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Environmental effects of transmission congestion management in a regulated, competitive electricity market
- A case study from the northern part of the Netherlands -

Gabe van Wijk
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First supervisor: dr. ir. Wina Graus MSc, Faculty of Geosciences, Utrecht University
Second supervisor: Diana Böttger, Wirtschaftswissenschaftliche Fakultät, Leipzig University

Gabe van Wijk
Student nr 3813215
Croesestraat 88 bis A
3522 AH Utrecht

Preface

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Executive summary

Since the liberalisation of the Dutch electricity market in 2004 large investments have been made to increase the installed capacity for producing electricity in the Netherlands. Especially in the harbours of Maasvlakte and Eemshaven large power plants were constructed. In both regions the Dutch Transmission System Operator (TSO) TenneT B.V. had doubts whether the available high voltage transmission lines in the regions could transport the electricity produced in those regions. If the production of electricity exceeds the maximum transport capacity it is called congestion. TenneT has a legal instrument to avoid congestion on lines in an area. This method of congestion management is called 'basic system redispatch'; if too much electricity is produced in an area where congestion is expected, the excess of produced electricity in that area is 'redispatched' (replaced) to other power plants in the Netherlands. The question in this research is whether redispatch of power plants in Eemshaven has consequences on total CO_2 and NO_x emissions in the Netherlands. At Eemshaven the installed capacity consists of the RWE coal-fired power plant (1600 MWe), Nuon's gas-fired Magnum power plant (1311 MWe), the gas-fired Eemscentrale power plant of GDF Suez (1800 MWe), TenneT's high voltage direct current cable from Norway (700 MWe), and 183 MWe of wind turbines. Three steps were taken to give an answer to this question.

Firstly, the circumstances under which congestion in the northern part of the Netherlands is expected were determined. Especially in Eemshaven and Delfzijl it is expected that the amount of MWe installed capacity will rise. Under different scenarios it is investigated whether this rise in installed capacity will cause congestion on the transmission grid in the northern part of the Netherlands. In the different scenarios different combinations of electricity production by various power plants is modelled. The total amount of produced electricity is compared with the available transport capacity in the high voltage transmission grid in the northern part of the Netherlands. This led to the conclusion that the 380kV line between Eemshaven and Meeden is the first line whose capacity will be crossed in an n-1 situation (the outfall of one circuit in a line or one transformer in a combination of transformers). If the sum of import from Norway and production of power plants at Eemshaven is more than 3800 MWe, the line will reach its maximum n-1 capacity of 2635 MVA. All power plants at Eemshaven are in the area under influence of congestion management.

The second step was to define how likely it is that congestion will occur at Eemshaven. To determine this, merit orders for four possible future scenarios have been developed. Along with Residual Load Duration Curves an estimation could be made on the amount of time the power plants at Eemshaven would be producing under different load patterns and input variables (gas price, coal price, import and export values, amount of must-run CHP). One conclusion is that in a business as usual scenario, in rare occasions with extremely high electricity demand, around 124 MW of congestion is expected. In more extreme scenarios, with a lot of export, amounts of more than 1500 MW of congestion are expected. In the business as usual scenario the power plants that are redispatched at Eemshaven (Magnum turbines) are replaced by power plants with the same input fuel and building year. This means the redispatch, and thus congestion management, won't have consequences for electricity prices or emissions. In the other three scenarios the power plants at Eemshaven that are redispatched are replaced by older power plants and/or power plants with another input fuel. Because of this differences in electricity prices and emissions can arise because of congestion management.

The consequences for emissions because of congestion management are determined in step three. The focus in this step is to determine whether redispatch of the expected congestion from the scenarios in step two had an effect on emissions of NO_x and CO_2. Only emissions of NO_x and CO_2 are chosen because it is most likely that gas-fired power plants are replaced by other gas-fired power plants in case of congestion management. Gas-fired power plants are expected to produce the peak electricity load. Since gas-fired power plants have no emissions of SO_2 or particle matter (PM10) these to emissions are left out in this research. The business as usual scenario didn't show an increase because redispatched power plants from Eemshaven were replaced by power plants with the same characteristics (building year, efficiency, emissions, etc.). In extreme scenarios the emissions of NO_x and CO_2 increased. However, the increases are relative small (not more than 1% of the total emissions). The maximum increase in CO_2 emissions is 204 KtonCO_2 per year starting from 2018. The maximum increase in NO_x emissions is 184 tNO_x per year. These increase are quite small compared to the total emissions of NO_x and CO_2 per year in the Netherlands by the energy sector. Congestion management therefore is not likely to have an effect on reaching NO_x and CO_2 emission reduction targets in the Netherlands.

Table of content

1. Introduction

Figure 1: Eemshaven, the Netherlands. On the left, between the wind turbines, the gas-fired Eemscentrale power plant (1800 MWe) of GDF Suez can be seen. The large building in the middle is the RWE coal-fired power plant (1600 MWe). The yellow object on the right is an offshore platform that will connect future wind parks at sea.

1.1 Problem description

1.1.1 Consequences of a regulated competitive electricity market – the Dutch case

International companies (RWE, Vattenfall, E.ON, GDF Suez) took over Dutch energy suppliers (Nuon, Essent, Electrabel) since the market liberalisation of the electricity market in the Netherlands in 2004. Since then it became a regulated competitive electricity market. The companies planned to construct new power plants in the freshly build harbours in Rotterdam and Groningen. The location next to the sea is geographically very suited for the supply of hard coal and liquid natural gas and because of the abundant availability of cooling water. As a result around 3000MW of supply capacity is being build at both the Maasvlakte (Rotterdam) and Eemshaven (Groningen). In Eemshaven (figure 1) there are plans for extending the capacity with another 1000MW in addition this 3000MW. Unfortunately, especially Eemshaven is located far away from the electricity demand, which is for a large part located in the Randstad (the metropolitan region of Amsterdam, Utrecht, The Hague and Rotterdam with over seven million inhabitants). The electricity needs to be transported from the Maasvlakte and Eemshaven to the Randstad via high voltage transmission lines. In the case of Eemshaven it is not sure whether the high voltage power transmission lines have enough capacity to transport all the produced electricity at all times of the day[1]. This depends mostly on the amount of power that will be produced by the present power plants and wind turbines and power that will be imported from other countries. If there is too little capacity, congestion management is the legal instrument that can be used by the Dutch Transmission System Operator (TSO) TenneT to prevent overuse of lines.

1.1.2 Hypothesis on environmental effects of congestion management

The method for congestion management in the Netherlands is basic system redispatch. This means that a maximum amount of electricity production (cap) will be in place in the congested area. As a consequence electricity that was normally produced in the congested area should be produced elsewhere in the Netherlands. Since the power plants in the congested areas (Eemshaven and Maasvlakte) are relatively new and thus efficient, the power plants that replace them are assumed to have higher emissions (CO_2 and NO_x) per MWh produced electricity. Only emissions of NO_x and CO_2 are chosen because it is most likely that gas-fired power plants are replaced by other gas-fired power plants in case of congestion management. Gas-fired power plants are expected to produce the peak electricity load. Only in peak load situations it is likely that capacity of lines will be crossed. Since gas-fired power plants have no emissions of SO_2 or particle matter (PM10) these to emissions are left out in this research. More CO_2 emissions will increase climate change and more NO_x emissions will increase ozone formation and causes more respiratory diseases.

1.1.3 Until 2018

The time horizon in this research is until 2018. This year is chosen for several reasons. First of all, the different new build power plants (Maasvlakte and Eemshaven) will be ready in 2014. The scenarios until 2018 will give an impression of the first years that they will be active on the electricity market. Next to that 2018 is close to the important year of 2020 for sustainable development targets within the European Union, and thus within the Netherlands. All the 28 member states together should have 20% CO_2 reduction, 20% increase in energy efficiency and 20% renewable energy in 2020. Also NO_x emissions should be reduced to 202 Kton NO_x in 2020. Therefore this research is interesting for the question what the influence of congestion management is on the Dutch CO_2 and NO_x reduction targets in 2020. A third reason is that a new 380kV line (called 'Noord-West 380) from Eemshaven is expected to be finished in 2018. Thus, after 2018 it is likely that congestion management is not needed any more. A reason not to choose for 2020 as a time horizon is that predictability of events decreases as the time horizon increases.

1.1.4 Three steps in this research

Basically, this research consists of three steps. The first step is to investigate under which scenario the high voltage transmission network in the Northern part of the Netherlands becomes too heavily loaded. This leads to a conclusion on the possible size of the congested area, and at which amount of production which of the high voltage lines in the network will be overloaded. The method for this step is explained in chapter 3.1 and 3.2. The results are shown in chapter 4.1 and 4.2.

The second step is to map the electricity market in the Netherlands in cases with and without congestion management. This is done through merit order curves in combination with residual load duration curves. Merit order curves are constructed for four possible future scenarios up to 2018. These curves show the combination

[1] http://www.tennet.eu/nl/en/customers/congestion-management.html

of power plants that will deliver electricity during different load patterns. The curves will also reveal if it is likely that congestion in the northern part of the Netherlands will occur. In case of congestion - and thus a production limit in the congested area - the merit orders can also show which power plants will replace the power plants in the congested area. The method for this step is explained in chapter 3.3. The results of this step are shown in chapter 4.3.

The third step in this research is to predict the possible environmental effects of congestion management. The amount and the duration of congestion in the different scenarios from step two are used as an input. These outcomes predict which power plants in other parts of the Netherlands will replace the power plants in the congested area during a certain amount of time. The question is whether these power plants have higher emissions than the power plants that were originally supposed to produce this electricity in the congested area. In this step the difference in total emissions of NO_x and CO_2 is shown between situations with and without congestion management in all four scenarios.

In chapter two background information is given on the legislation of the electricity market in the Netherlands, congestion management in the Netherlands, other research regarding environmental effects of congestion management and the high voltage electricity transmission network in the research area. Chapter 3 describes the used method in the three different steps. Chapter 4 shows the results of the research that is carried out. A discussion on the used method and following results is presented in chapter 5. The conclusions of this research are in chapter 6.

1.2 Research objective and research question

The problem description leads to a main question and four sub questions. The sub questions are related to the three steps mentioned above.

1.2.1 Main question

- What are possible effects on CO_2 and NO_x emissions of transmission congestion management in a regulated competitive electricity market until 2018?

1.2.2 Sub questions

To answer the main research question, it is divided into four sub questions. The numbers below relate to the three steps mentioned above.

1. What is the total installed power production capacity in the congested area in the northern part of the Netherlands until 2018? (Chapter 3.1 and 4.1)
1. What is the expected area of congestion in the Northern part of the Netherlands until 2018? (Chapter 3.2 and 4.2)
2. Which power plants are expected to produce electricity in the upstream and downstream area the Netherlands until 2018 with and without congestion management? (Chapter 3.3 and 4.3)
3. What are the expected CO_2 and NO_x emissions of the total installed power production capacity in the congested area in the northern part of the Netherlands until 2018 with and without congestion management? (Chapter 3.4 and 4.4)

2. Background

Figure 2: 380kV station Eemshaven. From this station the high voltage power from the Magnum-, RWE-, and Eemscentrale power plant are transported to other parts of the Netherlands.

In this chapter background information is provided regarding the electricity market in the Netherlands and the method of congestion management that is used in the country. This research is also placed in the current debate around the consequences of new power plants in Eemshaven. In the end the high voltage transmission network in the research area is described.

2.1 Legislation of the electricity market

The electricity market in the Netherlands is liberalised since 2004. Since then it became a regulated competitive electricity market. This means that every individual or company has got access to the electricity market, and has the right to be connected to the grid. On the other hand, consumers can choose their electricity producer, and are no longer dependent on (regional) monopolies. The paper by Eric van Damme[2] gives a very useful oversight of the developments at the Dutch electricity market since the introduction of the new electricity law in 1998 and the following liberalisation.

TenneT TSO B.V. is the Dutch Transmission System Operator (TSO) that facilitates the electricity market, maintains the high voltage grid (with voltage levels of 110kV, 150kV, 220kV, and 380kV) and keeps control on the 50-Hertz (HZ) frequency on the electricity grid[3,4]. To maintain the necessary 50HZ frequency on the grid, supply and demand of electricity should be the same at all times. At the moment there are 31 companies in the Netherlands that have authorised Programme Responsibility (PR)[5]. This means they can produce and sell electricity and have access to high voltage transmission lines. Every Program Responsible Party (PRP) should send its expected production and consumption of every 15 minutes to TenneT for the next day. Every time step of fifteen minutes is called a Program Time Unit (PTU). Everyday TenneT makes sure the total production and consumption is equal for every PTU.

TenneT is also the host for different electricity markets in the Netherlands. The electricity is traded on different time spans. There is a market for long-term contracts, one for day ahead trading, one for during the day trading (intraday), and one for balancing the grid[6]. The last one is used for PRP's that have a discrepancy in their supply or demand. If their supply or demand is more or less than they announced to TenneT the day before, they have to pay or get paid according to the imbalance that is happening at that time. If there is too much supply on the grid at one moment, PRP's with too much supply can buy supply space from PRP's that have too little supply at the imbalance market.

According to article 23 and 24 of the Electricity law in the Netherlands (E-Law), Dutch TSO TenneT is obliged to connect whoever asks for it to the grid on a non-discriminatory base[7]. The conditions for a connection are elaborated upon in the so-called 'Network Code' for electricity[8]. In September 2012 new rules for the congestion management on the Dutch grid were set by the Minister of Economic affairs, Agriculture and Innovation[9]. However, currently most of these rules are already described in chapter 4.2, and more specifically 4.2.5 of the Network Code. Based on these obligations TenneT needs to inform producers about the size of the congestion (the geographical area), the expected period of congestion management, the cause of congestion, the total transport capacity available in the congested area versus the total transport capacity in contracts and the measures it will take to solve the congestion. Also the procedures for congestion management are described in the Network Code.

In 2007, the Minister of Economical affairs in the Netherlands reaffirmed the obligation for TenneT to connect every party that produces electricity to the grid with a letter to the parliament. In the letter was also stated that is likely to happen that planned production units in the Northern part of the Netherlands will be ready earlier than the connections of TenneT, since permits for building new transmission lines could take up to 10-years waiting time. Therefore, in 2007, the Minister expected congestion on the grid in the Northern part of the Netherlands. At that time there were requests for building production capacity in Eemshaven of almost 5000MW. The Minister announced additional measures to adjust the grid in the Northern part of the Netherlands to this many requests[1].

Figure 3: Letter of the Minister of Economical affairs in 2007 on the obligation of TenneT to connect parties to the high voltage grid.

[2] (van Damme, 2005)
[3] http://www.tennet.eu/nl/nl/klanten/diensten.html
[4] http://www.tennet.eu/nl/en/about-tennet/about-electricity/what-is-hertz.html
[5] http://www.tennet.eu/nl/customers/services/systemservices/program-managers/pr-register.html
[6] http://www.nma.nl/regulering/energie/elektriciteit/groothandelsmarkt/Europese_marktintegratie/default.aspx
[7] (Ministerie van Economische Zaken, 1998)
[8] (NMa, 2012)
[9] (Minister van Economische zaken, landbouw en innovatie, 2012)

2.2 Congestion management

Congestion on a high voltage transmission grid has been defined in literature as "*the situation in which a power line has reached its limits of safe operation, as a result of which requests for deliveries (transactions) cannot be physically implemented as requested*" [10]. A power line can reach its level of safe operation if there is more electricity input on the line than can be safely transported by the line. With too much input in Mega Volt Amperes, (MVA) the electricity transmission system can experience "cascade outages with uncontrolled loss of load"[11]. The challenge that arises in electricity markets in Europe, and thus in the Netherlands, is that there is a conflict between competiveness in an electricity market, and congestion on the electricity grid. The grid has got the above-mentioned constraints, which are not taken into account in liberalised markets. This leads to the following problem definition of van Blijswijk & de Vries: "*The technical objective of congestion management is to rearrange these (power) flows such that grid constraints, as well as market transactions, are adhered to*"[12].

There are different methods for congestion management. Van Blijswijk and De Vries[13] compared congestion management methods Basic system dispatch, Market splitting and Market redispatch. Their paper serves as a good basis for the literature study on advantages and disadvantages of different methods of congestion management. Also other papers give an oversight of different ways of congestion management in other countries in Europe[14,15,16].

Currently the Dutch method for congestion management, described in the Network Code, is basic system redispatch[17]. According to this method TenneT firstly has to define a congested area on the basis of expectations of flows on the grid. All companies (also called Program Responsible Parties or PRP's) that have power plants in this area will be under the restrictions of congestion management at certain times of the day (only at moments when the congestion is expected). At these times there will be a set maximum of power production. During this set maximum power production, a PRP in the congested area (also called Upstream Area) can make a bid to the market to not produce a part of its earlier promised amount of electricity. By not producing, the PRP will avoid variable costs of production of electricity (the PRP can choose to leave out an expensive gas-fired power plant for example). The PRP (or PRP's) with the highest bid will be left out of production. In the area that is not congested (the so-called Downstream Area) extra electricity needs to be produced because of the congestion in the upstream area. This will be done by bids of PRP's in the downstream area. In this area the PRP's with the lowest bids will get the permit to produce extra electricity.

2.3 Legislation on CO_2 and NO_x emissions in the Netherlands

Most environmental targets in the Netherlands are set by the European Union. Within the Union, each member state has got its own specific target that is agreed by all 28 member states of the Union. This is also the case for CO_2 and NO_x emissions.

2.3.1 CO_2 emissions

The Dutch government has agreed to the target to reduce its total CO_2 emissions per year with 20% in 2020 compared to 1990. This is a target that is part of the EU 20-20-20 goals. Part of this 20% targets will be achieved by lowering the yearly amount of Emissions Trading System (ETS) credits that can be received by companies in the Netherlands. In 2020 the ETS emissions should be 21% lower than the ETS emissions in 2005. The sectors that are not included in the ETS are expected to stay below 104 $MtCO_2$ in 2020 (in 2012 these sectors emitted 106 $MtCO_2$)[18]. The energy sector, which is part of the ETS, was emitting 51.3 $MtCO_2$ in 2005 and 46.7 $MtCO_2$ in 2012[19]. This is more than half of the total ETS emissions in 2012, and approximately a quarter of the total CO_2 emissions in the Netherlands in 2012.

[10] (Lesieutre & Eto, 2004)
[11] (Kumar, Srivastava, & Singh, 2005)
[12] (van Blijswijk & de Vries, 2012)
[13] (van Blijswijk & de Vries, 2012)
[14] (Ehrenmann & Smeers, 2004)
[15] (Androcec & Wangensteen, 2006)
[16] (Möller, 2010)
[17] (van Blijswijk & de Vries, 2012)
[18] (Rijksoverheid, 2013)
[19] (Dutch Emission Authority, 2012)

2.3.2 NO_x emissions

Dutch targets for NO_x emissions are based on legislation from two documents: the National Emissions Ceilings directive of the European Union[20], and the Gothenburg Protocol[21]. According to the Gothenburg Protocol the Netherlands should have reduced their NO_x emissions in 2010 with 54% compared to 1990 levels. This means a maximum yearly emission of 266 Kton NO_x in 2010. The maximum emission in 2010 according to the EU-directive was 260 Kton NO_x in 2010. The actual emissions in 2010 were 276 Kton NO_x in the Netherlands in 2010[22]. As a result both emission levels were exceeded. In 2011 and 2012 the 2010 target was achieved with emissions of respectively 259 and 253 Kton NO_x. The Dutch long-term target according to the renewed Gothenburg protocol is to have less than 202 Kton NO_x emissions in 2020. In 1990 the share in total NO_x emissions by the industry-, energy, and refineries sector was 33%. This reduced to 24% in 2012.

2.4 Environmental effects of congestion management

Currently there is a huge debate in the Province of Groningen around environmental effects of the construction of the thermal coal-fired power plant of RWE and the gas-fired power plant of Nuon/Vattenfall in Eemshaven[23]. A following question quite often asked by the Province of Groningen to TenneT is what the consequences of the congestion management are on the CO_2 and NO_x emissions in the Netherlands. Although the power plants in Eemshaven are expected to have relatively low emissions, it could happen that they will not be able to produce in the situation of congestion management.

In literature not much is written about the environmental effects of congestion management. There are papers that study the environmental effects in a liberalised electricity market[24], the environmental impacts of electricity demand[25] and the effects of market power on prices and the environment[26]. In these papers the possibility of congestion is sometimes taken into account, but effects are not specifically observed.

2.5 Research area

The high voltage grid in the Netherlands consists of voltage levels of 110kV (110 000 Volt), 150kV, 220kV and 380kV. It is maintained and operated by Dutch Transmission System Operator (TSO) TenneT B.V. Due to the fact that the high voltage grid was formerly maintained and operated by regional system operators, which were owned by provinces, the grid doesn't have the same voltage levels in every part of the country. In the Northwest of the country, in the provinces of Overijssel, Drenthe, Friesland and Groningen, a 220kV grid in combination with a 110kV grid is used. In the other provinces only a 150kV grid is present. The 380kV grid is present in all the provinces and acts as a power highway. This part of the grid is also connected to Belgium and Germany with alternating current lines, and to Norway and England with direct current lines (see figure 4)

Figure 4: High voltage grid in the Netherlands. Red represents the 380kV grid, green the 220kV grid, blue the 150kV grid and black the 110kV grid. (Source: Geonet, TenneT)

Different regional distribution companies own the regional grid of 20kV and underneath. The largest part of the regional grid is owned by Enexis (Noord-Brabant, Limburg, Overijssel, Drenthe en Groningen), Lliander (Noord-Holland, Flevoland and Gelderland), Stedin (Zuid-Holland and Utrecht), and Delta (Zeeland)[27]. Other small distribution companies own grids in a few cities.

This research focuses on congestion in the northern part of the Netherlands in the 380kV, 220kV and 110kV grid. Figure 5 shows the grid in more detail.

The 380kV grid in the northern part of the Netherlands (red lines in figure 5) has lines from Eemshaven (see figure 2 for the station at Eemshaven) via Meeden to

[20] (European Union, 2001)
[21] (UNECE, 1999)
[22] (Dutch Emissions Authority, 2013)
[23] http://www.provinciegroningen.nl/actueel/dossiers/rwe-centrale/actuele-ontwikkelingen-rwe/ and http://www.dvhn.nl/nieuws/groningen/article9596871.ece/Kritiek-op-rol-provincie-bij-kolencentrale
[24] (Lise & Kruseman, 2008)
[25] (Holland & Mansur, 2008)
[26] (Lise, The European electricity market–what are the effects of market power on prices and the environment, 2005)
[27] (Energieleveranciers.nl, 2013)

Zwolle and Ens. At Meeden there is a 380kV connection with Diele in Germany. At three different stations in the area there is a connection between the 380kV grid and the 220kV grid (Eemshaven, Meeden and Ens). From there electricity is distributed via the 220kV-, 110kV- and ultimately, the regional 20kV-grid of the cities and rural areas of Groningen, Friesland, Drenthe and the northern part of Overijssel. As is stated further on in this research, the 220kV- and 110kV grid are mostly used to transport local electricity demand. The 380kV grid is used to transport the bulk of the electricity towards other parts of the country.

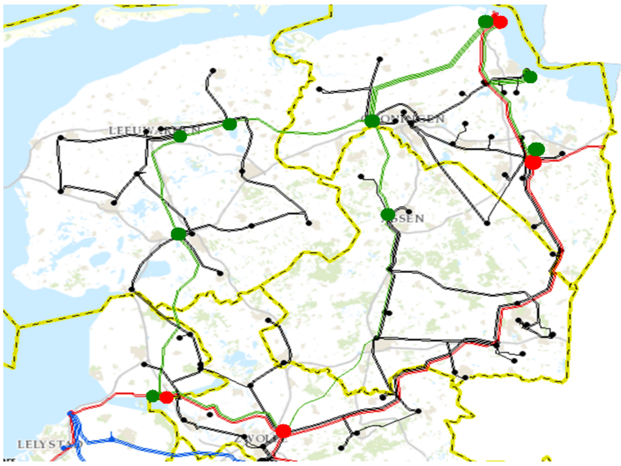

Figure 5: High voltage grid in the northern part of the Netherlands. Red is the 380kV grid, green the 220kV grid, blue the 150kV grid and black the 110kV grid. (Source: Geonet, TenneT)

The high voltage grid consists of components (lines, transformers, rails, cables, etc.). Each component has a capacity to deal with a certain amount of electricity. If more than this maximum capacity is going through a component, the component can be damaged or even be demolished. If the amount of electricity crosses the maximum legal set capacity, it is called congestion.

This research focuses only on congestion on lines and transformers. Lines consist of at least one circuit with three wires to support the alternating current of electricity. The types of transformers in the region are 380/220kV, 220/110kV, 220/20kV and 110/20kV transformers. Table 1 shows an oversight of the most important capacities of the lines and transformers in the region.

Table 1: Capacities of the most important lines and transformers in the northern part of the Netherlands (source: KLS, TenneT)

Line in grid	Number of circuits	Voltage level (kV)	Max. capacity per circuit (MVA)
Eemshaven - Meeden	2	380	2635
Meeden - Zwolle	2	380	2635
Meeden - Diele	2	380	1645
Eemshaven - Robbenplaat	2	220	950
Eemshaven - Vierverlaten	1	220	880
Robbenplaat - Weiwerd	2	220	880
Robbenplaat - Vierverlaten	2	220	880
Weiwerd - Meeden	2	220	880
Vierverlaten - Zeyerveen	2	220	455
Vierverlaten - Bergum	2	220	950

Transformers	Name	Voltage level (kV)	Max. capacity (MVA)
Eemshaven 380	TR 401 & 402	380/220	1500
Meeden 380	TR 402	380/220	750
Meeden 220	TR 201, 202, 221, 222	220/110/20	900
Weiwerd 220	TR 201, 222, 235, 261, 262	220/110/20	1260
Vierverlaten 220	TR 201, 202, 221, 222	220/110/20	560

3. Research methodology

Figure 6: Nuon/Vattenfall Magnum power plant at Eemshaven (1311 MWe). Three separate turbines of 437 MWe installed capacity can be seen. The blue colour is meant to match the power plant with its surrounding environment (the Waddenzee).

This chapter describes the used methodology in this research. Both chapter 3.1 and 3.2 describe the method for carrying out the research questions for step one (see *1.2.2 Sub questions).* Chapter 3.3 describes the method used in step two. Step three is described in chapter 3.4.

3.1 Installed production capacity in the northern part of the Netherlands until 2018

Data from all the power plants connected to the high voltage grid (110kV, 220kV and 380kV) in the northern part of the Netherlands (provinces of Friesland, Groningen and Drenthe) is collected. From all the power plants the maximum production capacity in 2013 and 2018, is mapped (i.e. some power plants are improved or removed in the coming years). For both capacities TenneT has the exact data. TenneT also has an oversight of which power plant is connected to which high voltage station (place where different lines cross each other). An oversight of the available installed capacity in 2013 and 2018 will be given for each high voltage station in the northern part of the Netherlands. The maximum production capacities are an important input for determining the expected area of congestion in the Northern part of the Netherlands (chapter 3.2). An oversight with all the power plants in the northern part of the Netherlands is presented in Annex I of this research.

3.2 Expected area of congestion in the Northern part of the Netherlands until 2018

3.2.1 Goal of the chapter

The goal in this sub chapter is to investigate under which scenario(s) the high voltage transmission network in the Northern part of the Netherlands becomes too heavily loaded. This leads to a conclusion on the geographical area of congestion and the cause of congestion under different circumstances. Four future scenarios will be modelled to compare the expected electricity transmission flows until 2018 (in MW) with the transport capacity in Mega Volt Amperes (MVA, see table 1) in the region. Future expected electricity transmission depends on the use of certain power plants and thus on market prices of gas and coal, political choices, variable costs of power plants, etc. Which power plants will be producing under which scenarios will be shown in step two of this research (chapter 3.3 and 4.3). In this step (step 1) it is only checked what the consequences of production of different power plants in the Northern part of the Netherlands are on the high voltage transmission grid.

3.2.2 Used data

Each transmission line on the grid has its maximum capacity based on the amount of circuits and material properties of the lines. Beyond that capacity electricity transport can be dangerous by low hanging lines and potential fall out. TenneT has data on transmission line capacity (MVA) and data on maximum production capacities of current and future planned power plants until 2018 (gas, wind, biomass, hard coal, high voltage direct current line from Norway and alternating current line from Germany). Also TenneT has the exact measurements of electricity flows from the past 2-3 years. This data is collected in a program called eBase. The data can be used to give an historical oversight of which line has been transporting which amount of electricity under certain circumstances (for example: import from Norway, import from Germany). This historical oversight can be used to make a prediction for the future. The scenarios that are used in this part of the research are described in figure 7. The input variables used in the scenarios are shown in Annex II.

3.2.3 Assumptions in the load flow model

For every scenario a load flow analysis is made in Excel. In this way an insight is given in the load flows in the grid in the northern part of the Netherlands under different circumstances. The model is based on the following assumptions: firstly the model takes into account the first Kirchhoff's circuit law which states that at a junction in an electrical circuit the sum of the incoming and outgoing electricity needs to be zero. The production at power plants can be seen as input in a circuit, and the demand of consumers can be seen as output. If all the demand of all the junctions (stations) in the network is known, the currents flowing over the lines in the grid can be calculated. In the model the demand in the region can be adjusted in according to the different scenarios.

A second assumption in the model is that if more power is produced than consumed in the region, it leaves the region via the 380kV connection Eemshaven-Meeden-Zwolle to flow to other parts of the Netherlands. In the period between April 2012 and April 2013 the 220kV network in Friesland, Groningen and Drenthe is hardly used as a route to transport power from the production units in Eemshaven to Ens. In 98,21% of the hours there was a power flow from Ens 380kV towards the 220kV network at Hessenweg and Oudehaske. This means only in less than 2% of the time there was a transport of power from the 220kV network in Groningen, Friesland and Drenthe towards the 380kV grid at Ens.

