Demand Response to Alleviate National Congestion in the Dutch Power System: Evaluation under Future Wind Scenarios

R.H. Plink
Delft University of Technology
Delft, the Netherlands
r.h.plink@student.tudelft.nl

Abstract— **The increase of electricity generation by Renewable Energy Sources is desired in the next decade to achieve the European 2020 targets. Wind is considered to have the largest potential in achieving these targets. Taking into account the development of wind parks in the North Sea congestion is expected to increase in the Dutch electricity grid. This paper investigates the value of the application of Demand Response to alleviate national grid congestion. A model is used to simulate network flows based on the 2020 generation portfolio. In terms of model outcome three values are introduced the expected congestion, the market share and DR potential of different sectors compared to the congestion, and the social cost of congestion. The simulation illustrated that congestion occurred around the North-Holland area. When considering the Dutch electricity sector, the application of Demand Response to the alleviate congestion, presents significant value for the Transmission System Operator, electricity suppliers and end users. The paper concludes with recommendations for the design of a potential Demand Response program for congestion.**

Keywords—component; Congestion management, aggregation, Demand Response, network modelling, Dutch electricity grid

I. INTRODUCTION

The electricity sectors in Europe are undergoing several fundamental transitions towards a more sustainable system. One of the transitions is the implementation of smart grids and advanced metering. This transitions towards "smarter" electricity grid enable more detailed information into electricity consumption. With the introduction of smart metering active participation of consumers in the electricity market becomes an option [1]. Active participation or Demand Response indicates increased or decreased load of end-users in reaction to an event or price signal, to regulate the balance of the electricity grid. In particular industry and the commercial sector are considered interesting in applying this concept, because of the use of energy intensive electric devices (cooling device, pumps, process machinery, etc.) and the high consumption level [2].

Alongside the evolution to smarter electricity infrastructure the need for Renewable Energy Sources (RES) becomes more important. In Europe, targets are set to fight against climate change. The EU is committed to reducing its overall greenhouse gas emissions by at least 20% below 1990 levels by 2020 [3]. Additionally the EU proposed a 20 % target for the overall share of energy from renewable sources by 2020[4]. Despite the fact that RES are widely available, they are unevenly and insufficiently utilized in Europe Union. Their contribution is only around 8% of the EU overall national energy consumption [5]. Of all RES, wind energy production accounted for the largest share of electricity production. At European-27 level wind generation obtained the larges market share followed by solar and biomass [5]. In 2012 the share of wind capacity in Europe increased by 10.5% of the total installed power generation capacity. At the moment Germany has the largest wind portfolio 29,060 MW from all EU member states [6].

In the Netherlands, the development of wind projects has stagnated over the years. In 2011, capacity 2316 of which 2088 MW onshore and 228 MW offshore [7][8]. Although, the climate targets of the Netherlands aim to meet the EU 2020 objectives with 20% of the electricity generated through RES technologies. In terms of this target the government planned to increase the installed capacity of wind power in the North Sea from the current 228 MW to 6000 MW [9]. Therefore, offshore wind capacity is expected to grow significantly in the coming years.

Wind generation is characterized by high capital investment and low operational costs [10]. Therefore the technology is located in the beginning of the merit order and should be dispatched first in the compared to thermal generation units. Increased electricity production in the North Sea a change in electricity could be the result. Especially in periods with high wind generation, these changed electricity flows could cause congestion.

This paper investigates the value of the application of Demand Response to alleviate congestion due to physical network constraints. A model is utilized in order to simulate network flows based on the 2020 generation portfolio. This paper is structured as follows. The first section describes the concept of Demand Response. In the second section, a definition of congestion is presented an introduction to congestion is provided and the method used to prevent congestion in the Netherlands. In section 4 the simulation model used is described. This section presents the goal and objective, followed by the performance indicators and the outcome of the model. In section 5 recommendations are presented for a potential DR program to alleviate congestion. Finally, conclusions and recommendation for further research are presented.

II. DEMAND RESPONSE

Through the technology innovation and new market mechanisms, active participation of consumers through DR is more realistic. End-users can be triggered to participate in DR programs through incentive-based and price-based programs. For this article market based programs are considered. Market based programs are based on a fixed compensation to participants when changing their load based on an events announced by the program supplier. In incentive-based programs the program provider is responsible for the decision-making process. Demand Response presents the possibility of end-users to increase or decrease their individual load curve in response to an event or price Demand Response is defined as *"…. the changes in electric usage by end-users from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized"* [11]. The potential of DR is defined by the electricity consumption of end-users and devices used. Especially, smaller loads direct participation in to capacity is not always interesting. Aggregators reduce this barrier by offering incentive- and price-based programs. The difference in these programs is explained in section A. Followed by the concept of aggregated DR in section B, and the benefits of DR in section C.

