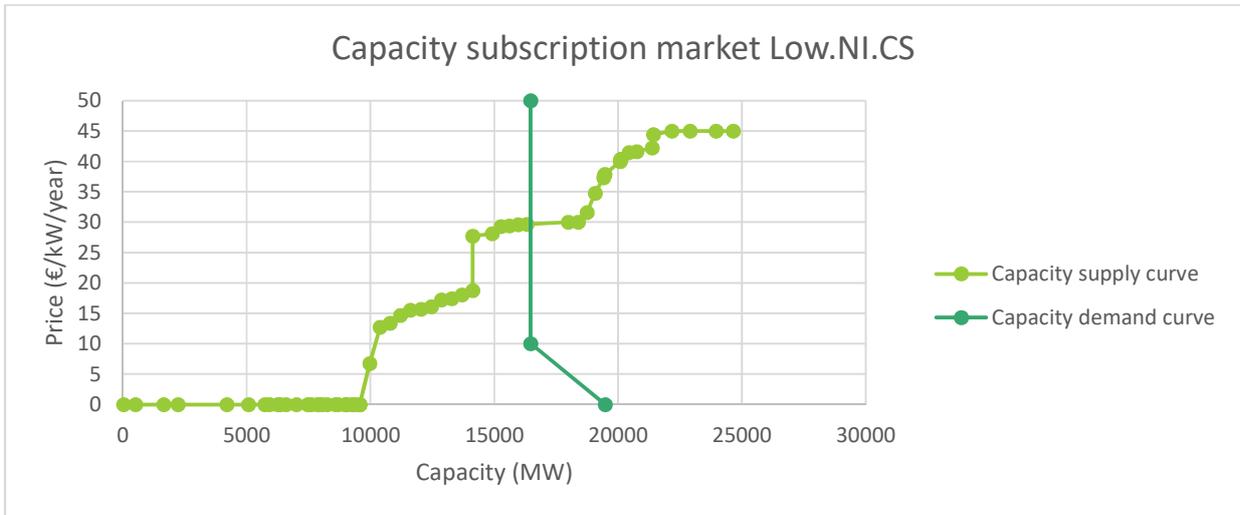
Graph 10: Electricity market revenue S5-S8

	Scenario 5	Scenario 6	Scenario 7	Scenario 8
# times price cap	3	23	1	4

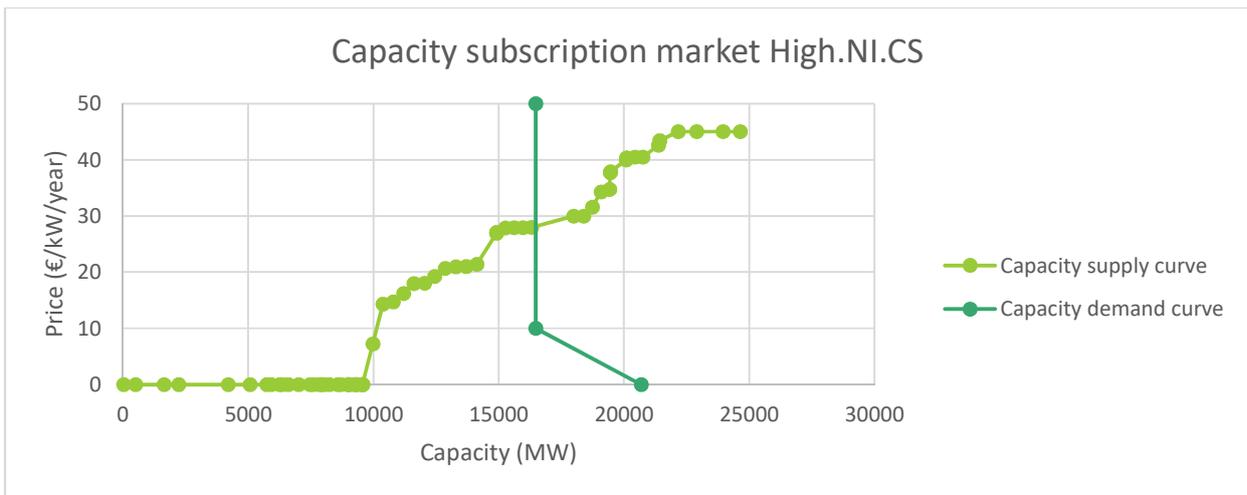
Table 11: Number of shortage hours S5-S8

5.2.4. The difference on the CS market in different weather years

There is little difference between the missing money in both CS scenarios. The difference can be explained by the higher renewable energy output. This causes more revenue to end up at wind and solar production units, and less at the dispatchable generation. The CS market revenue is the same for both scenarios, as they have the same residual peak demand, and the same price for the marginal plant that is needed to reach this residual peak demand. The price of the marginal plant is the same in both scenarios (30 €/kW/year) (Graph 11: Capacity subscription market Low.NI.CS, Graph 12: Capacity subscription market High.NI.CS).



Graph 11: Capacity subscription market Low.NI.CS



Graph 12: Capacity subscription market High.NI.CS

5.3. Conclusions and answering the sub question

The results of the scenarios lead to some expected, and some unexpected conclusions. First, the sub question of this chapter, “*What would be the price of capacity in a functioning capacity subscription market?*” will be answered. Then, the most important arguments that led to this conclusion will be elaborated.

To answer the sub question of this chapter, the four scenarios with a CS market are used. In this context, only existing capacity is taken into account. The next chapter shall reflect on the impact new build capacity would have on the capacity market. While companies might not cover their CAPEX, it is expected that in a capacity market, they will not bid higher than their OPEX, meaning prices will likely not exceed 40 €/kW/year, which are the approximate fixed cost of a gas turbine. In the scenarios used, the price per kW per year is between 5 and 30 euros. These prices are in the same order of magnitude as other capacity mechanisms in the UK and in France.

In the future electricity market, the weather will have a large impact on revenues. In months with low renewable energy production, electricity prices will go up, even to the price cap for multiple hours, if the capacity margin is too low. When renewable energy production is high, electricity prices can become zero for multiple hours or days. This variability increases risk for electricity producers, as they are less able to predict their revenue in advance.

The Netherlands is a net exporting country, meaning it exports more electricity than it imports. This has a price increasing effect in the Netherlands, meaning the electricity prices would be lower on the short term if the Dutch market was disconnected from the North European grid. However, the disconnection would have a negative effect on the long term, as even more generators would not be able to cover their operational costs. On the long term, more interconnection will enable increased competition and therefore a more efficient market (Woo et al., 2003).

6. Evaluation

The evaluation phase in the DSRM method is about the contribution of the results to the solution of the problem. In this chapter, the third sub question “*What is the impact of capacity subscription on the electricity market?*” will be answered. The answer will be given by interpreting the results of chapter 5 in the context of the KPI’s from chapter 3. The results of the metrics for KPI’s affordability, sustainability and reliability will be presented in the first three sections. The fourth section will discuss the constraints set by the EU, and the fifth part will reflect on the impact on different types of stakeholders. Lastly, the results of this paper will be evaluated in the light of economic theory on electricity markets.

6.1. Impact on affordability

To determine the impact on the affordability of the system, the following indicators were identified:

- The average electricity price (€/MWh): the average electricity price over the considered period
- The average cost to consumers of the capacity market (€/MWh): the cost incurred by consumers for contracting the mandated capacity credits from the capacity market, divided by the total units (MWh) of electricity consumed
- The total average cost to consumers (€/MWh): the sum of the electricity price, the cost from the capacity market and the cost of missing money.

The outcomes per scenario can be found below in Table 12: Electricity affordability S1-S4 and Table 13: Electricity affordability S5-S8. Based on these numbers, the conclusion can be drawn that on the short term, the implementation of a capacity subscription market will slightly increase the cost per MWh. In the BAU scenarios this effect is about 4%, while the scenarios without interconnection show a range between -2 and 4%. This price increase would be on average, calculated by dividing the total system cost of the capacity market over the total amount of electricity consumed. However, it is not as simple just comparing the total system cost. Where the CS scenarios are theoretically possible, the EOM scenarios assume that it is possible to compensate the generators that are at a loss for the exact amount of money that they lose per year. In the actual EOM, it would be more realistic that

generators that lose money every year are closed down, resulting in a higher electricity price. Compared to the capacity market in the UK, capacity subscription has two other impacts. Because capacity subscription is consumer-based, there is less chance for overcapacity, as in the UK system, the government is responsible for the security of supply, instead of the consumer themselves. Because consumers or their suppliers are expected to be better in valuing their own value of adequacy, the system is expected to be more efficient. On the other hand, the system of the UK is expected to give more certainty to investors, as the government can take on 15-year contracts with producers who are building new capacity (Grubb & Newbery, 2018).