***Scenario Business as usual**: In this scenario current trends will continue. The gas price will stay high in comparison with the hard coal price. In the northern part of the Netherlands the old gas power plants will be shut down most of the time. The new build Magnum gas power plant of Nuon/Vattenfall will be running for a large part, because it needs to overcome its warranty period (Nuon/Vattenfall has two years to discover failures in the turbines. After that there is no guarantee on the gas turbines any more). Electrabel/GDF Suez will produce with one more gas turbine after 2016 because it has to close its hard coal-fired power plant in the end of 2015 according to the SER Energy Accord. The current trend of electricity import from Germany will continue. Also the import from Norway will continue. All the building plans for wind power production will be executed before 2018. The current trend of decentralised power production (for example by PV-panels on houses) and increasing energy efficiency will continue. This will cause a decreasing power demand in the region and in the other parts for the Netherlands. ENTSO-E uses a comparable scenario in its Ten Year Network Development Plan 2012 (Scenario B).*

***Scenario Gas and hard coal prices will converge**: In this scenario certain events that bring the gas- and hard coal price closer to each other will take place. Examples of such events are large-scale production of shale gas, decreasing availability of hard coal, a high ETS CO_2 price, or a higher hard coal tax in the Netherlands. Consequently the hard coal-fired power plant of RWE at Eemshaven will be shut down most of the time. The gas-fired power plants will produce on maximum capacity, except the already shut down plant EC20 of GDF Suez. Electricity will be imported from Norway and Germany. Just like the business as usual scenario the increasing decentralised power production and increasing energy efficiency will lead to a lower electricity demand in the region. ENTSO-E uses a comparable scenario in its Ten Year Network Development Plan 2012 (Scenario EU2020).*

***Scenario the Netherlands transport country:** In this worst-case scenario the Netherlands will become a transport country to transport cheap own produced electricity and electricity from Germany and Norway to the UK and France. This can happen in a case France decides to shut down nuclear power plants for a while (due to an accident or a heat wave), or the UK decides to step away from old hard coal power plants suddenly. In this case all the power plants in Eemshaven will be producing at maximum production capacity. Next to that there will be import from Norway and from Germany. Wind production won't be built, because it's not necessary in the energy mix. The electricity demand will rise because electricity is very cheap. It doesn't give an incentive to invest in decentralised power production of energy efficiency measures.*

***Scenario nuclear phase out Germany:** In this scenario Germany will become a net importer of electricity because of its plans to phase out nuclear power production in 2022. This phase out will take place in steps, which means a lot of nuclear power plants will be closed long before 2022. Next to the nuclear phase out Germany has another phase out to deal with: the stop of hard coal production in 2018. The hard coal power plants that are currently located closely to the mines will have too high marginal costs as soon as the mines close. Importing electricity can suddenly become more profitable. A third argument for Germany as future importer of electricity is the increasing public resistance against open cast lignite mining. Especially in situations with low wind availability the import demand from Germany can become high. In these situations all the power plants in Eemshaven will produce at maximum production capacity. There will be a big amount of export to Germany, and still import from Norway to the Netherlands. Electricity demand in the region will decrease a little bit, as energy efficiency measures and decentralised power production is still profitable. Planned wind parks will be built according to the building requests that are currently on the table. ENTSO-E uses a comparable scenario in its Ten Year Network Development Plan 2012 (Scenario B in combination with nuclear phase out).*

Figure 7: Description of scenarios used to investigate future congestion in the northern part of the Netherlands.

Another argument for the second assumption is that the historical data of TenneT show that at moments of high power production at Eemshaven, most of the power flows over the 380kV lines. Figure 9 shows a correlation between the amount of megawatts produced at the 220kV grid at Eemshaven and the percentage of production at 380kV that flows over the line Eemshaven-Meeden at 380kV. This correlation shows that the power plants at 220kV mostly produce for local demand. If the power plants are not in production the demand is met by the power plants at 380kV. At a production at 220kV of around 1100MW more than 90% of the power produced at Eemshaven 380kV is transported over the 380kV connection between Eemshaven and Meeden.

An oversight of the power flows in the period of April 2012-April 2013 is shown in figure 8. The arrows represent the flow direction that is in place most of the time. It is interesting to take a closer look at stations where the 220kV grid and the 380 kV grid come together (Eemshaven, Meeden and Ens). At those stations it can be seen that most of the time there is a flow from the 380kV grid towards the 220kV grid. This means the 220kV grid is not used as power transport route to transport power from Eemshaven to Ens and to the rest of the Netherlands.

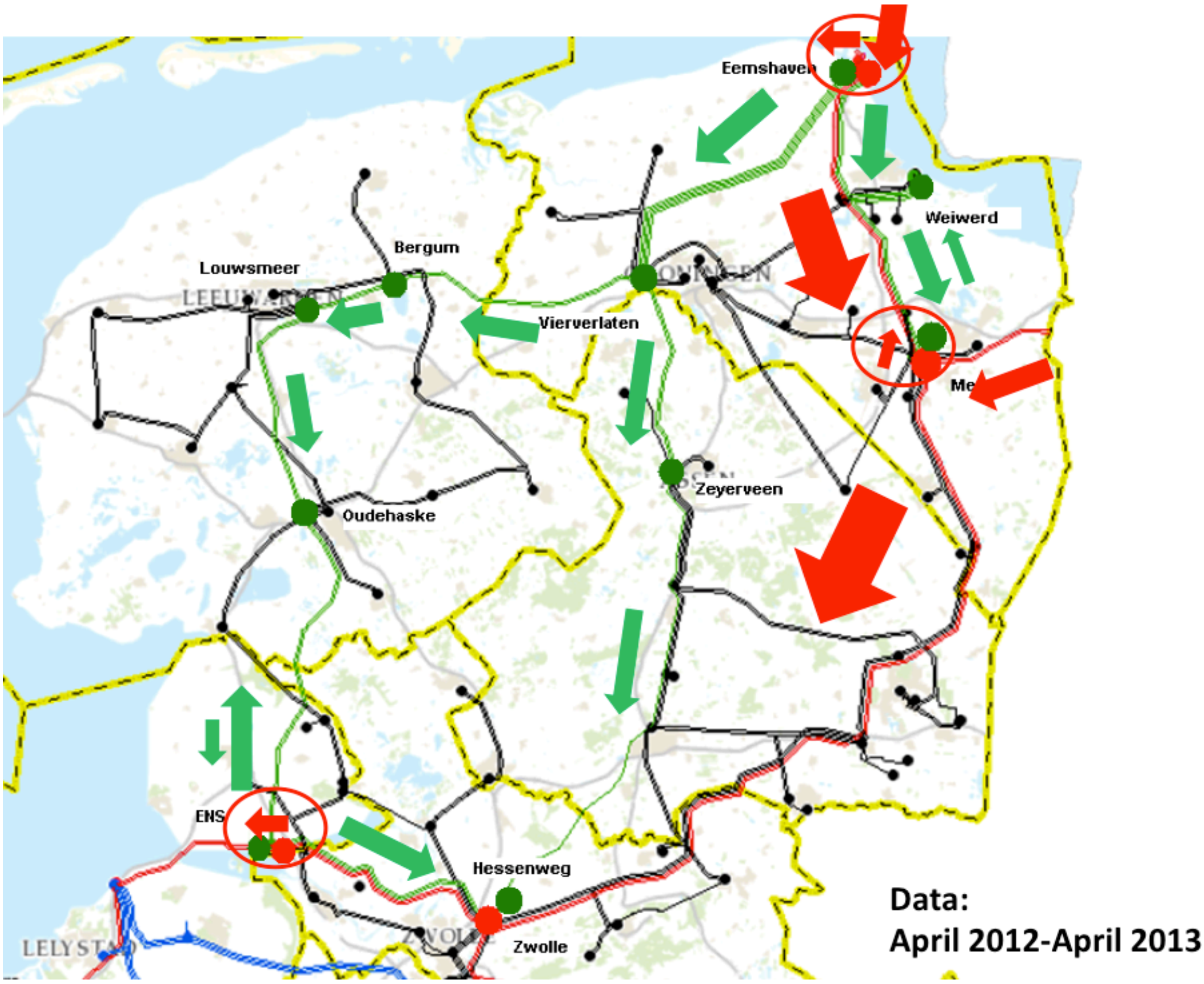

Figure 8: Power flows in the period of April 2012-April 2013 in the northern part of the Netherlands. The size of the arrows represents the amount of MW of the flow. The direction of the arrows represents the direction of the flow that is in place most of the time. The red circles show that the power flows were mainly from the 380kV grid towards the 220kV grid and not vice versa (source Geonet TenneT in combination with own drawings.

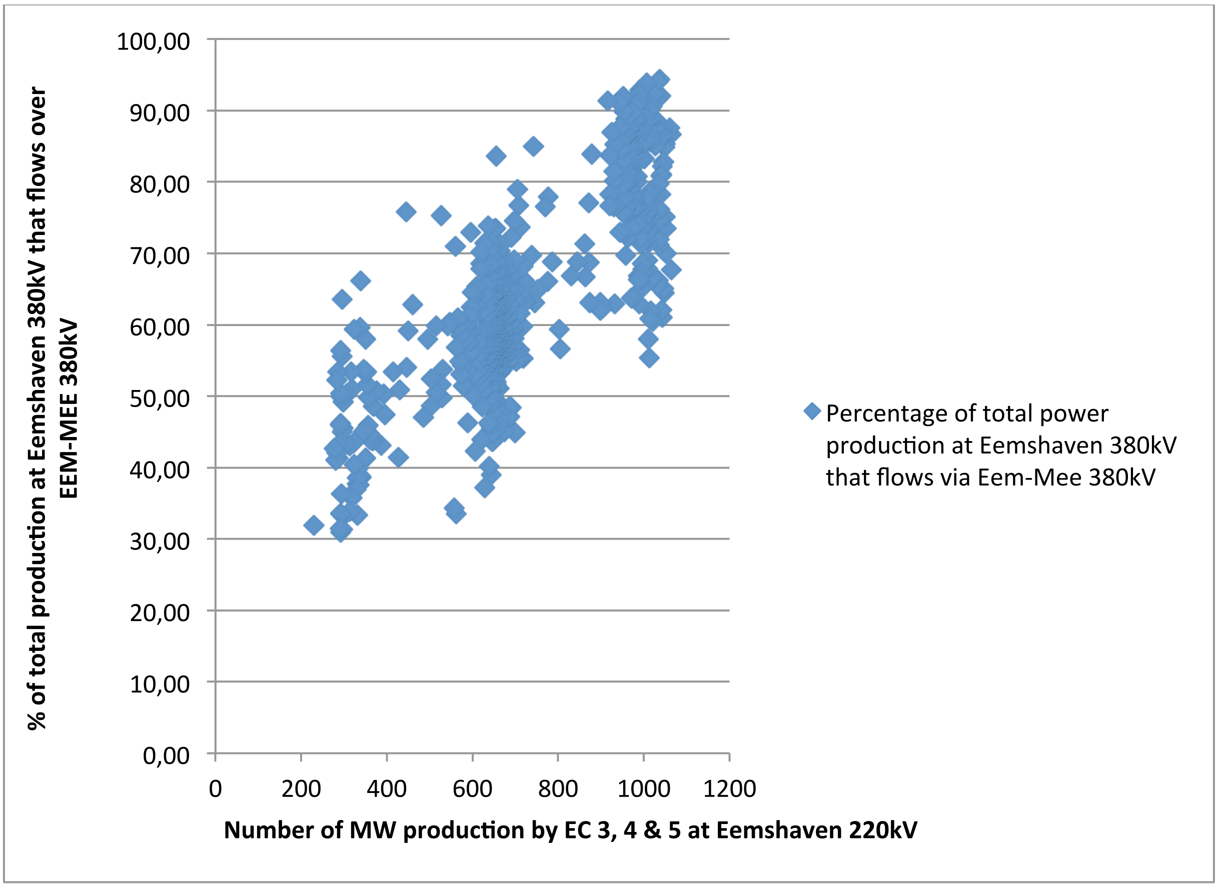

Figure 9: Percentage of power flow that goes via Eemshaven to Meeden (380kV) in case there is full production at Eemshaven 380kV. The percentage on the y-axis is dependent on the production of EC's 3-5 at 220kV (Source: GEN eBase TenneT).

A third assumption is that there will only be changes in production of power plants in Eemshaven, Delfzijl and Meeden. The other power plants in the region are assumed to produce 24/7. This assumption is made because the bulk of installed capacity is already in Eemshaven and Delfzijl, and the planned capacity to be installed is mostly at these three locations. It is not interesting what the consequences of changes of production at other places are, because they have little influence due to the low amount of installed capacity.

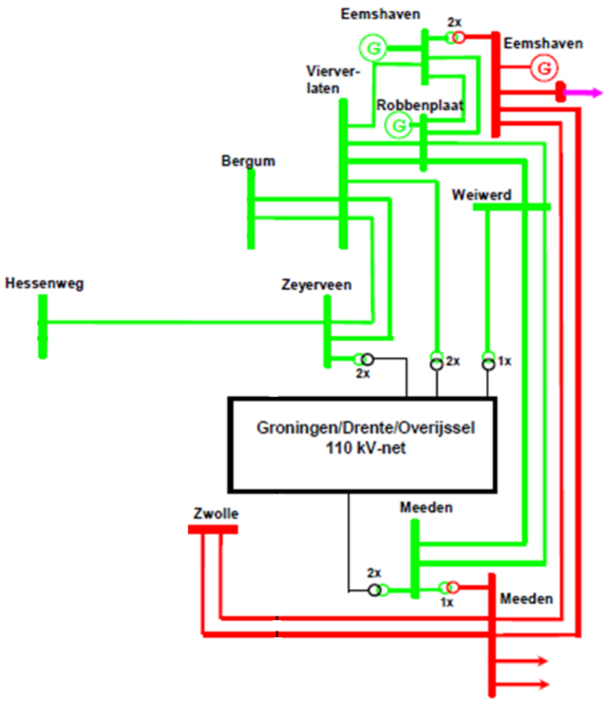

Figure 10: Schematic overview of the high voltage transmission grid in the northern part of the Netherlands (source: www.hoogspanningsnet.com).

To estimate the amount of power that will flow over the 380kV line from Eemshaven to Meeden under different scenarios, it is necessary to know what the demand is in the Northern part of the Netherlands in different situations. Therefore a fourth assumption is made. This assumption states that the consumer demand behind the stations (Hessenweg 220kV, Bergum 220kV, Vierverlaten 110kV, Zeyerveen 110kV, Weiwerd 110kV, Meeden 110kV) are all an average percentage of the total consumer demand in the period of April 2012-April 2013 between 12.00 midday and 16.00 in the afternoon in the whole region. The average percentage is chosen because the share of demand of all the locations was (almost) equally divided in the period April 2012 – April 2013. For example, during peak hours always 15% of the total power demand in the region went to Vierverlaten. By giving all the junctions a share of the total demand in the region the total demand can easily be adjusted in the model. The time of midday is chosen because it is the moment of the day highest peak electricity demand in the region (see figure 11). If there is congestion, it will in any case take place during peak demand. Because of this assumption this model does not look at congestion on lines in the 110kV grid.

A fifth assumption is the n-1 assumption. According to the Network Code TenneT has to guarantee a grid in which one component per circuit or station can fall out. This is called the n-1 criterium. If, for example, a line between two stations has two circuits, it must be safe for one of the two to be offline. The same holds for transformers at a station. If a station has three transformers that are responsible to deal with transforming power from a 380kV into a 220kV voltage level, at least two of them need to be able to deal with the full maximum load that the three of them deal with normally. At the station at Meeden temporarily only one transformer of 750MVA is in place to transform the 380/220kV power. This is because TenneT is not expecting this transformer to be unable to deal with the load at that part of the grid in the near future. It is assumed that this transformer cannot fall out.

According to the n-1 assumption in this research mentioned above 100% of the power that was originally flowing via two circuits is now flowing via one circuit. This is not completely realistic, because one circuit has different properties than two combined circuits (in terms of electrical resistance for example). As a result not 100% of the power that was flowing of the two circuits will now flow via the one circuit that is left. A share of the power will flow via connecting lines and transformers that have lower resistance in the n-1 situation. The n-1 assumption with 100% is made because it will give an indication on which lines will probably experience heavy loads in the different scenarios. For the lines and transformers that show the most likely chance of experiencing congestion a more in detail calculation (sensitivity analysis) is made on the exact flow in a n-1 situation (chapter 4.2.5).

Table 2: Division of demand at different stations in the northern part of the Netherlands (source: GEN eBase TenneT)

Station	**% Of total demand that is needed at this station**	**Reason energy demand**
Weiwerd	25%	Industry Harbour Delfzijl, Groningen city, Slochteren
Meeden	21%	East Groningen, Groningen city, Slochteren
Vierverlaten	15%	Groningen city, North West Groningen
Bergum	21%	Friesland
Zeyerveen	10%	Drenthe
Hessenweg	8%	Overijssel, Drenthe, Friesland

In the end the variables in the model that can be adjusted are the production of the power plants and the decentral demand in the region.

As reference data, internal data from TenneT is used. This data provides an oversight of power plant productions (MW) and power flows over lines in the grid (MW) over the period April 2012 – April 2013. The reference data is also used to validate the outcomes of the model. For the validation the circumstances in the different scenarios are filtered out of the reference data and compared with the outcomes of the model. The results of the validation are described in chapter 4.2.4.

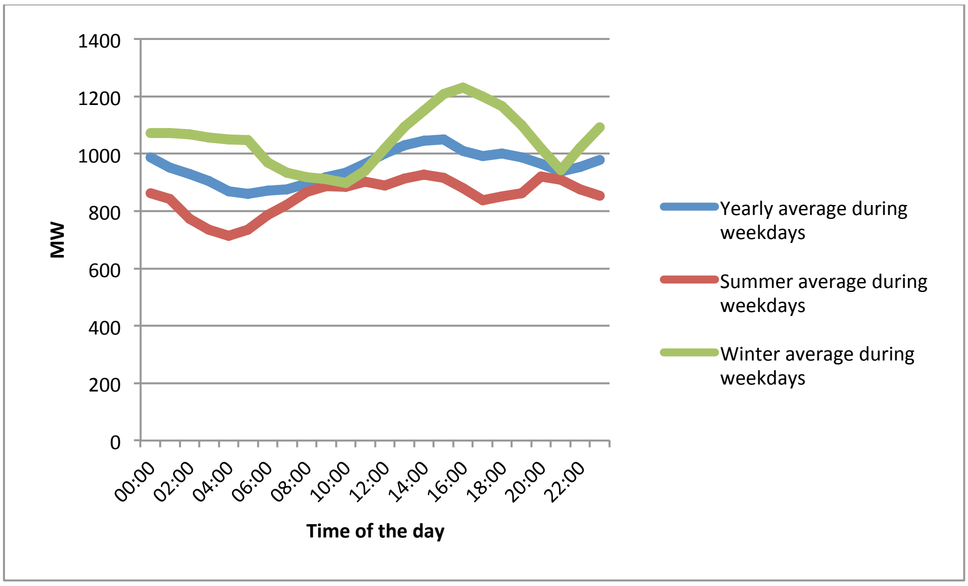

Figure 11: Average aggregated intraday transport towards the 110kV and 20kV grid in Groningen, Friesland, Drenthe and the northern part of Overijssel (Source: GEN eBase TenneT).

3.3 Market situation in the Netherlands with and without congestion management

Step two consists of mapping future market situations in the Netherlands. The four scenarios from step 1 are used to construct four possible future scenarios for the year 2018. This step is necessary to make estimations on the likeliness of possible congestion in the Northern part of the Netherlands in 2018. In step one it is checked under what circumstances congestion is actually happening in this part of the Netherlands.

Merit order curves including all the available conventional power plants in the Netherlands will be made. The merit order curves will be combined with residual load duration curves that represent 'average' days in summer, winter, spring and autumn. Input variables in the merit order curve data and residual load duration curve are adjusted according to the given scenario. With the combination of merit order curves and residual load duration curves the percentage of time that power plants in Eemshaven and the rest of the Netherlands will be producing electricity can be determined in the different scenarios.

How the merit order curves and the load duration curves are constructed is explained in chapters 3.3.1 and 3.3.2. The results of this chapter are shown in chapter 4.3.

3.3.1 Input variables in the merit order curve

A merit order curve shows the production capacity of power plants (in MW) on the x-axis, and the variable costs per produced MW (€/MW) on the y-axis. This will give a view on the order in which power plants will be switched on or off in a free market situation (the power plant with the lowest variable costs will be switched on first, etc.).

The installed capacity in the Netherlands from the PLATTS World Electric Power Plant (WEPP) database for the Netherlands is used as an input[28]. This database gives the location, the amount of installed capacity, the utility company, and other technical characteristics of all the power plants (types of turbines, scrubbers, etc.). It doesn't give information on emissions, operation and maintenance costs or variable production prices.

The PLATTS database categorises fuel types of power plants into sixteen categories. These sixteen categories are brought back to five categories in this research, as can be seen in table 3. Only the categories that are used in the merit order curves are shown in table 3. The merit order curves in this research do not include wind power, solar power (PV), hydro power, and must-run CHP-installations such as waste burning installations, green house CHP-installations and CHP-installations connecting to universities, hospitals, etc. The reason to exclude must-run CHP-installations is that they do not react very flexible on changes in market situations. They will (mostly) be running regardless market prices of fuels, CO_2 taxes, and so on. Wind power-, hydropower-, and solar PV-production are excluded because they will always be the power producers with the lowest

[28] (PLATTS, 2006)

variable costs. The focus in this research is which conventional power plants will deliver the electricity in the future in the Netherlands. However, both CHP, and the renewable energy sources are used in the Residual Load Duration curves (RLDC's). In the calculation of the RLDC's, they are subtracted from the load that has to be produced by conventional power plants. More information on the load duration curves is given below. An oversight of the used conventional power plants in the Netherlands is given in Annex III.

Table 3: Power plant fuel categories (source: WEPP database of the Netherlands from PLATTS)

PLATTS database fuel category power plant	Fuel category power plant in this paper
Coal	Coal (bituminous coal)
Gas	Gas (natural gas)
Biogas	
Dgas	
Lgas	
Rgas	
Waste gas	
Uranium	Uranium
Oil	Oil

The variable costs of the power plants in the merit order curves are dependent on a couple variables, namely:

- Operation and maintenance costs
- Fuel costs
- Costs of CO_2 allowances
- Efficiency of power plants

The operation and maintenance costs are obtained from a paper of the U.S. Energy Information Administration[29], and adjusted to €/MWh (conversion rate: 1$ = €0,76). These operation and maintenance costs are based on power plants in the United States in 2018. However, it is assumed in this paper that the relative differences between operation and maintenance costs of different power plants are comparable to the situation in the Netherlands.

The fuel costs are based on market prices as present in august 2013, and adjusted according to the assumptions in the different models. The taxes that are in place in the Netherlands are added to the prices. The fuel- and operation and maintenance costs of different fuel types are shown in table 4.

Table 4: Fuel prices, O&M costs, tax costs, and CO2 emission factors for different input fuels in power plants in 2013 (source: data sources of the given numbers in the table are shown in footnotes in the table)

Fuel type	Fuel price (€/MWh)	O&M costs (€/MWh)	Tax (€/MWh)	Total costs (€/MWh)	CO_2 emission factor (kgCO2/GJ)
Natural gas	32[30]	1.5	1[31]	35	56[32]
Bituminous coal	13.5[33]	5	1[26]	20	95[27]
Uranium	0.0038[34]	9	-	9	0
Oil	47[35]	7.5	0.02[26]	55	74[27]

In the European Union an Emissions Trading System (ETS) is in place. This is a cap and trade system with the goal to reduce greenhouse gas emissions. The ETS has got different phases. At the moment the ETS is in its third phase. This phase will be running until 2020. By then, all companies that emit greenhouse gasses should buy so-called 'allowances' at the CO_2 market. At the current phase of the ETS every EU member state can still allocate a certain amount of free allowances to companies in the country. In 2013 60% of the CO_2 allowances per country are freely allocated. However, this percentage is decreasing exponentially every year up to 2020. The remaining 40% of allowances are auctioned according to a free market principle[36]. In the Netherlands the Dutch Emissions Authority is handing out the free allowances. The free allowances are allocated to a location

[29] (U.S. Energy Information Administration, 2013)
[30] (CBS statline, 2013)
[31] (Belastingdienst, 2013)
[32] (Graus & Worrell, Trend in efficiency and capacity of fossil power generation in the EU, 2009)
[33] (CBS statline, 2012)
[34] (European Commission, 2012)
[35] (Oilprice.com, 2013) A oil price of $105 (€80) per barrel is taken
[36] (European Commission, 2013)

(for example: a CHP plant, or a refinery). A list of all the locations that get free allowances in the period of 2013-2020 is found on the webpage of the Dutch Emissions Authority[37].

Installations that emit CO_2 with the production of electricity do not receive free allocated CO_2 allowances since 2013. This means power plants have to buy allowances at the CO_2 market. The price in august 2013 was around €4.50/tonCO_2[38]. This price is taken as the price for 2013. Various financial institutions predict a CO_2 price of €30-€48/tonCO_2[39].

The efficiency is the amount of power output of a power plant divided by the amount of fuel input of the power plant. The efficiencies of fossil power plants that were build before 2005 are retrieved from the paper 'Comparison of efficiency of fossil power generation' by Wina Graus and Ernst Worrell[40]. Efficiencies from power plants that were build after 2005 were retrieved from websites of the respective companies that own the power plants[41].

Table 5: Assumptions of efficiencies of power plants in the Netherlands (source: Graus and Worrell 2007, websites of respective power plant owning companies, and calculations using data of TenneT and the Dutch Emission Authority)

	Gas	Coal	Oil
-1980	34%	35%	30%
1980-1990	40%	38%	35%
1990-2000	48%	40%	42%
2000-	59%	46%	45%

The efficiencies of gas and coal-fired power plants in table 5 can also be verified using real data. The method to do this is to combine data on CO_2 emissions of power plants with data with total production of power plants. The data with CO_2 emissions per power plant can be obtained at the website of the Dutch Emissions Authority[42]. The data of the total production of power plants can be obtained via the internal databank of TenneT (GEN eBase). Using the following formula, the efficiency of the power plant can be obtained:

$$\eta = \frac{Emission\ factor\ fuel}{CO2perMWh}$$

Whereby:
η= efficiency of power generation
Emission factor= the amount of CO_2 emitted per by burning 1 kg of fuel (see number in table 7)
CO2perMWh= the total amount of CO_2 in 2012 divided by the total amount of MW produced in 2012

Table 6: Efficiencies of hard coal- and gas-fired power plants in the Netherlands (source data: TenneT and Dutch Emissions Authority)

Hard coal		
Building year	**Power plant**	**Efficiency**
1975	Maasvlakte 1&2	37%
1981	Gelderland 13	46%
1987	Borssele 12	43%

Gas		
Building year	Power plant	Efficiency
1989	Merwedekanaal	38%
1995	Lage Weide	45%
1996	Eemscentrale	51%

Table 6 shows the efficiencies of six randomly chosen gas- and coal-fired power plants in the Netherlands. Their efficiency is determined using data of the year 2012. The results from table 6 show slight discrepancies with the assumptions taken from literature in table 5. Especially with the coal-fired power plants. This could possible

[37] (Dutch Emissions Authority, 2013)
[38] (Thomson Reuters, 2013)
[39] (McKinsey and Companies, 2008)
[40] (Graus, Worrell, & Voogt, International comparison of efficiency fossil power generation, 2007)
[41] For example: Efficiency new hard coal-fired power plant: (Essent, 2013), Efficiency new gas-fired power plant: (Nuon, 2013)
[42] (Dutch Emissions Authority, 2012)

be explained by the fact that the coal-fired power plant of Gelderland 13 is using biomass partly as an input fuel. Biomass is probably not taken into account into the CO_2 emissions. This will lead to a higher efficiency.

With the combination of the efficiencies and the fuel costs, the fuel costs per MWhe output can be calculated.

$$€/MWhoutput = \eta * €fuel$$

Whereby:
€/MWhoutput = total fuel costs cost in Euro per MWhe output of the power plant
η= efficiency of power generation
€fuel = costs in Euro per MWhe of unit input fuel in the power plant

Also the amount of CO_2 emissions per MWhe can be calculated using the following formula:

$$CO2/MWh = \frac{\eta}{Emission\ factor}$$

Whereby:
CO_2/MWh = CO_2 emissions per MWh output of the power plant
η= efficiency of power generation
Emission factor= the emission factor of the respective fuel (see table 7)

Table 7: Emission factors per input fuel (source: Graus and Worrell, 2011)

	KgCO2/MWh	KgCO2/GJ
Gas	201.96	56.10[40]
Hard coal	340.56	94.6[40]
Oil	266.76	74.1[43]

The total variable costs of a power plant are:

$$€Total = €output + €CO2 + €O\&M$$

Whereby:
€Total = total variable costs in Euro per MWhe of a power plant
€output= total fuel costs cost in Euro per MWhe output of the power plant
€CO_2= total costs in Euro per MWhe for buying CO_2 allowances
€O&M= total operation and maintenance costs in Euro per MWhe

3.3.2 Input variables in the Residual Load Duration Curves

The merit order curves will be combined with a Residual Load Duration Curve (RLDC). This curve shows the power demand (load) profile of a day by showing the fraction of time that the demand is higher than a certain value.

Table 8 shows an example of data input for a load duration curve. In the first two columns the load pattern of a random day in the Netherlands is shown. The last three columns show the load duration curve. It can be seen, for example, that during 18 hours of the day the load is more than 9GW. This is 75% of the time. So, during 75% of the day power plants in the Netherlands need to produce at least 9GW of electricity. The data from the load duration curves used in this research is obtained from the TenneT website[44].

[43] (Graus & Worrell, Methods for calculating CO2 intensity of power generation and consumption: A global perspective, 2011)
[44] (TenneT, 2013)

Table 8: Example of input for a load duration curve (source data: random numbers from own database)

Hour	Load (GW)
0:00	8.9
1:00	8.4
2:00	8.2
3:00	8.1
4:00	8.2
5:00	8.3
6:00	9.3
7:00	11.0
8:00	12.5
9:00	13.2
10:00	13.3
11:00	13.5
12:00	13.4
13:00	13.7
14:00	13.7
15:00	13.6
16:00	13.5
17:00	13.3
18:00	12.6
19:00	12.2
20:00	11.8
21:00	11.3
22:00	11.3
23:00	10.7

Load (GW)	Freq. original	% freq. Original
1	24	100%
2	24	100%
3	24	100%
4	24	100%
5	24	100%
6	24	100%
7	24	100%
8	24	100%
9	18	75%
10	17	71%
11	16	67%
12	12	50%
13	9	38%
14	0	0%
15	0	0%
16	0	0%
17	0	0%
18	0	0%
19	0	0%
20	0	0%

From the load duration curve a Residual Load Duration Curve can be made. This curve shows the load during a day, minus the amount of wind power, solar power, hydropower and must-run CHP power, since the power production of these power sources cannot be predicted, or influenced. Thus, assumptions have to be made regarding these power sources.

In the case of wind power, Dutch Central Bureau for Statistics (CBS statline)[45] serves as a data source. It gives total production capacities of wind power (on land and on sea), and also shows how much electricity is actually produced by the available installed capacity. Using these numbers, the average efficiency of the installed capacity of wind can be determined. Table 9 shows an oversight of the resulting wind statistics in the Netherlands. The data for the months of February, November, June and April is also shown, because the four chosen RLDC's are taken from days in these months.