A. Demand Response Programs

In incentive-based programs compensations is granted for the curtailment of load as a bill credit or discount rate to the electricity bill [12]. The signal for curtailment originates from a third party who is responsible for the decision-making process. This third-party could represent Transmission System Operator, an electricity supplier, or an individual program utility. In this type of programs signals are usually triggered by an event where transportation capacity in the grid becomes scarce e.g. congestion, extreme peak periods, or system malfunction. Next to the incentive-based mechanism there is the price-based mechanism. The biggest difference between the two is that instead of the program owner, participant is involved in the decision-making process. In these programs a participant voluntary chooses to change demand depending on the electricity price. The priced-based mechanism, also referred to as dynamic pricing, uses retail rates for electricity that reflect short-term changes in wholesale electricity costs. This stimulates end-users to reconsider their electricity use and to consume electricity on a more cost-efficient way.

B. Aggregated Demand Respsonse

For direct participation in the capacity market for DR, significant volumes are required. This makes the participation for smaller end-users less interesting. To remove this barrier aggregators have emerged. Aggregators are parties contracting multiple loads of end-users. These loads are combined to larger capacity block tradable on the electricity market. This enables participates with smaller loads to enter the market through incentive-based programs. Program suppliers, or aggregators are able to remotely adjust the load of participants from a centralized control room. This is referred to as Direct Load Control (DLC). With DLC utility or system operator remotely shuts down or cycles end-users electrical equipment on short notice [12].

A concept that is related to the application of DLC is the Virtual Power plant. In a VPP the operation of supply and demand-side resources are integrated to meet customer demand for energy services. To balance short-term load fluctuations, the use of several elements is incorporated including, information technology, advanced metering, automated control capabilities, and electricity storage [13]. The Aggregation of Demand Response is an application that can be included in the portfolio of the VPP.

C. Benefits of Demand Response

Participation in Demand Response programs incorporates a number of benefits expressed in three perspectives:

- E*conomic/market:* With DR it's possible to introduce the "real-time" value of electricity. This indicates that the correlation between electricity price and the value consumers place on electricity is brought forward [11]. Moreover, participants of DR programs receive compensation for increasing or decreasing their load in addition to an overall decrease in wholesale electricity price because of reduced demand.
- *Network:* operational security increase security resulting because of DR, decreases the likelihood and consequences of forced outages that force financial costs and inconvenience on customers [11]
- *Environmental:* carbon emission is decreased through better utilization of fuels, indirectly improving the quality of the environment [12].

One of the benefits that will be discussed further in this paper is the application of DR programs to solve congestion in the grid to increase network reliability. This problem is introduced in the next section.

III. CONGESTION IN ELECTRICITY GRIDS

Electricity grids are fundamental for delivering electricity from produces to suppliers. However, not all flows resulting from commercial transactions can be allowed. Due to physical constraints many of these transitions result in flows that exceed the maximum value that a system operator considers to be secure [14]. When such an event is expected to occur this is identified as congestion. In existing literature congestion in a competitive electricity market congestion is defined as when the production and consumption of electric energy is desired to be produced and consumed in amounts that would cause the transmission system to operate at or beyond one or more transfer limits [15], [16]. In order to anticipate such events, two congestion management tools are utilized to maintain stability in the electricity grid. Through these tools arising of congestion events is avoided. Congestion can be managed technically through adjustments of network topology or network characteristics e.g. grid extension or through a market-mechanism [10]. In terms of market-mechanism there are a number of alternatives available. These alternatives are not discussed in this paper. The mechanism that is discussed is the re-dispatch. This is the mechanism that is currently used in the Netherlands. The next section explains how this system works.

A. Congestion management through Redispatch

Re-dispatching relieves congestion by curtailing and increasing generation capacity. Based on the supply and demand schedule bids submitted by the market participants, the market is cleared while ignoring physical constraints on the transmission grid. As a result the price for electricity is defined by the traded amount of electricity. If these transitions result in line flows that exceed the maximum value of security, the TSO selects the most economic bids for increasing and decreasing capacity. The costs encountered by the price difference of the high and low power electricity are ascribed to the TSO. These costs create an incentive for the TSO to invest and facilitate enough transportation capacity to supply electricity to all end-users. The concept of re-dispatch is illustrated bellow in .

