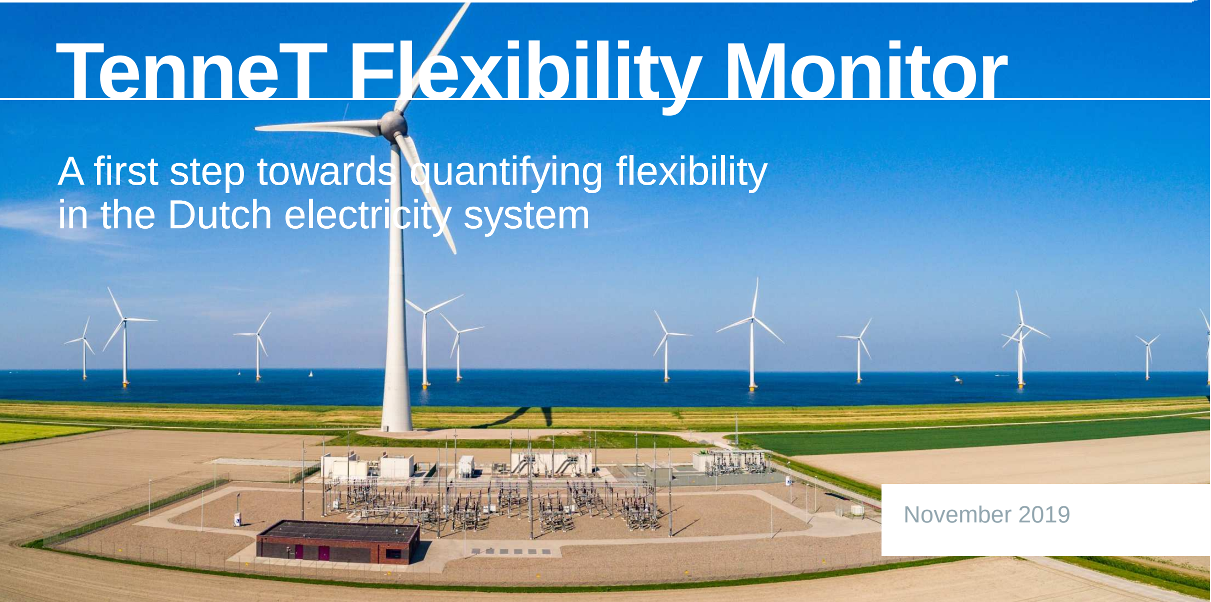
# TenneT Flexibility Monitor

## A first step towards quantifying flexibility in the Dutch electricity system



November 2019

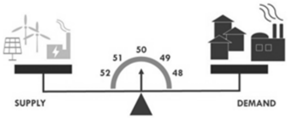
# Contents

# Objective

This analysis is a first step
to quantify the capacity and nature
of flexibility resources active in the Dutch
electricity system, and
to propose a method for tracking these
parameters in the years ahead.

# 1. What is flexibility?






**A stable electricity system requires flexibility to ensure that supply equals demand, while corresponding electricity transport can take place within technical constraints.**

- Continuous variation of supply and demand impact system stability.
- Both due to forecasted variations and unexpected disturbances.

**From an electricity system perspective, flexibility can be defined as the ability to change from one supply and demand state to another.** Drivers for the need for flexibility:

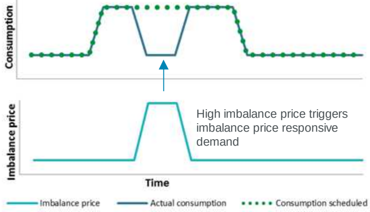
- Demand for electricity fluctuates and wind and solar generation varies over time.
- Managing capacity constraints or congestion in the electricity grid requires location-specific flexibility.
- In addition, unexpected events, such as grid faults and generation or demand outages drive a need for flexibility.

| | |
|---|---|
| **Flexibility Needs** | **Variations in demand**<br>**Variable generation wind & solar**<br>**Grid capacity constraints**<br>**Grid faults and outages** |
| **Flexibility Means** | **Flexible generation**<br>**Demand response**<br>**Energy storage** |

**Flexibility is delivered by flexible resources that adjust scheduled a demand or generation profile in order to contribute to a stable system.** Means to provide flexibility:

- Demand, generation and storage resources can be operated and controlled so as to deliver flexibility.
- Import and export through interconnection can facilitate a cross border exchange of demand, generation and storage resources to support a balanced system.