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Year	Low	High	Low	High
Market	EOM	EOM	CS	CS
Interconnection	BAU	BAU	BAU	BAU
Name	Low.BAU.EOM	High.BAU.EOM	Low.BAU.CS	High.BAU.CS
Variable Revenue EEX (M€)	€ 5.999	€ 6.501	€ 5.969	€ 6.435
Electricity price (€/MWh)	€ 47	€ 51	€ 46	€ 50
CS price (€/kw/year)	€ -	€ -	€ 17	€ 5
Fixed Revenue CS (M€)	€ -	€ -	€ 282	€ 82
CS Cost (€/MWh)	€ -	€ -	€ 2	€ 1
Missing money (M€)	€ 112	€ 125	€ -	€ -
Total (M€)	€ 6.110	€ 6.626	€ 6.251	€ 6.517
Total Cost (€/MWh)	€ 48	€ 52	€ 49	€ 51

Table 12: Electricity affordability S1-S4

	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Year	Low	High	Low	High
Market	EOM	EOM	CS	CS
Interconnection	NI	NI	NI	NI
Name	Low.NI.EOM	High.NI.EOM	Low.NI.CS	High.NI.CS
Variable Revenue EEX (M€)	€ 4,501	€ 4,724	€ 4,464	€ 4,384
Electricity price (€/MWh)	€ 35	€ 37	€ 35	€ 34
CS price (€/kw/year)	€ -	€ -	€ 30	€ 30
Fixed Revenue CS (M€)	€ -	€ -	€ 494	€ 494
CS Cost (€/MWh)	€ -	€ -	€ 4	€ 4
Missing money (M€)	€ 257	€ 290	€ -	€ -
Total (M€)	€ 4,758	€ 5,015	€ 4,958	€ 4,878
Total Cost (€/MWh)	€ 37	€ 39	€ 39	€ 38

Table 13: Electricity affordability S5-S8

6.2. Impact on sustainability

While a capacity subscription market will enable the implementation of large-scale renewable energy systems, the goal of this market intervention is to improve the affordability and reliability of the system. However, it should be evaluated how this market will change the amount of emissions. The outcomes show that while CO₂-emissions do not change significantly, there is a difference in revenue changes for dispatchable generation on one side, and renewable energy systems on the other side. Where dispatchable generation is able to attract additional revenue from the capacity subscription market, there is little impact on the revenue of renewable energy systems. The paragraphs below will elaborate on these outcomes.

As discussed in section 4.1.4, the market can be adjusted to give extra incentives towards sustainable capacity, for example by a maximum or a de-rating factor for carbon intensity. In the model used, no capacity was excluded from the supply side. The results below will thus show how the CS market, without extra sustainability measures, influence the CO₂-emissions. As can be seen in Table 14: CO₂-emissions S1-S4 and Table 15: CO₂-emissions S5-S8, there is very little difference in CO₂-emissions between the scenarios with and without the CS market.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Sustainability (kt CO2)	21347	19248	21342	19198

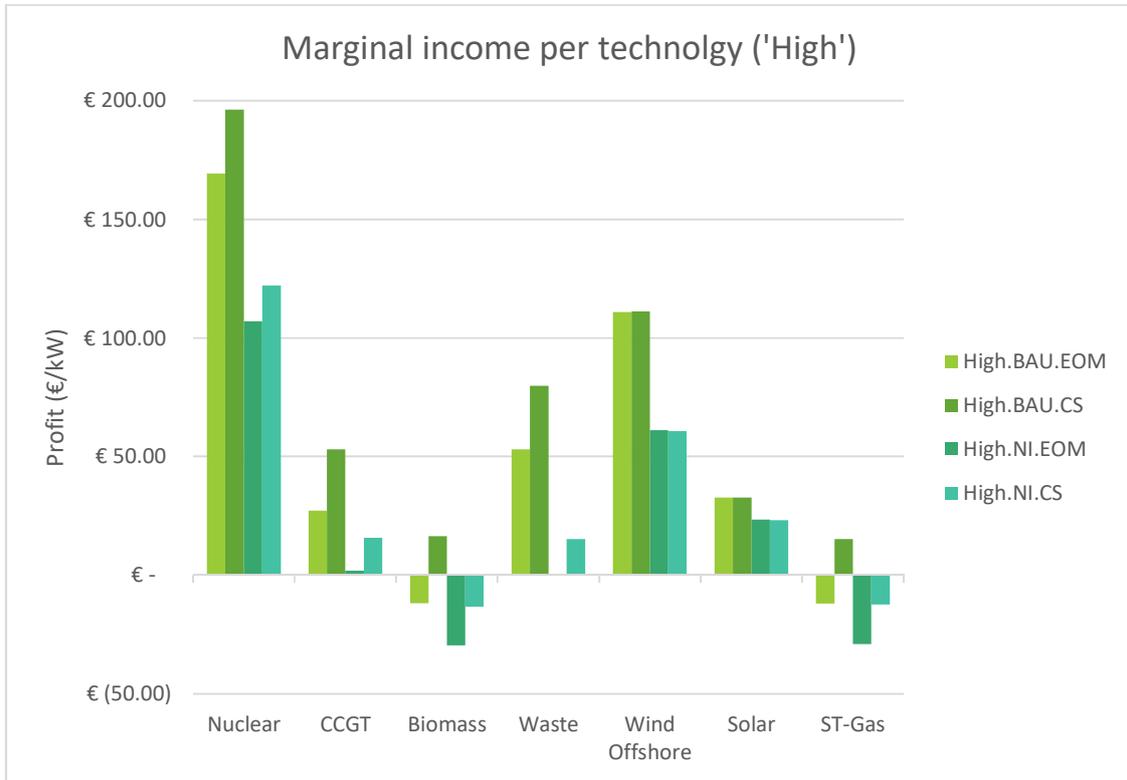
Table 14: CO₂-emissions S1-S4

	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Sustainability (kt CO2)	19706	18514	19704	18501

Table 15: CO₂-emissions S5-S8

However, as can be seen in Graph 13: Plant profit for different technologies in ‘High’, the income per technology would change considerably. For baseload plants, like nuclear, waste, and biomass, the income from the electricity market goes slightly down, while the total profit increases. The latter one even shows negative figures in the energy only market, and makes a profit with the capacity subscription market. The peak load plants, the gas powered steam turbine and the CCGT plant, both lose revenue from the EEX, while the total profits increase. Both the biomass and the ST-Gas plant lose money in the energy-only market, while making a profit with CS. This makes it less likely that the plants close down, which results in a higher long term reliability.

The impact on RES is very limited. This makes sense, because RES have the lowest marginal costs and will therefore almost always run if the weather conditions allow it. There are two forces that can explain this stable electricity price. The first force is that of price peaks. Because demand is shifted away from the peaks, price peaks occur less often. Although this reduces income for all electricity producers, it has the least impact on RES, because the hours with high residual demand, are hours where renewable energy production is low. This demand is then shifted towards other hours, which drives the prices up for those hours. And these hours in their turn have higher renewable output. This is the second force, with drives up the income for RES.



Graph 13: Plant profit for different technologies in 'High'

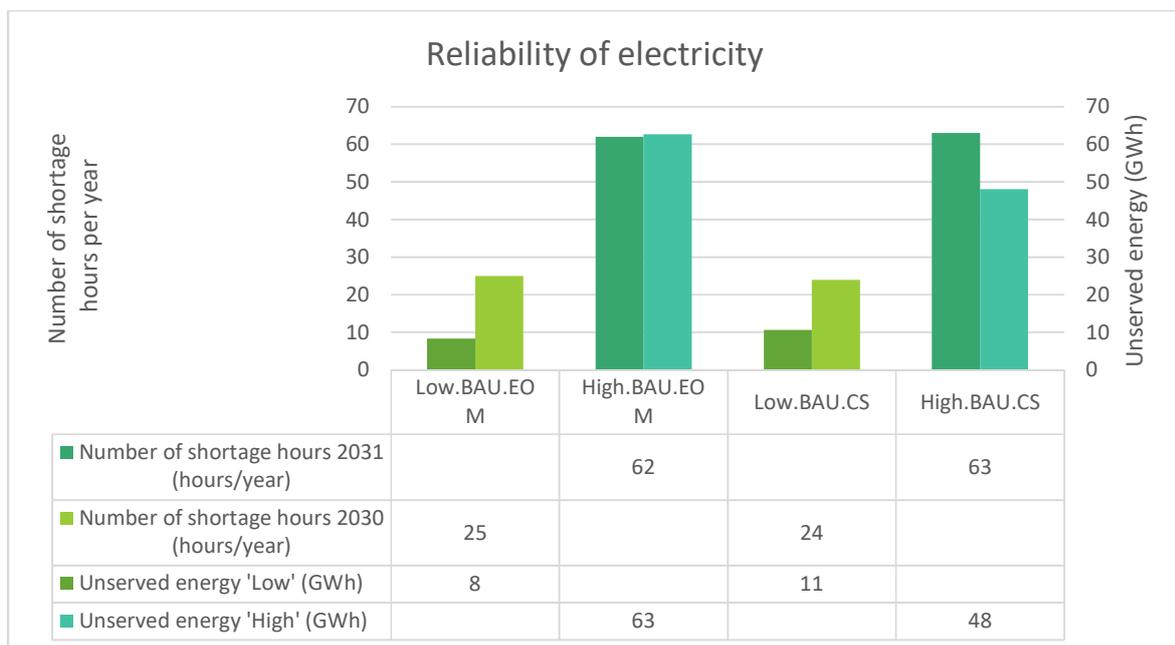
6.3. Impact on reliability

This CS system is designed to increase reliability. This chapter shall reflect if this impact can be found in the results. As this section will show, this will largely depend on the design of the system. In general, the results show that reliability is improved with the implementation of a CS market. The CS market provides decreased risk for investors by two means. First, a part of the variable income from the electricity market is replaced by a fixed income from capacity subscription. Second, it decreases demand uncertainty as it gives a clear signal to the market which capacity is required. The impact on risk is further discussed in section 6.5.3. To measure the impact on general system reliability, the following KPI's were identified:

- The number of shortage hours (hours/year): the average number of hours per year with scarcity prices, and the amount of unserved energy (GWh/year)
- The de-rated capacity margin (MW/MW): the ratio of available supply over peak demand

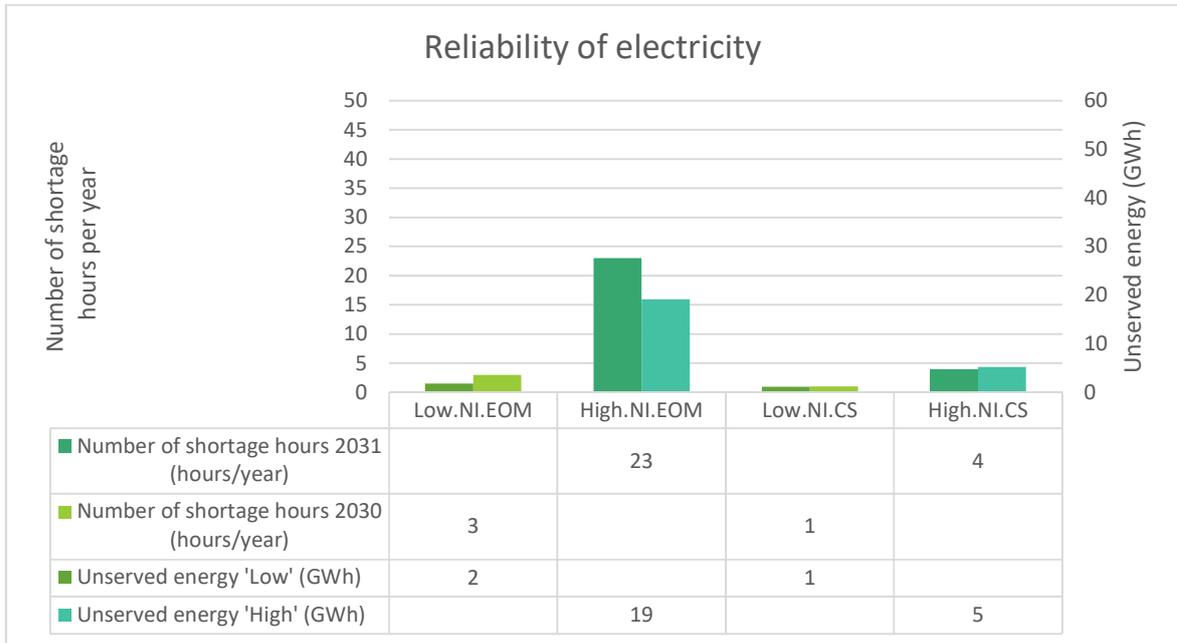
- Import / Export (GWh/year)

The results of the first KPI can be found in Graph 14: Reliability of electricity in S1-S4 and Graph 15: Reliability of electricity in S5-S8. As can be seen, the indicators for reliability do not change considerably in the scenarios with interconnection. This means that capacity subscription does not improve the reliability if no additional measures are taken to prevent the electricity to flow abroad during times of shortage.



Graph 14: Reliability of electricity in S1-S4

In the scenarios without interconnection however, the overall reliability is higher in scenarios with a capacity subscription market. The number of hours with shortage and the amount of unserved energy is decreased by half in 'Low'. In 'High', this effect is even larger, where the number of hours with shortages decreases from 23 in the energy-only market to 4 in a market with capacity subscription. The amount of unserved energy is also decreased by almost 75%.

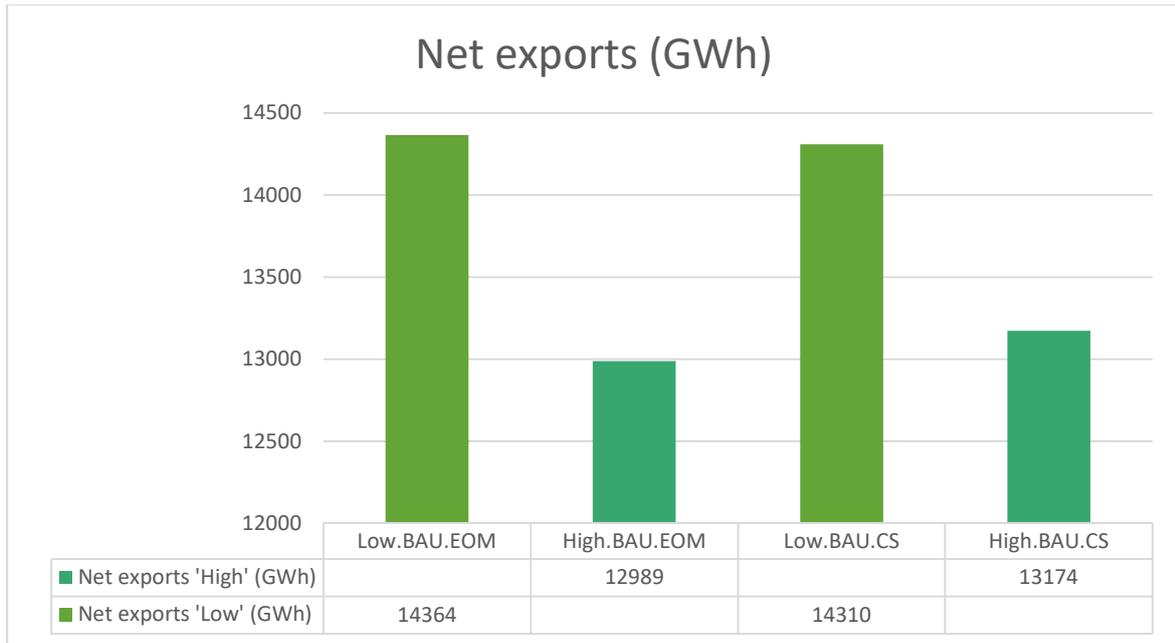


Graph 15: Reliability of electricity in S5-S8

The difference between the scenarios with and without interconnection show how much impact the neighboring countries have on the Netherlands. This seems contrary to economic theory. Interconnection increases the number of suppliers and consumers, so it should improve competition and decrease prices. Newbery (2016) shows that interconnection improved the reliability of the UK power system. However, as Höschle (2016) remarks, interconnection can sometimes have a negative effect on the net exporting country. In this experiment, this is the case when a shortage occurs abroad, this effect can spill over to the Netherlands.

The other KPI's: capacity margin and net exports, show no significant differences between the scenarios with and without CS (see Graph 16: Net exports S1-S4, Graph 17: De-rated capacity margin S1-S4, and Graph 18: De-rated capacity margin S5-S8). However, the annual results on export do not show at which time this export takes place. As discussed in chapter 5, reliability was negatively impacted by interconnection. In depth analysis of the export data show that the amount of export increased during hours of shortage in the scenarios with capacity subscription. This is because when the demand response from capacity subscription

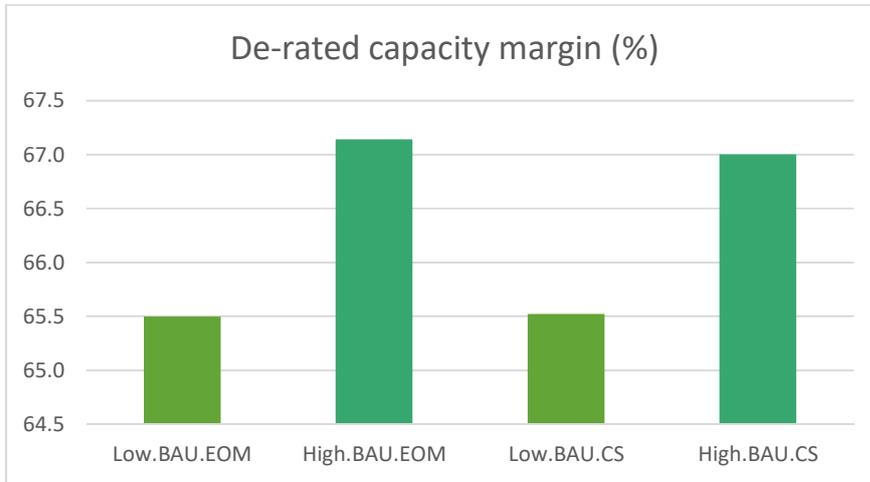
in the Netherlands is triggered, the capacity that becomes available will immediately be exported, as there is still a shortage abroad. The total export does not increase, because the Dutch demand that was shifted, is moved to a different time, at which the amount of export will decrease. So while the demand shifts away from the shortage, the price peak is not prevented (see Table 16: CS market effect on exports).