To illustrate how re-dispatching work, Figure 1 presents two areas that are connected through a single power line. Here S_A/D_A and S_B/D_A represent respectively the aggregated production/demand in point A and B. The equilibrium where demand and supply intersect, result in the price (P_A and P_B). The parameter K defines the capacity of the connection line between the two areas. In this figure there is not enough capacity available to transport the required electricity from A to B. To maintain system boundaries, the quantity of produced electricity should be decreased from Q_A to Q_A". This results in a downscaling production from Q_A' to Q_A" (purple line). The same is done in area B, where a shortage of electricity is allocated. Here the production is increased from Q_B' to Q_B". This adjusted allocation of sources avoids congestion. The following section explains how DR can be used in this mechanism.

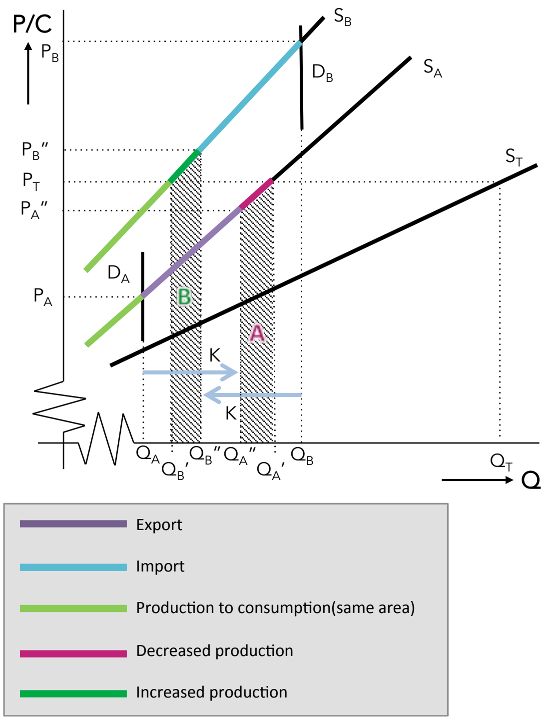

Fig. 1. Illustration Re-dispatch [17]

B. Historic congestion

Redispatch as a congestion mechanism has only been used in the Netherlands since May 2011. Since then a number of congestion issues occurred. In this period all of the congestion cases where located at the Maasvlakte. Figure 2 shows an overview of the amount of congestion on this connection in the period from May 2011 till March 2013 during which time a total of 304 hours of congestion occurred.

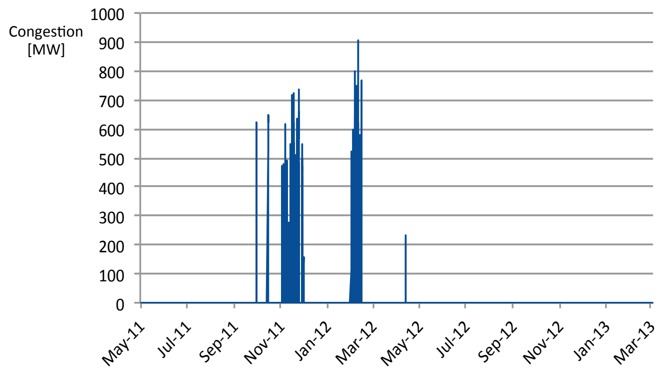

Fig. 2. History congestion in the Netherlands [18].

C. Demand Response for the alleviation of congestion

Traditionally congestion is alleviated through up and downscaling generation capacity. However, with the introduction of active customer participation in the power market, regulation with end-user capacity could also be considered an option. Technically there are three combinations possible next to the up and downscaling of generation.

- *Decreasing demand*, instead of increasing the generation capacity in a non-congested area the level of demand is decreased. This decreases the need for electricity from the congested area, and less electricity transport is needed between the two areas.
- *Increasing demand*, instead of decreasing generation in a congested area the demand is increased. This increases the consumption of electricity in the congested area, which leads to a reduction of export to other areas. To maintain balance production is increased in another area.
- *Increasing and decreasing demand,* is considered a combination of the first two options. In this option demand is decreased in the non-congested area and increased in the congested area, in turn leading to less transport between the two areas.