In the RLDC's the wind data is used in the following way: In the RLDC for a day in February (2012), 2318MW of total wind capacity is installed in the Netherlands (see table 9). During that month 437GWh was actually produced by this wind capacity. This is an efficiency of 30%. As a consequence during every hour in the RLDC 30% of 2318MW is produced by the wind turbines in the Netherlands, namely 0.73GW. The same method is applied for the RLDC's from other months.

[45] (CBS statline, 2013)

Table 9: Oversight of installed wind power capacity in the Netherlands (onshore and offshore), wind production, and efficiency of installed capacity (source data: CBS Statline, 2013)

Period	Wind production total (GWh)	Wind production land (GWh)	Wind production sea (GWh)	Wind installed capacity total (MWe)	Installed capacity land (MWe)	Installed capacity sea (MWe)	Produced power as % of installed capacity (total)	Produced power as % of installed capacity (land)	Produced power as % of installed capacity (sea)
2007	3438	3108	330	1749	1641	108	22%	22%	35%
2008	4260	3664	596	2149	1921	228	23%	22%	30%
2009	4581	3846	735	2222	1994	228	24%	22%	37%
2010	3993	3315	679	2237	2009	228	20%	19%	34%
2011	5100	4298	802	2316	2088	228	25%	23%	40%
2012	4999	4210	789	2434	2206	228	23%	22%	40%
2012 February	467	391	76	2318	2090	228	30%	28%	50%
2012 November	463	385	78	2422	1311	228	27%	24%	48%
2013 April	472	405	67	2434	2206	228	27%	25%	41%
2013 June	452	386	66	2434	2206	228	26%	24%	40%

In September 2013 the Social Economic Council completed an accord between 40 different organisations in the Netherlands. This so-called Energy Accord[46], among other things, points out the ambitions in the field of sustainable energy supply up to 2023. Part of these plans is the extension of installed wind energy capacity. The accord concludes that the Netherlands doesn't have a lot of space to increase its installed wind capacity on land, but it does have a lot of opportunity to increase its installed capacity at sea. In the accord, which is accepted by the Dutch government, the ambition is to increase installed wind capacity towards 4450MW in 2023. In table 10 the different phases in the installation of the planned capacity in the accord can be seen. The accord assumes that already 1000MW of wind capacity will be installed in the coming years. In 2013 the total installed wind capacity was 228MW. This means in 2019 there will be an increase of 1222MW of installed wind capacity at sea.

Table 10: Planned increase of wind capacity at sea according to the plans in the 'Energy Accord' of the Dutch Social Economic Council (source: SER, 2013)

Start to build:	Planned increase installed capacity	Operational in:
2015	450 MW	2019
2016	600 MW	2020
2017	700 MW	2021
2018	800 MW	2022
2019	900 MW	2023

The method for calculating the solar power production in the RLDC is slightly similar to the one of wind power. The difference is that solar power is only produced during the period of the day that the sun is actually shining, while wind can be produced during every hour of the day. From table 11 can be seen that the produced power as a percentage of installed capacity is quite stable since 2007 (around 15%). As a result, in the RLDC's every hour that the sun is shining during the day 15,85% of the installed capacity of 340MW is produced: 0,054GW.

[46] (SER, 2013)

Table 11: Oversight of installed solar PV capacity, production and efficiency in the Netherlands (source: CBS statline, 2013)

Period	New installed capacity (MW)	Removed installed capacity (MW)	Net installed capacity (MW)	Power production (GWh)	Produced power as % of installed capacity
2007	1	0	53	36	15.5%
2008	4	0	57	38	15.2%
2009	11	0	68	46	15.4%
2010	21	0	88	60	15.6%
2011	58	1	145	100	15.8%
2012	195	1	340	236	15.9%

The prediction of installed capacity for solar PV is quite hard because current developments are precarious. In none of the scenarios for development of solar PV in the Netherlands was predicted that installed capacity of solar PV would be 340 MW in 2013[47]. All the expectations were lower. A group of companies in the energy sector in the Netherlands (regional distribution companies, consultants and research bureau's) has the expectation to have 4000 MWe of installed solar-pv power in 2020[48].

Another important input variable is the amount of must-run CHP's in de RLDC's. Must-run CHP-installations (or so-called "auto users") are installations that produce power for their own primary activity. Earlier described examples are refineries, greenhouses, heavy industries, etc. In the PLATTS database the power plants are categorised according to their company type. Company types in PLATTS are: U, A and P. The U stands for 'regulated utility'. This category consists of the bulk of electricity producers. The A stands for 'auto producers'. These are mostly companies that produce electricity mostly for their own use. Normally they don't bid into the market. The P stands for 'private independent power plants'. In the Netherlands the private power plants mostly include wind turbines. The must-run CHP installations are the installations in category A. In PLATTS the total operational installed capacity for this category is 2980MW. However, this is conflicting with data of the Dutch Bureau for Statistics (CBS). From their data there is around 8000MW of installed CHP capacity (the CBS doesn't define how much of the CHP is must-run CHP), from which on average 3,7GW is produced per hour in 2012[49]. CBS also has monthly data on decentral produced electricity. 'Decentral' produced electricity is defined by the CBS as electricity that is produced by producers that are connected to regional high voltage transmission grids (20kV and below). In table 12 is shown in the last column what amount of average decentral electricity production was present in the different months that were chosen in the RLDC's. These values are both higher in winter and autumn (around 4.2 GWe), and in summer and spring (around 3.3 GW) than the total installed capacity that the PLATTS database gives on auto producers. The difference between summer/spring and autumn/winter can be explained by the fact that CHP installations that are mend to produce heat (and produce electricity as a second product) are only active in winter times with low temperatures. In summer and spring this leads to a 1 GW lower amount of decentral (must-run) CHP production. In the RLDC's the values from table 12 are used as must-run CHP values during the different days.

Table 12: Decentral electricity production by CHP installations in the Netherlands in months of the days chosen for the RLDC's (source: CBS statline, 2012)

Period	Decentral electricity production total (GWh)	Average decentral production per hour (GWe)	Average decentral production per hour excluding solar- and wind power (GWe)
2012 February	3485	5	4.3
2012 November	3440	4.8	4.1
2013 April	2912	4	3.4
2013 June	2850	4	3.3

[47] (ECN, 2013)
[48] (DNV Kema, 2012)
[49] (CBS statline, 2012)

The must-run CHP numbers from table 12 are not the perfect values for must-run CHP in the Netherlands. However, they are assumed to be quite likely. A more in depth analysis by *Energy Matters* shows that must-run CHP production between 3 and 4 GWe is quite likely[50].

The categories assumed as must-run CHP add up to around 13% of the total installed conventional power capacity in the Netherlands (28GWe). According to Graus and Worrell[51] auto producers have a worldwide share of 6% in power generation. Some countries have a higher share (Finland 21%, Japan 12%, India 11%, UK 10%).

The two last important input variables in the RLDC's are the import and export values. These variables are both very dependent on available transport capacity and market situations. The available transport capacity for import and export is approximately 5650MW in the Netherlands. This includes connections with Belgium (1501MW alternating current), Germany (2449MW alternating current), Norway (700MW direct current) and England (1000MW direct current)[52]. Intraday there is also a flexible amount of 200 MW available at some times. This intraday amount has not been taken into account in the models of this research. The import and export balance fluctuates per hour. On the average in 2013 one third of the transport capacity was used for export and two third for import (see table 13). This balance is used in scenarios 1 and 2. In scenario 3 and 4 is assumed that two third of the available transport capacity for import and export is used for export. One third in those scenarios is used for import.

Table 13: Electricity import and export data for the Netherlands in 2010, 2011, 2012 and the four months of the residual load duration curve in GWh. (source: CBS statline, 2012)

	2010	2011	2012*	2013 April	2013 June	2012 February	2012 November
Import	15 584	20 621	32 155	2 562	3 151	1 556	2 725
Export	12 808	11 530	15 045	1 447	756	1 707	1 561

3.3.3 Calculating the outcomes of the merit order curves and the RLDC's

Based on the merit orders in combination with the RLDC's a prediction on the total amount of electricity production (GWh) in different scenario's can be made. Next to that the amount of congestion at the 380kV line Eemshaven-Meeden can be checked with the predicted production of the conventional power plants at Eemshaven. The method for calculating the total production is that the outcomes of the RLDC's in different seasons will be extrapolated to a whole season. It is assumed that the RLDC of the summer day is representative for the whole summer. The same holds for RLDC's for the days in spring, autumn and winter. From the RLDC of the summer day a load pattern can be read in which can be seen that power plant 1 with production capacity X_1 is producing Y_1% of time, and power plants 2 is producing Y_2% of time with production capacity X_2. Power plant 1 in this case is the first power plant in the left side of the merit order. In the end the total amount of GWh produced is a summation of the power production of all the power plants in the merit order. The following formula can be applied to calculate to total amount of power production

$$\sum_{i=1}^{n} X_i * Y_i * t = X_1 * Y_1 * t + X_2 * Y_2 * t + X_n * Y_n * t$$

Whereby:

X_i= Installed capacity of power plant i (MW)
Y_i= Percentage of time that power plant i is producing (%)
t= Total number of hours per year (8760)

The same formula can be applied only to the power plants at Eemshaven in the different scenarios. In this way it can be seen how much total production by conventional power plants is in place at Eemshaven. Only the amount of wind production and import of electricity from Norway needs to be added to the conventional production in Eemshaven. If this combination of conventional production, wind production and import from Norway exceeds the limit of 3800MW[53], congestion management is necessary. The amount of import from Norway and production of wind is shown in table 14.

[50] (Energy Matters, 2013)
[51] (Graus, Worrell, & Voogt, International comparison of efficiency fossil power generation, 2007)
[52] (TenneT, 2013)
[53] Conclusion from chapter 4.3

3.3.4 Input variables per scenario

In tables 14 and 15 all the input variables for both the merit order curves (table 14) and the Residual Load Duration Curves (table 15). In both tables the input variables for the years 2012/2013 are shown (second column). These are real numbers from data sources that were shown in earlier tables. The numbers in the scenario-columns are adjusted according to the situations in the respective scenarios. In table 16 the variables for calculating congestion at Eemshaven are presented.

Table 14: Oversight of input variables in the different merit order curves in different scenarios (own chosen numbers based on data explained in this chapter)

Merit order variables (€/MWh)	2012/2013	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Uranium price	0.0038	0.0038	0.0038	0.0038	0.0038
Gas price	32	32	32	32	32
Gas tax	1	1	1	1	1
Oil price	47	47	47	47	47
Oil tax	0.02	0.02	0.02	0.02	0.02
Biomass price	27	27	27	27	27
Hard coal price	14	14	14	14	14
Hard coal tax	1	1	1	1	1
CO2 price	4.50	4.50	35	4.50	4.50

Table 15: Input variables in the Residual Load Duration Curves in different scenarios (source: own chosen numbers based on data explained in this chapter)

Residual Load Duration Curve variables	2012/2013	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Must-run CHP (yearly average GW/h)	3.7	3.7	3.7	3.7	3.7
Must-run CHP Spring (Average GW/h)	3.4	3.4	3.4	3.4	3.4
Must-run CHP Summer (Average GW/h)	3.3	3.3	3.3	3.3	3.3
Must-run CHP Autumn (Average GW/h)	4.1	4.1	4.1	4.1	4.1
Must-run CHP Winter (Average GW/h)	4.3	4.3	4.3	4.3	4.3
Solar PV (MWe installed capacity)	340	4000	4000	340	4000
Wind land (MWe installed capacity)	2206	2206	2206	2206	2206
Wind sea (MWe installed capacity)	228	1222	1222	228	1222
Load increase/decrease (%)	1%	16%	16%	21.4%	16%
Export (GW)	1.9	1.9	1.9	3.8	3.8
Import (GW)	3.8	3.8	3.8	1.9	1.9

Table 16: Input variables in different scenarios for calculating the total electricity production at Eemshaven

Congestion Eemshaven variables	2012/2013	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Installed wind capacity Eemshaven (MW)	183	783	783	183	783
Average production wind capacity (MW)	73	313	313	73	313
Import NorNed Eemshaven (MW)	700	700	700	700	700

The used input variables in the different scenarios are explained in more detail below. Most is explained for scenario 1. For the other scenarios only the difference with scenario 1 is explained.

Scenario 1:
In this business as usual scenario almost all the variables are the same as they were in the year 2012/2013. The only difference is the load increase of 16% in 2018. This 16% is based on an estimation of TenneT that the electricity demand is increasing with the same growth factor as the economical growth. In 2013 the Dutch Central Bureau for Statistics (CBS) estimated a 1% growth in 2014. In the period of 2015-2017 CBS expects 1.3% growth[54]. With a 1% growth per year the electricity demand will grow from 115 TWh in 2013 towards 133 TWh in 2018. This increase of 18 TWh means an increase of 16%. With a growth of 1.3% per year the total electricity demand in 2018 will be 139 TWh. This is an increase of 25 TWh and thus 21.4%. This percentage is used in other scenarios. For import and export respective values of 3.8 GW and 1.9 GW are chosen. As scenario 1 is a business as usual scenario, an average number for import/export balance over the whole year of 2012 is taken. Data from CBS shows that in 2012 32 155 GWh of electricity was imported, and 15 045 GWh of electricity was exported[55]. This leads to a conclusion that on average 2/3 of the total import/export capacity (5 650 MW) in the Netherlands was used for import in 2012. It is assumed that in 2018 the total amount of wind at sea is increased until 1 222 MW of installed capacity. This is the amount that is planned in the Energy Accord that was agreed on in the Netherlands at 6 September 2013[56]. Furthermore it is assumed that 600 MW of this increase of approximately 1 000 MW is build at the coast of Eemshaven. The total wind capacity at Eemshaven will then increase to 783 MW in 2018. This amount of installed capacity will be mostly offshore wind parks. From table 9 could already be concluded that these wind parks on average have higher efficiencies than wind parks on land. The yearly average for offshore installed wind capacity was 40% in 2012. For scenario 1 in 2018 it is assumed that all the installed wind capacity at Eemshaven will reach this 40% of efficiency. On average the wind parks at Eemshaven will thus produce 313 MW per hour. The installed capacity of solar-pv is expected to grow towards the 4000 MW that is predicted by a group of companies busy in the energy sector in the Netherlands[57].

Scenario 2:
In this scenario the prices marginal costs for electricity produced with hard coal and natural gas will converge. Therefore, the largest difference in scenario 2 compared to the other scenarios is the higher CO_2 price. As mentioned earlier in this chapter, various financial institutions predict a CO_2 price of €30-€48/tonCO_2 in 2030[58]. In the input variables of the merit order curve a CO_2 price of €35 is chosen in scenario 2.

Scenario 3:
In this scenario renewable energy won't develop because of abundant availability of fossil fuels. It is assumed that there is a lot of export because the Netherlands is producing electricity cheaper than England, Belgium and France. There is still some import from Norway and Germany because the marginal costs of hydro- and wind power electricity are very low. Two third of the import/export capacity is used for export in this scenario. This is a reverse compared to scenarios 1 and 2. The increase in electricity demand is expected to be 21.4%. This is based on the 1.3% growth of electricity demand per year in the period of 2014-2018. At Eemshaven there is no increase of installed capacity of wind parks, because it is assumed that renewable energy won't develop in this scenario.

Scenario 4:
This scenario is the 'green energy' variant of scenario 3. There is a lot of electricity production in the Netherlands that is destined for export (mostly because of the nuclear phase out in Germany). In contrast to scenario 3 this electricity is produced more by solar-pv (increase towards 4 000 MW in 2018) and wind (increase of wind capacity at sea towards 1 222 MW in 2018). As a consequence the wind capacity at Eemshaven increases towards 783 MW. In this scenario five coal-fired power plants will be closed because of the plans in the Energy Accord. This means Borssele 12 (408 MW), Amer 8 (645 MW), Gelderland 13 (592 MW), and Maasvlakte 1 and 2 (both 555 MW) will be closed in 2018.

3.3.5 Congestion in scenarios

In the case of (expected) congestion in these scenarios it is assumed that congestion management, and thus, redispatch will be in place. The expected congestion is based on the conclusion from chapter 4.3. In this chapter is concluded that the 380kV line Eemshaven-Meeden is likely to be the first line whose capacity will be crossed. This is likely to happen with a production of more than 3800 MW at Eemshaven 380kV and 220kV.

54 (TenneT, 2013)
55 (CBS statline, 2013)
56 (SER, 2013)
57 (DNV Kema, 2012)
58 (McKinsey and Companies, 2008)

Thus, every MW electricity production at Eemshaven that exceeds the 3800 MW needs to be redispatched by TenneT. Table 22 shows that already more than 4700MW of installed capacity is in place at Eemshaven in 2013. However, only conventional power plants can be part of congestion management according to article 4.2.5.17, sub a, of the Dutch network code. This article states that only installed capacity with an adjustable output can be part of congestion management. Therefore the 3800MW minus the amount of wind power production is the capacity that is left for conventional power plants in Eemshaven (the upstream region). If this capacity is crossed the overproduction should be redispatched by TenneT, and produced in the downstream region.

3.4 Expected CO2 and NOx emissions in the Netherlands until 2018 with and without congestion management

The hypothesis in this research is that the electricity production of relatively new and thus more efficient power plants in Eemshaven (upstream area) will be replaced by older, less efficient power plants in other parts of the Netherlands (downstream area) in case of congestion on the transmission lines between Eemshaven and the rest of the Netherlands. A following question is what effects this redispatch has on emissions of various exhaust gasses (CO_2, NO_x). In this chapter the method for determining this so called environmental effects of congestion management is explained. The results of the method are presented in chapter 4.4.

Electricity is mostly produced in the Netherlands by conventional power plants. As can be seen in table 17, 82% of the total electricity production in 2012 came from fossil fuel sources. From this 82TWh of electricity production by fossil fuel sources natural gas-fired turbines produced 66% (table 18). Hard coal-fired turbines produced 29%. The small share of renewable energy in the total electricity production in the Netherlands (12%) is mostly produced by wind energy (40%, see table 19) and biomass energy (57%).

Table 17: Oversight of electricity production in the Netherlands in 2012. The production is shown in TWh and as a percentage of total production. (Source: CBS statline[59])

	TWh	%
Total electricity production	102.1	100
Total electricity production by fossil fuel power plants	82.2	80.6
Total electricity production by renewable energy sources	12.5	12.2
Nuclear energy	4.0	3.9
Other	3.4	3.3

Table 18: Electricity production with fossil fuel sources in the Netherlands in 2012 (source: CBS statline)

	TWh	%
Total electricity production by fossil fuel power plants	82.2	100
Natural gas	54.1	65.7
Hard coal	24.0	29.2
Oil	0.1	0.1
Other fossil fuels	4.1	5.0

Table 19: Electricity production with renewable energy sources in the Netherlands in 2012 (source: CBS statline)

	TWh	%
Total electricity production by renewable energy sources	12.5	100
Solar PV	0.2	1.9
Wind	5.0	40.0
Hydro power	0.1	0.8
Biomass	7.2	57.3

[59] (CBS statline, 2013)

3.4.1 Differences between hard coal and natural gas

Although both hard coal and natural gas are fossil fuels, they have different characteristics. These differences explain the fact that hard coal and natural gas do not have the same emissions of exhaust gasses such as carbon dioxide (CO_2). The most obvious difference is that hard coal is solid, whereas natural gas is gaseous. Other characteristics that determine the difference between natural gas and hard coal are energy content (GJ/kg), sulphur content, nitrogen content and particle matter content. Figure 6 shows the gas-fired magnum power plant at Eemshaven.

3.4.2 Only emissions of NO_x and CO_2 are taken into account

Hard coal-fired power plants are expected to have lower marginal costs compared to gas-fired power plants in the Netherlands. History proves that hard coal-fired power plants are used as base load power plants, whereas gas-fired power plants provide peak power. As congestion is mostly expected in times when the peak power is very high, it is very likely, in moments of congestion, that gas-fired power plants at Eemshaven are replaced by other gas-fired power plants. Gas-fired power plants emit reasonable amounts of CO_2 and NO_x. Hard coal-fired power plants also emit significant amounts of SO_2 and particle matter (PM10). Because of the expectation that it is most likely that gas-fired power plants will cause differences in emissions between situation with and without congestion, only NO_x and CO_2 emissions are taken into account.

3.4.3 Calculating CO_2 emissions

The amount of emitted CO_2 per MWh of power production for every power plant is calculated with a combination of the efficiency of the power plant and the emission factor of the input fuel. In table 20 the used CO_2 emission factors are shown.

Table 20: CO2 emission factors (Graus & Worrell, Methods for calculating CO2 intensity of power generation and consumption: A global perspective, 2011))

Fuel type	KgCO2/MWh	KgCO2/GJ
Gas	201.96	56.1
Hard coal	340.56	94.6
Wood pellets	26	7
Oil	266.76	74.1

The following formula is used to calculate the amount of CO_2 that is emitted per produced amount of MWh:

$$CO2perMWh = \frac{Emission\ factor\ fuel}{Efficiency\ power\ plant}$$

Whereby:

CO_2 per MWh=	$kgCO_2$ that is emitted per MWh power produced
Emission factor fuel=	$kgCO_2$ that is present in one MWh of the respective fuel type
Efficiency power plant=	The amount of power output of a power plant divided by the amount of fuel input of the power plant

A list of the assumed efficiencies of all power plants in the Netherlands can be found in Annex III of this research.

3.4.4 Calculating NO_x emissions

Opposite to CO_2, the input fuel does not determine the emission of NO_x. The emissions of NO_x are more dependent on the temperature at which the input fuel is combusted. Air consists for a large part of nitrogen (N_2, 78%). During combustion this nitrogen reacts, like the input fuel, with the present oxygen in the air (+/- 20%). Bonds of nitrogen and oxygen are formed as a consequence. These bonds can be present in the form of NO_2 (nitrogen dioxide) and NO (nitrogen oxide). The collection of nitrogen and oxygen bonds that are emitted during a combustion process of a fuel is called NO_x.

Environmental reports of the power plants are investigated to determine the emission of NO_x from the respective power plants In the Netherlands. Companies that would like to build a power plant are obliged to construct a report in which they describe the environmental consequences of the power plant (noise, emissions, etc.). This report is called a MER in Dutch (Milieu Effect Rapport). Among other things this report gives information on the expected amount of NO_x emissions per MWh produced. Independent 'third parties' construct the environmental reports. Therefore it is assumed that the NO_x emission factors described in these reports are a good indicator for the real emissions per MWh of produced power. In this research environmental reports from most of the power plants in the Netherlands that have been build after 1987 are investigated. In 1987 the construction of an environmental report became obliged in the Netherlands. In table 21 an oversight of the emissions factors that were retrieved from the environmental reports is given.

Table 21: NOx emission factors of different fuel types. The emission factors are based on environmental reports from power plants in the Netherlands (source of environmental reports: www.commissiemer.nl)

Period	Gas Kg/MWh	Coal Kg/MWh	Oil Kg/MWh
-1980	0.72	0.40	0.72
1980-1990	0.26	0.20	0.72
1990-2000	0.25	0.20	0.72
2000-	0.14	0.20	0.72

3.4.5 *Calculating the total amount of CO_2 and NO_x emissions*

The total amount of CO_2 and NO_x emissions is determined via the same formula is the total amount of production by all power plants.

$$\sum_{i=1}^{n} X_i * Y_i * Z_i * t = X_1 * Y_1 * Z_1 * t + X_2 * Y_2 * Z_2 * t + X_n * Y_n * Z_n * t$$

Whereby:
X_i= Installed capacity of power plant i (MW)
Y_i= Percentage of time that power plant i is producing (%)
Z_i= CO_2 or NO_x emission factor of power plant i (kg/MWh)
t= Total number of hours per year (8760)

This formula will give a total amount of kg CO_2 or NO_x that is emitted in the scenario. Per scenario also the average amount of emitted CO_2 or NO_x per MWh is calculated. This is useful because total amounts of electricity production, and thus emissions, differ per scenario. Therefore it is hard to compare outcomes of scenarios. Calculating average emissions in a scenario can compare outcomes. This is done via the following formula.

$$CO2Av = \frac{kgCO2total}{MWhtotal}$$

Whereby:
CO_2Av= The average amount of CO_2 per MWh that is emitted in a scenario ($kgCO_2$/MWh)
KgCO2total= The total amount of CO_2 that is emitted in a scenario ($kgCO_2$)
MWhtotal= The total amount of MWh that is produced in a scenario (MWh)

The same formula can be applied to calculate the average emissions of NO_x per produced MWh ($KgNO_x$/MWh).

The above-mentioned formulas can both be applied to scenarios with and without congestion management. In this way differences in total emissions per scenario can be seen.

An oversight of the power plants that were used in the model, including the emissions per MWh (NO_x and CO_2) can be found in Annex III.

In the Excel model that is used sometimes the total amount of GWh that is produced differs. This can be explained by the fact that the RLDC's are composed with rounded numbers. If a lot of numbers in the RLDC without congestion management are rounded up, whereas a lot of numbers in the RLDC with congestion management are rounded down, differences emerge. In all scenarios this is corrected; the total amount of GWh production in the scenario with congestion management is equalled with the total amount of GWh production in the scenario without congestion management.

In the end the results that show total NO_x and CO_2 emissions in different scenarios will be put into the perspective of the future Dutch emission targets. To do so data is used from the Dutch Pollutant Release and Transfer Register (in Dutch: Emissieregistratie). This register holds data of total CO_2 emissions by different sectors including ETS and non-ETS sectors. Also data on total NO_x emissions per sector are available.

4. Data analysis and results

Figure 12: Converter station of TenneT at Eemshaven. At this converter station direct current (DC) power is converted to alternating current (AC) power and vice versa. The station is connected to the high voltage direct current (HVDC) cable to Feda, Norway.

In this chapter the results of the three different steps are shown. Step one will be shown in chapter 4.1 and 4.2. The results for step two are presented in chapter 4.3. In the end the results of step three are shown in chapter 4.4.

4.1 Installed production capacity in the northern part of the Netherlands until 2018

The results of the first step in this research (chapter 4.1 and 4.2) are meant to give an impression of the circumstances (production of which power plants in the region) at which congestion is likely to happen in the northern part of the Netherlands. It is purely a network analysis. In this step it is not checked whether the circumstances in different scenarios that were used are likely according to market situations (gas price, import/export values, etc.). This is further investigated in step two (chapter 4.3).

Most installed capacity in the northern part of the Netherlands is located in Eemshaven and Delfzijl (figure 13 & table 22). Also, most plans to build new capacity are located in these two harbours. It is very unlikely that all theoretical capacity described in table 22 will be realised in 2018. This theoretical capacity includes all plans, varying from very concrete plans with allowance from the provinces, to very theoretical plans that have only requested for the possibility of a future grid connection at TenneT. In the scenarios used to determine the congestion area (chapter 4.2) the future installed capacity will be varied per scenario.

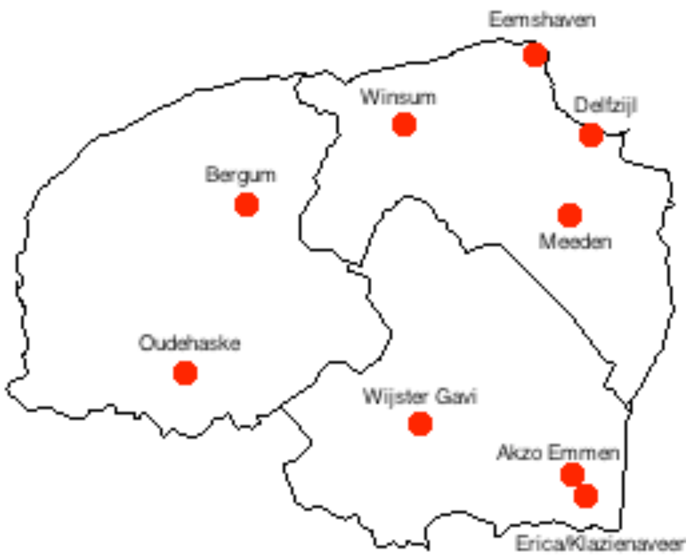

Figure 13: Oversight of locations with installed capacity in the northern part of the Netherlands (Source: own drawing).

Table 22: Installed capacity in the Northern part of the Netherlands in 2013 and 2018 (source: data from TenneT and the province of Groningen)

	Installed capacity 2013 (MW)	Theoretical installed capacity 2018 (MW)
Akzo Emmen	58	**58**
Bergum	664	**664**
Delfzijl	939	**1849**
Eemshaven	4779	**8827**
Erica	63	**63**
Klazinaveen	63	**63**
Oudehaske	0	**364**
Wijster Gavi	48	**48**
Winsum	121	**121**

The future installed capacity depends on the various circumstances that will be further elaborated on in chapter 4.2. In figure 13 the locations of different power plants in the northern provinces are shown.
Table 22 gives an oversight of the current and future installed capacities per location. Details of all the power plants including the Maximum capacity in MW are shown in Annex I.

4.2 Expected area of congestion in the Northern part of the Netherlands until 2018

4.2.1 Congestion results from scenarios

The tables in this chapter show the amount of congestion that is expected under the varying circumstances in the different scenarios. Only the lines and transformers that experience congestion are shown. An oversight of all lines and transformers in the northern part of the Netherlands can be found in table 1. The numbers are based on the flow analysis made in Excel (see assumptions in chapter 3.2). The first four columns on the left give information on the line- or transformer capacities. The line Eemshaven-Meeden, for example, has got 2 circuits with a capacity of 2635MVA each. Since TenneT has to guarantee n-1 safety, the line must be able to transport a load of 2635 MWe with one circuit. Thus, in the case of the line Eemshaven-Meeden the maximum n-1 capacity is 2635MVA. The last five columns on the right show the amount of congestion as a percentage in the respective scenario. Congestion of 10% means the line or transformer needs to transport 10% more than its maximum n-1 capacity on average.

Scenario 1

In scenario 1 there is almost immediate congestion because of the power plants of RWE and Vattenfall that will go in production in the beginning of 2014 (see table 23). Although Vattenfall's Magnum is not yet into full production, the 874MW of production in scenario 1 is enough to cross the n-1 safety of the 380kV lines Eemshaven-Meeden and Meeden-Zwolle. In 2016 the assumption is that the Vattenfall power plant will no longer be in its testing phase. At that time its variable costs will be too high because of the gas price, and it will be shut down. However, it is assumed that GDF Suez will put an extra gas turbine into production in 2016, since it has to close its out-dated coal-fired power plant in Nijmegen (500MW) because of the new Energy Accord made by the Dutch Social Economic Council (SER). The plans for large-scale wind parks at the Waddenzee, in Delfzijl and around Meeden cause mostly congestion on the line Meeden-Zwolle in 2018. Also the 380/220kV transformer at Meeden will have too low capacity to deal with the amount of electricity (table 24). If the electricity (480MW) doesn't go via the transformer at Meeden, it will cause congestion at the line Weiwerd-Meeden.