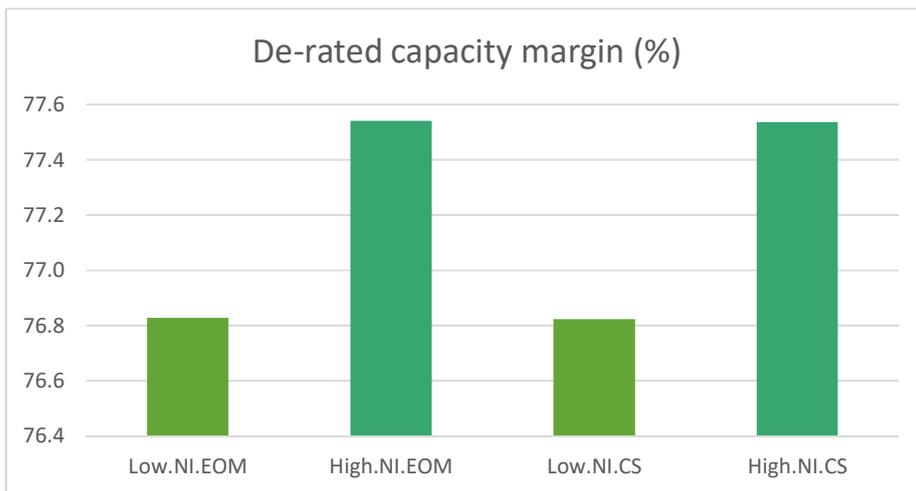
Graph 16: Net exports S1-S4

High.BAU.EOM	Demand	Net exports	System Marginal Price	High.BAU.CS	Demand	Net exports	System Marginal Price
Units	GW	GW	€/MWh		GW	GW	€/MWh
21-01-2031 05:00	15.5	0.5	84		16.9	-0.6	94
21-01-2031 06:00	18.2	5.7	1000		16.9	5.7	1000
21-01-2031 07:00	19.9	-1.6	1000		16.9	1.3	1000
21-01-2031 08:00	20.2	-1.2	1000		17.6	1.3	1000
21-01-2031 09:00	20.2	-0.2	1000		18.7	1.3	1000
21-01-2031 10:00	20.1	2.2	1000		19.7	2.9	1000
21-01-2031 11:00	19.8	0.5	94		20.2	0.5	94

Table 16: CS market effect on exports



Graph 17: De-rated capacity margin S1-S4



Graph 18: De-rated capacity margin S5-S8

6.4. European capacity market constraints

As discussed in chapter 3, the European Commission has formulated constraints for capacity mechanisms applied in Europe. Based on the results, each of these constraints will be discussed in a separate paragraph.

Analysis of generation adequacy has to correspond with the ENTSO-E forecast for generation adequacy. CS is designed to support long term capacity. ENTSO-E and TenneT both identified that shortages can occur in the Netherlands from 2025 (Entso-E, 2017;

Tennet, 2017). By creating an extra market layer to support generation adequacy, generators have a lower price risk, and are expected to stay in the market longer. In addition, when adequacy goes down, the price for capacity goes up, and new capacity can enter before an actual shortage appears.

The necessity of the capacity mechanism must be demonstrated. The literature study showed the financial forces of renewables that drive dispatchable generation out of the market. This demonstrates a possible shortage when there is an ever larger penetration of renewable energy systems.

The capacity mechanism should be technology-neutral. In this thesis, abroad capacity was not taken into account. Apart from that, all firm capacity was considered in the capacity subscription market. As the European commission mentions, non-neutrality will cause inefficiencies. The sustainability target, that excludes coal plants from capacity mechanisms, can be seen as a market imperfection, as it drives up the price and causes overinvestment.

The measure must be proportional. By definition, capacity subscription ensures that only the amount of generation is contracted that there is demand for. Thereby, the adequacy is optimized for demand. Over- or underinvestment would be caused by respectively risk aversion and risk taking of consumers.

The measure must have an incentive effect. By design, capacity subscription incentivizes both supply and demand to provide flexibility at the right time. Consumers pay to consume and suppliers are paid to supply at times of shortage. These incentives should lead to optimal investment.

The mechanism should avoid undue negative effects on competition and trade. The effect on competition and trade is unknown based on the results of this research.

6.5. Impact on different stakeholders

The impact on stakeholders will be based upon the outcomes of the previous parts of the chapter. First, a calculation example will be discussed to provide context in the other paragraphs. Then, the results will be interpreted in the context of electricity producers, suppliers, small consumers and industrial consumers.

6.5.1. Calculation example

This section is meant to give the order of magnitude of financial changes that can be expected. This way, behavior can be predicted. The results from chapter 5 show a price for capacity between 5 and 30 €/kW. This price will fluctuate with the under- or overinvestment. For this example, the higher end of the spectrum is chosen. Assuming that a single consumer cannot influence the price of the auction, the cost would be 30€/kW/year. Now, this has to be compared to the value of lost load. Therefore, it is relevant to know how often the amount of shortages take place per year. Say, these type of shortages happen once a year, for 55 hours (Pelka, 2018). If an electric steel plant has a peak demand of 100 MW (Breitschopf et al., 2015), and it would subscribe to this peak, it would pay $100 \text{ (MW)} * 1000 \text{ (kW/MW)} * 30 \text{ (€/kW)} = \text{€ } 3.000.000 / \text{year}$. Shutting down the plant during shortages would save 3 million euros. Value of Lost Load of industrial processes is estimated at 5€/kWh(Castro, Faias, & Esteves, 2016; Leahy & Tol, 2011). It would cost the plant $5 * 1000 * 100 = \text{€}500.000$ euro per hour to shut down. This means that if there is shortage for more than 6 hours, it will be economically viable to pay for the required peak demand. However, there is a third option: if the company uses forecasting and smart electricity management, and by those means is able to temporarily shave its peak by 10% without losing production value, it does not have any economic damages, and would save $10 \text{ (MW)} * 1000 \text{ (kW/MW)} * 30 \text{ (€/kW)} = \text{€ } 300.000 / \text{year}$.

6.5.2. Electricity producers

For electricity producers, three main effects are discussed. First, the difference between types of producers is discussed. In the second paragraph, the impact on price stability and risk is considered. The last paragraph will get into operational and capital costs and what these mean for the capacity subscription market.

The impact on electricity producers will be different for every type of producer. First of all, the results show that the revenue from the electricity market will decrease, while there will be new revenue in the CS market. However, not all producers can capture this new revenue (completely). While dispatchable generators can receive revenue for their full capacity, batteries and RES cannot. However, as flexibility will be rewarded, in general the business

case for batteries will improve. And, as section 6.2 showed, there is little effect on RES revenues.

The most important impact on electricity producers has to do with price stability and risk. The CS market decreases the risk for electricity producers, because the amount of price peaks will decrease. In addition, there will be a steady income stream from the CS market, with a price per kW per year independent of power output. Therefore, the income of generators will become more predictable. The results show that total revenue will be more stable between different weather years when a capacity subscription market is implemented. This advantage does not apply to electricity suppliers of renewable electricity, but as seen in 6.2, the effect on wind and solar generation is expected to be low.

As discussed, the values in the model are based on operational costs, which are necessary to keep current generation units operational. This makes economic sense if the plant is already there, because then it is more profitable to remain operational as compared to shutting down. However, when regarding new capacity, it is important to look at capital expenditures as well. Recent publications by the Energy Information Administration (EIA) show capital costs for natural gas plants at 895 \$/kW (802 €/kW) (Eia, 2018). Dividing this over the life time of an average gas plant (30 years), this results in capital costs of 27 euro/kW/year. This means the price for capacity could go up to approximately 57 euro/kW during years with capacity scarcity. This is a very rough estimation. While business cases of electricity plants are a lot more complex, this does give the order of magnitude to which the price for capacity could rise at most.

6.5.3. Electricity suppliers

This section will reflect on the impact on electricity suppliers. These companies are in between the wholesale market, where they buy electricity, and small consumers like households or small businesses. Because the electricity suppliers are in between, they would need to buy the peak capacity for all their customers. In turn, they can then choose how to recover these extra costs. This means that, with the CS market, electricity suppliers will get another market to trade in. It will provide benefit to suppliers to develop technologies and applications that increase the flexibility of their consumers. Of course, when their customers

all lower their peak demand during shortages, the supplier is able to subscribe to less capacity. In turn, they will have to compensate the consumers that are shifting their demand. A workshop conducted at Eneco showed that this company is very eager to help their customers get more engaged in their electricity consumption, and in some cases, production. The company would be able to create value by giving customers insight in their consumption and tools or technology to make this consumption more flexible (see Appendix 7: Workshop Capacity Subscription Eneco - Confidential). Suppliers with a large consumer base will have an advantage, as every consumer will need to adapt to this market. This incentive will also drive innovation for creating flexibility. If the company is able to adapt to this new market and create the right products, this will provide benefit, while companies unable to cope will struggle.

6.5.4. Small consumers

For small consumers, the effects will differ depending on their consumption pattern. Three important trends are derived from the results. Based on the calculation example, an average household (8 kW demand peak) will pay €256 euro per year if it is completely inflexible to shift demand. This is expected to be a considerable incentive to lower peak demand. These impacts are based on the assumption that consumers understand and engage in the capacity subscription market. Expert feedback from a workshop at Eneco suggests that the majority of consumers might not be able or willing to engage in this market. With rising electricity prices, market intervention on the electricity should be done with care. For example, when households have bought a heat pump to get off the gas, as the government stimulates them to do, this would result in a need for higher capacity subscription, and thus increased costs. Other consumers might not completely comprehend the system, or will not see the need for backup capacity, as black- or brownouts have been rare in the last years (see Appendix 7: Workshop Capacity Subscription Eneco - Confidential). This emphasizes the need for simple solutions, provided by the electricity suppliers, for consumers who are not willing to engage in the market.

Engagement in the electricity market

By implementing the CS market, small consumers are included in the flexibility challenge. People that are not interested, will be guided by their electricity suppliers towards standard solutions, while interested consumers will have the option to buy extra services or technologies that help them create more flexibility and thereby save costs on their electricity and CS bill.