The replaceability of generation by capacity through Demand Response, indicates that they are direct competitors in these markets. When the costs for demand are compared to the costs generation capacity, it is noted that these costs are not directly defined by the costs of electricity production, but the price at which DR clients are willing to participate. Meaning that program providers can establish the price under the assumption that sufficient clients participate at this price. To explore the value of DR for congestion a model is constructed to simulate the magnitude of congestion in the Dutch power system and to see how much DR can contribute to alleviate this congestion. This simulation mode is explained in the following section.

IV. Congestion in the Dutch Power System

In this section a description of the simulation model is presented and the modeling outcomes are presented. It starts with the goal, followed by the model structure, performance indicators, and scenarios. Finally the results are presented.

A. Goal

The goal of the model is to simulate the electricity flows between nodes caused by increased wind production in the Norht Sea. These flows are based on the market mechanism of supply and demand. It is assumed that the generation units are traded in an integrated power pool where supply meets demand. Based on the allocation of resources electricity flows are defined. The line is defined as congested when the transmission capacity is exceeded.

B. Model structure

The model is structured taking into account a 5-node network. The areas defined are Zeeland (ZL), South Holland (SH), North Holland (NH), North of Netherlands (NN), and the ring structure (RG). Additionally 4 wind development areas are identified [19], each connected to one of the nodes. An overview of the structure of the network is illustrated in figure 2. The model simulates the outcome for 1 year with a time step of 1 hour. The start date of the simulation model is on 1st January 2020. To reduce complexity of the system the model has included the following assumptions in the simulation process:

1. In the simulation the complexity is reduced to a 5-node network. As a result, it became impossible to identify potential congestion within the defined areas. This is a characteristic that I think could have an effect on the outcome of the simulation. In this respect, the model is not applicable for detailed simulation of transmission flows within the grid.
2. The wind production on/offshore is calculated depending on the average wind speed throughout the year. This excludes the fluctuate behavior inherent to wind generation from the simulation study. This type of behavior is irrelevant because the simulation has an explorative character.
3. Only limited data is available on the demand per hour for different locations in the grid. Therefore the demand per node is calculated through a distribution per node based on a peak load, combined with the monthly demand curve. This shows the consumption of electricity on distribution level, with fluctuation over the year. The result of this assumptions is that simulation model does not show different load curves for different days.
4. The total generation needed is calculated through an integrated market model. The model determines the needed generation capacity based on the total demand in the grid. Based on the merit order of generation capacity the generation per node is calculated. The limitation in this context defined by the modeling technique is the inability to specify different merit orders during a simulation run. Meaning that the malfunctioning or operation and maintenance of generation units.
5. In the simulation each generation units is defined as an individual unit. The Marginal Cost Price (MCP) of a unit defines the position within the merit order. The merit order. In the simulation three elements taken into account; fuel costs, operating costs, and costs for CO_2 emission right

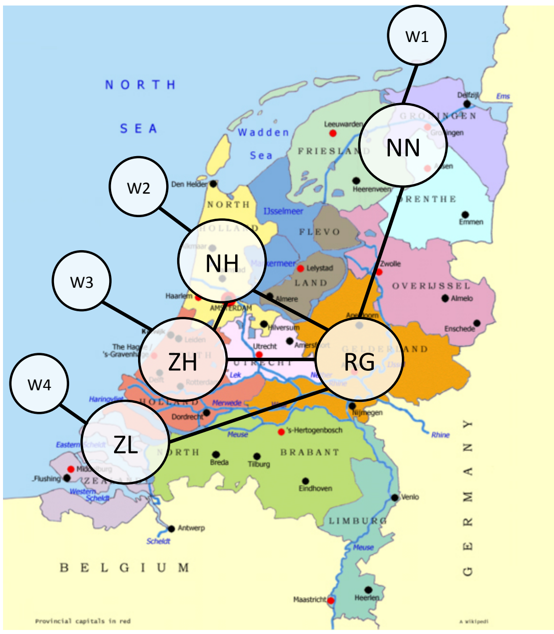

Fig. 3. Simplified representation transmission grid

C. Performance indicators

To measure the outcome of the model a set of performance indicators is defined. The ones considered most relevant for this article are presented bellow. In formulating indicators a distinction has been made between technical and economical characteristic to determine the performance of the model. Technical performance indicators are separated into four dimensions, frequency, total amount, magnitude and sensitivity of an area. The economic performance indicators are used to define the costs and benefits relevant to the management of congestion. This is used as the basis when determine the value of demand Response. The performance indicators are explained individually in table I.