**Example of market flexibility based on imbalance price signal**



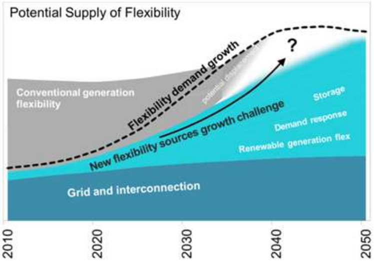

**Flexible resources responding to market signals are referred to as *“market flexibility”.***

- *Technical flexibility* is the full range and capabilities of resources, of which not all may be operated in this way.
- *Market flexibility* is a subset of this and relates to resources that respond to market signals and thus contribute to system stability.

# 2. Growing importance of flexibility

## The Energy Transition leads to a changing and growing demand for flexibility

- Today's electricity system already includes a sizeable demand for flexibility to ensure that generation and net-imports adjust to match the demand variability. Gas-fired generation, a strongly interconnected grid, and some demand response are the main providers today: **Demand varies** → **Generation adjusts**
- The growth of variable wind and solar generation and electrification of energy demand is expected to lead to an increasing demand for flexibility, because of (i) the variability of wind and solar generation, (ii) increasing load and generation connected to the distribution grid level leading to an increase in the occurrence of congestion and (iii) more pronounced peaks in demand. Increasingly, **Generation fluctuates** → **Demand adjusts**




**The growth of new flexibility from demand response, storage and renewable generation is key to enable the role of conventional generation plants as flexibility provider to shrink.**

**'Unlocking flexibility' is a key element in TenneT's ambition to drive the energy transition. This report is part of the development of a method to monitor flexibility over time.**

TenneT is committed to:

1. Share its insights in sum quantities and characteristics of flexibility resources with stakeholders, in particular market parties and policy makers.
2. Account for new flexibility, in particular demand response and storage, in the annual Adequacy Assessment (in Dutch: 'Monitor Leveringszekerheid') which has historically focused on generation adequacy.

*"**Flexibility** is the new renewable"*

*"Our strategy can be summarised in four words: Invest, Digitalise and **unlock flexibility**"*

*– Manon van Beek CEO TenneT*

**Previous studies have focussed on new potential flexibility in some sectors, rather than what is unlocked and active in the market today.** (An overview presented on pages 28 and 29.)

# Approach

Multiple approaches were used to quantify flexibility in the system today.

TenneT invites all stakeholders to provide feedback on this first step towards a standardised method to monitor flexibility.

# 3. How to make an inventory of flexibility?

**The full scope of flexibility is structured along two axes ‘Resource Type’ and ‘Market Segments’. A set of five analyses was used to quantify flexibility, with results organised in a matrix format.**

| Market segments | Resource Type | | | |
|---|---|---|---|---|
| | Generation (G) | Demand Response (DR) | Storage (S) | Total (T) |
| Day-ahead market (DAM) | | page 23 | | page 23 |
| Ancillary services (AS) | page 24 | page 24 | page 24 | page 24 |
| Voluntary balancing (VB) | | | | page 26 |
| Total (T) | page 18, 20 | page 20 | page 20 | |

Completed matrix is presented on page 13.

**Page numbers refer to a set of specific analyses described there, including quantitative insights for the respective matrix fields.*

**Compacted Matrix** used to clarify the cross section provided by each analysis.

→

| | G | DR | S | T |
|---|---|---|---|---|
| DAM | | | | |
| AS | | | | |
| VB | | | | |
| T | | | | |

Some pragmatic choices were made at this stage with respect to the scope of flexibility considered. Consumption patterns driven by household day/night tariffs were not considered, but may play an increasing role in the future with flexible prices for small consumers.