Table 23: Congestion results on lines in scenario 1

Line in grid	Number of circuits	Voltage level (kV)	Max. capacity (MVA)	Congestion 2014 (%)	Congestion 2015 (%)	Congestion 2016 (%)	Congestion 2017 (%)	Congestion 2018 (%)
Eemshaven - Meeden	**2**	**380**	**2635**	**7**	**7**	**0**	**9**	**9**
Meeden - Zwolle	**2**	**380**	**2635**	**22**	**22**	**15**	**53**	**85**

Table 24: Congestion results on transformers in scenario 1

Transformers	Name	Voltage level (kV)	Max. n-1 capacity (MVA)	Congestion 2014 (%)	Congestion 2015 (%)	Congestion 2016 (%)	Congestion 2017 (%)	Congestion 2018 (%)
Meeden 380	**TR 402**	**380/220**	**750**	**0**	**0**	**0**	**0**	**89**

Scenario 2

Since the prices of gas and hard coal will converge in scenario 2 both the gas turbines of GDF Suez and Vattenfall, and the hard coal power plant of RWE are mostly producing at full capacity. This causes a considerable amount of congestion on the 380kV lines Eemshaven-Meeden and Meeden-Zwolle, especially if the Eemsmond power plant will be build and will be producing electricity in 2017 (table 25). The transformers experience no congestion in this scenario because of the absence of wind parks at Meeden and Weiwerd.

Table 25: Congestion results on lines in scenario 2

Line in grid	Number of circuits	Voltage level (kV)	Max. n-1 capacity (MVA)	Congestion 2014 (%)	Congestion 2015 (%)	Congestion 2016 (%)	Congestion 2017 (%)	Congestion 2018 (%)
Eemshaven - Meeden	**2**	**380**	**2635**	**16**	**16**	**15**	**60**	**60**
Meeden - Zwolle	**2**	**380**	**2635**	**33**	**32**	**32**	**77**	**76**

Scenario 3

The events in scenario 3 cause a great congestion amount on the 380kV lines Eemshaven-Meeden and Meeden-Zwolle (table 25). Since the assumption is that there will be no further power plants built up to 2018, the congestion decreases a little bit up to 2018 due to the higher amount of decentral electricity demand in the region. Due to this increasing demand the line Eemshaven-Robbenplaat will have to transfer more electricity than it is capable of. The transformers don't have difficulties in this scenario.

Table 25: Congestion results on lines in Scenario 3

Line in grid	Number of circuits	Voltage level (kV)	Max. capacity (MVA)	Congestion 2014 (%)	Congestion 2015 (%)	Congestion 2016 (%)	Congestion 2017 (%)	Congestion 2018 (%)
Eemshaven - Meeden	**2**	**380**	**2635**	**73**	**71**	**70**	**69**	**68**
Meeden - Zwolle	**2**	**380**	**2635**	**83**	**82**	**80**	**79**	**77**
Eemshaven - Robbenplaat	**2**	**220**	**950**	**0**	**0**	**0**	**2**	**5**

Scenario 4
Little congestion is expected in the first years of scenario 4. The start looks a bit like scenario 1 (business as usual). From the moment Germany starts to close its coal-fired power plants and nuclear power plants, the power plants at Eemshaven start to produce at full capacity (both RWE and Vattenfall). The combination with the construction of the large-scale wind parks at Weiwerd and Meeden will cause congestion a large amount of congestion in 2017 and 2018. In 2018 the transformer at Meeden will have trouble with the electricity produced in the wind parks at Weiwerd and Meeden (table 26 and 27).

Table 26: Congestion results on lines in Scenario 4

Line in grid	Number of circuits	Voltage level (kV)	Max. capacity (MVA)	Congestion 2014 (%)	Congestion 2015 (%)	Congestion 2016 (%)	Congestion 2017 (%)	Congestion 2018 (%)
Eemshaven - Meeden	2	380	2635	22	22	0	60	60
Meeden - Zwolle	2	380	2635	0	0	0	34	82

Table 26: Congestion results on transformers in Scenario 4

Transformers	Name	Voltage level (kV)	Max. n-1 capacity (MVA)	Congestion 2014 (%)	Congestion 2015 (%)	Congestion 2016 (%)	Congestion 2017 (%)	Congestion 2018 (%)
Meeden 380	**TR 402**	**380/220**	**750**	**0**	**0**	**0**	**0**	**89**

In figure 14 a summary of congestion at all congested lines and transformers in all scenarios in 2018 is shown. It can be seen that highest congestion is modelled in scenario 1 and 4 in 2018. This is caused by the assumption that large-scale wind parks will be built in 2018. Due to these wind parks also the transformer at Meeden is and the 380kV line from Meeden to Zwolle are congested to a high extend. In scenario 2 and 3 congestion is more caused by the high production at Eemshaven itself. In scenario 3 Eemshaven-Robbenplaat is congested because of the high-assumed electricity demand rise in the region.

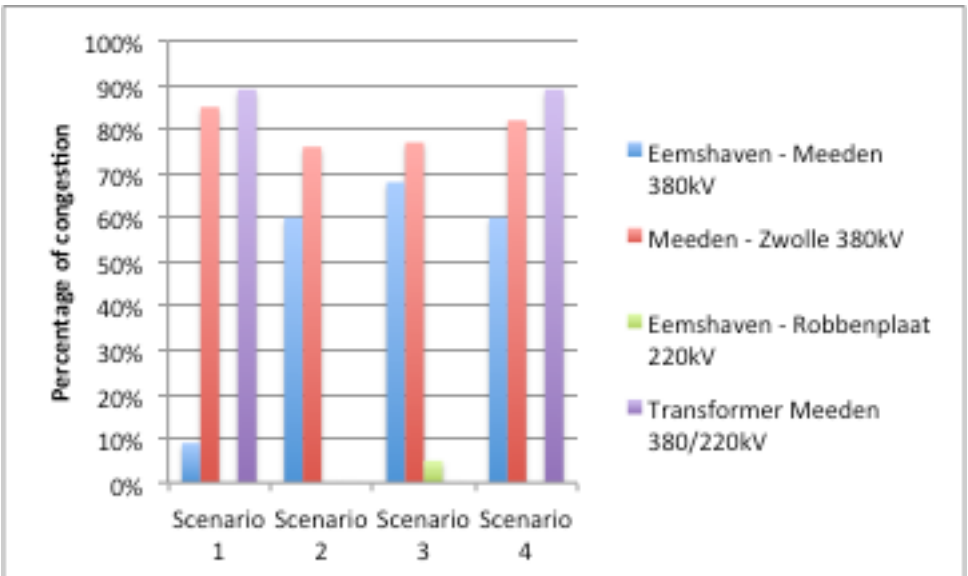

Figure 14: Congestion at different lines and transformers in 2018 in the respective scenarios.

4.2.2 Historical events of congestion in Groningen, Friesland and Drenthe

In the period of April 2012-April 2013 already events, where the 100% n-1 safeties limit was crossed, occurred. Historical flow data from TenneT shows that the 220kV line Eemshaven-Robbenplaat already experienced 830 hours in which the load exceeded its 950MVA n-1 capacity. The highest flow measured at this line was 1296MW. Figure 15 shows that high demand in the region of Friesland, Groningen and Drenthe has a correlation with this high flow. Another line that already exceeded its 100% n-1 capacity a couple of times between April 2012 and April 2013 was the 220kV line of Vierverlaten-Zeyerveen. During 38hours the flow exceeded the 100% n-1 capacity of 455MVA. The highest amount of Megawatt that was measured over this line was 526MW. Table 31 shows an oversight of the highest loads and congestion on every line in the period of April 2012 and April 2013. Note that these events didn't cause dangerous situations. Only the n-1 capacity would be crossed in case 100% of the power that was originally flowing over two circuits is now flowing via one circuit. In reality this is not the case. This will be further explained in chapter 4.2.5.

Table 27: Hours of congestion in the period of April 2012-April 2013

Line	Number of circuits	Voltage level (kV)	Maximum n-1 capacity per circuit (MVA)	Number of congestion hours between April 2012-April 2013	Highest measured load (MW)
Eemshaven - Meeden	2	380	2635	0	1317
Meeden - Zwolle	2	380	2635	0	1771
Meeden - Diele	2	380	1645	0	1455
Eemshaven - Robbenplaat	2	220	950	830	1296
Eemshaven - Vierverlaten	1	220	880	0	690
Robbenplaat - Weiwerd	2	220	880	0	629
Robbenplaat - Vierverlaten	2	220	880	0	866
Weiwerd - Meeden	2	220	880	0	316
Vierverlaten - Zeyerveen	2	220	455	38	526
Vierverlaten - Bergum	2	220	950	0	436

4.2.3 General conclusions with n-1 assumption of 100%

If a n-1 assumption of 100% is made (in case of a fall out of 1 circuit in a line with two circuits, all the power that was originally flowing via the two circuits is now flowing via the one circuit left) all scenarios show congestion for a period longer than one year. However, the congestion on the lines is expected to be fewer than 30% until 2016 in scenarios 1,2 and 4. After 2016 most scenarios show a large amount of congestion. This large amount is mostly caused by the increasing capacity of large-scale wind parks that were added in the scenarios. The only lines where congestion is expected to happen are the 380kV lines from Eemshaven to Meeden and from Meeden to Zwolle and the 220kV line from Eemshaven to Robbenplaat and from Vierverlaten to Zeyerveen. In a n-1 situation of 100% especially the line from Eemshaven to Robbenplaat will be under pressure, because the 220kV line of Eemshaven to Vierverlaten only has one circuit. The only problem with transformers is expected to happen at the Meeden 380/220kV transformer. In the scenarios with large-scale wind parks (1 & 4) the transformer at Meeden will not have enough capacity to deal with the produced amount of wind power.

In situations where the sum of production at Eemshaven (220kV and 380kV) is higher than 3200MW most likely congestion is about to happen at the 380kV line from Meeden to Zwolle with the n-1 criterium of 100%. At least if the import from Diele to Meeden is higher than 550MW (average import between April 2012 and April 2013). The area of congestion management in this case will be only Eemshaven area. The power plants in the congestion management area will be EC 3,4,5,6,7 (GDF SUEZ), Magnum 10,20,30 (Vattenfall) and the hard coal-fired power plant of RWE.
The congestion between Eemshaven and Robbenplaat seems to be driven by the demand in the region of Groningen, Friesland and Drenthe. If this demand is very high, the transport over the line Eemshaven-Robbenplaat is higher as well. This correlation is shown in figure 15. A same correlation could be made for the 220kV line Vierverlaten-Zeyerveen. Although the model doesn't show congestion on this line, the historical data proof that high demand at Zeyerveen causes high power flows on the line.

To conclude, two different causes for congestion in the region can be determined. The first reason is the high demand at certain locations in the region. The capacity of some of the lines is not capable of transporting all this peak demand. High load on these lines already occurred in the period of April 2012-April 2013. The second reason that could possibly cause congestion is the new build power plants at Eemshaven. Although it is not sure they will be in full production at the same time, the 380kV lines from Eemshaven to Zwolle won't have enough capacity to transport the power produced by these two power plants (in combination with the already existing power plants). The chance that they will be producing power is investigated in chapter 4.3. Further on in this chapter a validation of the model is made. Next to that a sensitivity analysis is made on the n-1 assumption of 100%. In reality power will not necessarily flow over the other circuit if one of the two circuits in a line will fall out. If more transport routes are available (i.e. other lines, transformers, etc.) the power will just follow the lowest resistance. In chapter 4.2.5 the n-1 assumption is put into a more realistic perspective.

4.2.4 Validation of the outcomes of the model

Although the model presents possible future situations, a validation using historical data is made and described in this chapter. Situations in historical data between April 2012 and April 2013 that look most like the situations in the different scenarios are used to check the accuracy of the model. These situations are compared with the outcomes of the model for every scenario. To give an example: for scenario 1 historical events from data between April 2012 and April 2013 have been selected that show the same features as scenario 1 (import from Norway and Germany, high production at 380kV in Eemshaven, etc.). The average amount of production in these historical events serves as an input in the model (on average X MW is produced at Eemshaven 380kV). In the next step it is checked whether the flow outcomes in the model match the flows that were registered by the real production during the historical events (compare column 2 and 3 in table 32-25). The differences in amount of MW and % give information on how accurate the model is in simulating certain events. This serves as an indication on how accurate the model is in predicting future events. The outcomes of the validation of all the scenarios are shown in tables 32 - 35.

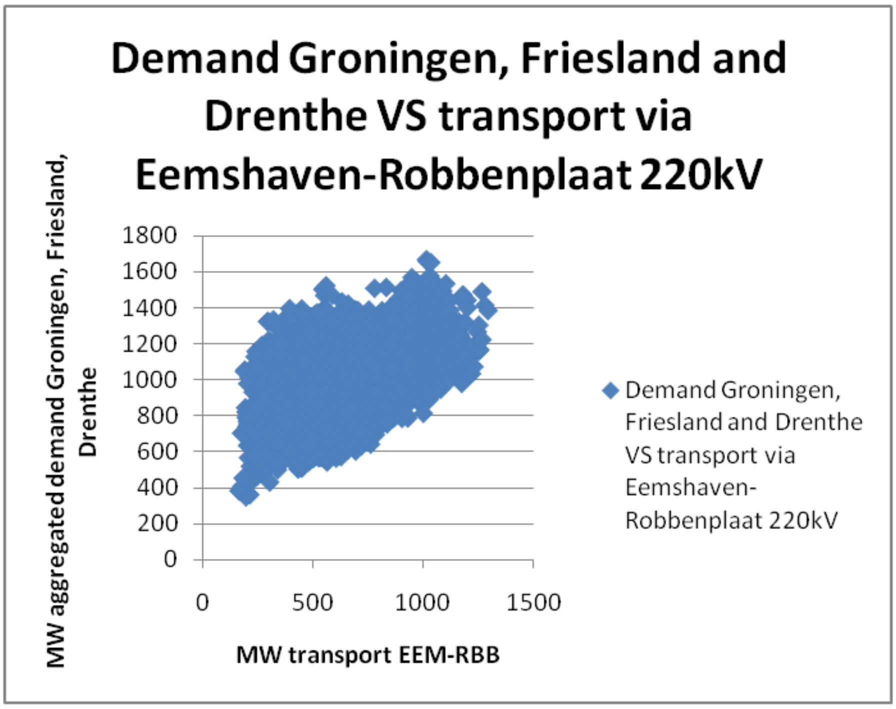

Figure 15: Correlation between demand in Groningen, Friesland and Drenthe, and the transport from Eemshaven to Robbenplaat (Source: GEN eBase TenneT).

Table 28: Validation scenario 1

	Load in model scenario 1 (MW)	Average load validation data (MW)	Difference between model and validation (MW)	% Difference
Eemshaven - Meeden	**619**	**564**	**55**	**10**
Meeden - Zwolle	**864**	**749**	**114**	**15**
Meeden - Diele	**440**	**437**	**3**	**1**
Eemshaven - Robbenplaat	**767**	**764**	**2**	**0**
Eemshaven - Vierverlaten	**162**	**173**	**-11**	**-6**
Robbenplaat - Weiwerd	**281**	**295**	**-13**	**-4**
Robbenplaat - Vierverlaten	**485**	**494**	**-9**	**-2**
Weiwerd - Meeden	**60**	**68**	**-8**	**-11**
Vierverlaten - Zeyerveen	**212**	**241**	**-29**	**-12**
Vierverlaten - Bergum	**251**	**256**	**-6**	**-2**

Table 29: Validation scenario 2

	Net load in model scenario 2 (MW)	Average from transport validation data (MW)	Difference between model and validation (MW)	% Difference
Eemshaven - Meeden	**1291**	**932**	**359**	**39**
Meeden - Zwolle	**1352**	**1051**	**302**	**29**
Meeden - Diele	**249**	**243**	**6**	**2**
Eemshaven - Robbenplaat	**936**	**1163**	**-227**	**-19**
Eemshaven - Vierverlaten	**188**	**253**	**-65**	**-26**
Robbenplaat - Weiwerd	**373**	**486**	**-113**	**-23**
Robbenplaat - Vierverlaten	**563**	**718**	**-155**	**-22**
Weiwerd - Meeden	**109**	**227**	**-118**	**-52**
Vierverlaten - Zeyerveen	**246**	**388**	**-142**	**-37**
Vierverlaten - Bergum	**291**	**377**	**-86**	**-23**

Table 30: Validation scenario 3

	Load in model scenario 3 (MW)	Average load validation data (MW)	Difference between model and validation (MW)	% Difference
Eemshaven - Meeden	**1061**	**1000**	**60**	**6**
Meeden - Zwolle	**806**	**665**	**141**	**21**
Meeden - Diele	**156**	**160**	**-4**	**-2**
Eemshaven - Robbenplaat	**1190**	**1123**	**67**	**6**

Eemshaven - Vierverlaten	**214**	**265**	**-51**	**-19**
Robbenplaat - Weiwerd	**547**	**524**	**23**	**4**
Robbenplaat - Vierverlaten	**643**	**622**	**21**	**3**
Weiwerd - Meeden	**240**	**239**	**1**	**0**
Vierverlaten - Zeyerveen	**281**	**332**	**-51**	**-15**
Vierverlaten - Bergum	**332**	**348**	**-16**	**-5**

Table 31: Validation scenario 4

	Load in model scenario 4 (MW)	Average load validation data (MW)	Difference between model and validation (MW)	% Difference
Eemshaven - Meeden	**1330**	**1215**	**115**	**9**
Meeden - Zwolle	**459**	**431**	**28**	**6**
Meeden - Diele	**715**	**715**	**0**	**0**
Eemshaven - Robbenplaat	**922**	**947**	**-25**	**-3**
Eemshaven - Vierverlaten	**183**	**197**	**-14**	**-7**
Robbenplaat - Weiwerd	**372**	**394**	**-22**	**-6**
Robbenplaat - Vierverlaten	**550**	**584**	**-34**	**-6**
Weiwerd - Meeden	**134**	**183**	**-49**	**-27**
Vierverlaten - Zeyerveen	**241**	**272**	**-32**	**-12**
Vierverlaten - Bergum	**285**	**327**	**-43**	**-13**

The validation shows the model mostly has a difference between 0-15% in scenarios 1,3 and 4. The outcomes of scenario 2 are less accurate. This could be explained by the fact that the situation as described in scenario 2 have never occurred during the past year. One big difference between the outcomes of the model and the outcomes of the reference data is that the model assumes a larger share of the power to flow via the 380kV grid (compared to the share flowing to the 220kV grid). This could be explained by the fact that the model assumes an average peak demand in the local electricity demand, while in most of the reference data extreme peak demand is happening. This explanation also explains the underestimation of the transport at the 220kV lines.

4.2.5 Sensitivity analysis on congestion results

The assumption of a 100% n-1 criterium made in this research states that if one circuit in a line with two circuits falls out, all the power that was originally transported over two circuits is now transporter over the circuit that is left. The same holds for transformers; if one transformer in a combination of two transformers falls out, the model assumes that all the power that was originally going through the two transformers is now transported through the transformer that is left. This assumption would be completely right if an electrical system only consisted of one line with two circuits. With the fall out of one circuit the consequence would be that all the power would be going via the other circuit. However, the transmission grid as present in the northern part of the Netherlands is a complicated grid with different connections at every junction (station) in the grid. In n-1 situation of a line not 100%, but a lower amount will flow via the circuit that is left. The remaining power will flow via ways that have a higher conductivity.

In this sub chapter the lines that show most congestion in chapter 4.2.1 are checked in more detail. With flow analysis software from TenneT a n-1 situation on these lines can be simulated. This simulation shows the share of power that is still flowing via the circuit that is left, and the share of power that is flowing via other components in the grid in the n-1 situation.

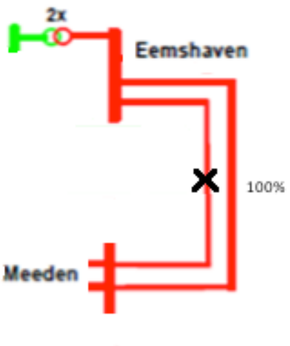

Figure 16: Power distribution following the n-1 assumption made in this research. If one circuit falls out, 100% of the power will be transported over the other circuit.

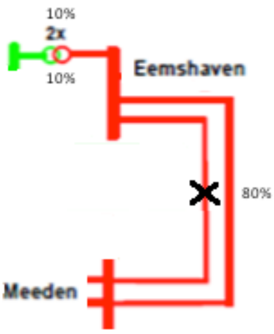

Figure 17: Real power distribution in the case of a fall out of a circuit in the 380kV line Eemshaven-Meeden.

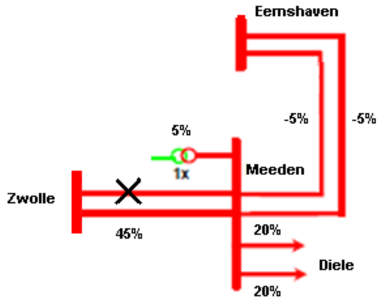

Figure 18: Real power distribution if one circuit in the connection between Meeden and Zwolle will fall out.

Figures 16 and 17 show the differences between the n-1 assumption made in this research, and the real behaviour of electricity if the one circuit in the 380kV line Eemshaven-Meeden will fall out. It can be seen that only 80% of the power, that would originally flow via the circuit that is now broken down, flows via the remaining 380kV circuit. The other 20% flows via the two 220/380kV transformers at Eemshaven.

Thus, the results made in chapter 4.2.1 have to be put into perspective. The lines and transformers that show congestion in the different scenarios therefore are examined in more detail in this sensitivity analysis. The examined lines and transformers are:

- Eemshaven-Meeden 380kV (figure 17)
- Meeden-Zwolle 380kV (figure 18)
- Transformers Eemshaven 220kV/380kV (figure 19)
- Eemshaven-Robbenplaat-Vierverlaten 220kV (figure 20)

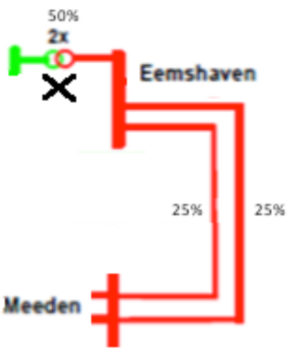

Figure 19: Power distribution if one 220kV/380kV transformer is down at Eemshaven.

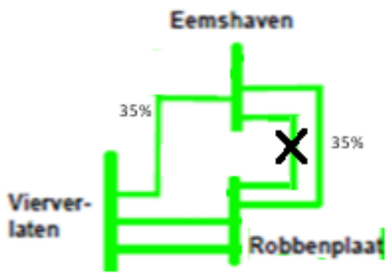

Figure 20: Power distribution if one circuit in the connection between Eemshaven-Vierverlaten 220kV is down.

The power distribution in a n-1 situation at different lines is shown in figures 17-20. Using these new n-1 percentages, the outcomes from chapter 4.2.1 can be checked again. The numbers for the power flows from chapter 4.2.1 are still relevant. Only the effect of these power flows on congestion in a n-1 situation is checked again. For scenario 1 (business as usual) a new look has been done on the effects on congestion of these power flows. The question is whether these power flows still cause congestion with the new percentages shown in figures 17-20. In tables 32-35 is shown if the power flows that are predicted by the model in scenario 1 in 2014 cause congestion. In the first four columns general information on the respective line is given. In the fifth column the load per circuit as it was in scenario 1 in 2014 is shown. For table 32 it shows that the two circuits between Eemshaven and Meeden were both transporting 1408 MW. In the n-1 situation the circuit that is left transports 2534MW. With the old n-1 assumption of 100% this would have been 2816 MW. With the new n-1 assumption of 80% the line doesn't show congestion anymore. The transformers are still not congested in this situation.

Table 32: Power distribution after one circuit in the 380kV line Eemshaven-Meeden is down. The numbers are calculated for scenario 1, year 2014.

Line/transformer	Number of circuits/transformers	Voltage level (kV)	Max. Capacity per circuit/transformer (MVA)	Original net load per circuit/transformer in model	New net load per circuit/transformer (MW)
Eemshaven - Meeden	1 (other circuit is down)	380	2635	1408	2534
Eemshaven 380	TR 401 & 402	380/220	750	271	411

Table 33: Power distribution after one circuit in the 380kV line Meeden-Zwolle is down. The numbers are calculated for scenario 1, year 2014.

Line/transformer	Number of circuits/transformers	Voltage level (kV)	Max. Capacity per circuit/transformer (MVA)	Original net load per circuit/transformer in model	Net load per circuit/transformer (MW)
Eemshaven - Meeden	2	380	2635	1408	1327
Meeden - Zwolle	1 (other circuit is down)	380	2635	1608	2331
Meeden - Diele	2	380	1645	275	597
Meeden 380	TR 402	380/220	750	150	231

Table 34: Power distribution after one circuit in the 220kV line Robbenplaat-Vierverlaten is down. The numbers are calculated for scenario 1, year 2014.

Line	Number of circuits	Voltage level (kV)	Max. Capacity per circuit (MVA)	Original net load per circuit in model	Net load per circuit (MW)
Eemshaven - Robbenplaat	2	220	950	372	413
Eemshaven - Vierverlaten	1	220	880	157	239
Robbenplaat - Vierverlaten	1 (other circuit is down)	220	880	235	318

Table 35: Power distribution after one 220kV/380kV transformer at Eemshaven is down. The numbers are calculated for scenario 1, year 2014.

Line/transformer	Number of circuits/transformers	Voltage level (kV)	Max. Capacity per circuit/transformer (MVA)	Original net load per circuit/transformer in model	New net load per circuit/transformer (MW)
Eemshaven - Meeden	2	380	2635	1408	1476
Eemshaven 380	TR 401 (402 is down)	380/220	750	271	406

From tables 32-35 can be concluded that firstly congestion problems will occur with a fall out of the 380kV line Eemshaven-Meeden. Table 32 shows that with a total production of 3716MW (this is the total amount of electricity production at Eemshaven in scenario 1, year 2014) at Eemshaven 220kV and 380kV this line will just have enough capacity to transport the produced electricity in a n-1 situation (2534MW transport via 2635MVA capacity). Thus, the expectation is that in the occasion of more than 3800MW production at Eemshaven 380kV this line will not have enough capacity to transport the electricity in a save way. As the 380kV line from Eemshaven to Meeden will always be the first line that will show congestion, this line will be the benchmark for determining congestion in the area of Eemshaven. In the following two steps of this research a maximum of 3800 MW production in Eemshaven will be assumed to be within the save limit. A production beyond 3800 MW at Eemshaven will be assumed to cause congestion. Congestion management, and thus redispatch of power plants, will be necessary in this case.

4.3 Market situation in the Netherlands with and without congestion management

In chapter 4.1 and 4.2 the circumstances under which congestion management in the northern part of the Netherlands is necessary are investigated. From this chapter a conclusion is that the 380kV line from Eemshaven to Meeden is the first line that will reach its maximum capacity. This capacity is reached at an electricity production of around 3800 MWe at Eemshaven by the power plants, wind parks, and the NorNed cable from Norway (see figure 12 for a picture of the converter station connected to the cable at Eemshaven). In this chapter it is checked if it is likely that more than 3800 MWe will be produced at Eemshaven in the future up to 2018. This is done by constructing a merit order curve, with all the power plants in the Netherlands, in combination with a residual load duration curve.

4.3.1 Residual Load Duration Curves

Load data of four days in 2012 and 2013 is chosen as a data input for the Residual Load Duration Curves. The days are chosen to represent weather during the four seasons in the Netherlands. The days are:

- Saturday 4-2-2012 (coldest day in 2012)
- Wednesday 21-11-2012 (typical autumn day with strong wind)
- Monday 29-4-2013 (typical spring day with clear blue skies)
- Monday 17-6-2013 (hottest day in 2013)

The chosen days in summer and winter ought to represent extreme scenarios, but could also be seen as representative for winter and summer.

Figures 21 - 24 show the load curves during these days. The blue line reflects the net load, and thus the electricity demand in the Netherlands. The red line represents the electricity production by power plants. The green line represents the import of electricity from all the interconnectors (BrittNed, NorNed, and the six interconnections with Germany and Belgium). The purple line represents the export.

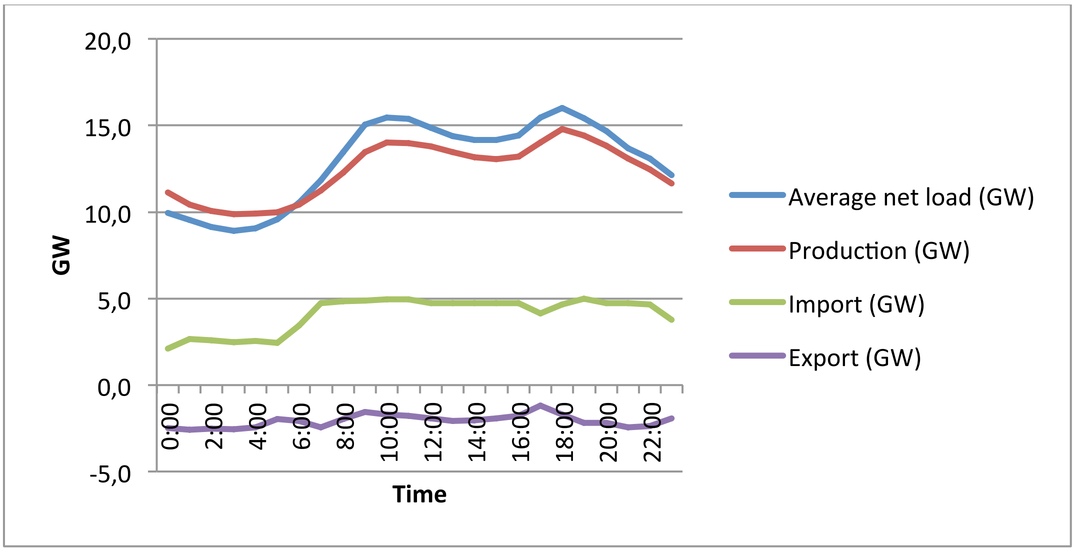

Figure 21: Load curve taken from 4-2-2012. This was the coldest day in 2012. (Source: http://www.tennet.org/bedrijfsvoering/ExporteerData.aspx).