Flexibility pays

The impact on the electricity bill will depend on the flexibility and peak demand of the consumer, and the flexibility of the system. If a single household is able to shift its peak demand to other moments in time, it will be able to save costs on their CS bill. In addition, if a lot of people are able to shift their demand, this will result in a lower electricity price for everyone. However, consumers with inflexible demand, will have to pay more for their subscription on the CS market.

Social tariffs

While the price for electricity has been dropping for the last years, the electricity bill of households has been steadily rising, due to increased taxes. This has led to concerns that lower income households are hit harder by this, as the electricity bill represents a larger part of their expenses. This measure however, is expected to have a more progressive effect. This is because households with higher incomes usually have a higher peak demand, because they have more electrical equipment. On the other hand, it is possible that rich households have more ability to buy batteries or other technologies that help them reduce peak demand and eventually paying less.

6.5.5. Industrial consumers

For industrial consumers, some of the same principles as for small consumers apply. But, in the case of flexibility, this could be even more extreme. Small consumers usually do not have the option to reduce their demand to (almost) zero, and if they do, their reduction will be small. Industrial consumers use more electricity, and if they have the ability to shift their demand in a smart way, they can save a lot of money on the CS market. It can already be observed that some industrial companies are eager to work on their environmental impact

(Parnell, 2019). The combination of corporate responsibility and financial incentive could result in a big impact on the demand response of industrial parties.

6.6. Impact on electricity market theory

As discussed in chapter 3, the theory for an efficient market no longer completely applies. It is therefore relevant to assess the implications of this thesis for the theory of the electricity market. These implications will be related to the market imperfections identified in chapter 3, the results from chapter 5 and the previous sections of this chapter. Chapter 3 showed how various effects created increasing risks for electricity producers, which could cause underinvestment in a market with a lot of renewable energy. This chapter will reflect on the impact of a capacity subscription market on these market imperfections.

The market imperfections were demand uncertainty, investment cycles, and regulatory uncertainty. Because electricity producers do not know how demand patterns of electricity consumers will change in the future, they might rather produce too little than too much. For example, the socially optimal volume of generation capacity is higher than the theoretical optimum with perfect knowledge (L. De Vries & Heijnen, 2007). This risk is increased by renewable electricity, as dispatchable generators are able to run less hours per year (Linklaters, 2014). A CS market would create a clear signal to the market how much demand there is during times of shortage. This would not only remunerate generators that are needed to generate this peak demand, but it would also give a clear signal to generators which are not needed. These results show that a more consumer based capacity mechanism, like a CS market, can lead to a more efficient long term investment climate, as demand side response is fully utilized.

Investment cycles are expected to remain within a CS market. However, as the prices in a capacity market would rise before shortages occur, this would send an earlier signal to the market when new capacity is needed compared to the current market. Where the current electricity market design is based upon centrally organized production, a consumer-based capacity mechanism could lower information asymmetry, and thereby the intensity of investment cycles. This is in line with the results of Bhagwat et al. (2017), who also concludes that forward capacity markets have a diminishing effect on investment cycles.

Regulatory uncertainty is the last market failure that was identified. While this uncertainty remains in a CS market, the current speculation on market reform would decrease. As multiple European countries have implemented some form of capacity management, the Netherlands has not. Lacking a policy on capacity management increases the uncertainty for investors. Giving clarity on the Dutch approach to capacity management would decrease this uncertainty. This does not just apply to a CS market, but for every decision made, as long as it is clear and consistent over time. This is consistent with literature on electricity market intervention on carbon emissions, where more regulatory uncertainty caused less efficient investment (Fan et al., 2010).

7. Synthesis

In this chapter, the main question “*How will a capacity subscription market affect the Dutch electricity market in a (near) 100% renewable system?*” will be answered. In the DSRM method, this is part of the evaluation phase, as it provides information on how the research supports a solution to the problem. First, the answer to the question will be presented. Then, the arguments on which this conclusion is based will be discussed. These arguments are based on the answers on the sub questions from chapter four to six. If a capacity subscription would be implemented in the Netherlands, this would have multiple implications.

Although this market favors dispatchable generation, it does not lead to less profit for renewable energy systems. In addition, the demand in a capacity subscription market will be more flexible, meaning the need for backup generation will decrease. When a capacity subscription market is implemented, this will result in more efficient allocation of electricity scarcity. Lastly, the price risks for electricity producers decreases, as the variable income from the electricity market is partly replaced by fixed revenue from the capacity subscription market. This will reduce the intensity of investment cycles and create a more stable market.

Eight scenarios were defined, where three variables were differentiated on two levels. These scenarios were designed to show the impact of weather, interconnection, and the implementation of a capacity subscription market on the electricity market and on each other. The key performance indicators for the electricity market are categorized into affordability, reliability, and sustainability.

The KPI's have to be considered in their mutual relationship. The plant profitability results (Appendix 5: Model results) show that multiple electricity generators would lose money in an energy only market with a lot of renewables. If as a result these generators shut down, this would lead to both a lower reliability and a higher electricity price. The capacity subscription market would provide enough financial incentives for these generators to stay operational. Because the market compensates all generators based on the missing money of the most expensive generator needed, the revenue of the capacity subscription market is higher than the total amount of missing money. However, a system where generators are compensated for exactly the amount of money they lose on a yearly basis, seems unlikely

because this would not result in fair competition and would not comply with European state aid law. In addition, the costs taken into account are just the operational costs. In reality, a company also needs to recover its capital costs. The amount of missing money is therefore hard to compare to the cost of the capacity subscription market, but it can be seen as the absolute minimal system costs without some form of capacity management. Lastly, this model has looked at a static situation, and compared a certain year with and without a CS market. Because the model did not allow a dynamic implementation of the CS market, the model did not include a feedback effect, and no long-term price effect could be calculated. This should be taken into account when interpreting the results. As de Vries & Heijnen (2007) note, a design that performs well in a static equilibrium, might not do so in a dynamic situation. As the fundamental difference between both markets is the increased demand response, the long-term efficiency would be higher in a system with capacity subscription.

The reliability is increased in all scenarios with a capacity subscription market. This effect is bigger in the scenarios without interconnection, which shows the potential of the CS market is larger if it would be applied in the whole (coupled) market. Although demand response will be beneficial to the power system either way, the financial benefits will only be substantial to the Netherlands if this effect does not leak away towards other countries. This can be achieved by implementing this market in the united electricity market in Northwest Europe, or by introducing a financial construction like option contracts. This observation is in line with an assessment of the UK capacity market, where the missing money problem was not completely solved after implementation of the capacity market. Newbery (2017) notes that reliability options are preferred over capacity payments, *“as they address missing money problems, hedge high and uncertain prices for generators and consumers while ensuring that the wholesale market and international trade clear at efficient prices”* (Grubb & Newbery, 2018). These outcomes are also coherent with observations by Ringler, Keles, & Fichtner (2017) who state that changing the electricity market design should be done *“cautious and coherent”* across Europe.

8. Conclusions and recommendations

This chapter shortly summarizes the findings of the previous chapters and presents the conclusions that can be drawn from them. Then, as a result of these conclusions, recommendations will be made to both policy makers and researchers in the field, in order to provide steps that can be taken as a result of this thesis. This is part of the communication phase in the DSRM method, where the problem, the artifact, its utility and novelty, the design, and the effectiveness to researchers is discussed.

8.1. Conclusions

The energy system is in the middle of a large energy transition. Major changes are happening on a short term. The addition of large numbers of renewable energy systems results in intermittency and dropping electricity prices, and therefore reduction of profits for conventional electricity producers. In the future, it is expected that this will continue to the point they are not able to cover their operational cost. However, with no economically viable systems for (long-term) storage of electricity, it might be too soon to let these old generators close down. This thesis explores the option of a capacity subscription market in addition to the electricity market, and specifically aims to fill the knowledge gap on the impact on the performance on the electricity market, on affordability and reliability. The following research question is formulated: *“How will a capacity subscription market affect the Dutch electricity market in a (near) 100% renewable system?”*

When considering electricity market performance, four performance indicators are defined: affordability, reliability, safety, and sustainability. In the future electricity market, reliability will become harder to maintain, as dispatchable generators will shut down as a result of less run time and lower prices caused by a growing number of renewable energy sources. Theoretically, a capacity subscription market will fix the market imperfection that is causing the lower reliability, while also resulting into a more affordable system. Results from this thesis show that this market would have a positive effect on the reliability of electricity supply. The costs for reliability are privatized, so consumers are able to decide how much they are willing to pay for reliability. The costs of this market depend on the risk profile and the flexibility of electricity consumption of the Dutch consumer. While more flexibility should

result in a more efficient system, it is hard to determine long-term price effects. However, the system is designed to create a more supply dependent demand, which eventually will create a more efficient system. This market sets the right incentives for flexible demand and is therefore suitable for a near 100% renewable system.

This chapter shall discuss all sub questions that were used to come to this answer in separate paragraphs. The sub questions that will be answered are:

1. *How is the performance of the electricity market defined?*
2. *What is the design of a capacity subscription market?*
3. *What will the price of capacity be in a functioning capacity subscription market?*
4. *What is the impact of capacity subscription on the electricity market?*

8.1.1. How is the performance of the electricity market defined?

The performance of the electricity market is defined by three main categories, being affordability, reliability, and sustainability. In addition, there are boundary conditions from the EU that have to be satisfied. While there are certain rules which can be applied to see if a market is effective, the literature showed that the electricity market does not always perform as the theory states. There are three important market imperfections that this thesis takes into account. The first one is the presence of investment cycles. Investment cycles occur in the practice of the electricity sector and mean that periods of overinvestment are alternated with periods of underinvestment. The other two market imperfections are demand and regulatory uncertainty. As both demand and regulation are hard to predict, these form a risk to investment in assets in the electricity sector, especially because the lifetime of these assets is mostly multiple decades.