In the simulation outcome a distinction in made between theoretic and realistic value of congestion. The difference between the two approaches how the costs are determined. In the theoretic approach it is assumed that bid into the congestion management mechanism are based on the ideas of perfect competition. This means that capacity bids are based on the Marginal Cost Price (MCP) of congestion. In reality bids differ significantly from the market price and MCP [18].

TABLE I. PERFORMANCE INDICATORS

Performance Indicator	***Description***
Frequency of congestion	The model is developed to simulate the transportation flows of 8760 hours. To create insight in the frequency of congestion, the number of hours of congestion is measured.
Total amount of congestion	Beside the frequency the magnitude of each event is relevant to determine the costs and create insight in the extent of potential alleviation measures. The amount is illustrated in total MW of congestion per year.
Magnitude of congestion	To show the level of congestion during different events a graph is presented showing the number of events by their magnitude clustered in ranges from 100 MW.
Sensitivity of the congested area	To identify if congestion persist in certain areas the sensitivity of congestion is determined. In this analysis the lines within the different scenarios are compared. Sensitivity is measured by looking at the frequency of congestion under different scenarios.
Total costs for up scaling	The total cost for up scaling generation define the market for downscaling demand. In other words, it measures the total potential costs for the TSO resulting from in creasing production in non-congested areas.
Total costs for down scaling	The total cost for downscaling generation define the market for up scaling congestion. In other words, it measures the total potential revue for the TSO resulting from decreasing production in congested areas.
Total costs of congestion	The total costs for congestion are calculated by the difference between the revenues from downscaling Social costs are calculated through the difference in revenue from generation capacity and the costs for up scaling generation capacity. These costs, which are barred by TenneT, and are considered being the social costs of congestion.

D. Scenarios

To simulate how the model behaves under the influence of different circumstances a scenario analysis is executed. In this simulation study an iterative approach is used the show this behavior. The two scenarios simulated during this study take into account two allocation of wind capacity in the North Sea. The allocation under the different scenarios is presented in Table II.

TABLE II. DISTRIBUTION OF WIND FOR SCENARIOS

Coastal area	**Scenario A**		***Scenario B***	
	Percentage *[%]*	Capacity *[MW]*	Percentage *[%]*	Capacity *[MW]*
W1: Borssele	25 %	711	0 %	0
W2: The Hague	15 %	426	20 %	568
W3: Ijmuiden	35 %	994	50 %	1420
W4: Eemshaven	25 %	710	30 %	852

E. Outcome model and value

In terms of model outcome three values are illustrated the expected congestion, the market share of different sectors compared to the congestion, and the social cost of congestion.

1) Expected congestion

In the simulation study two main scenarios explained in the previous chapter were tested each resulting into congestion. The result of these simulations illustrated congestion occurring in the North Holland Area. Scenario B simulated the highest level of congestion. In figure 3 the level of congestion per hour in this scenario is illustrated. From this graph can be derived that the maximum level of congestion would be around 800 MW. Collectively scenario B resulted in 275.848 MW of congestion arose in the NH area during 1159 hours per year. In contrast, 30.839 MW during 239 hours was identified in the other scenario. Comparing this to historical data showed that the location of congested is changed and more frequently congestion will occur [20].

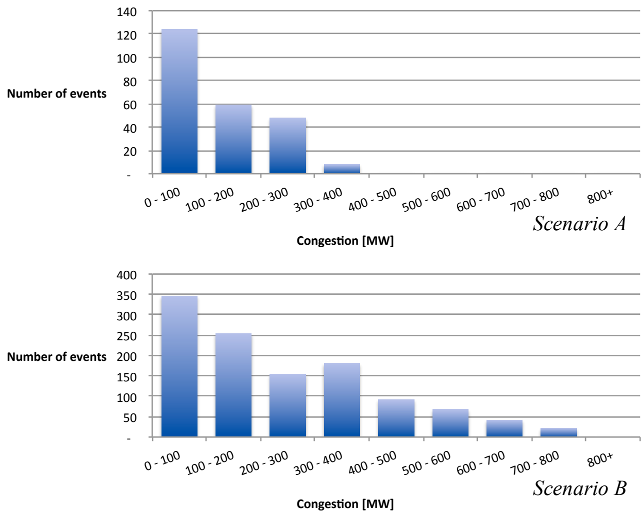

Fig. 4. Congestion in the North Holland area, scenario A and B [20]

Based on level of congestion the market value it determined. In this context the market for up-scaling generation capacity (decrease demand), and the market for downscaling generation capacity (increasing demand) are identified. In wind scenario A the total value of these markets resulted in 1,7-2 and 0,4-1,4-million euro per year, for respectively decreasing and increasing demand. In wind scenario B the level of congestion was significantly higher. Therefore, the value in both market increased with a factor 8-9 compared to scenario A [20].