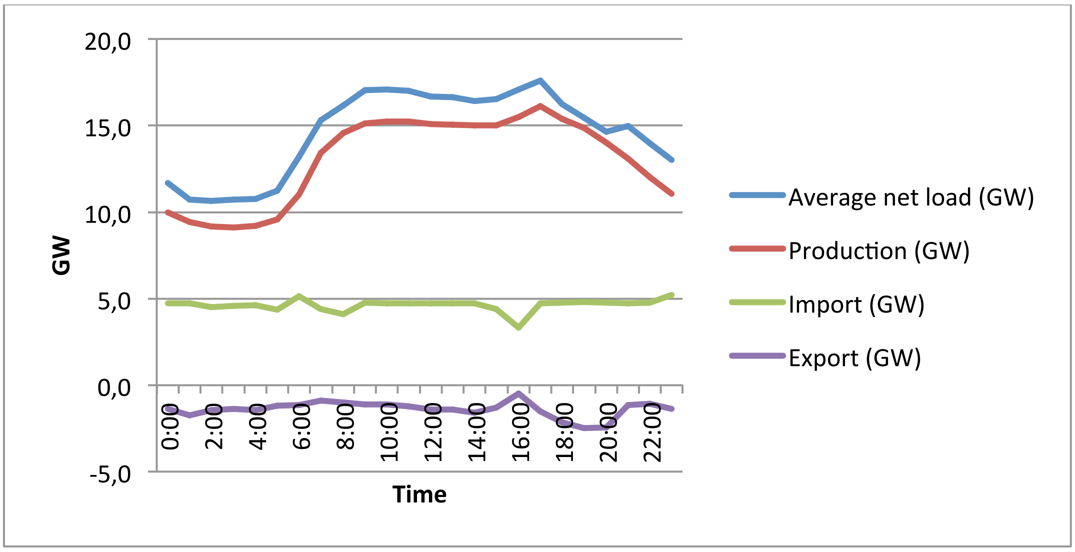

Figure 22: Load curve taken from 21-11-2012. This day was a typical autumn day with strong winds (data source: http://www.tennet.org/bedrijfsvoering/ExporteerData.aspx).

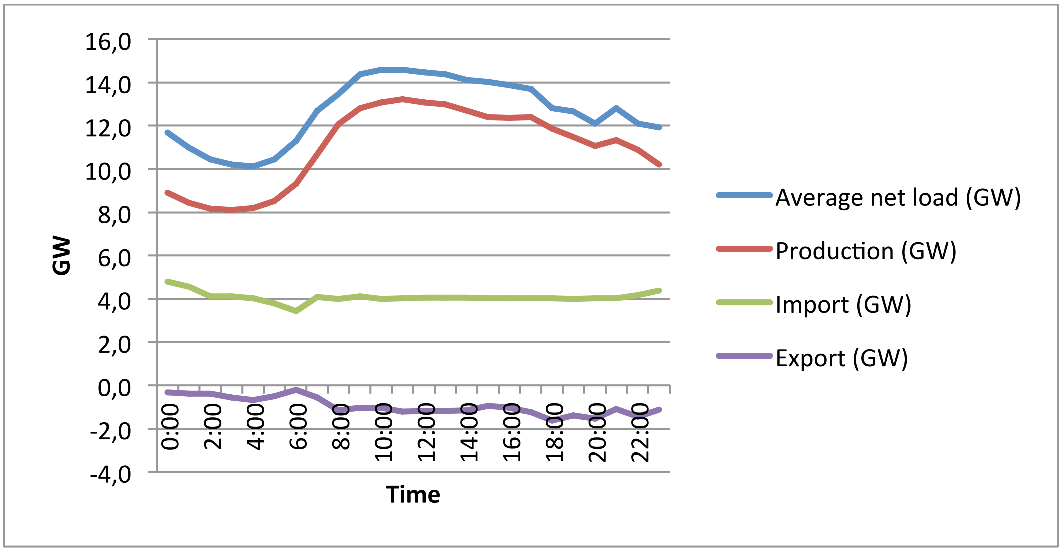

Figure 23: Load curve taken from 29-4-2013. This was a typical spring day with clear blue skies (data source: http://www.tennet.org/bedrijfsvoering/ExporteerData.aspx).

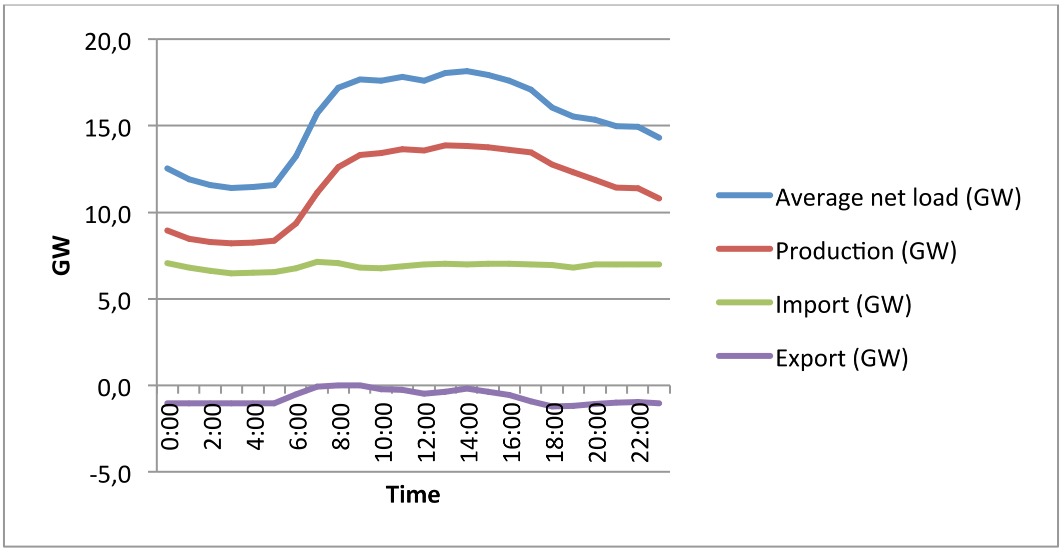

Figure 24: Load curve taken from 17-6-2013. This was the warmest day of 2013 (data source: http://www.tennet.org/bedrijfsvoering/ExporteerData.aspx).

At the winter and autumn days (figure 20 & 21) two peaks in electricity demand can be seen. These are the typical morning and evening peak. People switching on lights cause both peaks. In the morning because they wake up and go to work, and in the evening because they arrive home from work while the sun is already gone. In the summer there is more or less one peak that is mostly caused by air conditioners that are running all day until people go home from work. Another interesting fact from the load curves is the import/export balance. Almost all the time the import exceeds the export (except from the night hours during the winter). At the summer day there is almost no export and a lot of import (>6GW). It could be explained by the huge amount of installed solar PV capacity in Germany that is flowing towards the Netherlands at a nice summer day. Power plants have highest production at the autumn day, sometimes producing over 17GW of electricity.

From these load curves Residual Load Duration Curves (RLDC's) can be made. These curves show the fraction of the time that the electricity demand that needs to be produced by conventional power plants is higher than a certain amount of GW. In the RLDC's the amount of wind-, solar-, and CHP-production is already subtracted from the normal load curves (see input in RLDC's in table 15). Figures 25 - 28 show both the original Load Duration Curves (the right curves) and RLDC's (the left curves) of the four days.

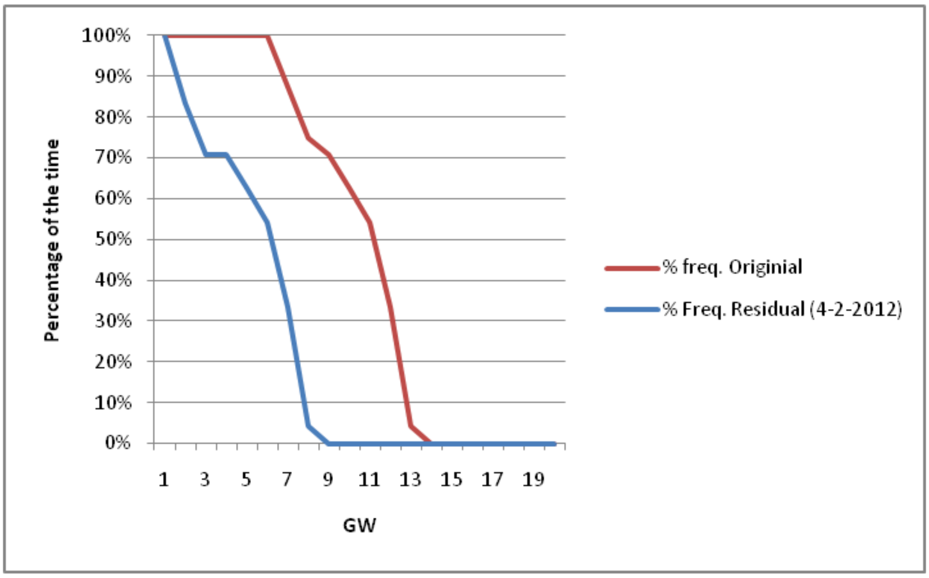

Figure 25: Residual Load Duration Curve of 4-2-2012 (source: own drawing with data input described earlier in this chapter).

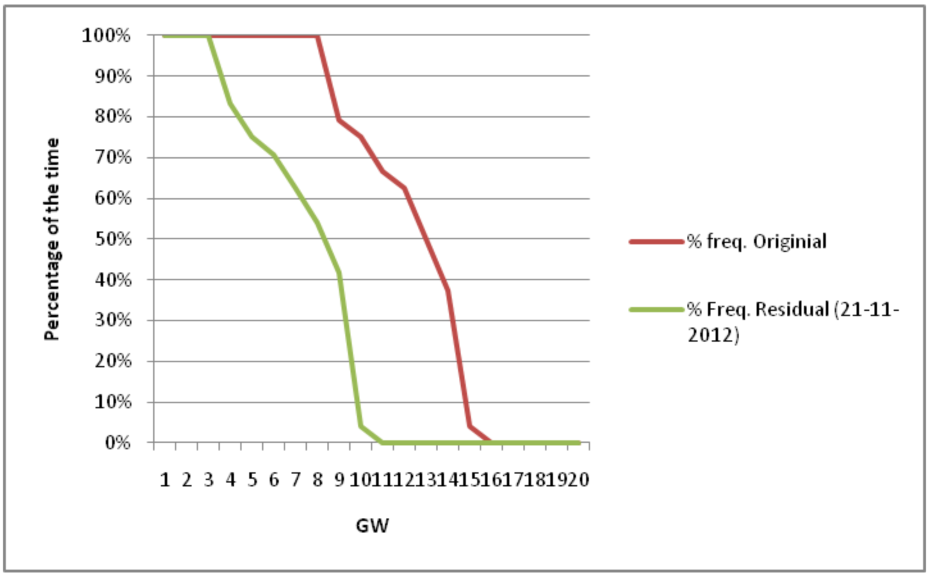

Figure 26: Residual Load Duration Curve of 21-11-2012 (source: own drawing with data input described earlier in this chapter).

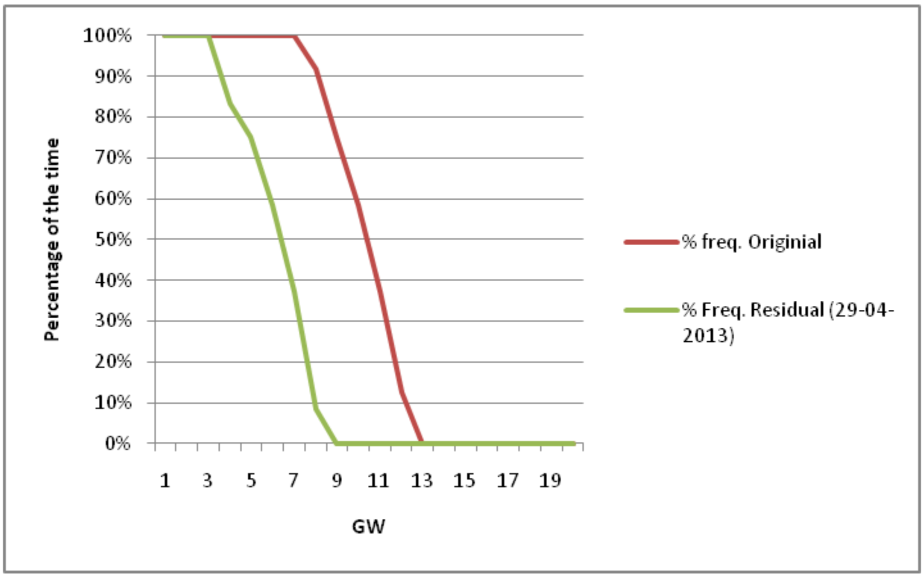

Figure 27: Residual Load Duration Curve of 29-4-2013 (source: own drawing with data input described earlier in this chapter).

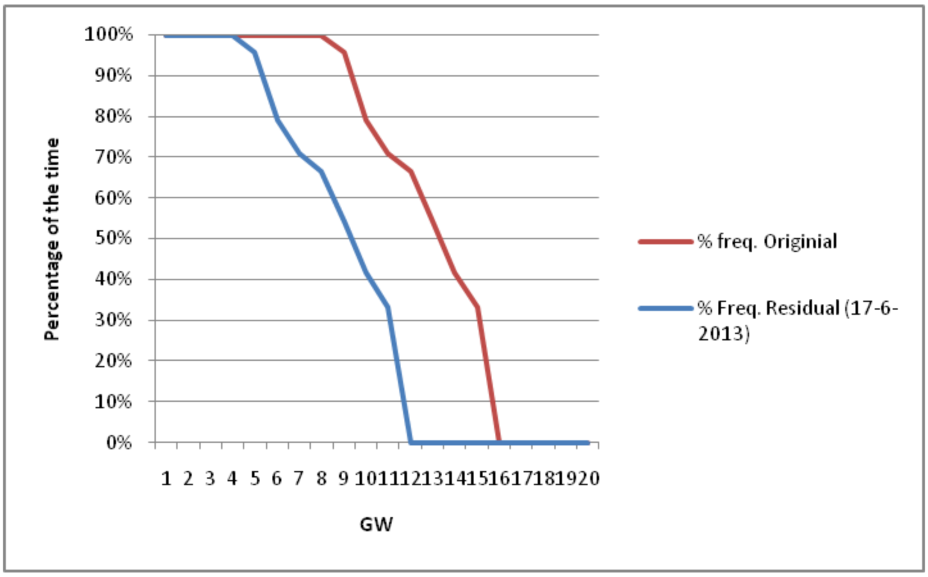

Figure 28: Residual Load Duration Curve of 17-6-2013 (source: own drawing with data input described earlier in this chapter).

From the RLDC's can be concluded that the residual load during winter days is the lowest. The lowest amount of electricity that needs to be produced by conventional power plants at that day is 1,3 GW, while in the autumn the lowest residual load was 5 GW. The maximum load in winter was between 9 and 10 GW, while in summer it was between 11 and 12GW.

These RLDC's are also projected in the Merit Order curves in this chapter. Further on they will be adjusted to the respective scenarios 1 t/m 4 (see input variables in table 15).

4.3.2 Merit order curves and Residual load duration curves

With a combination of the input from table 14 and the PLATTS database Merit Order curves have been constructed for all four scenarios. The residual load duration curves of the four chosen days have also been added to the curves. The outcomes in the figures are discussed in chapter 4.3.3.

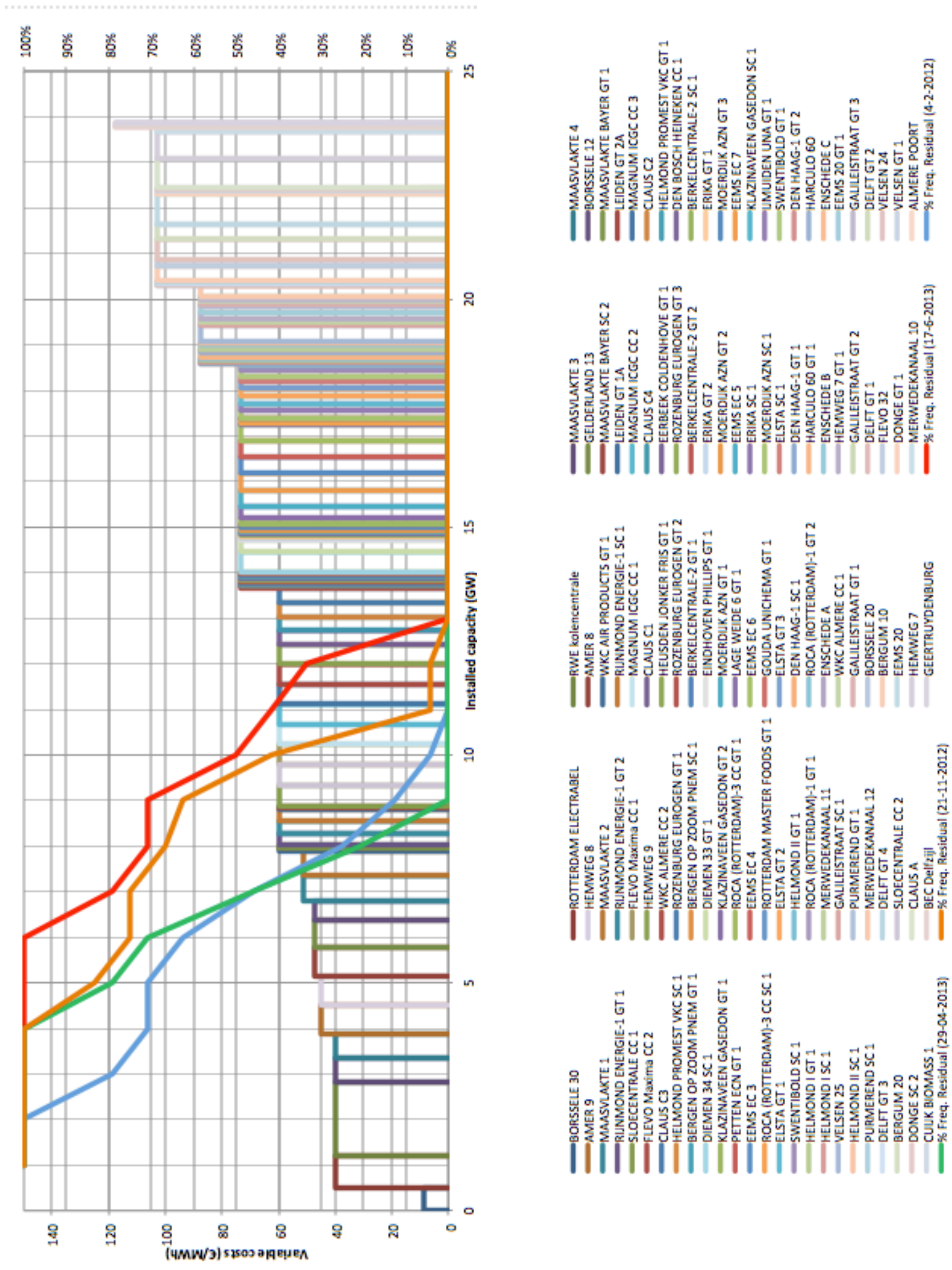

Figure 29: Merit order curves in combination with residual load duration curves. Scenario 1.

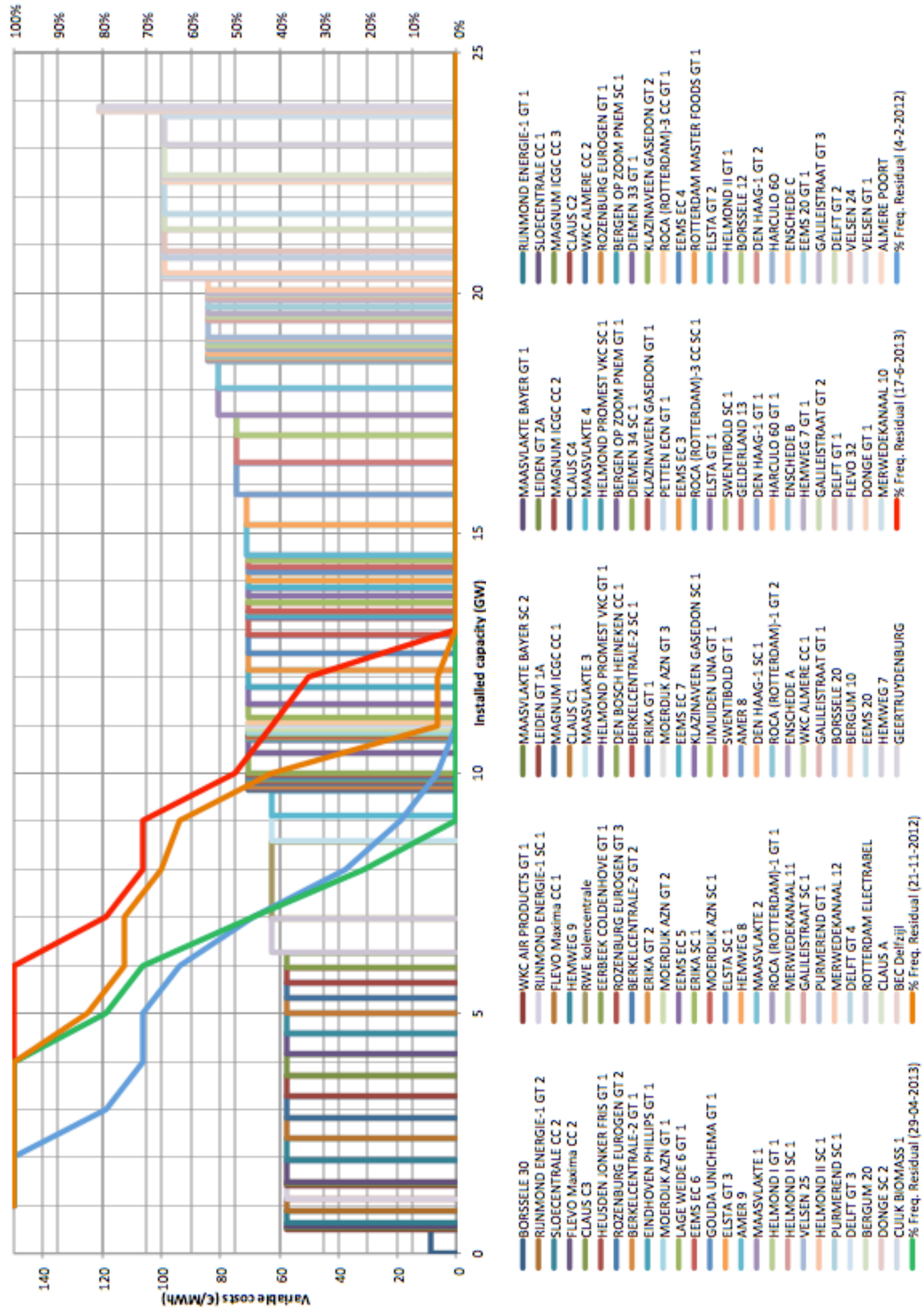

Figure 30: Merit order curve in combination with residual load duration curves. Scenario 2.

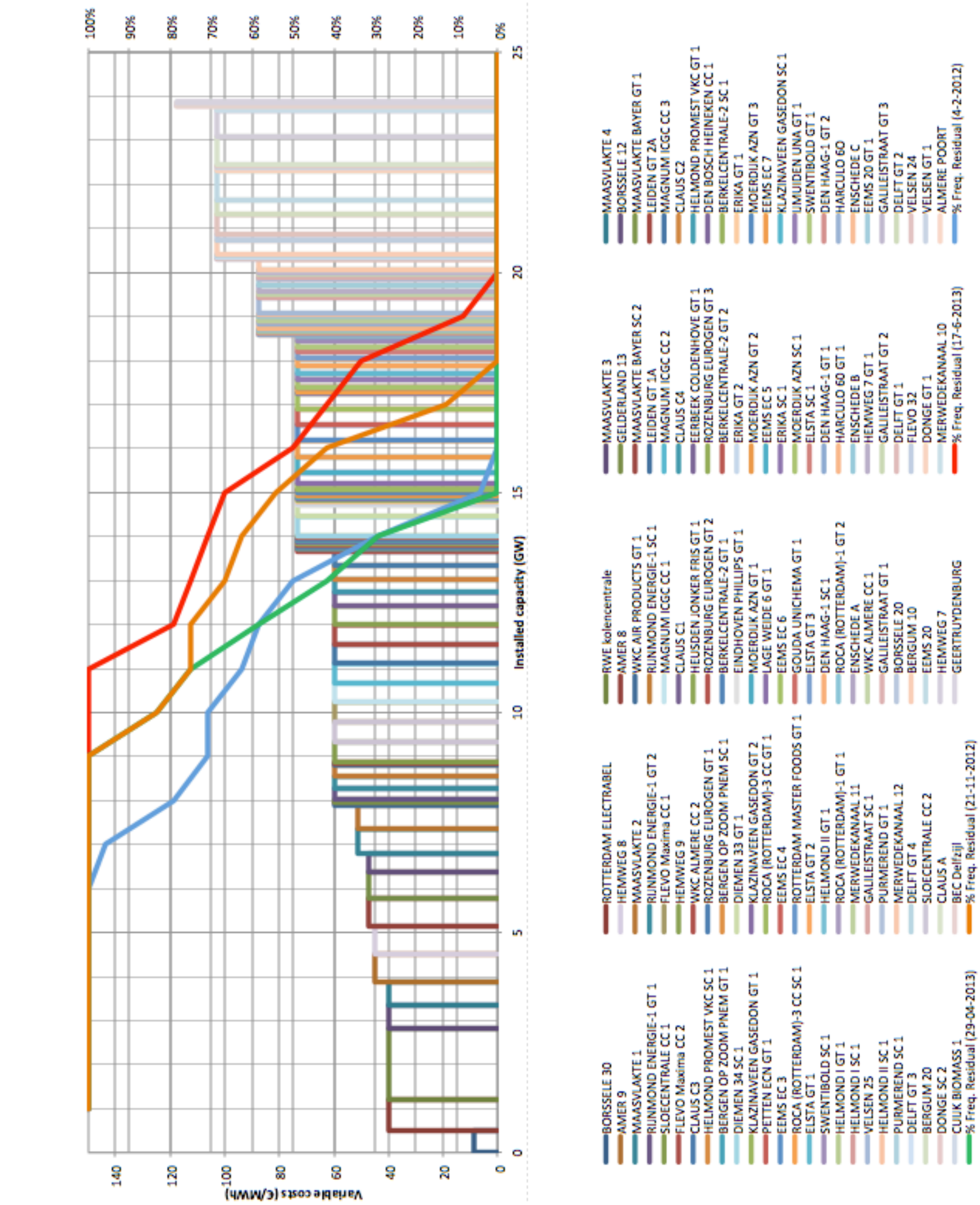

Figure 31: Merit order curve in combination with residual load duration curves. Scenario 3.

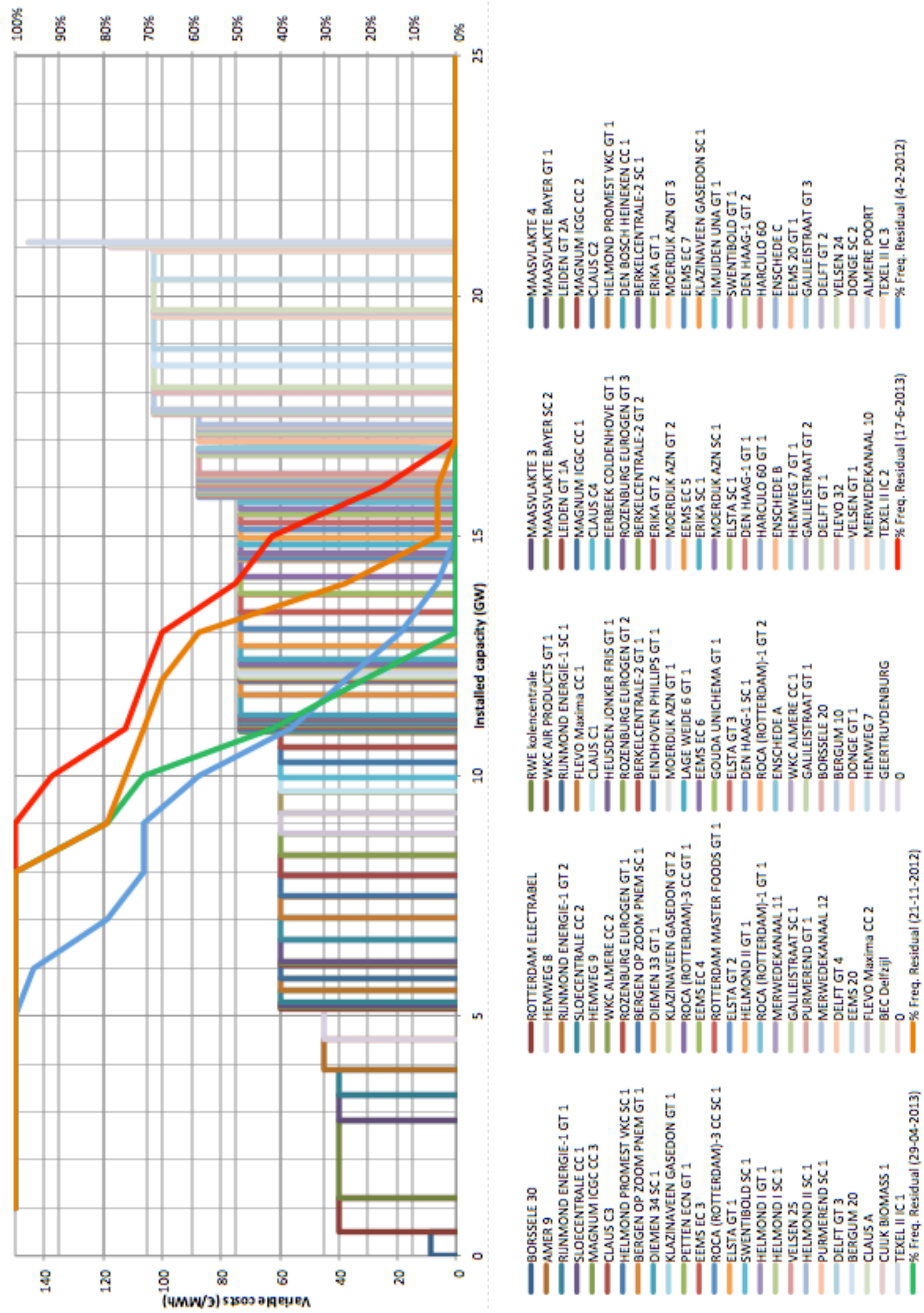

Figure 32: Merit order curve in combination with residual load duration curves. Scenario 4.