8.1.2. What is the design of a capacity subscription market?

The design of a capacity subscription market is generally based on the work of Doorman (2017; G. L. Doorman, 2000; G. L. Doorman & Solem, 2005). There were a couple design elements that were discussed in more detail, as these affected the model implementation. Storage of electricity was assumed to be used to lower consumer demand, as opposed to supplying electricity in the CS market. Interconnection was included by using both scenarios with and without interconnection. Cross border capacity was excluded from the model, as

this made the model too complex. The sustainability requirements on capacity mechanisms issued by the European Commission were discussed, but not applied in the model. This was partly as all generation units effected (the coal plants) were already phased out in the target years used.

8.1.3. What will the price of capacity be in a functioning capacity subscription market?

The price for capacity is expected to be between €5 and €30 euros per kW per year. This would result in a total revenue of the CS market between 250 and 500 million euros per year. The difference depends on how the market is implemented. If just the Netherlands implements this system, the price will be higher than when multiple European countries participate in the same system. The price also changes with the amount of installed capacity compared to demand. If demand is growing, without new capacity being installed, the price for capacity will rise to the point where investors decide to invest. The results show that a capacity subscription market would result in lower demand peaks, and give the right incentives to match supply and demand of electricity. Without further development of the market, for example by expanding the capacity subscription market to neighboring countries or option contract, there is a risk the reliability advantage “leaks” away to neighboring countries, meaning shortages in Germany could still cause black- or brownouts in the Netherlands.

8.1.4. What is the impact of capacity subscription on the electricity market?

To answer this question, two important relations for the outcome of the result will be discussed, after which the impact on the key performance indicators is presented. The first finding is that the impact of the weather is significant on the revenues from the electricity market. The results show that the revenues of the electricity market can be up to twice as high as a result of the weather. This affirms the view of increased uncertainty that generators have to cope with in the future market. Secondly, interconnection has a big influence on the Netherlands. As the Netherlands is very well connected to its neighboring countries, the electricity price is mostly based on supply and demand in Belgium, the UK, and Germany.

In extremis, this could lead to black- or brownouts in the Netherlands if shortages occur abroad.

In a disconnected scenario, a capacity subscription market works as the theory describes. The number of hours with a shortage and the total amount of unserved energy decreases. On the short term, this results in a lower average price per MWh. When missing money and the costs for the capacity market are included, this leads to total system costs that are very close to each other in all scenario's, with one scenario showing lower and another with higher cost after implementation of CS. This means that all generators included in the capacity market would at least cover their fixed costs, eliminating the possibilities for shortages in the long term. This effect is a lot smaller in the interconnected scenarios. In the long term, the results affirm the view that in the energy-only market, multiple generators would leave the market, causing higher electricity prices. The effect on the sustainability, measured in CO₂-emissions, is very small. While some conventional technology generation units would increase their revenue with this market, the effect on revenues of wind and solar energy is very small.

8.2. Policy recommendations

A fast transition towards an electricity market with mostly renewable energy systems could cause the closure of most dispatchable generation units. This would result in decreased reliability of electricity and high electricity prices. A capacity subscription market would increase reliability, decrease risk for generators, and introduce incentives for demand and supply of electricity to match. However, the interconnectedness of the Netherlands will cause some of the reliability gains to leak away to neighboring countries. Additional policy is possible to counter this. If a CS market would be applied in the whole NW Europe area, this problem would not occur at all. If that is not a possibility, another option would be to extend the contracts in the CS market with a price for electricity as well. This would protect Dutch consumers from peak prices that are a result of shortages abroad.

Although the CS market is designed to decrease peak prices and blackouts, overall there would be some system costs. The implementation of a CS market is expected to result in extra costs for electricity consumers on the short term. The amount of costs depends on the

level of flexibility of the consumer, but would be their current peak demand in kilowatts times the price for capacity (between 5 and 30 €) at its most. In the long term however, the missing money problem would lead to lower reliability and higher electricity price, a value that is currently not included in the electricity bill. As this model only looked at the static effect on the two target years, it is unclear what the exact effects on the electricity price are in the long term, but increased flexibility should in theory result in a more efficient outcome.

As the Netherlands currently, in 2019, has overcapacity, it is advised to implement CS sooner rather than later, as capacity prices would be low, and the market has time to develop technology and services to accommodate consumers with this new price scheme. If CS would be implemented during a time of shortage, the price for capacity would be high. With energy bills rising sharply over the last years, another price increase might be unacceptable for consumers (Vereniging Eigen Huis, 2018).

8.3. Research recommendations

This thesis explored the general implication of a capacity subscription market. Although this gives a good insight in the order of magnitude and general effect, additional research could provide better insights and more reliable numbers. Three recommendations will be presented to continue the research into the capacity subscription market.

Chapter 6 showed that some benefits of the CS market will leak away towards other countries. There are possibilities to avoid this leakage, for example by adding a price component to the CS contract. Another option is to implement this market internationally, with all neighboring countries of the Netherlands. Future research could extend the current model to discover if this would reduce the leaking effect.

As discussed in the experiment design, this thesis has looked at a static situation, in the expected market of 2030, and compared a market design with and without a capacity subscription market. In addition, the model is based on the current stack of generation capacity. Therefore, only recovery of operational expenses is considered in the bidding of capacity subscription. Chapter 6 shows that including new capacity could result in a price for capacity which is almost twice as high. As an effect, the thesis does not show the dynamic effect of the electricity and CS market. Ideally, the model would be run with and without a

CS market for multiple years for multiple times to provide a bandwidth of results. It would provide great insight in market dynamics if the model could be made dynamically over multiple years. Additional research is required what effect new build capacity would have on this market.

In the model implementation, an assumption was made on the amount of demand response in the Netherlands. This model assumed a demand response of 3 GW below the residual demand peak from the 'low' demand curve, but this can be done a lot more specific. For example, what exactly does the demand response curve look like? How does the ability to shift demand differ between seasons? And how would the demand curve change if shortages will occur more often? Future research into demand response could give great insight into the flexibility potential of the Netherlands.

9. Discussion and reflection

This thesis provides an insight in the effect of a capacity subscription market, but is not perfect. This chapter discusses the most important choices that impacted the results and will reflect on the process.

9.1. Discussion

This section will discuss some of the choices that have been made in this thesis, and aims to give better understanding in which situations the results from this thesis can be applied. Four important assumptions will be discussed. The first paragraph will cover the static approach of the model. Then, the data assumptions will be discussed. After that, the assumption on demand patterns and demand response will be evaluated. The last paragraph discusses the design of the CS market.

As pointed out in the research recommendations, this thesis has looked at a static situation, and only considered the current stack of generation units. This does not show the dynamic effect of the electricity and CS market. In practice, the price for capacity would be expected to rise slowly, keeping old generators operational, until the price is so high that new generation can be build. After this is realized however, the capacity price would drop again, as more capacity would enter the market. The static aspect of this model provides less insight than a dynamic model would have done.

“Garbage in, garbage out”. The most important assumption is the numbers that go into the model. The most important one being the fixed operating cost per plant. These numbers are determined by the dispatch model, but are of course estimations of the actual numbers. A more thorough analysis of operating costs of plants could improve the model. Another important assumption is that there will be no new construction of generation plants in the countries considered, apart from plants that are already being build or announced. In practice, it is expected that the politics would intervene, before a shortage of the proportion observed in the results would occur. The results of this thesis are therefore applicable under the assumption that there will be no market intervention until the target year 2030.

The amount of assumed demand side response (DSR) is another assumption that has a large impact on the results. This thesis assumes that there would be 3 GW (compared to peak residual demand in the 'Low' scenario) of DSR available for less than 10€/kW. This is based on similar numbers in the UK and France, but in practice this could turn out quite different. This is because the price of DSR is a balancing act. As long as DSR is not activated often, for no or very little amount of hours per year, the price of DSR would remain low. However, if DSR is activated more often, and people need to adjust their demand more often, the price for DSR would rise. Secondly, the demand patterns that are used in the model are extrapolations of historic demand, combined with the weather data from a certain year. However, if the Netherlands will decrease its gas consumption and increase its electricity use, the dependence of the weather might become even higher. In addition, with the electrification of industrial processes, the volatility of electricity use could also increase. Therefore, the outcomes of this thesis would change with new research on future correlation between weather patterns and electricity demand.

As discussed in the research approach, this thesis assumes a change of demand patterns as a result of the implementation of a capacity subscription market. For the implementation of the market, these design choices would be crucial. Appendix 1 reflects on possible design choices. If the CS market will be implemented, these choices should be revised more thoroughly in order to find the optimal design.

9.2. Reflection

In this chapter I will look back onto the process of this thesis and will reflect on multiple choices. First, the method and the model will be discussed. Then, I'll reflect on the questions: where they the right questions to ask, and was the approach to answering them the right one. Lastly, I will explain what I personally learned from doing this thesis.

As this paper was written in cooperation with Eneco, some bias is hard to avoid. Although I did my best to stay objective, the longer I studied this market intervention, the more I became convinced that it was the right thing to do. By continuing to use the predefined method and KPI's, I think bias was mostly prevented. As this intervention is currently seriously

considered as a market intervention that is needed by multiple stakeholders in the energy sector, I tried to provide the information as neutral as possible.