### Technology categories:

- **Generation** flexibility is delivered by resources that are intended to produce electricity, such as a gas turbines (OCGT, CCGT) or Combined Heat and Power (CHP) systems.
- **Demand Response** is flexible consumption of electricity, for example demand response by the temporary reduction of a production process or by switching to another energy source in hybrid systems. More specifically those flexibility resources that have a demand that is controllable/flexible.
- **Storage** are flexibility resources that store electricity with the purpose to provide electricity later, such as batteries. There can be a combination when for instance Electric Vehicles (EVs) provide demand response in case of smart charging, but can also provide storage in a 'Vehicle to Grid' setup.

**Categories of flexible resources**

| Generation | Demand Response | Storage |
|---|---|---|
| Conventional Fossil | Cooling | Stationary batteries |
| Conventional CHP | Power-to-x (heat, gas, products) | EV Batteries (V2G) |
| Biomass | Electrochemical processes | Mechanical energy |
| Renewable (wind & solar) | Lighting, ventilation or AC systems | Hydraulic energy |
| | Electric Motor Driven Systems | |
| | Smart charging EV’s | |

# 3. Broad range of flexible energy resources

**A broad range of energy resources and sectors are active in delivering market flexibility, responding to electricity prices or control signals. Market parties are increasingly active in unlocking small scale decentral flexibility resources as part of this.**

### Combined Heat and Power (CHP)

Relates systems that produce electricity and heat, typically in applications where there is demand for both. Often such CHP installations are connected to the grid in order to sell excess electricity or to buy a shortfall of electricity. Additionally, heat buffers are available decoupling the time of heating from the time of demand. Such systems can deliver flexibility by adjusting their level of heat and electricity generation, typically maximizing income and minimising costs based on market prices.



### Gas-fired power plants

Can maintain a margin between operating capacity and maximum capacity. Flexibility can be utilised by ramping up or down, for instance in response to real-time balancing prices.

Another option is to utilise this margin by offering it's capacity as emergency power that TenneT can activate at moments of significant power outages.



### Smart charging Electric Vehicles (EVs)


Relates to managing the charging rate of Electric Vehicles within constraints set by the EV user. Flexibility is delivered by adjusting time of charging and charging speed in order to respond to low market prices.

EV's provide **demand response** in case of smart charging, but can in principle also provide **storage** ('Vehicle to Grid', with rare exceptions not yet used today) where electricity is stored to be fed back into the grid.



### Industrial Power-to-Heat

Can relate to large-scale heat processes for which electricity is converted into heat. The timing of energy input can be flexible if these processes are not continuous (base load) or if heat buffers are included in the process. Flexibility can be delivered by adjusting the time of heating in order to respond to low market prices.

Flexibility potential can be increased when the system can leverage multiple resources (hybrid systems) such as gas or biomass boilers. This can contribute to optimising the cost of energy

# 3. Flexibility across Market Segments



## The day-ahead market is an auction a day before delivery: buyers and sellers submit anonymous bids with prices and electricity quantity per hour.

- It is the responsibility of each BRP to balance its portfolio of electricity produced/bought and sold/consumed by their customers over each 15 minute block. To this end, Balance Responsible Parties (BRP's) are trading in the wholesale markets (forward, day-ahead and intra-day). The resulting sum capacities allocated match the national consumption.
- Parties with variable wind and solar generation and firm delivery commitment to their customers, need to procure flexibility from other parties or adjust their own generation or demand to balance their portfolio.

## TenneT procures balancing services from Balancing Service Provider (BSP):

- Frequency Containment Reserves (FCR) are used to limit and stabilise frequency disruptions.
- Frequency Restoration Reserves (automated aFRR, manual mFRR) correct for real-time power imbalances.
- BSP's reserve the contracted capacity for these products from flexible resources. TenneT coordinates the activation of these reserves proportional to the real-time system imbalance.