2) Potential of Demand Response

In the Netherlands the total electricity consumption in 2011 was 117.330 GWh. figure 4 shows the history of the total electricity consumption during the last decade. From this figure can be derived that industry, commercial[2] and residential sectors consume most of the electricity. These shares are respectively 31%, 37%, and 20% [21]. If we would assume that 5% of the hourly load could be used for Demand Response, this would lead to an average of respectively 207, 242, and 133 MW of curtailable load in each sector. This would lead to a total of 582 MW that can be used to alleviate congestion, compared to the 800 MW of congestion in the worst-case scenario [20].

It has to be noted that in this calculation the exact level of the potential of DR is difficult to predict. This depends on the application of devices that are compatible with DR controlling devices. Examples proven to work with DR technology are pumps, HV/AC equipment, cooling towers, air handling units, process machinery, and onsite generators [22]. In addition, these estimates are based on the average consumption of each sector. Taking into consideration that the most congestion would occur during peak hours, these estimations could increase significantly.

In reality including all electricity users in a DR program is considered difficult to achieve, especially in the first phase of DR utilization. Therefore, an additional analysis is conducted taking into account a limited availability of DR capacity. As example, it is assumed that 1 percent of the total pool of electricity users participates. This indicates that 6 MW of capacity is available for participation in the congestion market each hour. In case of the increased wind scenario A, a total value of 71-54 thousand euro per year is gained in the market for congestion for downscaling demand. This shows, that with a small DR portfolio a considerably large share of the value (approximately 6 %) can be utilized [20].

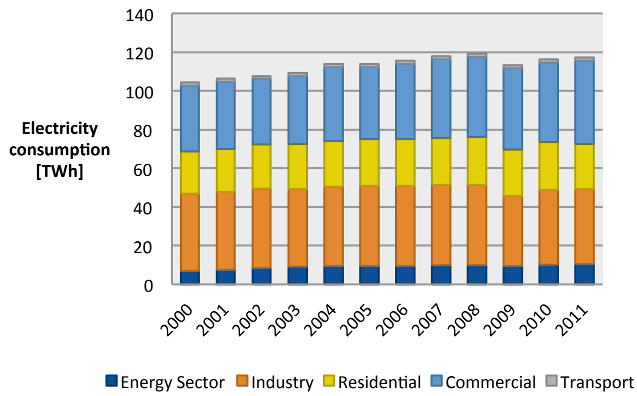

Fig. 5. Electricity consumption per sector [21]

3) Social costs of congestion

The social costs of congestion illustrate the trade-off between congestion management through technical adjustments or through a market mechanism. If the costs for congestion management are significantly lower compared to the costs of grid extension, the TSO will decide to solve congestion through the Congestion Management mechanism. In this comparison the cost for grid extension are estimated at 100 million euro [23]. It is assumed that when the costs for congestion over a time period of 10 years are higher than the costs for grid extension, TenneT will choose to investment in grid extension. These costs for TenneT are shown in Table III.

[2] Commercial sector represents small medium enterprises and small industries

When considering the realistic value it can be stated that in wind scenario A, the costs of congestion do not exceed the costs for grid extension. If this scenario would occur, TenneT would choose not to invest in grid expansion while in scenario B, where the costs for congestion exceed the costs for grid extension, this would be the case.

TABLE III. COSTS FOR TENNET [20]

	Theoretic value	***Realistic value***
Base-case	-	-
Scenario A	€ 11M	€ 73M
Scenario B	€ 14M	€ 132M

V. DR PROGRAM DESIGN

Demand Response can be conceived in many different ways, each program can have a different goal e.g. peak shaving or short-term balancing. When setting up a new program it is important to have these goals and objectives clear. Keeping these in mind, there are a number of elements that are critical for designing a DR program [24]. Clarifying these elements gives insight into the type of clients that are needed for the DR pool. The balance between the goals and objectives of the TSO or aggregator and the DR clients is essential when designing a specific DR service. In the following section these elements are defined for a DR program used for national congestion management.