The DSRM approach was very helpful in structuring the paper. Although I kept on shifting chapters back and forth, the approach forced me to at least dedicate a chapter to all steps that the method prescribes. As discussed before, especially the definition of objectives for a solution chapter was very helpful in defining KPI's at the start of the thesis, and keeping to those in answering the questions.

Working at Eneco, the dispatch model that was used was the only hourly dispatch model I had access to. The model that I made, was made around this model. Therefore, it is hard to reflect on the appropriateness of the model. However, the model has everything that one could expect from an hourly dispatch model, so even if I did not consider other models, this was almost perfect for the purpose it served. The only disadvantage that I found was the ability to create a dynamic CS market. As discussed in the discussion, this could have provided greater insight in CS market dynamics. But as this was not an option in the model, I had to find a substitute way to simulate the CS market as good as possible.

During model development, the amount of scenarios run was too high. Initially, there were four levels of CS included, while the model was not final yet. As each scenario takes some time to run and process, this took a lot of time. In retrospect, it would have been smarter to optimize the base case scenario, after which the other scenarios could be developed and ran.

My research question has been changed many times. With the goal of scoping the paper down, it evolved from a design question to an explorative research. I think the question that ended up being the research question catches the essence of the research. Getting rid of the design challenge prevented a discussion on details. It does not matter if someone is physically limited in their consumption or they receive a fine if they use more than contracted. What matters is the result, in this case that either way people are assumed to change their demand pattern based on the existence of the CS market.

Finally, personally I learned how effective feedback can be. I think the interaction of both academic and business feedback had a very positive effect on the quality of this paper. While

the workshop at Eneco was relatively short, it gave me great input on how people from different perspectives looked at this idea and challenged me to answer tough questions. The meeting from ENL was similar, but at a higher aggregation level, between different companies. Overall it was a very challenging and engaging period of time, in which I learned a lot about the electricity sector, but just as much on business and academic practice.

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Appendix 1: Design choices

In the market design, an assumption is made that the model works as Doorman described. However, there are multiple ways to achieve these results. This appendix reflects on these options by going over the categories of design choices and discussing possible options.

Market structure

For the capacity subscription market, a structure is proposed that has not been used before. An independent market operator should be in control of the capacity market. This regulator will organize auctions to organize the required back-up capacity. In the Netherlands, the most suitable instance to be this regulator would be the TSO, as will be further explained later. The contracted capacity will be based on market clearing where both supply and demand of capacity will bid for capacity at a price. The auctions will be based on the English model, with the important adjustment that the amount of contracted capacity is dependent on the demand curve. After the first auction at T-4, capacity for suppliers and consumers is tradable until T-1.

Contract structure

There are two main options to regulate the market. The first one is to have the regulator (most likely the TSO) control the market. In the case of CS, this means the regulator both enforces the contracted capacity of suppliers and consumers. This method is used in the UK capacity market. The second option is to create bilateral contracts between suppliers and consumers. This method is used in the French supplier obligation market. The advantage of bilateral contracts is that the contracts are easily tradeable, and anyone can participate. The downside is that there is no organization that has the complete overview of the system. If a supplier is unable to provide electricity, how would the consumer then be able to receive electricity at all? The advantage of a regulator is that there would be more control over which entities are able to participate in the market. The regulator could use the data to evaluate the reliability of the system. However, this would entail more bureaucracy and transaction costs.

Penalty for non-compliance

There are multiple ways to enforce the subscribed capacity. Consumers could get a LLD or receive a financial penalty. For suppliers, it seems that a financial penalty is the only option.

It is important that this penalty is balanced. It should prevent gaming and speculation, where suppliers bid to supply more capacity than they can give. But it should also be reasonable, where suppliers will not go bankrupt over a single financial penalty. Both extremes will lead to respectively under- and overinvestment.

Safety margin

In order to account for market and technological failures, it is optional to include a safety margin in a capacity market. In both the English as well as the French capacity market, this is done through de-rating factors. In the English market, this means that all suppliers can sell 96.11% of their capacity.

There are generally two options for the capacity subscription market to apply a safety margin. The first one would be the method used in the English market, where all capacity suppliers use a de-rating factor. The second option would be for the TSO to bid for capacity themselves.

In the first years of introducing the capacity subscription market, the regulator can contract a safety margin based on the contracted amount and the expected demand. If the contracted demand is too low, consumers will start paying penalties, and the market is expected to correct this. However, if the first clearing of the market causes too much capacity to be decommissioned, building new capacity will take too long. The safety margin can be phased out after the first years.

The amount of vRES that will be there during shortage periods can also be seen as “safety margin”. The amount of vRES that is available will be discussed further later on.

Data management and transaction cost

Data management and transaction costs are important issues to take into account when designing a market. These issues will be discussed on two levels, the national and the retail market. On the national market, data management of electricity data is currently in the hands of the TSO. Giving the responsibility for data management on the national level to the TSO, would require the minimal amount of effort and transaction costs. In addition, transaction cost are minimized by not allowing trade within the delivery year. This way, the TSO will

have supply and demand for capacity clear at the start of the year. In addition, the same contracts should be used for all supply and demand. Lastly, the TSO already handles all electricity delivery data and analyses forward supply and demand. Extra efforts will be limited to: Organizing the capacity auctions, managing the supplier obligations, announcing shortage periods, and enforcement of capacity limits and executing penalties. On the retail market, electricity suppliers pay for the peak demand of their customers. It is up to these companies how complex they will make their contracts and thus how high their transaction cost will be.

Consumer

Consumer subscription

Consumers subscribe to a specific amount of peak demand. They have the right to consume this amount of electricity during times of storage. The consumers that participate are the consumers that operate on the wholesale market. In this way, the industry participates, and energy suppliers will have a choice how to organize the demand flexibility with their customers. This market has demand side response (DSR) embedded in its structure, and therefore DSR cannot participate at the supply side of the auction, as is the case in the UK market.

Retail consumers

Organizing flexibility with retail consumers is the responsibility of the retail companies. This can be done through load limiting devices, as proposed by Doorman and the Vries, by providing financial incentives, or with whatever other mechanism they can think of. By giving this choice to the energy suppliers, a range of energy contracts will emerge, with different prices, peak demand, and security of supply. By not imposing a specific technology, the market will determine which contracts are sought-after, and which way of monitoring works best. It is believed however, that real time monitoring of electricity use, will be essential to be able to give demand shift incentives.

Consumer contract

Consumer contract need to include a number of aspects. The most important ones are price per month and the peak capacity demand. This peak capacity is enforced during shortages, and imposes a penalty for non-compliance.

Gaming

It is possible that consumers will use gaming to avoid paying the subscription fee. Possibilities to avoid this could be a minimum amount of subscription based on last year (but at which price?) or an increase of the penalty level for non-compliance. Lastly, it is also possible to increase the amount of shortages per year, by increasing the margin at which ratio between supply and demand there is a shortage. In the French capacity supplier obligation scheme, there are multiple occasions per year where a shortage is simulated to test if all supplier can comply with their obligation.

Suppliers

Suppliers of capacity will bid the price for which they are willing to provide capacity. In principle, all suppliers can participate. Some exceptions on specific technologies will be discussed below.

Storage

Storage is a difficult design variable, as storage can only provide electricity for a certain amount of time. Multiple options for using storage in the model. The first, most obvious, way to use storage is to lower consumer demand peak. If storage is connected to demand, this consumer can then lower its subscribed peak demand, and save costs. This way, the consumer will select the type of storage that fits best with its own demand pattern.

The second options is to, like in the UK model, consider storage as a supplier of capacity, and use de-rating factors to account for the time limiting constraint. The de-rating factors are determined based on expected timeframe of shortages. Then, the improvement on LOLE or EEU is calculated using a reliability model simulation. The outcomes are then compared to the amount of firm capacity that is needed to gain the same improvement on reliability. The outcome could look like the following example:

Storage duration	De-rated factor
1 hour	25%
2 hours	33%
3 hours	50%

4+ hours	80%
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Both options can be used in addition to each other. Allowing the second option will benefit centrally organised storage options by giving them an easier way to earn a profit from the capacity market.

Interconnection and cross border capacity

If a CRM is implemented, there is a big chance that interconnection and cross border capacity will have to be included, as the EU Commission is expected to make this mandatory for capacity mechanisms (European Parliamentary Research Service EPRS, 2017). The market for capacity subscription could be integrated in a larger European market for capacity. However, a more elaborate design for congestion should be implemented. Because at this moment, other countries have applied their own capacity mechanisms, in which Dutch generators and interconnection can participate, the model does not include interconnection. This is because this thesis assumes a shortage in the whole of NW Europe, where interconnection and abroad capacity could provide little help. In addition, it would be complicated to determine profitability of an interconnector, and thereby its bids in a capacity market.

Sustainability

It is possible to, line with European legislation, only allow suppliers with a carbon footprint of <550 gCO₂/kWh (European Parliamentary Research Service EPRS, 2017). This is to avoid polluting technologies gaining profits. In practice, this would mean that all coal plants and the least carbon efficient gas plants couldn't participate. This would result in an increase of the capacity price (as some capacity is excluded), but would also secure payment for less polluting plants.