Table 36: Total electricity production, electricity import and electricity export in different scenarios (GWh)

	Total electricity production by conventional power plants (GWh)	Total electricity import (GWh)	Total electricity export (GWh)
2012 (data CBS)	63 685	32 155	15 045
Scenario 1	64 496	32 990	16 495
Scenario 2	64 003	32 990	16 495
Scenario 3	114 775	16 495	32 990
Scenario 4	98 358	32 990	16 495

4.3.3 Expected market behaviour in case there is no congestion management

Scenario 1

In the merit order curve from scenario 1 (figure 29) shows a business as usual scenario. The input data for the Residual Load Duration Curves in this scenario is taken directly from load duration curves based on real data. The only variable that is adjusted is the import/export balance. Also the commodity prices of natural gas, hard coal, oil, and wood are assumed to be the same as they were in August 2013. Therefore, the merit order curve shows a situation in which the most modern hard coal power plants (RWE Eemshaven, Electrabel Rotterdam, and Maasvlakte 3 and 4) are the cheapest power plants (in terms of marginal costs). They produce electricity with production costs of around €40/MWh (€0.04/kWh).

Even the very old, inefficient coal-fired power plants (Gelderland 13 from 1981 and Maasvlakte 1 and 2 from 1975) have lower variable costs than the newest, high efficient (59%) gas-fired power plants. All the RLDC's cross the merit order curve at the point of the group of high efficient gas-fired power plants. That's why in this scenario probably some of the high efficient gas-fired power plants will be turned off almost all the time. It's difficult to say from the available data which of the newest gas-fired power plants will be running (Sloecentrale 1,2, Flevocentrale 1,2, Magnum centrale 1,2,3, Hemweg 9, Clauscentrale C1, 2,3,4). The RLDC's show that in summer and autumn at least half of these gas-fired power plants will be running. In spring and winter only a couple of these power plants will be running, and only during 10-20% of the time.

In scenario 1 it is quite unlikely that the power plants with higher marginal costs than €70/MWh in the merit order curve will be producing electricity. Data from TenneT shows that power plants in this part of the merit order curve (EC's 3-7, Diemen 33-34, Lage Weide 6, ROCA's, etc.) were most often shut down in the period of 2012-2013.

The total electricity production in scenario 1 is comparable to the total electricity production in 2012 (around 64 000 GWh, see table 36). The import/export balance is in favour of the import and is responsible for 16 495 GWh of electricity import. At Eemshaven the RWE coal-fired power plant is running most of the time. Only in winter time the electricity demand is sometimes too low for the RWE power plant to produce at full capacity. The Magnum gas-fired power plants have to be switched on in summer and autumn (see table 38). In summer at least one magnum turbine needs to be running most of the time. The other turbines and the Eemscentrale turbines are not needed.

Congestion is in this scenario expected in summer and autumn. Mark in this case that the total load in the Netherlands exceeds the 20GW in peak times because of the rise of 16% of electricity demand in 2018 (compared to 2013). This high load in combination with the position of the Magnum turbines in the merit order curve, and the newly installed wind parks at Eemshaven will cause a little bit of congestion; 124MW during 33% of the time in summer and 4% of the time in autumn (see the fourth column in table 38).

Table 37: Different combinations of electricity production by conventional power plants at Eemshaven. The values in the first column are used in table 38-41 to show the percentage of time that this amount of electricity is produced.

MW	Power plants
4711	RWE hard coal + 3 magnum turbines + 5 Eemscentrale turbines
4352	RWE hard coal + 3 magnum turbines + 4 Eemscentrale turbines
3993	RWE hard coal + 3 magnum turbines + 3 Eemscentrale turbines
3633	RWE hard coal + 3 magnum turbines + 2 Eemscentrale turbines
3270	RWE hard coal + 3 magnum turbines + 1 Eemscentrale turbine
3111	3 magnum turbines + 5 Eemscentrale turbines
2911	RWE hard coal + 3 magnum turbines
2751	3 magnum turbines + 4 Eemscentrale turbines
2474	RWE hard coal + 2 magnum turbines
2392	3 magnum turbines + 3 Eemscentrale turbines
2037	RWE hard coal + 1 magnum turbine
2033	3 magnum turbines + 2 Eemscentrale turbines
1674	3 magnum turbines + 1 Eemscentrale turbine
1600	RWE hard coal
1311	3 magnum turbines

Table 38: Electricity production at Eemshaven in Scenario 1. In the left column the different amounts of MW produced electricity can be seen. This correspond with production the values in table 38. In the second columns the amount of time that the production from the first column is in place is shown. The third column shows the amount of congestion in MW. The last column shows the amount of renewable electricity production at Eemshaven (NorNed + wind parks).

Season	Electricity **production** power plants **Eemshaven (MW)**	**% Of time that this electricity output produced**	**Congestion (MW)**	Renewable electricity **production Eemshaven (MW)**
Summer	1600	100%	0	1013
	2037	42%	0	1013
	2474	38%	0	1013
	2911	33%	124	1013
	3274	0%	0	1013
	3634	0%	0	1013
	3993	0%	0	1013
	4352	0%	0	1013
	4711	0%	0	1013
Winter	1600	79%	0	1013
	2037	0%	0	1013
	2474	0%	0	1013
	2911	0%	0	1013
	3274	0%	0	1013
	3634	0%	0	1013
	3993	0%	0	1013
	4352	0%	0	1013
	4711	0%	0	1013
Spring	1600	100%	0	1013
	2037	0%	0	1013
	2474	0%	0	1013

	2911	0%	0	1013
	3274	0%	0	1013
	3634	0%	0	1013
	3993	0%	0	1013
	4352	0%	0	1013
	4711	0%	0	1013
Autumn	1600	100%	0	1013
	2037	4%	0	1013
	2474	4%	0	1013
	2911	4%	124	1013
	3274	0%	0	1013
	3634	0%	0	1013
	3993	0%	0	1013
	4352	0%	0	1013
	4711	0%	0	1013

Scenario 2
In the merit order curve of scenario 2 the most modern coal-fired power plants have become more expensive than the gas-fired power plants that were build after 2000. The old coal-fired power plants (from the 80's) are even more expensive than the gas-fired power plants from the 90's. This is all due to the high CO_2 price (€35/tCO_2 compared to €4,50/tCO_2 in scenario 1). The load curves in scenario 2 are identical to those in scenario 1.

The cheapest gas-fired power plants have variable costs of €58/MWh in scenario 2. New coal-fired power plants have variable costs of €63/MWh. This difference is explained by the higher CO_2 price in this scenario. This shows that at a CO_2 price of €35 the costs of CO_2 rights are 41% of the variable costs of coal-fired power plants build after the year 2000 and 20% of the costs of gas-fired power plants of this generation. Scenario 2 shows that the CO_2 price can have significant influences on power production in the Netherlands.

Power plants with higher variable costs of €71/MWh seem to be out of the running in scenario 2. The gas-fired power plants that were built in the 90's are battling for the last load that should be produced according to the RLDC's. At an autumn or summer day these power plants have a chance to produce electricity up to 50% of the time. On the contrary in winter and spring time only one or two of these power plants will be running at most 5% of the time.

The total electricity production in scenario 2 is also comparable to the electricity production in 2012. The import/export balance, as well as the renewable electricity production at Eemshaven (700 MW NorNed and 313 MW wind production) is the same as in scenario 1.

Congestion is more likely to occur in this scenario. Even with an equal load compared to scenario 1 (>20 GW during peak hours) two out of the five Eemscentrale turbines are expected to be switched on in summer (8-33% of the time) and in autumn (4% of the time). This is possible because the gas-fired power plants from the '90's are less expensive than the coal-fired power plants from the 80's in scenario 2. With electricity production of two Eemscentrale turbines the congestion in scenario 2 can reach up to 847 MW (see the fourth column in table 39).

Table 39: Electricity production at Eemshaven in Scenario 2. In the left column the different amounts of MW produced electricity can be seen. This correspond with production the values in table 37. In the second columns the amount of time that the production from the first column is in place is shown. The third column shows the amount of congestion in MW. The last column shows the amount of renewable electricity production at Eemshaven (NorNed + wind parks).

Season	Electricity production Power plants Eemshaven (MW)	% Of time that this electricity output produced	Congestion (MW)	Renewable electricity production Eemshaven (MW)
Summer	437	100%	0	1013
	874	100%	0	1013
	1311	100%	0	1013
	2911	71%	124	1013
	3274	33%	487	1013
	3634	8%	847	1013
	3993	0%	0	1013
	4352	0%	0	1013
	4711	0%	0	1013
Winter	437	75%	0	1013
	874	71%	0	1013
	1311	71%	0	1013
	2911	13%	124	1013
	3274	0%	0	1013
	3634	0%	0	1013
	3993	0%	0	1013
	4352	0%	0	1013
	4711	0%	0	1013
Spring	437	100%	0	1013
	874	100%	0	1013
	1311	100%	0	1013
	2911	0%	0	1013
	3274	0%	0	1013
	3634	0%	0	1013
	3993	0%	0	1013
	4352	0%	0	1013
	4711	0%	0	1013
Autumn	437	100%	0	1013
	874	100%	0	1013
	1311	96%	0	1013
	2911	63%	124	1013
	3274	4%	487	1013
	3634	4%	847	1013
	3993	0%	0	1013
	4352	0%	0	1013
	4711	0%	0	1013

Scenario 3

In scenario 3 the load increase (21,4% instead of 16%) and the import/export balance of 1,88 GW net export per hour causes the RLDC's to shift to the right compared to business as usual scenario 1. The other input variables didn't change compared to the business as usual scenario 1.Therefore the merit order doesn't change compared to scenario 1. As a consequence of the shifted RLDC's it is expected that Nuon's Magnum power plant at Eemshaven will have more full load hours than in scenario 1. Even in periods with the lowest expected load (spring and winter), all the magnum power plants will be running at least 58% of the time (+/- 14 hours per day on average).

Despite the load- and export increase the Eemscentrales of Electrabel/GDF Suez are expected only to produce in extreme situations during autumn and summer. The RLDC in autumn shows a production of two Eemscentrale turbines during 2% of the time and three Eemscentrale turbines during 4% of the time. In summer it's even more. Three Eemshaven turbines are expected to produce 42% of the time in summer.

As a consequence of the high load in this scenario (>22 GW in peak hours) and the net export (1,9 GW) power plants in the merit order curve sometimes have to produce 19 GW per hour. This will cause the Eemscentrale turbines to produce electricity, and causes up to 1 684 MW of congestion (see the fourth column in table 40).

Table 40: Electricity production at Eemshaven in Scenario 3. In the left column the different amounts of MW produced electricity can be seen. This correspond with production the values in table 37. In the second columns the amount of time that the production from the first column is in place is shown. The third column shows the amount of congestion in MW. The last column shows the amount of renewable electricity production at Eemshaven (NorNed + wind parks).

Season	Electricity production Power plants Eemshaven (MW)	% Of time that this electricity output produced	Congestion (MW)	Renewable electricity production Eemshaven (MW)
Summer	1600	100%	0	1013
	2037	100%	0	1013
	2474	100%	0	1013
	2911	100%	124	1013
	3274	54%	487	1013
	3634	54%	847	1013
	3993	50%	1206	1013
	4352	42%	1565	1013
	4711	42%	1924	1013
Winter	1600	100%	0	1013
	2037	71%	0	1013
	2474	71%	0	1013
	2911	71%	124	1013
	3274	4%	487	1013
	3634	4%	847	1013
	3993	4%	1206	1013
	4352	0%	0	1013
	4711	0%	0	1013
Spring	1600	100%	0	1013
	2037	100%	0	1013
	2474	88%	0	1013
	2911	79%	124	1013
	3274	0%	0	1013
	3634	0%	0	1013

	3993	0%	0	1013
	4352	0%	0	1013
	4711	0%	0	1013
Autumn	1600	100%	0	1013
	2037	100%	0	1013
	2474	83%	0	1013
	2911	79%	124	1013
	3274	50%	487	1013
	3634	50%	847	1013
	3993	25%	1206	1013
	4352	8%	1565	1013
	4711	8%	1924	1013

Scenario 4

Again, all the merit order variables (commodity prices, etc.) are the same as in scenario 1. As a consequence the merit order is the same as in scenario 1. Also a lot of load curve variables are comparable to scenario 1. The difference between scenario 1 and 4 is the higher load increase (21,4% instead of 16%), and a net export of 1,9 GW per hour (due to the nuclear phase out in Germany). Next to that the five power plants from the 80's have been decided to shut down.

The result of these input variables is that the RLCD's move slightly to the right compared to scenario 1. The RWE hard coal-fired power plant will be producing all the time in all seasons. The three magnums are expected to produce electricity at full capacity for more than 70% of the time in winter. During the other seasons their production is even more frequent.

In extreme situation in summer and autumn all five Eemscentrales are expected to be in full production. In summer this is expected during 42% of the time, whereas in autumn this is only during 8% of the time. In winter only three Eemscentrale turbines are needed. In spring not even one.

In scenario 4 there are already events of congestion if the RWE coal-fired power plant is producing along with three magnum turbines. In combination with the 700 MW import from NorNed and the 313 MW of production by wind parks in Eemshaven this is enough to cross the 3800 MW production border. That why congestion up to 1 924 MW can occur in this scenario in case five Eemscentrale turbines are producing electricity. In summer it can even happen during 42% of the time. In every season is congestion during more than 71% of the time (see the fourth column in table 41).

Table 41: Electricity production at Eemshaven in Scenario 4. In the left column the different amounts of MW produced electricity can be seen. This correspond with production the values in table 37. In the second columns the amount of time that the production from the first column is in place is shown. The third column shows the amount of congestion in MW. The last column shows the amount of renewable electricity production at Eemshaven (NorNed + wind parks).

Season	Electricity production Power plants Eemshaven (MW)	% Of time that this electricity output produced	Congestion (MW)	Renewable electricity production Eemshaven (MW)
Summer	1600	100%	0	1013
	2037	100%	0	1013
	2474	100%	0	1013
	2911	100%	124	1013
	3274	54%	487	1013
	3634	54%	847	1013
	3993	50%	1206	1013
	4352	42%	1565	1013

	4711	42%	1924	1013
Winter	1600	100%	0	1013
	2037	71%	0	1013
	2474	71%	0	1013
	2911	71%	124	1013
	3274	4%	487	1013
	3634	4%	847	1013
	3993	4%	1206	1013
	4352	0%	0	1013
	4711	0%	0	1013
Spring	1600	100%	0	1013
	2037	100%	0	1013
	2474	88%	0	1013
	2911	79%	124	1013
	3274	0%	0	1013
	3634	0%	0	1013
	3993	0%	0	1013
	4352	0%	0	1013
	4711	0%	0	1013
Autumn	1600	100%	0	1013
	2037	100%	0	1013
	2474	83%	0	1013
	2911	79%	124	1013
	3274	50%	487	1013
	3634	50%	847	1013
	3993	25%	1206	1013
	4352	8%	1565	1013
	4711	8%	1924	1013

4.3.4 Expected behaviour in case there is congestion management

In all scenarios congestion is expected in 2018. The amount of expected congestion differs per scenario. In this chapter an analysis is given per scenario on the market situation in case congestion management is applied.

Scenario 1

In this scenario a maximum of 124 MW congestion is expected during summer (33%) and autumn (4%) time. This 124 MW needs to be redispatched and produced by another power plants somewhere else in the Netherlands. In scenario 1 the power plant that will have to reduce its production will be the Magnum power plant at Eemshaven. After this redispatch the Residual Load Duration Curves are still in the area of the newest gas-fired power plants. This means a power plant with the same efficiency, same marginal costs and same emissions per MWh will replace the 124 MW of the Magnum power plant. In table 42 a list of these power plants is given. In reality these power plants won't have the exact same amount of marginal costs. Therefore it is not sure which power plant will be the one to replace the production at Eemshaven. In figure 32 the merit order curve of scenario 1 can be seen after the 124 MW have been removed from the Magnum power plant.

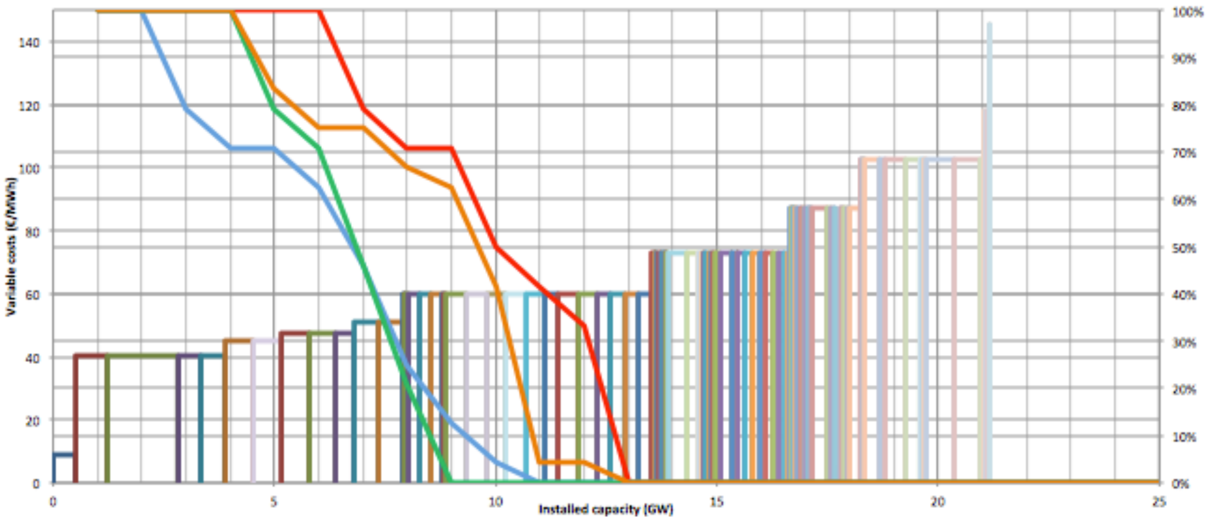

Figure 32: Merit order in case congestion management is applied in scenario 1. 124 MW of installed capacity is removed from Magnum turbine 3. The same legend as in figure 29 can be used.

Scenario 2

In this scenario 124-847 MW of congestion is expected in 2018. The RWE power plant has more expensive marginal costs compared to the Magnum turbines, which means this is the power plant that will have to produce 124 MW less in situations of congestion. In some cases even some of the Eemscentrale turbines need to be redispatched. If only the RWE power plant is redispatched, the gas-fired turbines in the same marginal costs category as the Eemscentrales will produce a little bit more. The same holds for the hard coal-fired power plants with same marginal costs levels of the Eemscentrale turbines. In case of high demand and necessary redispatch of the Eemscentrale turbines other turbines with same cost level will take over production. A list of these power plants can be found in table 43. Even some of the old coal-fired power plants (Amer 9 and Hemweg 8) will be producing a little bit of the power that would otherwise be produced by the Eemscentrale turbines in a situation without congestion constraints. In figure 33 the merit order curve without the 124 MW of the RWE power plants, and without the Eemscentrale turbines can be found.

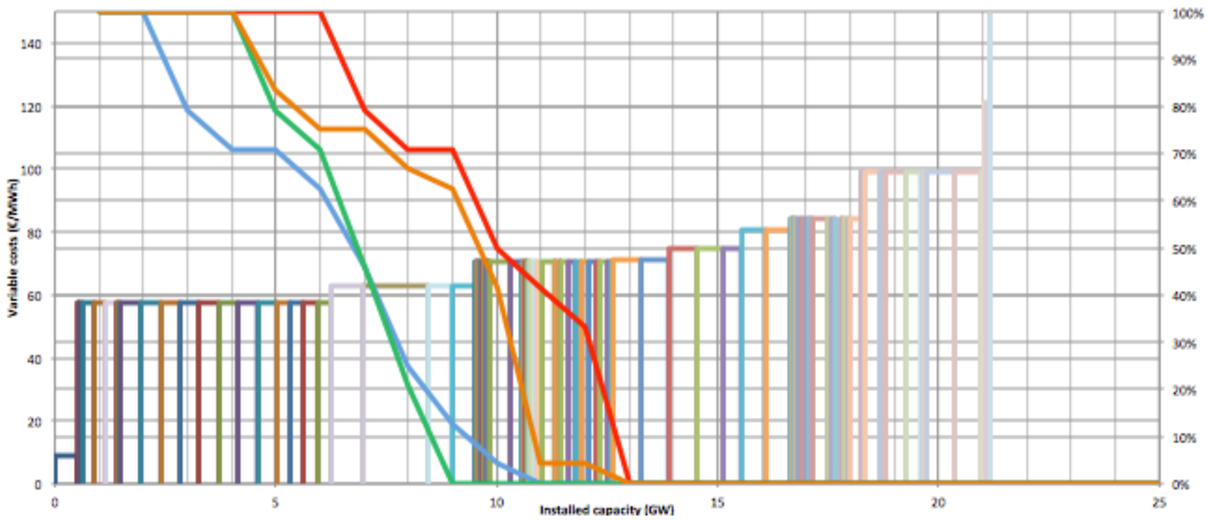

Figure 33: Merit order in case congestion management is applied in scenario 2. 124 MW of installed capacity is removed from the RWE turbine, and all the Eemscentrale turbines are removed. The same legend as in figure 30 can be used.

Scenario 3

In scenario 3 even more congestion is expected, despite the fact that the amount of installed wind capacity is not increased since 2013 in this scenario. 247-1684MW of congestion is expected. The RWE- and Magnum turbines don't need to be redispatched. All Eemscentrale turbines except one turbine need to be redispatched though. This means one Eemscentrale turbine can still produce 116 MW. The Eemscentrale turbines are mostly replaced by power plants with the same cost level. However, in extreme situation even the oldest and most expensive gas-fired power plants in the Netherlands need to be switched on (8% of the time in summer). In figure 34 the merit order curve without the Eemscentrale turbines (except the one with 116 MW) can be found.

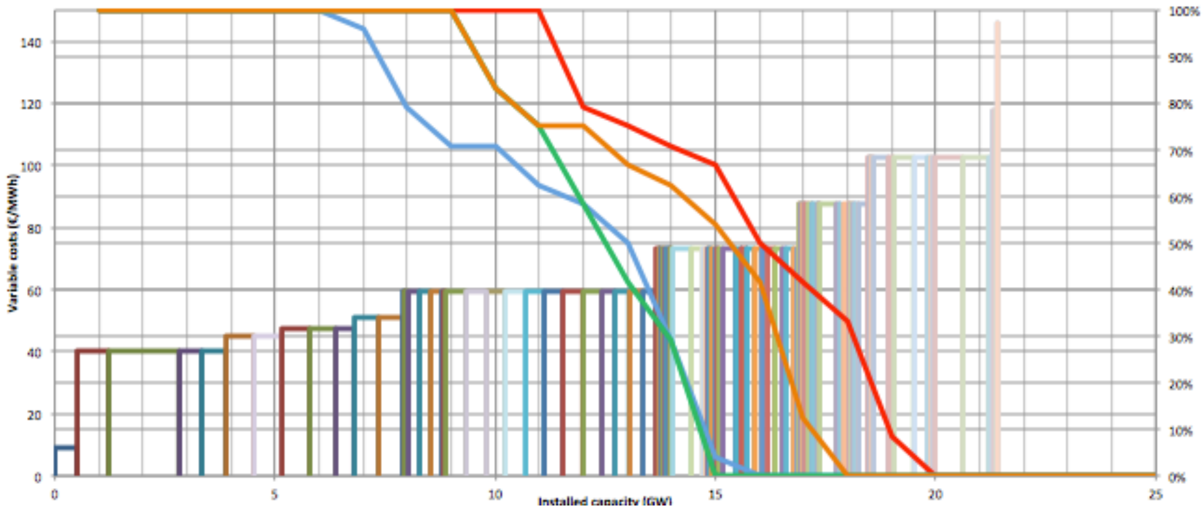

Figure 34: Merit order in case congestion management is applied in scenario 3. 274 MW is removed from the first Eemscentrale turbine. All the other Eemscentrale turbines have been removed completely. The same legend as in figure 31 can be used.

Scenario 4

Like in scenario 3, a lot of congestion is expected in scenario 4. Amounts of congestion differing from 124 MW-1924 MW can be expected. Like in scenario 1, the magnum power plant needs to redispatch 124 MW with its third turbine. All the Eemscentrale turbines need to be redispatched in extreme situations. In situations of redispatch of the Eemscentrale turbines, these turbines are partly replaced by the very old-fashioned gas-fired turbines with high marginal costs in the merit order. In figure 35 the merit order curve without the Eemscentrale turbines and 124 MW from the Magnum turbines can be found.

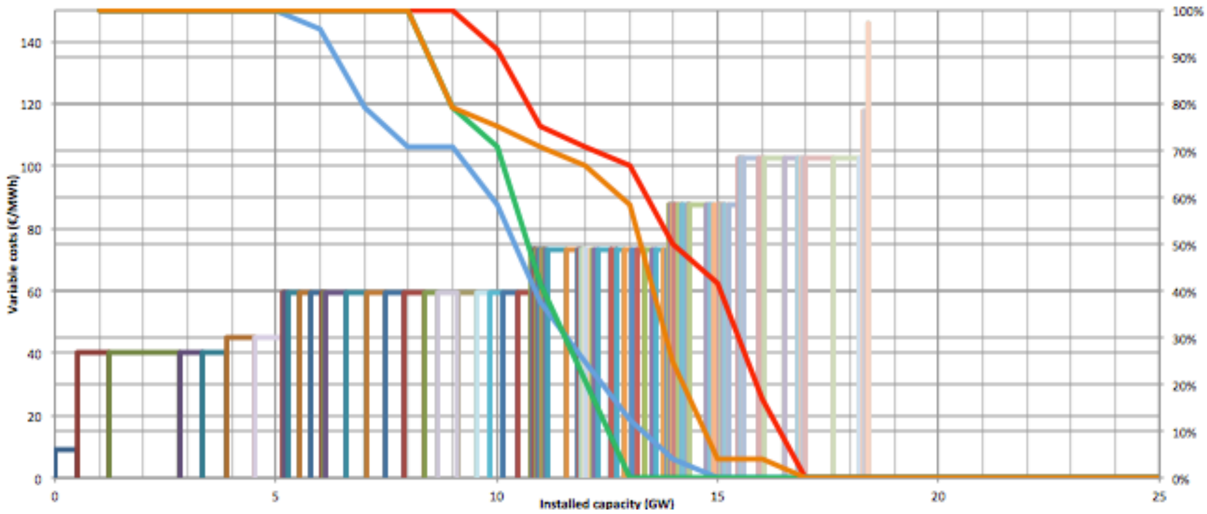

Figure 35: Merit order in case congestion management is applied in scenario 4. 124 MW is removed from the third Magnum turbine. All the Eemscentrale turbines have been removed completely. The same legend as in figure 32 can be used.

Table 42: List of power plants with the same efficiency, marginal costs and emissions as the Magnum power plant at Eemshaven (source: PLATTS database in combination with data from TenneT)

Location	Name power plant	Owner power plant	Production capacity (MW)	Currently available for redispatch
Europoort	ENECOGEN	ENECO HOLDING NV	435	No
Pernis (Rotterdam)	RIJNMOND ENERGIE-1 GT 1	INTERGEN (UK) LTD	260	Yes
Pernis (Rotterdam)	RIJNMOND ENERGIE-1 GT 2	INTERGEN (UK) LTD	260	Yes
Pernis (Rotterdam)	RIJNMOND ENERGIE-1 SC 1	INTERGEN (UK) LTD	260	Yes
Leiden	LEIDEN GT 1A	E.ON BENELUX	40	Yes
Leiden	LEIDEN GT 2A	E.ON BENELUX	40	Yes
Flushing (Vlissingen)	SLOECENTRALE CC 1	DELTA NV	456	Yes
Flushing (Vlissingen)	SLOECENTRALE CC 2	DELTA NV	456	Yes
Lelystad	FLEVO Maxima CC 1	ELECTRABEL NEDERLAND	439	Yes
Lelystad	FLEVO Maxima CC 2	ELECTRABEL NEDERLAND	438	Yes
Amsterdam	HEMWEG 9	NUON NV	432	No
Maasbracht	CLAUS C1	ESSENT NV	310	Yes
Maasbracht	CLAUS C2	ESSENT NV	310	No
Maasbracht	CLAUS C3	ESSENT NV	310	No
Maasbracht	CLAUS C4	ESSENT NV	310	Yes
Maasvlakte	MAASVLAKTE BAYER GT 1	E.ON BENELUX	70	Yes
Botlek	WKC AIR PRODUCTS GT 1	ELECTRABEL NEDERLAND	43	Yes

Table 43: List of power plants with the same efficiency, marginal costs and emissions as the Eemscentrale power plant at Eemshaven (source: PLATTS database in combination with data from TenneT)

Location	Name power plant	Owner power plant	Production capacity (MW)
Diemen	DIEMEN 34 SC 1	NUON NV	435
Diemen	DIEMEN 33 GT 1	NUON NV	266
Utrecht	LAGE WEIDE 6 GT 1	NUON NV	266
Rotterdam	ROCA (ROTTERDAM)-3 CC GT 1	E.ON BENELUX	116
Rotterdam	ROCA (ROTTERDAM)-3 CC SC 1	E.ON BENELUX	104
Almere (FL)	WKC ALMERE CC 2	NUON NV	55
Eindhoven	EINDHOVEN PHILLIPS GT 1	ESSENT NV	42
Rozenburg (Rotterdam)	ROZENBURG EUROGEN GT 1	EUROGEN CV	38
Rozenburg (Rotterdam)	ROZENBURG EUROGEN GT 2	EUROGEN CV	38
Rozenburg (Rotterdam)	ROZENBURG EUROGEN GT 3	EUROGEN CV	38
Helmond	HELMOND PROMEST VKC GT 1	ESSENT NV	24
Helmond	HELMOND II GT 1	ESSENT NV	22
Helmond	HELMOND PROMEST VKC SC 1	ESSENT NV	10
Eemshaven	EEMS EC 5	ELECTRABEL NEDERLAND	363
Eemshaven	EEMS EC 7	ELECTRABEL NEDERLAND	360
Eemshaven	EEMS EC 3	ELECTRABEL NEDERLAND	359
Eemshaven	EEMS EC 4	ELECTRABEL NEDERLAND	359
Eemshaven	EEMS EC 6	ELECTRABEL NEDERLAND	359

Moerdijk	MOERDIJK AZN SC 1	ESSENT NV	180
Hoek	ELSTA GT 1	AES ELSTA BV	160
Hoek	ELSTA GT 2	AES ELSTA BV	160
Hoek	ELSTA GT 3	AES ELSTA BV	160
Geleen	SWENTIBOLD GT 1	ESSENT NV	156
Velsen	IJMUIDEN UNA GT 1	NUON NV	144
Hoek	ELSTA SC 1	AES ELSTA BV	100
Geleen	SWENTIBOLD SC 1	ESSENT NV	90
Moerdijk	MOERDIJK AZN GT 1	ESSENT NV	59
Moerdijk	MOERDIJK AZN GT 2	ESSENT NV	59
Moerdijk	MOERDIJK AZN GT 3	ESSENT NV	59
's-Hertogenbosch	DEN BOSCH HEINEKEN CC 1	ESSENT NV	34
Erika	ERIKA GT 2	GASEDON EMMEN VOF	31
Klazinaveen	KLAZINAVEEN GASEDON GT 1	GASEDON EMMEN VOF	31
Klazinaveen	KLAZINAVEEN GASEDON GT 2	GASEDON EMMEN VOF	31
Borculo	BERKELCENTRALE-2 GT 1	MORGAN STANLEY NETHERLANDS	29
Borculo	BERKELCENTRALE-2 GT 2	MORGAN STANLEY NETHERLANDS	29
Erika	ERIKA GT 1	GASEDON EMMEN VOF	25
Bergen Op Zoom	BERGEN OP ZOOM PNEM GT 1	ESSENT NV	24
Petten	PETTEN ECN GT 1	ENERGIE CENT NEDERLAND (ECN)	20
Erika	ERIKA SC 1	GASEDON EMMEN VOF	17
Borculo	BERKELCENTRALE-2 SC 1	MORGAN STANLEY NETHERLANDS	14
Bergen Op Zoom	BERGEN OP ZOOM PNEM SC 1	ESSENT NV	10
Klazinaveen	KLAZINAVEEN GASEDON SC 1	GASEDON EMMEN VOF	10
Gouda	GOUDA UNICHEMA GT 1	E.ON BENELUX	7
Coldenhove	EERBEEK COLDENHOVE GT 1	NUON NV	5
Heusden	HEUSDEN JONKER FRIS GT 1	ESSENT NV	4
Rotterdam	ROTTERDAM MASTER FOODS GT 1	ENECO HOLDING NV	2

It must be noted that redispatch is only possible if the power plant is already running on a partial load, so its spinning reserves can be used to quickly adjust to a situation of too much or too little electricity production. The availability for redispatch is based on the statistical data of TenneT. If the power plant has been producing power in the period of April 2012-April 2013 the power plant is noted as available for redispatch (the last column in table 42). If data from TenneT shows that the power plants weren't available for producing power in the above-mentioned period, the power plant is noted down as unavailable for redispatch.