A. Compensation

The participation of clients is highly related to the compensation a client receives for curtailing demand. In general, higher payments increase the willingness for more frequent customer reductions [24]. These calculations resulted in, on the one hand, a compensation for downscaling demand ranging from 25 to 50 euro per MW per hour taking into account the market value of all different scenarios. On the other hand, it showed that the price for up-scaling demand ranges from 26 to 69 euro per MW per hour. Taking into account an electricity price of 80 euro per MW, the discount to participants could range from a high of 56 euro per MW hour to a low of 11 euro per MW per hour [20].

B. Response time

The response time represents the time between the notification signal from an aggregator/or controller and the actual curtailment DR resource. In terms of congestion, flow analysis is conducted day-ahead. If a situation would cause congestion, TenneT takes notice of this day-ahead. This leaves a rather large time gap between the time of realization and the actual event. This does, not pressure the response time of clients. A client has almost 24 hours to respond after the notification of an event. The advantage compared to short reaction time is that the client is able to reschedule a certain process or activity.

C. Non-performance

When DR is used to balance the grid, it is critical that the reliability of the resource is guarantied. In the congestion management mechanism no specific non-compliance penalties are specified. However, parties are held responsible when imbalance is generated.

D. Dispatch trigger

The dispatch triggers are situations were congestion is expected on the electricity network of the Netherlands. Because of the aggregated structure a response, it is not fixed that every clients has to respond to each congestion event.
However, congestion does not automatically imply that the DR capacity is used. An auction mechanism is used to select to most cost effective alternative for relieving congestion. Because the capacity is auction, dispatch triggered when the capacity bid is accepted.

E. Window of availability

Demand Response resources availability is specified in two dimensions; when and for how long. A bidding into the congestion management mechanism should at least contain a time slot of 15 minutes. There is the possibility to include a longer time period in a bid. When this bidding is accepted, the consecutive is accepted. For the window of availability for clients this indicates that the changed load level should be retained for at least 15 minutes. If an aggregated bid is submitted including a response time longer than 15 minutes, there is the possibility to change the load of different clients in turns.

VI. CONCLUSIONS AND RECCOMENDATIONS

This research showed that there are three additional options available in the existing congestion management mechanism, apart from up and downscaling generation capacity. The alternatives identified; increasing demand and increasing generation, decreasing demand and decreasing generation, and both increasing and decreasing demand. All of these options are considered valuable in aggregated demand for response to alleviate congestion. Based on this study, the value of DR is different for multiple parties. In case of TenneT, DR offers an additional steering instrument next to the existing generation capacity, which can lead to a reduction in congestion costs. For aggregators or electricity suppliers it introduces a business opportunity in the form of a new service. For customers it shows value in the form of a compensation or discount for changing their electricity load. On a global level, Demand Response can result in more efficient use of electricity helping to achieve the 2020 targets for the Netherlands and Europe.
The Dutch government identified a high potential for wind capacity along the coast of North- and South-Holland. The simulation showed. The simulation showed that significant amount of congestion could occur when this is capacity is

realized. In terms of social value an allocation plan for offshore wind capacity that results in small levels of congestion is preferred. Based on the simulation results it is recommended the capacity allocate along the coast of North-Holland for the next tendering round is relocated.

The study illustrated that use of demand capacity to alleviate congestion is technically possible. However, especially in the development phase of DR, when the capacity is limited, barriers are identified for participation e.g. validation of curtailing behavior. With respect to TenneT, it is recommended re-evaluate the participation requirements for the congestion market and invest in possibilities to gain from DR. Especially in the first phase of deploying of DR program the aggregated loads are limited. TenneT should research how For additional research it is recommended to adapt the model to other countries using a similar congestion management mechanism. With adjustments and relevant data the existing model can be modified to function in other countries. For instance, Germany would be considered a rather interesting alternative since the congestion management mechanism applied is considered to be more transparent and stable. Secondly, the integration of renewables has increase significantly increased in the past decade, and will continue to do so, aimed at 80%-95% carbon reduction by 2050 [25]. Especially increased solar and wind capacity have led to constant changing electricity flows through the grid, which are currently inducing congestion and will continue to do so in the future.

REFERENCES

[1] W. Jia, C. Kang, and Q. Chen, "Analysis on demand-side interactive response capability for power system dispatch in a smart grid framework," *Electric Power Systems Research*, vol. 90, pp. 11–17, Sep. 2012.

[2] E. R. O. R. L. Awrence, C. Goldman, N. Hopper, R. Bharvirkar, B. Neenan, and P. Cappers, "Estimating Demand Response Market Potential among Large Commercial and Industrial Customers : A Scoping Study," 2007.