Existing versus new capacity

This thesis only considers existing capacity. The reasoning behind this, is practical. If the existing capacity will stay available, there is enough capacity to meet demand. However, some generators will eventually close down anyway due to ageing. This means the capacity subscription market should also accommodate new build capacity. As the business case of new capacity also depends on CAPEX, this will result in a whole different price level, and

thus higher impact. The advantage of this would be that this price peak in the capacity market would replace the price peak on the electricity market, which only occur during shortages.

Retail companies

It seems efficient to position retail companies in between the capacity market and the small consumers. This means that retail companies are responsible for the capacity of their consumers. This incentivizes DSR and innovative solutions to shave peak demand. Retail companies can choose to use smart meters, load limiting devices or other applications to monitor or steer the demand of their consumers. This will also result in different types of contracts, some with ‘unlimited’ capacity or other that minimize monthly payments, similar to mobile phone contracts.

Difference with other mechanisms

The table below gives an overview on the most important design choices, and how this system differs from the UK and French capacity mechanisms. The most important unique feature of the designed market is direct market involvement - all consumers have a financial incentive to lower demand.

	CS	UK	FR
Market structure	Supply and demand clearing	Capacity auctions	Supplier obligations
Required capacity based on	Consumer demand	TSO forward analysis	Historic peak demand of consumers
Costs	Costs of CS are payed based on peak demand during shortage	Costs of CM are shared among suppliers (distribution of costs unclear)	Suppliers pay an amount relative to the contribution to peak demand of their consumers
Trade mechanism	Auctions and OTC trade	Auction	Auctions and OTC trade

Safety margin	Optional	Through de-rating factors	Through de-rating factors
Enforcement	TSO monitors and enforces capacity limit on consumers and suppliers during shortages	TSO (National Grid) enforces supply of capacity on suppliers	The Regulations Committee of Disputes and Penalties
Capacity is bought	By consumers from the TSO	By the TSO from suppliers	By retail suppliers from electricity suppliers
DSR	All consumers have an incentive to lower peak demand	DSR can participate as a supplier of capacity	France has a separate policy (tenders) for DSR
Peak demand incentives	Consumers have a direct financial incentive to lower peak demand during shortages	-	Suppliers have an incentive to lower peak demand of their consumers
Supplier participation	Differentiation and competitions on flexibility by retail suppliers	-	Differentiation and competitions on flexibility by retail suppliers
Capacity is sold	By suppliers to the TSO	By suppliers to the TSO	By electricity suppliers to retail suppliers
Storage	To lower consumer need for peak demand	Can participate in auction at de-rated factor	

Retail participation	All consumers participate (retail through suppliers)	-	Retail consumers participate through supplier
Other related policies		Contracts-for-Difference to compensate / reduce risk for electricity suppliers	Demand response tenders

Table 17: Difference with UK and FR capacity mechanisms

Appendix 2: Demand response

Capacity subscription are a form of demand response, which aims to change the demand for electricity at certain times. To gain insight in how susceptible consumers are to change their demand based on financial incentives, it is useful to look at previous initiatives to achieve this. The initiatives that will be discussed are *direct load control*, *curtailment*, *demand bidding*, and *price based programs*.

Direct load control and curtailment

Utilities that provide direct load control (DLC) programs, can have direct control over certain devices. Consumers will have to give permission for the utility company to use this power, mostly in exchange for reduced prices in general. The most important elements is that the system operator has control over utilities from consumers. This makes it possible to shed huge loads of demand efficiently, but it would require people to give up part of their freedom to use electricity. Direct load control is mostly applied to interruptible appliances, like air conditioners and electrical heating. Important variables in a DLC contract are: number of control events, quantity of load reduction, period of reduction, and the type of restriction (seasonal, week, daily)(Jones, 2003). Mortaji et al. (Mortaji, Ow, Moghavemi, & Almurib, 2017) found that using ‘smart direct load control’ via the internet of things can result in a 30% reduction of peak load. In addition, power outages were significantly reduced.

Curtilment is basically the same as direct load control, but with large consumers. Companies that participate in curtilment programs are usually not dependent on their production at a certain time. Examples include chemical production facilities or waste management plants. The advantage over DLC is that companies act on a much larger scale. Therefore it would have to take only one contract to shed a load of 100 MW, instead of fifty households. A good example for curtilment is the use of variable speed heat pumps (VSHP). These heat pumps can be used for long-term energy storage, so they are not required to perform their operation in a specific time(Kim, Norford, & Kirtley, 2015). As this curtilment can reduce peak prices in the spot market, and heat pumps can reduce peaks over seasons, this can be considered killing two birds with one stone. Aalami et al. (Aalami, Moghaddam, & Yousefi, 2010) emphasize that price elasticity is very important for the effectiveness of curtilment.

Demand bidding

In a demand bidding (DB) market, consumers can buy specific load reduction packages. They are then required to reduce their consumption by the required amount and receive the agreed price. For consumers to access the DB market, it requires knowledge on the up-to-date electricity price, and technology to provide up-to-date information about their electricity consumption. Therefore, demand bidding is mostly only interesting for large companies, who could make investment in this knowledge and technology worthwhile.

Liuhui et al. argue that wind power producers (WPP) in an electricity market with demand bidding, have an incentive to strategically change their day-ahead bids to get a higher revenue (Liuhui, Xian, & Shaohua, 2016). This involves bidding too low during off-peak hours, and too high during peak hours. Because the sum of deviation is then still around zero, the WPP can make an extra profit when wind outputs are higher than expected. The difference in profits can be significant, in the case of Liuhui et al. around one forth more profits (See table 1).

Case of DR	Parameters of conventional generators			
	G1's profit(\$)	G2's profit(\$)	Wind firm's profit(\$)	Sum of absolute value(MW)
With DR	7148.154	6066.262	3266.005	23.80
Without DR	8333.693	6974.832	2598.671	36.94

Table 18: Profit of generators with and without DR

Price based programs

Price based programs are a form of demand response where the price of electricity changes over time, to incentivize electricity use at certain times. Different forms of pricing include Time of Use (TOU), Critical Peak Pricing (CPP), Extreme Day Pricing (EDP), and Real Time Pricing (RTP).

Time of use pricing is the most common form of price based programs, and has been used for some time. The idea is that prices are predefined for certain times. This works by installing two or more separate electricity meters for different times. Most common approach is a day- and night- tariff, where the night tariff the lower. In the USA, Pacific Gas & Electric

has used this form of pricing since 1982. More than 86,000 households participated in this pricing program, saving over \$240 dollar per year, while the company saved money by the shift to off-peak hours (Jones, 2003).

Research in California found that CPP can have a significant effect on peak consumption. Consumers with programmable communicating thermostats used 25% and 41% less energy during 5 hour and 2 hour critical events respectively, when incentivized by critical peak prices. Consumers without these automatic thermostats still reduced their consumption with 13% (Herter, McAuliffe & Rosenfeld, 2005).

Extreme day pricing is similar to CPP, but applies for a full day. This would result in a by contract determined number of days per year of high pricing, and lower pricing during the rest of the year. The disadvantage in contrast with CPP is that it is less accurate, because even these days have off-peak hours. However, the advantage is that this does not require a lot of equipment at the consumer side, measuring their electricity use.

Real time pricing can be seen as the ideal scenario for price based programs. It would result in an exactly accurate electricity price at all times. There have been multiple studies with RTP, and all consistently result in a significant and constant high load response. This load response is relative to the height of the price incentive, giving higher response the larger the price volatility is (Jones, 2003). The disadvantage of RTP is that it is complicated, and consumers must be able to get significant incentives to participate. While RTP would incentivize demand shift, it could still be beneficial for both companies and electricity producers to use demand bidding (Aghaei & Alizadeh, 2013).

Conclusion

Time of use (TOU) pricing is the simplest way of creating demand response. TOU pricing is effective to reduce price peaks. However, TOU gives predefined prices and can't therefore be adjusted to actual electricity supply. Extreme day pricing (EDP) does have the ability to reflect actual price peaks. EDP does not require smart meters and could therefore be applied fairly easy. Critical peak pricing (CPP) reflects the actual wholesale prices even more, but as the time of these peaks is not predefined, would require some form of smart meters. Real time pricing (RTP) is the most effective way of creating demand response, as it perfectly

reflects the supply in the market. However, this requires advanced technology and consumer involvement. It can be expected however, that companies will get into the market by creating apps to make responding to demands more understandable.

In addition to these price incentives, there are multiple options for decreasing the demand peak further. Direct load control (DLC) seems to be the most effective, as the system operator can determine exactly how much demand should be decreased. This does require appliances that are controllable from a distance and cooperation from consumers. Here again, it is important that consumers have enough benefit of participating in these programs, as they can reduce convenience. Demand bidding is an effective tool that can be used with large consumers. As it requires knowledge and specific technology, demand bidding (DB) will probably not attract small consumers. Capacity subscription (CS) can be effective, as they increase consumer participation in the market. This makes consumers more aware when and how much electricity they use. It could however be too complicated for a lot of consumers. This could also be a market where companies start up to assist people.

As renewable energy systems increase, so should efforts for demand response. System operators should start conducting larger scale experiments with different forms of price based programs. In addition, forms of DLC, DB and CS can already be applied to reduce peak prices. Some of these will require initial investment, but all will have a beneficial effect for both the system operator and the consumer in the long term. The reduction in electricity price will fast forward the phasing out of conventional power plants.

Demand response can reduce equity in the electricity sector, as rich people would have more access to knowledge and technology to make smart use of demand response programs. Also, this system assumes little or no storage. If a large breakthrough in storage technology would occur, then there would be no or less need for demand response programs.