4.4 Expected CO_2 and NO_x emissions in the Netherlands until 2018 with and without congestion management

4.4.1 Summary of environmental results of congestion management

In this chapter the differences in emissions of CO_2 and NO_x are shown per scenario in situations with and without congestion management. Total absolute emissions per scenario are shown in table 60.

Scenario 1

As already explained in the previous chapter, scenario 1 doesn't show a situation in which the production that was normally produced in Eemshaven is now produced by more polluting power plants somewhere else in the Netherlands. The 124 MW of congestion that is expected in this scenario in 2018 (only in summer and autumn) is simply produced by gas-fired power plants with the same efficiency, and thus emissions per MWh of electricity produced. As a consequence there are no differences between situations with congestion management (table 45) and without congestion management (table 44). The differences between the situations are shown in table 46.

Table 44: Average CO2 and NOx emissions in the situation without congestion management in scenario 1.

Average emissions	Summer	Winter	Spring	Autumn	Yearly average	Unit
Average CO2 emissions	673	716	732	692	699	**KgCO2/MWh**
Average NOx emissions	0.19	0.19	0.19	0.20	0.19	**KgNOx/MWh**

Table 45: Average CO2 and NOx emissions in the situation with congestion management in scenario 1.

Average emissions	Summer	Winter	Spring	Autumn	Yearly average	Unit
Average CO2 emissions	673	716	732	692	699	**KgCO2/MWh**
Average NOx emissions	0.19	0.19	0.19	0.20	0.19	**KgNOx/MWh**

Table 46: Differences between situations with and without congestion management in scenario 1.

	Summer	Winter	Spring	Autumn	Difference	Unit
Average CO2 emissions	0	0	0	0	0	**KgCO2/MWh**
Average NOx emissions	0	0	0	0	0	**KgNOx/MWh**
Total CO2 emissions	0	0	0	0	0	**Kton**
Total NOx emissions	0	0	0	0	0	**Kton**
% CO2 emissions increase	N/a	N/a	N/a	N/a	0	**%**
% NOx emissions increase	N/a	N/a	N/a	N/a	0	**%**

Scenario 2

In this scenario the state of the art gas-fired power plants have lower marginal costs compared to the newest hard coal-fired power plants (see figure 30). Gas-fired power plants will be producing the base load electricity production. As a consequence the average CO_2 emissions per MWh drop significantly compared to scenario 1 (from 699 in scenario 1 to 395 $kgCO_2$/MWh, see table 47). The average NO_x emissions drop as well, but with a lower amount (0.19 to 0.15 $KgNO_x$/MWh). The RWE power plant at Eemshaven needs to reduce its production with 124 MW in moments of high electricity demand and thus congestion. This 124 MW is partly replaced by other coal-fired power plants in the Netherlands, but also by gas-fired power plants from the 90's. This leads to an interesting situation because these gas-fired power plants have lower CO_2 emissions per MWh than the coal-fired power plant of RWE. The application of congestion management thus leads to a lower amount of CO_2 emissions in the Netherlands in case coal-fired power plants are more expensive than gas-fired power plants. In table 49 can be seen that a decrease of 0.19% in total CO_2 emissions is expected in scenario 2 if congestion management is applied. This equals an absolute decrease that is a little bit less than 50 $KtonCO_2$ (see table 49). The opposite is true for NO_x emissions. The gas-fired power plants from the 90's have a higher amount of NO_x

emissions per MWh compared to the newest coal-fired power plants (see table 21). In the end congestion management leads to an increase of 0.18% in NO_x emissions compared to a situations without congestion management. This is an absolute increase of 20 tNOx per year. In tables 47-49 the exact results of scenario 2 can be seen.

Table 47: Average CO2 and NOx emissions in the situation without congestion management in scenario 2.

Average emissions	Summer	Winter	Spring	Autumn	Yearly average	Unit
Average CO2 emissions	428	359	343	424	396	**KgCO2/MWh**
Average NOx emissions	0.16	0.13	0.13	0.15	0.15	**KgNOx/MWh**

Table 48: Average CO2 and NOx emissions in the situation with congestion management in scenario 2.

Average emissions	Summer	Winter	Spring	Autumn	Yearly average	Unit
Average CO2 emissions	427	359	343	423	396	**KgCO2/MWh**
Average NOx emissions	0.16	0.13	0.13	0.15	0.15	**KgNOx/MWh**

Table 49: Differences between situations with and without congestion management in scenario 2.

	Summer	Winter	Spring	Autumn	Difference	Unit
Average CO2 emissions	-1	0	0.01	-1.5	-0.73	**KgCO2/MWh**
Average NO_x emissions	0	0	0	0	0	**KgNOx/MWh**
Total CO2 emissions	-20.7	0.04	0.09	-26.78	-47.3	**Kton**
Total NO_x emissions	0.02	0	0	0	0.02	**Kton**
% CO2 emissions increase	N/a	N/a	N/a	N/a	-0.19	**%**
% NO_x emissions increase	N/a	N/a	N/a	N/a	0.18	**%**

Scenario 3

In this scenario with high amounts of export the average amount of CO_2 emissions drops a little bit compared to scenario 1 (from 699 to 607 $kgCO_2$/MWh). A reason for this is that relatively more GWh is produced by gas-fired power plants, which have lower CO_2 emissions per MWh than coal-fired power plants. The average NO_x emissions stay more or less equal. There is both an increase in CO_2 emissions as well as in NO_x emissions in case congestion management is applied in scenario 3. The fact that older gas-fired turbines need to replace the new magnum- and medium aged Eemscentrale turbines in situations of congestion can explain this. These older power plants have lower efficiencies and thus higher emissions. CO_2 emissions will increase with 0.15% compared to the situation without congestion management. This equals an absolute increase of 104 $KtonCO_2$ on a yearly basis. The total amount of emitted NO_x increases with 0.23%. This is comparable with an absolute amount of 50 tNO_x per year. In tables 50-52 the exact results of scenario 3 can be seen.

Table 50: Average CO2 and NOx emissions in the situation without congestion management in scenario 3.

Average emissions	Summer	Winter	Spring	Autumn	Yearly average	Unit
Average CO2 emissions	578	635	628	599	608	**KgCO2/MWh**
Average NOx emissions	0.20	0.19	0.19	0.19	0.19	**KgNOx/MWh**

Table 51: Average CO2 and NOx emissions in the situation with congestion management in scenario 3.

Average emissions	Summer	Winter	Spring	Autumn	Yearly average	Unit
Average CO2 emissions	581	635	628	600	609	**KgCO2/MWh**
Average NOx emissions	0.20	0.19	0.19	0.19	0.19	**KgNOx/MWh**

Table 52: Differences between situation with and without congestion management in scenario 3.

	Summer	Winter	Spring	Autumn	Difference	Unit
Average CO2 emissions	2.94	0	0	0.18	0.91	**KgCO2/MWh**
Average NOx emissions	0	0	0	0	0	**KgNOx/MWh**
Total CO2 emissions	98.62	0	0	5.43	104	**Kton**
Total NOx emissions	0.05	0	0	0	0.05	**Kton**
% CO2 emissions increase	N/a	N/a	N/a	N/a	0.15	**%**
% NOx emissions increase	N/a	N/a	N/a	N/a	0.23	**%**

Scenario 4

This scenario also shows a huge decrease in average CO_2 emissions because more gas-fired power plants are used to produce the necessary (high) amount of demanded GWh. Next to that the old fashioned coal-fired power plants from the 80's are shut down in scenario 4. They have been removed from the merit order. As a consequence of this shut down also the average NO_x emissions have decreased. Like in scenario 3, there are both increases in CO_2 and NO_x emissions in case of congestion management. These increases are even larger compared to scenario 3, despite the higher amount of renewable installed capacity. This can also be explained by the absence of the five old power plants. Because of their absence the magnum turbines at Eemshaven have to produce more frequently at full load (more than 71% of the time). In scenario 3 the magnums produced at full load during more than 58% of the time. As a consequence congestion management is applied more often in scenario 4. In this scenario it happens more often (71% of the time) that the magnum power plants need to be redispatched and older less efficient power plants need to replace them. In this scenario also the Eemscentrale turbines quite often have to be replaced by the most expensive and most polluting power plants in the merit order. In the end this leads to an increase of 0.40% in CO_2 emissions compared to the situation without congestion management. This is the highest increase of all scenarios. An absolute increase of 204 KtonCO_2 per year is connected to this relative increase. The relative NO_x increase is even higher. A 1.1% increase in NO_x emissions is expected compared to the situation without congestion management in scenario 4. This is equal with an absolute increase of 184 tNO_x per year. In tables 53-55 the exact results of scenario 4 can be seen.

Table 53: Average CO2 and NOx emissions in the situation without congestion management in scenario 4.

Average emissions	Summer	Winter	Spring	Autumn	Yearly average	Unit
Average CO2 emissions	495	535	524	506	513	**KgCO2/MWh**
Average NOx emissions	0.18	0.17	0.16	0.17	0.17	**KgNOx/MWh**

Table 54: Average CO2 and NOx emissions in the situation with congestion management in scenario 4.

Average emissions	Summer	Winter	Spring	Autumn	Yearly average	Unit
Average CO2 emissions	501	535	524	508	515	**KgCO2/MWh**
Average NOx emissions	0.18	0.17	0.16	0.18	0.17	**KgNOx/MWh**

Table 55: Differences between situations with and without congestion management in scenario 4.

	Summer	Winter	Spring	Autumn	Difference	Unit
Average CO2 emissions	5.26	0.23	0.56	1.32	2.07	KgCO2/MWh
Average NOx emissions	0	0	0	0	0	KgNOx/MWh
Total CO2 emissions	153	4.8	12.44	34.61	204	Kton
Total NOx emissions	0.12	0.01	0.02	0.04	0.18	Kton
% CO2 emissions increase	N/a	N/a	N/a	N/a	0.40	%
% NOx emissions increase	N/a	N/a	N/a	N/a	1.10	%

4.4.2 Outcomes of scenario in the perspective of Dutch emission targets

In the background of this research (chapter 2) already a short introduction was made on the Dutch emission targets for CO_2 and NO_x emissions in 2020. In the EU Emission Trading System voor CO_2 emissions (ETS), the target is to reduce the emissions with 21% compared to 2005[60]. In 2005 the total ETS emissions (according to the method of the third ETS period) were 98 Mton CO_2[61]. Thus, in 2020 the ETS emissions in the Netherlands should not exceed 77.5 Mton CO_2. In table 56 and 57 the absolute and relative CO_2 emissions in the Netherlands under the ETS system are shown. In the tables can be seen that the emissions by some sectors are quite stable over the years (Industry and construction, refineries, buildings). Agriculture is even increasing since 2009. The energy sector shows a decrease since 2005. The "other" sector faced a huge decrease between 2007 and 2008. It is more likely that this is caused by another choice in data collection. If looked at the relative numbers (table 57), the energy sector has a quite stable share of around 53% in the total ETS CO_2 emissions. Therefore it could be meaningful to extrapolate this share to 2020. With this share and the 2020 target for ETS CO_2 emissions (77.5 Mton) the absolute targets for 2020 per sector could be defined. In the last column of table 56 these absolute targets can be read. Given the 2012 share of the energy sector, their total emissions in 2020 should not exceed 41.7 Mton.

Table 56: Absolute CO2 emissions by ETS sectors in the Netherlands in the period 2005-2012 in Mt CO2. (Source: Dutch Pollutant Release and Transfer Register)

	2005	2006	2007	2008	2009	2010	2011	2012	Target 2020 (with shares 2012)
Energy sector	51.3	47.8	50.9	49.8	50.6	51.7	48.9	46.7	41.7
Industry and construction sector	27.7	27.7	28.4	28.1	25.6	28.6	27.5	27.6	24.6
Refineries	12.3	11.6	11.7	11.8	10.8	10.6	10.8	10.7	9.6
Agriculture	0.6	0.6	0.7	0.7	0.8	1.1	1	1	0.9
Buildings	0.4	0.5	0.4	0.4	0.4	0.5	0.4	0.5	0.4
Other	5.7	5.7	4.4	0.6	0.5	0.4	0.3	0.3	0.3
Total	98	93.9	96.5	91.4	88.7	92.9	88.9	86.8	77.5

Table 57: Relative CO2 emissions by ETS sectors in the Netherlands in the period 2005-2012. (Source: Dutch Pollutant Release and Transfer Register)

	2005	2006	2007	2008	2009	2010	2011	2012
Energy sector	52%	51%	53%	54%	57%	56%	55%	54%
Industry and construction sector	28%	29%	29%	31%	29%	31%	31%	32%
Refineries	13%	12%	12%	13%	12%	11%	12%	12%
Agriculture	1%	1%	1%	1%	1%	1%	1%	1%
Buildings	0%	1%	0%	0%	0%	1%	0%	1%
Other	6%	6%	5%	1%	1%	0%	0%	0%
Total	100%	100%	100%	100%	100%	100%	100%	100%

With the same method the NO_x emission target for the energy sector can be extrapolated to 2020. Table 58 shows the absolute numbers for NO_x emissions by different sectors since 1995. Table 59 shows the relative emissions per sector. It can be seen that the National Emission Ceiling (NEC) target of 260 Mton in 2010 was exceeded by the Netherlands. Table 58 also shows that some sectors faced a very drastic decrease in NO_x emissions (Industry and refineries, energy, consumers, traffic). Others were more or less stable (buildings, agriculture). The energy sector also showed a decrease in their share in total NO_x emissions (from 14% in 1990 to 7% in 2012). The last three years this share is quite stable around 7% (see table 59). If this share is extrapolated to 2020, and the NO_x target for 2020 (202 Mton NO_x) is taken as total emissions, the energy sector should emit no more than 14.3 Mton NO_x in 2020. This target for 2020 is shown in the last column in table 58.

[60] (Rijksoverheid, 2011)
[61] (Dutch Pollutant Release and Transfer Register, 2012)

Table 58: Absolute NOx emissions in the Netherlands in the period 1995-2012 in Mton NOx. (Source: Dutch Pollutant Release and Transfer Register)

	1990	1995	2000	2005	2010	2011	2012	Target 2020 (with shares 2012)
Industry and refineries	111.9	83.1	52.8	51	43	43.2	42.1	33.6
Energy sector[62]	77.1	59.9	50.2	41	23	18.8	17.9	14.3
Traffic	327	272	239	198	162	159	154	123.0
Consumers	20	21	18	15	13	10	11	8.8
Buildings	14	15	14	13	14	10	11	8.8
Agriculture	17	22	20	18	19	18	17	13.6
Total	567	473	394	336	274	259	253	202

Table 59: Relative NOx emissions in the Netherlands in the period 1994-2012. (Source: Dutch Pollutant Release and Transfer Register and CBS statline)

	1990	1995	2000	2005	2010	2011	2012
Industry and refineries	20%	18%	13%	15%	16%	17%	17%
Energy sector	14%	13%	13%	12%	8%	7%	7%
Traffic	58%	58%	61%	59%	59%	61%	61%
Consumers	4%	4%	5%	4%	5%	4%	4%
Buildings	2%	3%	4%	4%	5%	4%	4%
Agriculture	3%	5%	5%	5%	7%	7%	7%
Total	100%	100%	100%	100%	100%	100%	100%

To conclude, given the current shares of the energy sector in CO_2 and NO_x emissions in 2012 and the emissions targets in 2020, the energy sector should not emit more than 41.7 Mton CO_2 and 14.3 Mton NO_x in 2020. The total emissions of CO_2 and NO_x in the different scenarios are shown in table 60. In almost all scenarios more than 41.7 Mton CO_2 is emitted. Only scenario 2 emits less than that because of the more expensive coal-fired power plants. Especially in case of more export (scenario 3 and 4) the CO_2 emissions rise significantly (more electricity needs to be produced in the Netherlands). The 14.3 Mton target for NO_x emissions in 2020 is only exceeded in scenario 3 and 4. Again this is because of the high export values and high demand. The electricity production is simply much higher than it is in 2012, with high emissions as a consequence. In the business as usual scenario it is likely that the NO_x target in 2020 will not be exceeded.

In any case the increase in emissions due to congestion management will not have very significant effects on reaching the targets. As can be seen in table 60, the absolute additions in emissions due to congestion management are quite small. In the scenarios with the largest increase due to congestion management (scenario 3 and 4), the targets for NO_x and CO_2 emissions would have been exceeded regardless of the congestion management.

[62] (CBS statline, 2013)

Table 60: Total emissions of CO2 and NOx in different scenarios in 2018 in situations with and without congestion management.

	CO2 (Kton)	NOx (Kton)
Scenario 1	45 042	12.50
Scenario 1 congestion man	45 042	12.50
Scenario 2	25 522	9.42
Scenario 2 congestion man	25 475	9.44
Scenario 3	69 809	22.19
Scenario 3 congestion man	69 913	22.24
Scenario 4	50 530	16.84
Scenario 4 congestion man	50 735	17.02

4.4.3 Conclusions of environmental results of congestion management

An increase or decrease in emissions due to congestion management is dependent on the power plants that replace the redispatched power plants (in this case at Eemshaven). In scenario 1 the power plants at Eemshaven were replaced by comparable power plants at other places in the Netherlands. In all other scenarios the method of congestion management causes an increase or decrease in emissions of NO_x and CO_2. The results of the calculation of all the scenarios are shown in table 61.

Table 61: Differences in CO2 and NOx emissions between situations with and without congestion management in the different scenarios.

	Total CO2 difference (Kton CO2)	% CO2 difference	Total NOx difference (tNOx)	% NOx difference
Scenario 1	0	0%	0	0%
Scenario 2	-47	-0.19%	17	0.18%
Scenario 3	104	0.15%	51	0.23%
Scenario 4	204	0.40%	184	1.10%

The highest increase in CO_2 emissions due to congestion management is 204 000 ton (scenario 4, table 55). This is 0.4% of the current emissions by the whole energy sector in 2012 and is comparable with the amount of CO_2 that is emitted by all trucks in the Netherlands in one month (CBS statline, 2012). The highest increase in NO_x emissions is 184 ton (scenario 4, table 55). This is 1% of the total NO_x emissions by the whole energy sector in 2012 (CBS statline, 2012).

Whether or not exceeding the Dutch CO_2 and NO_x targets will not be very much influenced by congestion management. In the scenarios that the emission targets are exceeded, it is not because of congestion management (see table 60).

5. Discussion

Figure 15: ***Start up turbine at Magnum power plant, Eemshaven. This turbine was meant to be used once to start up the three gas-fired turbines of the Magnum power plant. Since the gas-fired Magnum turbine has relatively high marginal costs it is shut down regularly. As a consequence, the start up turbine that was meant to be used once is used frequently.***

A lot of assumptions have been made in this research. The most important assumptions that could have an influence on the final results are discussed in this chapter.

5.1 N-1 assumption

In chapter 3.2 and 4.2 the n-1 assumption of 100% is taken. In chapter 4.2.5 this assumption is already put into perspective; less than 100% of the power that was originally flowing over two circuits in a line will flow via one circuit in case one of the two circuits will fall out. The percentages that were used in chapter 4.2.5 result in a maximum production of 3800 MW at Eemshaven. Beyond that production congestion is expected. Earlier rough estimates from TenneT predict that the maximum amount of electricity production at Eemshaven is in the range of 3200-3800 MWe. The assumption of a maximum of 3800 MWe production at Eemshaven could be lower in reality. This means at lower production values already congestion could be expected. In this research this would have led to higher emissions due to congestion management in scenarios 1,2 and 4.

5.2 Must-run CHP

As already explained in chapter 3.3, it is not easy to find data on must-run CHP power production in the Netherlands. Neither TenneT, nor the Dutch Central Bureau for Statistics (CBS) has accurate data on the exact amount of must-run CHP in the Netherlands at different moments during the year. Nonetheless, the amounts as they have been used in the research (see chapter 3.3) have been judged as quite likely by experts from TenneT. Also additional information from *Energy Matters*[63] shows that must-run CHP is producing between 2 GWe and 4 GWe on average per hour in the Netherlands. In the winter period it is a little bit more because of district heating. In summer a little bit less. However, it is still not clear which power plants in the Netherlands are taken as must-run CHP by *Energy Matters*. Future research could be conducted on the exact amount of must-run CHP in the Netherlands, and the influence it has on electricity prices. Must-run CHP could become too expensive with the increase in produced renewable electricity. It is interesting to investigate what consequences this would have for must-run CHP producers and system operators like TenneT. Higher or lower amounts of must-run CHP in the scenarios could lead to an increase or decrease of the load in the residual load duration curves. A higher amount of must-run CHP will lead to lower load that should be produced by conventional power plants. This will decrease the likeliness of congestion in the northern part of the Netherlands. The opposite will be true in case of a lower amount of must-run CHP.

5.3 Import/export

Import and export is assumed to be stable during whole year in chapter 3.3 and 4.3. In reality import and export values change every minute. It is also assumed that all import/export capacity is used all the time. This is also not the case in reality. The import/export values used in the different scenarios represent possible outcomes. Given the fact that in 2012 two thirds of the import/export capacity was used for import is an indication that this is also likely in the coming years. Especially, because Germany will increase its renewable electricity production in the coming years. In case of more export congestion is more likely to happen; more electricity should be produced in the Netherlands, which increases the chance that power plants at Eemshaven will be producing at the same time. In case of more import less congestion is expected.

5.4 Wind/solar

Electricity production by wind turbines (land and sea) and solar photovoltaic cells in this research is a product of average efficiency times installed capacity. To make these efficiency numbers more accurate actual wind patterns and solar intensity patterns could be used. During different wind intensities and solar intensities the efficiency of a wind turbine or solar-pv panel can differ. However, the model that is used is made to predict electricity production within four years in the near future. It predicts electricity production for a whole year. Because of this long time span averages are used. The expectation is that this average numbers won't have much influence on the final results. Especially because the relatively small power production by wind and solar power does not yet have a significant influence on the electricity market.

[63] (Energy Matters, 2013)

5.5 Order of power plants in the merit order curves

As can be seen in the merit order curves in this research, a lot of power plants have the same marginal costs. For example, all gas-fired power plants that were build after 2000 are assumed to have comparable cost levels. In reality small cost difference between these power plants will determine the order in which the power plants will be producing in the merit order. If power plants at Eemshaven have a little bit higher marginal costs than comparable power plants, the chance of having congestion is lower than is presented in this research. If the power plants at Eemshaven appear to have rather low marginal costs, congestion is more likely than in the scenarios in this research.

5.6 CO_2 and NO_x assumptions and the absence of other emissions

Emissions of SO_2 and particle matter (PM) are left out in this research. The reason for this is the earlier explained expectation that most often gas-fired power plants are redispatched. In scenario 2 in chapter 4.3 also a coal-fired power plant is redispatched. This will most likely lead to lower emissions of SO_2 and particle matter in the Netherlands (the coal-fired power plant is replaced by a gas-fired power plant in that scenario). This is not taken into account in this research because it is very unlikely that electricity produced by hard coal will become cheaper than gas in the near future. In future research emissions of SO_2 could also be taken into account. Also emissions of NH_3 could be interesting to look at.

Assumptions on NO_x emissions by different power plants could be a point of discussion. Power plants can have different types of NO_x filters. In this research it has not been checked which power plant has filters, and which power plant is emitting without filters. All the power plants with the same building year are assumed to have the same emissions factor for NO_x. If the emissions are determined per power plant more accurate outcomes could be generated. Now assumptions have been made on the basis of environmental reports dating from the building year of the power plant. In the meanwhile the power plant could be upgraded. This is not taken into account in this research.

5.7 Scenarios

Other uncertainties such as input fuel prices, import/export values, closure of power plants, load variations, etc., are varied in the four scenarios. In this way four possible outcomes have been shown, given the different inputs.

6. Conclusions

Figure 16: RWE coal-fired power plant at Eemshaven.

This research consists of three steps. Per step the most important conclusions are presented in this chapter.

6.1 Circumstances in which congestion is likely in the northern part of the Netherlands

Congestion on the high voltage transmission grid in the northern part of the Netherlands could be caused by two reasons: high demand by consumers in the region or high production at one location in the reason. As the region has a relatively low and decreasing population density it is not likely that the first reason will cause congestion in the near future. The second reason, however, is more likely. The model that is developed for this research shows that the 380kV connection between Eemshaven and Meeden is most likely to be the first line that will reach its maximum capacity in cases of high electricity production at Eemshaven. This line has to transport all the power that is not necessary in the northern part of the Netherlands towards the parts in which it is necessary (Randstad). In case of a n-1 situation (one of the two circuits of EEM-MEE 380 kV will fall out) 80% the power that was originally flowing via the two circuits of EEM-MEE 380kV will flow via the one circuit that is left. With a production of more than 3800 MW by different power plants, wind turbines and the import cable from Norway (NorNed) at Eemshaven the one circuit EEM-MEE 380kV will reach its save limit of 2635 MVA.

6.2 The market situation in the Netherlands with and without congestion management

Four scenarios with different assumptions have been developed to predict the future merit order in the Dutch electricity market. In one scenario with a very high CO_2 price of €35 (scenario 2), the most modern coal-fired power plants becomes more expensive compared to the newest gas-fired power plants in the Netherlands. In the business as usual scenario (scenario 1) even the hard coal fired power plants from the 80's have lower marginal costs compared to the newest gas fired power plants. In this scenario only in extreme cases congestion at Eemshaven is expected. Only 124MW of electricity production should be replaced from Eemshaven to somewhere else in the Netherlands. And this will only happen in summer and autumn. In the more extreme scenarios 3 and 4 more congestion is expected. It is caused by the high production at Eemshaven. Congestion in scenario 3 can reach up to 1684 MW, whereas scenario 4 shows values of congestion up to 1924 MW. In scenario 2, 3 and 4 the power plants at Eemshaven that need to be redispatched are replaced by power plants somewhere else in the Netherlands with different characteristics (building year, input fuel). This means that the redispatch (congestion management) will have influence on the costs for electricity, and, more important in this research, on the emissions of greenhouse gasses. In scenario 1 the power plant at Eemshaven that needs to be redispatched (Magnum) is replaced by power plants from the same age and fuel type (modern gas fired turbines). In this scenario redispatch won't cause any price increases or increases in emissions.

6.3 Expected CO_2 and NO_x emissions in the Netherlands until 2018 with and without congestion management

In the business as usual scenario no extra emissions will be caused by congestion management. The power plants at Eemshaven will be replaced by power plants with the same amount of emissions. In scenario 2, congestion management will lead to a lower amount of CO_2 emissions because the coal-fired power plant at Eemshaven (see figure 37) is replaced by gas-fired power plants with lower CO_2 emissions. NO_x emissions will increase in scenario 2, because the relatively old gas-fired power plants have higher NO_x emissions compared to the newest coal-fired power plants. The more extreme scenarios 3 and 4 show a higher increase in emissions due to congestion management. This is because relatively new gas-fired power plants are replaced more frequent by older, less efficient, and more polluting gas-fired power plants because of the high export and high electricity demand. The increase in CO_2 and NO_x emissions due to congestion management is small. Compared to the original emissions in the scenarios the increase is not more than 1%. Due to these small changes congestion management is not likely to be of influence in reaching the NO_x and CO_2 emissions targets of the Netherlands.

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Annex I: Production capacity Groningen, Friesland, Drenthe

Table 62: Current and future maximum production capacity of power plants in Groningen, Drenthe and Friesland (including large scale wind parks) (source: data TenneT).