[3] C. Böhringer, A. Löschel, U. Moslener, and T. F. Rutherford, "EU climate policy up to 2020: An economic impact assessment," *Energy Economics*, vol. 31, pp. S295–S305, Dec. 2009.

[4] European Union, "Directive 2009/28/EC," *Official Journal of the European Union 5.6.2009*, pp. 16–62, 2009.

[5] A. N. Menegaki, "Growth and renewable energy in Europe: A random effect model with evidence for neutrality hypothesis," *Energy Economics*, vol. 33, no. 2, pp. 257–263, Mar. 2011.

[6] EWEA, "Wind in power, 2011 European statistics," 2012, http://www.ewea.org/fileadmin/ewea_documents/documents/publications/statistics/Stats_2011.pdf.

[7] CBS, "Windenergie op land; productie en capaciteit per provincie," 2012. [Online]. Available: http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLNL&PA=70960ned&D1=0,4-9,12&D2=a&D3=a&HD=101220-1119&HDR=T&STB=G1,G2. [Accessed: 12-Apr-2013].

[8] Compendium voor de Leefomgeving, "Windvermogen in Nederland, 1990-2011," 2013, http://www.compendiumvoordeleefomgeving.nl/indicatoren/nl0386-Windvermogen-in-Nederland.html?i=6-139.

[9] Ministry of Economic Affairs, "Hoofdrapport Project Net op Zee", http://www.europa-nu.nl/9353000/1/j4nvgs5kjg27kof_j9vvikqpopjt8zm/vi657ydqz3ya/f=/blg20268.pdf 2010.

[10] F. Kunz, "Congestion Management in Germany - The Impact of Renewable Generation on Congestion Management Costs," 2011.

[11] U.S. Department of Energy, "Benifits of Demand Response in Electricity Markets and Recommendations fo Achieving Them," 2006.

[12] M. Albadi and E. El-Saadany, "Demand response in electricity markets: An overview," *Power Engineering Society*, pp. 1–5, 2007.

[13] KEMA, "The Virtual Power Plant," 2011. http://www.dnvkema.com/Images/KEMA%20whitepaper-Virtual%20Power%20Plant.pdf

[14] I. J. Pérez-Arriaga and L. Olmos, "A plausible congestion management scheme for the internal electricity market of the European Union," *Utilities Policy*, vol. 13, no. 2, pp. 117–134, Jun. 2005.

[15] R. D. Christie, B. F. Wollenberg, and I. Wangensteen, "Transmission management in the deregulated environment," *Proceedings of the IEEE*, vol. 88, no. 2, pp. 170–195, Feb. 2000.

[16] Y. Xiao, P. Wang, and L. Goel, "Congestion management in hybrid power markets," *Electric Power Systems Research*, vol. 79, no. 10, pp. 1416–1423, Oct. 2009.

[17] L. J. de Vries, "Course SPM9541 Electricity sector introduction." TU Delft, Delft, 2010.

[18] Tennet, "Verwachte Congestie," 2013. [Online]. Available: http://energieinfo.tennet.org/Connection/CongestionExpected.aspx. [Accessed: 01-May-2013].

[19] Rijkscoverheid, "Wind parks offshore," 2013. [Online]. Available: http://www.rijksoverheid.nl/onderwerpen/duurzame-energie/windenergie/windenergie-op-zee. [Accessed: 17-Apr-2012].

[20] R. Plink, "DR to alleviate national congestion in the Dutch power system," Technical University of Delft, 2013.

[21] CBS, "Energiebalans; aanbod, omzetting en verbruik," 2013. [Online]. Available: http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLNL&PA=70846ned&D1=36,74&D2=9,19&D3=0-1,7,27,32-33&D4=a&HD=130509-1055&HDR=G2&STB=G1,T,G3. [Accessed: 09-May-2013].

[22] Emacx, "The Power of Demand Response, control energy more efficient." emacx an energy technology company, 2012.

[23] Tennet, "Noordoostpolder," 2011. [Online]. Available: http://noordoostpolder.tennet.eu/achtergrond/projectbeschrijving/. [Accessed: 12-May-2013].

[24] Enernoc, “Designing a Successful Commercial and Industrial Demand Response Program.” pp. 1–8, 2012.

[25] European Climate Foundation, “Roadmap 2050, a practical guide to a prosperous low-carbon Europe,” 2010.