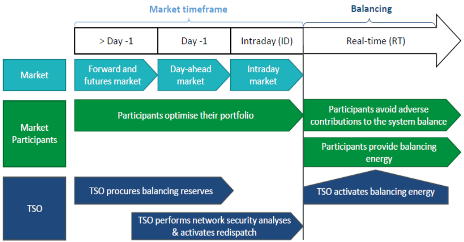
## Voluntary balancing contribution

- TenneT publishes near real-time balancing information (i.e. imbalance prices and activated quantities). This provides economic incentives that enables flexible resource operators to assist in system balancing.
- BRPs that adjust their portfolio in such a way that this alleviates imbalance will gain financial compensation. The BRP needs to pay a financial compensation if the portfolio position is contributing to system imbalance.

## Within the time and scope of this study markets of forward and futures, intraday and congestion management are not further considered.

- Due to increasing volumes traded on intraday and increasing needs for congestion management these markets should be studied in more detail to capture insights in flexibility supplied in these markets.

**Market timeframe and balancing**



# Results

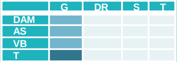
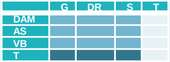
Findings from the set of five complementary analyses and
quantitative results on flexibility resources active in the Dutch market.

# Overview of analyses (1/2)

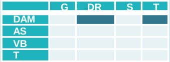
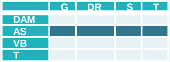
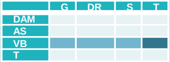


**Five complementary analyses were carried out, each capturing a different cross section of the flexibility capacity currently active in the Dutch electricity system. This provided the basis for an assessment of the sum capacity capacities, presented on page 13.**

Main findings and limitations for each analysis are summarised below. Pages numbers referred to present details of the approach and findings for each of these.

| Analysis | Flexibility cross section | Main observations | Opportunities and limitations |
|---|---|---|---|
| **Conventional generation**<br>*page 18* | The conventional generation analysis focusses on installed and operational conventional coal- and gas-fired power plants and aims to quantify and characterise these flexible resources.<br> | - Information mainly based on conventional generation data from TenneT's adequacy assessment complemented with installed CHP in horticulture from 'Energiemonitor Nederlandse Glastuinbouw 2017'.<br>- Categorisation used provides insight in the needs fulfilled by the conventional installed capacity, thus enabling more insight in the flexibility potential and operational or economic constraints for conventional generation. | **Opportunities**<br>- Categorising operational conventional generation based on the market segment where these are active. |
| **Market questionnaire**<br>*page 19 - 21* | The market questionnaire focusses on three market segments and aims to quantify those flexible resources that respond to market signals.<br> | - Design of the questionnaire is sufficient to obtain insight in flexible capacity. However, more specific information on the flexibility characteristics per sector still needs to be added from another source.<br>- Response and coverage of the total market were low. However, anecdotal evidence suggest that some of the most relevant Connected Parties, BRP's and aggregators, did respond. Most flexibility potential was reported by aggregators.<br>- The flexibility capacity found for generation were far lower than what was found in the preceding analysis. Some variable renewable capacity was found to be operated flexibly.<br>- For demand response and storage the questionnaire provided relevant insights in type of resource and capacity. | **Opportunities**<br>- Since conventional generation is well covered, improvement efforts are to focus on capturing flexibility from demand, storage and variable renewable generation .<br>- For comparability over time and in principle, connected parties could provide the most comprehensive coverage of flexible resources. However, their response rate and coverage then need to be substantially higher.<br>**Limitations**<br>- Quality and completeness are important when it comes to data collection through a questionnaire. For example, in the present adequacy questionnaire, it is unclear how certain the data are on the 10 year outlook on available generation assets. Key factors here are the ever changing business environment and business cycles that these commercial businesses are facing. |