Location	Producer	Year	Quarter	Name	Fuel	Maximum capacity (MW)
Akzo Emmen	EMMTEC SERVICES	2013	Q1	Emmtec 1	Gas	**26**
Akzo Emmen	EMMTEC SERVICES	2013	Q1	Emmtec 2	Gas	**26**
Akzo Emmen	EMMTEC SERVICES	2013	Q1	Emmtec 3	Other	**6**
Bergum	Electrabel/GDF SUEZ	2013	Q1	BG-10	Gas	**332**
Bergum	Electrabel/GDF SUEZ	2013	Q1	BG-20	Gas	**332**
Delfzijl	Eneco	2013	Q1	BEC Delfzijl	Biomass	**50**
Delfzijl	ESSENT ENERGY TRADING B.V.	2013	Q1	Delesto (Del1)	Gas	**454**
Eemshaven	Electrabel/GDF SUEZ	2013	Q1	Eemscentrale (EC3)	Gas	**359**
Eemshaven	Electrabel/GDF SUEZ	2013	Q1	Eemscentrale (EC4)	Gas	**359**
Eemshaven	Electrabel/GDF SUEZ	2013	Q1	Eemscentrale (EC5)	Gas	**363**
Eemshaven	Electrabel/GDF SUEZ	2013	Q1		Wind	**27**
Eemshaven	RWE/Essent	2013	Q1	Westereems	Wind	**156**
Eemshaven	Electrabel/GDF SUEZ	2013	Q1	Eemscentrale (EC6)	Gas	**359**
Eemshaven	Electrabel/GDF SUEZ	2013	Q1	Eemscentrale (EC7)	Gas	**360**
Eemshaven	Vattenfall	2013	Q3	Magnum Centrale (10)	Gas	**437**
Eemshaven	Vattenfall	2013	Q3	Magnum Centrale (20)	Gas	**437**
Eemshaven	Vattenfall	2013	Q3	Magnum Centrale (30)	Gas	**437**
Eemshaven	NorNed	2013	Q1	Cable Norway	HVDC	**700**
Erica	ESSENT ENERGY TRADING B.V.	2013	Q1	EDON ERC	Gas	**63**
Klazinaveen	ESSENT ENERGY TRADING B.V.	2013	Q1	EDON KLZ	Gas	**63**
Eemshaven	Gemini/Saturn	2013	Q1	Boven schiermonnikoog	Wind	**120**
Eemshaven	Electrabel/GDF SUEZ	2013	Q1	Eemscentrale (EC20)	Gas	**665**
Delfzijl	Kollo-Sic	2013	Q1		Other	**10**
Delfzijl		2013	Q1		Wind	**75**
Delfzijl	ESSENT ENERGY TRADING B.V.	2013	Q1	Delesto (Del2)	Gas	**350**
Wijster Gavi	Delta Energy	2013	Q1	Attero Noord B.V.	Waste	**48**
Winsum Radum	RWE wind	2013	Q1		Wind	**121**
Eemshaven	RWE	2013	Q4	RWE centrale	Coal	**1600**
Delfzijl		2014	Q1		Wind	**60**
Delfzijl	ESSENT ENERGY TRADING B.V.	2014	Q2	Delesto DE-2	CHP	**100**
Meeden	Readthuys/Exloërmond Drentse Monden	2015	Q2		Wind	**450**

Meeden	Blaaswind N33	2015	Q2		Wind	**180**
Meeden	Boerveen/Greveling Oostermoer	2015	Q2		Wind	**150**
Eemshaven	Typhoon	2015	Q2		Wind	**600**
Oudehaske	Ventolines	2016	Q4		Wind	**114**
Oudehaske	E-connection	2016	Q4		Wind	**250**
Eemshaven	Eemsmond Energie	2017	Q1	Eemsmond centrale	Gas	**1200**
Eemshaven	RWE Wind	2013	Q1	Westereems	Wind	**48**
Eemshaven	TenneT Cobra	2018	Q1	Cable Denmark	HVDC	**600**
Delfzijl	Windunie WP Reiderland	2018	Q1		Wind	**750**

Annex II: Input in scenarios in step one

Table 63: Input scenario 1

Company which owns power plant	Name power plant	Fuel	Max. Capacity (MW)	Production 2014 (MW)	Production 2015 (MW)	Production 2016 (MW)	Production 2017 (MW)	Production 2018 (MW)
Eneco	New Energy BEC	Biomass	50	50	50	50	50	**50**
Vattenfall	Magnum	Gas	1311	874	874	0	0	**0**
GDF Suez	Eemscentrale 6	Gas	359	0	0	359	359	**359**
GDF Suez	Eemscentrale 7	Gas	360	0	0	0	0	**0**
Eemsmond Energie	Eemsmond centrale	Gas	1200	0	0	0	0	**0**
GDF Suez	Eemscentrale 3	Gas	359	359	359	359	359	**359**
GDF Suez	Eemscentrale 4	Gas	359	0	0	0	0	**0**
GDF Suez	Eemscentrale 5	Gas	363	0	0	0	0	**0**
GDF Suez	Eemscentrale 20	Gas	665	0	0	0	0	**0**
Delesto	Delesto 1	Gas	180	60	60	60	60	**60**
Delesto	Delesto 2	Gas	350	0	0	0	0	**0**
Germany import	Meeden-Diele	HVAC	1645	550	550	600	600	**650**
Norway import	NorNed	HVDC	700	700	700	700	700	**700**
RWE		Hard coal	1600	1600	1600	1600	1600	**1600**
RWE	Westereems	Wind	156	156	156	156	156	**156**
GDF Suez	GDF Suez wind	Wind	27	27	27	27	27	**27**
Typhoon	Typhoon	Wind	600	0	0	300	600	**600**
Windunie	WP Reiderland	Wind	750	0	0	0	350	**750**
Readthuys/Exloërmond Drentse Monden		Wind	450	0	0	0	200	**450**
Blaaswind	Windpark N33	Wind	180	0	0	0	90	**180**
Boerveen/Greveling Oostmoer		Wind	150	0	0	0	75	**150**
Total production			11814	4376	4376	4211	5226	**6091**
	% Yearly electricity demand change		**Average peak demand 2013 (MW)**	**Demand 2014 (MW)**	**Demand 2015 (MW)**	**Demand 2016 (MW)**	**Demand 2017 (MW)**	**Demand 2018 (MW)**
Peak electricity demand Groningen/Friesland/Drenthe	1%		1147	1158	1170	1182	1194	**1206**

Table 64: Input scenario 2

Company which owns power plant	Name power plant	Fuel	Max. Capacity (MW)	Production 2014 (MW)	Production 2015 (MW)	Production 2016 (MW)	Production 2017 (MW)	Production 2018 (MW)
Eneco	New Energy BEC	Biomass	50	50	50	50	50	50
Vattenfall	Magnum	Gas	1311	1311	1311	1311	1311	1311
GDF Suez	Eemscentrale 6	Gas	359	359	359	359	359	359
GDF Suez	Eemscentrale 7	Gas	360	360	360	360	360	360
Eemsmond Energie	Eemsmond centrale	Gas	1200	0	0	0	1200	1200
GDF Suez	Eemscentrale 3	Gas	359	359	359	359	359	359
GDF Suez	Eemscentrale 4	Gas	359	359	359	359	359	359
GDF Suez	Eemscentrale 5	Gas	363	363	363	363	363	363
GDF Suez	Eemscentrale 20	Gas	665	0	0	0	0	0
Delesto	Delesto 1	Gas	180	60	60	60	60	60
Delesto	Delesto 2	Gas	350	0	0	0	0	0
Germany import	Meeden-Diele	HVAC	1645	550	550	550	550	550
Norway import	NorNed	HVDC	700	700	700	700	700	700
RWE		Hard coal	1600	0	0	0	0	0
RWE	Westereems	Wind	156	156	156	156	156	156
GDF Suez	GDF Suez wind	Wind	27	27	27	27	27	27
Typhoon	Typhoon	Wind	600	0	0	0	0	0
Windunie	WP Reiderland	Wind	750	0	0	0	0	0
Readthuys/Exloërmond Drentse Monden		Wind	450	0	0	0	0	0
Blaaswind	Windpark N33	Wind	180	0	0	0	0	0
Boerveen/Greveling Oostmoer		Wind	150	0	0	0	0	0
Total production			11814	4654	4654	4654	5854	5854
	% Yearly electricity demand change		**Average peak demand 2013 (MW)**	**Demand 2014 (MW)**	**Demand 2015 (MW)**	**Demand 2016 (MW)**	**Demand 2017 (MW)**	**Demand 2018 (MW)**
Peak electricity demand Groningen/Friesland/Drenthe	1%		1147	1158	1170	1182	1194	1206

Table 65: Input scenario 3

Company which owns power plant	Name power plant	Fuel	Max. Capacity (MW)	Production 2014 (MW)	Production 2015 (MW)	Production 2016 (MW)	Production 2017 (MW)	Production 2018 (MW)
Eneco	New Energy BEC	Biomass	50	50	50	50	50	50
Vattenfall	Magnum	Gas	1311	1311	1311	1311	1311	1311
GDF Suez	Eemscentrale 6	Gas	359	359	359	359	359	359
GDF Suez	Eemscentrale 7	Gas	360	360	360	360	360	360
Eemsmond Energie	Eemsmond centrale	Gas	1200	0	0	0	0	0
GDF Suez	Eemscentrale 3	Gas	359	359	359	359	359	359
GDF Suez	Eemscentrale 4	Gas	359	359	359	359	359	359
GDF Suez	Eemscentrale 5	Gas	363	363	363	363	363	363
GDF Suez	Eemscentrale 20	Gas	665	0	0	0	0	0
Delesto	Delesto 1	Gas	180	60	60	60	60	60
Delesto	Delesto 2	Gas	350	0	0	0	0	0
Germany import	Meeden-Diele	HVAC	1645	300	300	300	300	300
Norway import	NorNed	HVDC	700	700	700	700	700	700
RWE		Hard coal	1600	1600	1600	1600	1600	1600
RWE	Westereems	Wind	156	156	156	156	156	156
GDF Suez	GDF Suez wind	Wind	27	27	27	27	27	27
Typhoon	Typhoon	Wind	600	0	0	0	0	0
Windunie	WP Reiderland	Wind	750	0	0	0	0	0
Readthuys/Exloërmond Drentse Monden		Wind	450	0	0	0	0	0
Blaaswind	Windpark N33	Wind	180	0	0	0	0	0
Boerveen/Greveling Oostmoer		Wind	150	0	0	0	0	0
Total production			11814	6004	6004	6004	6004	6004
	% Yearly electricity demand change		**Average peak demand 2013 (MW)**	**Demand 2014 (MW)**	**Demand 2015 (MW)**	**Demand 2016 (MW)**	**Demand 2017 (MW)**	**Demand 2018 (MW)**
Peak electricity demand Groningen/Friesland/Drenthe	3%		1147	1181	1217	1253	1291	1330

Table 66: Input scenario 4

Company which owns power plant	Name power plant	Fuel	Max. Capacity (MW)	Production 2014 (MW)	Production 2015 (MW)	Production 2016 (MW)	Production 2017 (MW)	Production 2018 (MW)
Eneco	New Energy BEC	Biomass	50	50	50	50	50	50
Vattenfall	Magnum	Gas	1311	874	874	0	1311	1311
GDF Suez	Eemscentrale 6	Gas	359	359	359	359	359	359
GDF Suez	Eemscentrale 7	Gas	360	0	0	0	0	0
Eemsmond Energie	Eemsmond centrale	Gas	1200	0	0	0	0	0
GDF Suez	Eemscentrale 3	Gas	359	359	359	359	359	359
GDF Suez	Eemscentrale 4	Gas	359	0	0	0	0	0
GDF Suez	Eemscentrale 5	Gas	363	0	0	0	0	0
GDF Suez	Eemscentrale 20	Gas	665	0	0	0	0	0
Delesto	Delesto 1	Gas	180	60	60	60	60	60
Delesto	Delesto 2	Gas	350	0	0	0	0	0
Germany import	Meeden-Diele	HVAC	1645	-700	-700	-700	-700	-700
Norway import	NorNed	HVDC	700	700	700	700	700	700
RWE		Hard coal	1600	1600	1600	1600	1600	1600
RWE	Westereems	Wind	156	156	156	156	156	156
GDF Suez	GDF Suez wind	Wind	27	27	27	27	27	27
Typhoon	Typhoon	Wind	600	0	0	300	600	600
Windunie	WP Reiderland	Wind	750	0	0	0	350	750
Readthuys/Exloërmond Drentse Monden		Wind	450	0	0	0	200	450
Blaaswind	Windpark N33	Wind	180	0	0	0	90	180
Boerveen/Greveling Oostmoer		Wind	150	0	0	0	75	150
Total production			11814	3485	3485	2911	5237	6052
	% Yearly electricity demand change		**Average peak demand 2013 (MW)**	**Demand 2014 (MW)**	**Demand 2015 (MW)**	**Demand 2016 (MW)**	**Demand 2017 (MW)**	**Demand 2018 (MW)**
Peak electricity demand Groningen/Friesland/Drenthe	1%		1147	1158	1170	1182	1194	1206

Annex III: Oversight of power plants in the Netherlands

City	Unit	Plant	Company	Year	UType	Input fuel	Efficiency	KgCO2/MWhe netto	KgNOx/MWhe netto	MW installed capacity
Eemshaven	RWE kolencentrale	RWE kolencentrale	RWE ESSENT	2014	ST	COAL	46%	740	0,20	1600
Rotterdam	ROTTERDAM ELECTRABEL	ROTTERDAM ELECTRABEL	ELECTRABEL NEDERLAND	2012	ST	COAL	46%	740	0,20	716
Eemshaven	EEMS 20	EEMS	ELECTRABEL NEDERLAND	1975	ST	GAS	34%	594	0,72	665
Geertruidenberg	AMER 8	AMER	ESSENT NV	1980	ST	COAL	38%	896	0,20	645
Geertruidenberg	AMER 9	AMER	ESSENT NV	1993	ST	COAL	40%	851	0,20	640
Maasbracht	CLAUS A	CLAUS	ESSENT NV	1976	ST	GAS	34%	594	0,72	639
Amsterdam	HEMWEG 8	HEMWEG	NUON NV	1994	ST	COAL	40%	851	0,20	630
Nijmegen	GELDERLAND 13	GELDERLAND	ELECTRABEL NEDERLAND	1981	ST	COAL	38%	896	0,20	592
Amsterdam	HEMWEG 7	HEMWEG	NUON NV	1978	ST	GAS	34%	594	0,72	585
Maasvlakte	MAASVLAKTE 1	MAASVLAKTE	E.ON BENELUX	1975	ST	COAL	35%	973	0,40	555
Maasvlakte	MAASVLAKTE 2	MAASVLAKTE	E.ON BENELUX	1975	ST	COAL	35%	973	0,40	555
Maasvlakte	MAASVLAKTE 3	MAASVLAKTE	E.ON BENELUX	2014	ST	COAL	46%	740	0,20	530
Maasvlakte	MAASVLAKTE 4	MAASVLAKTE	E.ON BENELUX	2014	ST	COAL	46%	740	0,20	530
Vlissingen	BORSSELE 30	BORSSELE	NV EPZ	1973	ST	UR	NVT	0		504
Velsen-Noord	VELSEN 24	VELSEN	NUON NV	1974	ST	GAS	34%	594	0,72	459
Flushing (Vlissingen)	SLOECENTRALE CC 1	SLOECENTRALE	DELTA NV	2008	CCSS	GAS	59%	342	0,14	456
Flushing (Vlissingen)	SLOECENTRALE CC 2	SLOECENTRALE	DELTA NV	2008	CCSS	GAS	59%	342	0,14	456
Lelystad	FLEVO Maxima CC 1	FLEVO	ELECTRABEL NEDERLAND	2009	CC	GAS	59%	342	0,14	439
Lelystad	FLEVO Maxima CC 2	FLEVO	ELECTRABEL NEDERLAND	2011	CC	GAS	59%	342	0,14	438
Eemshaven	MAGNUM ICGC CC 1	MAGNUM ICGC	NUON NV	2011	CC	GAS	59%	342	0,14	437
Eemshaven	MAGNUM ICGC CC 2	MAGNUM ICGC	NUON NV	2011	CC	GAS	59%	342	0,14	437
Eemshaven	MAGNUM ICGC CC 3	MAGNUM ICGC	NUON NV	2011	CC	GAS	59%	342	0,14	437
Europoort	ENECOGEN	ENECO CC	ENECO HOLDING NV/DONG Energie	2009	CC	GAS	59%	342	0,14	435
Diemen	DIEMEN 34 SC 1	DIEMEN	NUON NV	1995	ST/C	GAS	48%	421	0,25	435
Amsterdam	HEMWEG 9	HEMWEG	NUON NV	2012	CC	GAS	59%	342	0,14	432
Vlissingen	BORSSELE 12	BORSSELE	NV EPZ	1987	ST	COAL	38%	896	0,20	408
Velsen-Noord	VELSEN 25	VELSEN	NUON NV	1986	ST/S	GAS	40%	505	0,26	375
Eemshaven	EEMS EC 5	EEMS	ELECTRABEL NEDERLAND	1996	CCSS	GAS	48%	421	0,25	363
Eemshaven	EEMS EC 7	EEMS	ELECTRABEL NEDERLAND	1996	CCSS	GAS	48%	421	0,25	360
Eemshaven	EEMS EC 3	EEMS	ELECTRABEL NEDERLAND	1996	CCSS	GAS	48%	421	0,25	359
Eemshaven	EEMS EC 4	EEMS	ELECTRABEL NEDERLAND	1996	CCSS	GAS	48%	421	0,25	359
Eemshaven	EEMS EC 6	EEMS	ELECTRABEL NEDERLAND	1996	CCSS	GAS	48%	421	0,25	359
Bergum	BERGUM 10	BERGUM	ELECTRABEL NEDERLAND	1974	GT/T	GAS	34%	594	0,72	332
Bergum	BERGUM 20	BERGUM	ELECTRABEL NEDERLAND	1975	ST	GAS	34%	594	0,72	332
Maasbracht	CLAUS C1	CLAUS	ESSENT NV	2012		GAS	59%	342	0,14	310
Maasbracht	CLAUS C4	CLAUS	ESSENT NV	2012		GAS	59%	342	0,14	310
Maasbracht	CLAUS C2	CLAUS	ESSENT NV	2012		GAS	59%	342	0,14	310
Maasbracht	CLAUS C3	CLAUS	ESSENT NV	2012		GAS	59%	342	0,14	310

Diemen	DIEMEN 33 GT 1	DIEMEN	NUON NV	1995	GT/C	GAS	48%	421	0,25	266
Utrecht	LAGE WEIDE 6 GT 1	LAGE WEIDE	NUON NV	1995	GT/C	GAS	48%	421	0,25	266
Pernis (Rotterdam)	RIJNMOND ENERGIE-1 GT 1	RIJNMOND ENERGIE	INTERGEN (UK) LTD	2004	GT/C	GAS	59%	342	0,14	260
Pernis (Rotterdam)	RIJNMOND ENERGIE-1 GT 2	RIJNMOND ENERGIE	INTERGEN (UK) LTD	2004	GT/C	GAS	59%	342	0,14	260
Pernis (Rotterdam)	RIJNMOND ENERGIE-1 SC 1	RIJNMOND ENERGIE	INTERGEN (UK) LTD	2004	ST/C	GAS	59%	342	0,14	260
Utrecht	MERWEDEKANAAL 12	MERWEDEKANAAL	NUON NV	1989	GT/C	GAS	40%	505	0,26	225
Moerdijk	MOERDIJK AZN SC 1	MOERDIJK AZN	ESSENT NV	1997	ST/C	GAS	48%	421	0,25	180
Hoek	ELSTA GT 1	ELSTA	AES ELSTA BV	1998	GT/C	GAS	48%	421	0,25	160
Hoek	ELSTA GT 2	ELSTA	AES ELSTA BV	1998	GT/C	GAS	48%	421	0,25	160
Hoek	ELSTA GT 3	ELSTA	AES ELSTA BV	1998	GT/C	GAS	48%	421	0,25	160
Geleen	SWENTIBOLD GT 1	SWENTIBOLD	ESSENT NV	1999	GT/C	GAS	48%	421	0,25	156
Velsen	IJMUIDEN UNA GT 1	IJMUIDEN UNA	NUON NV	1997	CCSS	GAS	48%	421	0,25	144
Amsterdam	HEMWEG 7 GT 1	HEMWEG	NUON NV	1988	GT/T	GAS	40%	505	0,26	135
Eemshaven	EEMS 20 GT 1	EEMS	ELECTRABEL NEDERLAND	1988	GT/T	GAS	40%	505	0,26	131
Lelystad	FLEVO 32	FLEVO	ELECTRABEL NEDERLAND	1974	GT	GAS	34%	594	0,72	119
Rotterdam	ROCA (ROTTERDAM)-3 CC GT 1	ROCA (ROTTERDAM)	E.ON BENELUX	1995	GT/C	GAS	48%	421	0,25	116
Rotterdam	ROCA (ROTTERDAM)-3 CC SC 1	ROCA (ROTTERDAM)	E.ON BENELUX	1996	ST/C	GAS	48%	421	0,25	104
Utrecht	MERWEDEKANAAL 11	MERWEDEKANAAL	NUON NV	1984	ST/C	GAS	40%	505	0,26	103
Hoek	ELSTA SC 1	ELSTA	AES ELSTA BV	1998	ST/C	GAS	48%	421	0,25	100
Utrecht	MERWEDEKANAAL 10	MERWEDEKANAAL	NUON NV	1979	ST/C	GAS	34%	594	0,72	96
Geleen	SWENTIBOLD SC 1	SWENTIBOLD	ESSENT NV	1999	ST/C	GAS	48%	421	0,25	90
Zwolle	HARCULO 60 GT 1	HARCULO	ELECTRABEL NEDERLAND	1982	GT/T	GAS	40%	505	0,26	85
Zwolle	HARCULO 6O	HARCULO	ELECTRABEL NEDERLAND	1982	ST	GAS	40%	505	0,26	80
Rotterdam	GALILEISTRAAT SC 1	GALILEISTRAAT	E.ON BENELUX	1986	ST	GAS	40%	505	0,26	79
Geertruidenberg	DONGE GT 1	DONGE	ESSENT NV	1975	GT/C	GAS	34%	594	0,72	76
Maasvlakte	MAASVLAKTE BAYER GT 1	MAASVLAKTE BAYER	E.ON BENELUX	2003	GT/C	GAS	59%	342	0,14	70
Almere (FL)	WKC ALMERE CC 1	WKC ALMERE	NUON NV	1988	CCSS	GAS	40%	505	0,26	70
Moerdijk	MOERDIJK AZN GT 1	MOERDIJK AZN	ESSENT NV	1995	GT/C	GAS	48%	421	0,25	59
Moerdijk	MOERDIJK AZN GT 2	MOERDIJK AZN	ESSENT NV	1995	GT/C	GAS	48%	421	0,25	59
Moerdijk	MOERDIJK AZN GT 3	MOERDIJK AZN	ESSENT NV	1995	GT/C	GAS	48%	421	0,25	59
Almere (FL)	WKC ALMERE CC 2	WKC ALMERE	NUON NV	1993	CCSS	GAS	48%	421	0,25	55
Rotterdam	GALILEISTRAAT GT 1	GALILEISTRAAT	E.ON BENELUX	1988	GT/C	GAS	40%	505	0,26	49
Rotterdam	GALILEISTRAAT GT 2	GALILEISTRAAT	E.ON BENELUX	1988	GT/C	GAS	40%	505	0,26	49
Rotterdam	GALILEISTRAAT GT 3	GALILEISTRAAT	E.ON BENELUX	1988	GT/C	GAS	40%	505	0,26	49
Delfzijl	BEC Delfzijl	Bec Delfzijl	ENECO HOLDING NV	2012	ST	WOOD	25%	104		49
Purmerend	PURMEREND GT 1	PURMEREND	NUON NV	1988	GT/C	GAS	40%	505	0,26	46
Botlek	WKC AIR PRODUCTS GT 1	WKC AIR PRODUCTS	ELECTRABEL NEDERLAND	2002	GT/S	GAS	59%	342	0,14	43
Geertruidenberg	DONGE SC 2	DONGE	ESSENT NV	1976	ST/C	GAS	34%	594	0,72	42
Eindhoven	EINDHOVEN PHILLIPS GT 1	EINDHOVEN PHILLIPS	ESSENT NV	1995	GT/S	GAS	48%	421	0,25	42
Leiden	LEIDEN GT 1A	LEIDEN	E.ON BENELUX	2005	GT/C	GAS	59%	342	0,14	40
Leiden	LEIDEN GT 2A	LEIDEN	E.ON BENELUX	2005	GT/C	GAS	59%	342	0,14	40
Rozenburg (Rotterdam)	ROZENBURG EUROGEN GT 1	ROZENBURG EUROGEN	EUROGEN CV	1994	GT/S	GAS	48%	421	0,25	38
Rozenburg (Rotterdam)	ROZENBURG EUROGEN GT 2	ROZENBURG EUROGEN	EUROGEN CV	1994	GT/S	GAS	48%	421	0,25	38
Rozenburg (Rotterdam)	ROZENBURG EUROGEN GT 3	ROZENBURG EUROGEN	EUROGEN CV	1994	GT/S	GAS	48%	421	0,25	38
's-Hertogenbosch	DEN BOSCH HEINEKEN CC 1	DEN BOSCH HEINEKEN	ESSENT NV	1994	CCSS	GAS	48%	421	0,25	34

Den Haag	DEN HAAG-1 SC 1	DEN HAAG	E.ON BENELUX	1982	ST/C	GAS	40%	505	0,26	33
Erika	ERIKA GT 2	ERIKA	GASEDON EMMEN VOF	1995	GT/C	GAS	48%	421	0,25	31
Klazinaveen	KLAZINAVEEN GASEDON GT 1	KLAZINAVEEN GASEDON	GASEDON EMMEN VOF	1995	GT/C	GAS	48%	421	0,25	31
Klazinaveen	KLAZINAVEEN GASEDON GT 2	KLAZINAVEEN GASEDON	GASEDON EMMEN VOF	1995	GT/C	GAS	48%	421	0,25	31
Geertruidenberg	GEERTRUYDENBURG	GEERTRUYDENBURG	ESSENT NV	2000	ST/S	WOOD	25%	104		29
Borculo	BERKELCENTRALE-2 GT 1	BERKELCENTRALE	MORGAN STANLEY NETHERLANDS	1995	GT/C	GAS	48%	421	0,25	29
Borculo	BERKELCENTRALE-2 GT 2	BERKELCENTRALE	MORGAN STANLEY NETHERLANDS	1995	GT/C	GAS	48%	421	0,25	29
Den Haag	DEN HAAG-1 GT 1	DEN HAAG	E.ON BENELUX	1982	GT	GAS	40%	505	0,26	28
Den Haag	DEN HAAG-1 GT 2	DEN HAAG	E.ON BENELUX	1982	GT	GAS	40%	505	0,26	28
Rotterdam	ROCA (ROTTERDAM)-1 GT 1	ROCA (ROTTERDAM)	E.ON BENELUX	1982	GT/S	GAS	40%	505	0,26	26
Rotterdam	ROCA (ROTTERDAM)-1 GT 2	ROCA (ROTTERDAM)	E.ON BENELUX	1982	GT/S	GAS	40%	505	0,26	26
Erika	ERIKA GT 1	ERIKA	GASEDON EMMEN VOF	1995	GT/C	GAS	48%	421	0,25	25
Cuijk	CUIJK BIOMASS 1	CUIJK BIOMASS	ESSENT NV	1999	ST	WOOD	25%	104		25
Helmond	HELMOND PROMEST VKC GT 1	HELMOND PROMEST VKC	ESSENT NV	1994	GT/C	GAS	48%	421	0,25	24
Bergen Op Zoom	BERGEN OP ZOOM PNEM GT 1	BERGEN OP ZOOM PNEM	ESSENT NV	1995	GT/S	GAS	48%	421	0,25	24
Delft	DELFT GT 1	DELFT	E.ON BENELUX	1973	GT	GAS	34%	594	0,72	24
Velsen-Noord	VELSEN GT 1	VELSEN	NUON NV	1975	GT	GAS	34%	594	0,72	24
Delft	DELFT GT 2	DELFT	E.ON BENELUX	1973	GT	GAS	34%	594	0,72	23
Delft	DELFT GT 3	DELFT	E.ON BENELUX	1973	GT	GAS	34%	594	0,72	23
Delft	DELFT GT 4	DELFT	E.ON BENELUX	1973	GT	GAS	34%	594	0,72	23
Helmond	HELMOND II GT 1	HELMOND	ESSENT NV	1999	GT	GAS	48%	421	0,25	22
Enschede	ENSCHEDE A	ENSCHEDE	ESSENT NV	1985	GT/C	GAS	40%	505	0,26	21
Enschede	ENSCHEDE B	ENSCHEDE	ESSENT NV	1985	GT/C	GAS	40%	505	0,26	21
Purmerend	PURMEREND SC 1	PURMEREND	NUON NV	1989	ST/C	GAS	40%	505	0,26	21
Helmond	HELMOND I GT 1	HELMOND	ESSENT NV	1982	GT/C	GAS	40%	505	0,26	21
Petten	PETTEN ECN GT 1	PETTEN ECN	ENERGIE CENT NEDERLAND (ECN)	1995	GT	BGAS	48%	421	0,25	20
Enschede	ENSCHEDE C	ENSCHEDE	ESSENT NV	1985	ST/C	GAS	40%	505	0,26	20
Vlissingen	BORSSELE 20	BORSSELE	NV EPZ	1972	GT	GAS	34%	594	0,72	18
Erika	ERIKA SC 1	ERIKA	GASEDON EMMEN VOF	1996	ST/C	GAS	48%	421	0,25	17
Borculo	BERKELCENTRALE-2 SC 1	BERKELCENTRALE	MORGAN STANLEY NETHERLANDS	1995	ST/C	GAS	48%	421	0,25	14
Maasvlakte	MAASVLAKTE BAYER SC 2	MAASVLAKTE BAYER	E.ON BENELUX	2003	ST/C	GAS	59%	342	0,14	10
Helmond	HELMOND PROMEST VKC SC 1	HELMOND PROMEST VKC	ESSENT NV	1994	ST/C	GAS	48%	421	0,25	10
Bergen Op Zoom	BERGEN OP ZOOM PNEM SC 1	BERGEN OP ZOOM PNEM	ESSENT NV	1995	ST/C	GAS	48%	421	0,25	10
Klazinaveen	KLAZINAVEEN GASEDON SC 1	KLAZINAVEEN GASEDON	GASEDON EMMEN VOF	1996	ST/C	GAS	48%	421	0,25	10
Gouda	GOUDA UNICHEMA GT 1	GOUDA UNICHEMA	E.ON BENELUX	1997	GT/S	GAS	48%	421	0,25	7
Almere (FL)	ALMERE POORT	ALMERE POORT	NUON NV	2007	ST	WOOD	25%	104		5
Coldenhove	EERBEEK COLDENHOVE GT 1	EERBEEK COLDENHOVE	NUON NV	1994	GT/S	GAS	48%	421	0,25	5
Heusden	HEUSDEN JONKER FRIS GT 1	HEUSDEN JONKER FRIS	ESSENT NV	1993	GT/H	GAS	48%	421	0,25	4
Helmond	HELMOND I SC 1	HELMOND	ESSENT NV	1984	ST/C	GAS	40%	505	0,26	4
Helmond	HELMOND II SC 1	HELMOND	ESSENT NV	1988	ST	GAS	40%	505	0,26	4
Texel Island	TEXEL II IC 2	TEXEL II	ELECTRABEL NEDERLAND	1986	IC/H	OIL	35%	762	2,05	2
Texel Island	TEXEL II IC 3	TEXEL II	ELECTRABEL NEDERLAND	1986	IC/H	OIL	35%	762	2,05	2
Texel Island	TEXEL II IC 1	TEXEL II	ELECTRABEL NEDERLAND	1986	IC/H	OIL	35%	762	2,05	2