# Overview of analyses (2/2)

| Analysis | Flexibility cross section | Main observations | Opportunities and limitations |
|---|---|---|---|
| **Day-ahead bid ladders**<br>*page 22 - 23* | The day-ahead bid ladder analysis focusses on the price-sensitive volumes bid into the day-ahead market (DAM) and quantifies the total flexible capacity that is supplied here.<br><br> | - Sound methodology to define volumes but it does not provide information on the types of energy resources that are behind these bids.<br>- The capacity of Price Sensitive Bids (PSB) is used as a measure of the total flexible volume in the day-ahead market. However, due to the wide variety of potntial the interpretation of this value is somewhat uncertain, as there can be a variety of it remains an open question how to value quantities found.<br>- The values for Market Response can serve as a proxy for demand response capacity. However, this is limited to only one direction: reducing demand at times of high prices. | **Opportunities**<br>- Methodology can be standardised to deliver results consistent over time. Flexible capacity within smart bids and intraday will need to be further assessed. Secondly, a better understanding of how a DSR bid is made and what it represents has to be obtained, in interaction with market parties.<br>- Using information in day-ahead bid ladders could open the way towards an aligned methodology across European Union countries.<br>**Limitations**<br>- Any demand response active at lower price levels (below 150 €/MWh) is not identified in the market response analysis. Secondly, future demand response in upward direction in response to low prices is also not identified in the present methodology. |
| **Ancillary services**<br>*page 24* | The Ancillary Services analysis focusses on the balancing products FCR and FRR. It quantifies the flexible resources that deliver these products to TenneT, including technology types.<br><br> | - Capacity of flexibility available for balancing by TenneT is well known based on the dimensioning of contracted capacity. | **Opportunities**<br>- Requesting more specific information on types of technologies, can deliver more insights in the range of flexible resources for ancillary services. Further improvement could be to characterise this per type of resources in order to track the development of the mix of offered flexible resources.<br>- In addition, by considering all offered or awarded contracts for FRR across multiple bid periods, more information can be derived on total capacity of flexible resources that could participate (by relating to the set of unique capacities offered and the depth of market/aggregated curves for ancillary services capacity.<br>**Limitations**<br>- Thus far, insights in type of resources is therefore unknown or based on anecdotal evidence from procurement. |
| **Voluntary balancing**<br>*page 25 - 26* | Voluntary Balancing analysis focusses on the response of BRP portfolios to imbalance price signals. It quantifies the capacity in these portfolios that provide a favourable response.<br><br> | - Ratio between whether a BRP had an imbalance position that amplifies or reduces system imbalance suggests it is likely that there are flexible resources in these portfolio's doing voluntary contributions on balancing.<br>- Event analysis suggests a significant capacity that is active in this way: a few 100 MW's. | **Opportunities**<br>- Further validation of these results through interaction with market parties.<br>**Limitations**<br>- The fact that BRP portfolio's change over time has an impact on comparability over results over the years. |

# Quantitative results flexible resources

- All quantitative results are summarised in this Flexibility Monitor Overview, bringing together the results from five complementary analyses, each of which captures a specific cross section of the flexible resource capacity utilised.
- Not all fields could be filled with these analyses, nor do the data in each field provide 100% coverage.
- The sum total Operational Flexible Capacity was derived by adopting across multiple analyses the highest of the ranges of flexible resources found across the various analyses. When using these results, the lower value of each resulting range may be considered a conservative estimate.

| | Generation | Demand Response | Storage | Total |
|---|---|---|---|---|
| **Day-ahead market** | | **700 MW – 2,000 MW** (↑)<br>*Market Response (page 23)* | | **2,800 MW – 5,300 MW**<br>*Price Sensitive Bids (page 23)* |
| **Ancillary services** | **1,380 MW – 1,730 MW** (↑)<br>**1,280 MW – 1,830 MW** (↓)<br>*FRR (page 24)* | **90 MW** (↑)<br>*FRR (page 24)* | **30 MW** (↑↓)<br>*FCR (page 24)* | **111 MW** (↑↓)<br>*FCR (page 24)*<br>**1,800 MW** (↑↓)<br>*FRR (page 24)* |
| **Voluntary balancing** | | | | **180 MW – 380 MW** (↑)<br>**80 MW – 160 MW** (↓)<br>*Event analysis (page 26)* |
| **Total** | **1,320 MW** (*375 MW* renewable)<br>*Questionnaire (page 20)*<br>**10,750 MW – 20,200 MW**<br>*Conventional generation (page 18)* | **730 MW**<br>*Questionnaire (page 20)* | **3 MW** (↑↓)<br>*Questionnaire (page 20)* | |

| | Generation | Demand Response | Storage |
|---|---|---|---|
| **Total Operational Flexible Capacity** | **10,750 MW – 20,200 MW** (↑↓)<br>*(Conventional)*<br>**375 MW** *(Renewable)* | **700 MW – 2,000 MW** (↑) | **30 MW** (↑↓) |

Quantitative analyses describing methodology and more detailed results of the values listed in the Flexibility Monitor Overview are presented on the page numbers indicated in the table.

Arrows (↑↓) are added if direction of flexible resources is known:
↑ upwards *(reducing demand, increasing generation)*
↓ downwards *(increasing demand, decreasing generation)*

# Conclusions & Recommendations

# Conclusions



**This report proposes a method and quantitative insights in current flexibility. For now, results are incomplete and more characteristics need to be captured for Security of Supply modelling, in particular for demand response and storage:**

- **Conventional generation currently provides** the most flexible capacity and is already adequately monitored in the annual adequacy assessment.
- **Variable renewable generation** is participating flexibly in the market already as 375 MW is reported in the questionnaire.
- **Demand Response** capacity is in the range of 700 – 2.000 MW, which is in line with the findings of a 2004 Deloitte study *(page 28)* that estimated a utilised capacity of 1.000 MW among large consumers in industry, businesses and horticulture, as part of 1.700 MW potential demand response capacity.
- **Storage** capacity is still small and concentrated with 30 MW found in the FCR market. Thus far, FCR may be the main market in which batteries have a positive business case, this may be a reasonable estimate for the total. However, in the future batteries are likely to play a broader role in multiple segments of the electricity market, for instance driven by the growing number of electrical vehicles. This makes it important to consider how to adequately capture this.

**Three methods can provide the basis for periodic monitoring of the development of flexibility:**

1. **Market Questionnaire**
   - The questionnaire provided improved insights in flexibility, especially in 'new flexibility' such as variable renewable energy and demand response. However the low response rate and coverage limited the insight in the whole Dutch market.
   - For practical reasons, the questionnaire did not seek information about other flexibility characteristics (e.g. location, availability, rebound effect, duration of activation, notification time). A next step in understanding these characteristics is necessary as input in Adequacy Assessment models.
2. **Bid ladder analyses**
   - Analysing day-ahead bid ladders provided insight in developments of total market flexibility volume (not technology or sector specific information). This result underestimates the actual capacity, as smart bids, the intraday market and flexible resources reserved for market portfolio's were excluded.
   - Additionally, demand response from the bid ladders for this analysis found a substantial volume of bids at higher price levels in the bid ladder. It is likely that these are associated with demand reduction.
   - Demand response in the direction of increasing consumption in response to lower price levels is likely to become an increasingly relevant category to monitor the development of this flexibility going forward.

3. **Ancillary services analysis**
   - This identified a mix of flexible resources participating in ancillary services markets, including renewable generation, demand response and storage. However, there is room for improvement in adequately capturing the types and characteristics of flexible resources participating in ancillary services.

*Credits for creative commons icons used: Davo Sime, Krisada, P Thanga Vignesh, iconsphere, Arthur Shlain, Good Ware*

# Recommendations

**Broaden the existing adequacy questionnaire by including demand response and variable renewable generation as specific categories for which data is to be provided by connected parties or market parties.**

- So far, these questionnaires are only used to approach generators with at least 10 MW installed capacity. Covering demand response implies that this should be broadened with connected parties associated with consumption. Practical threshold values for major consumers should be defined, as well as an approach for adequately capturing aggregated demand response assets.
- Secondly, the questionnaire for generators needs to be improved by adding fields on flexibility constraints and by including variable renewable generators.

**Improve and standardise the day-ahead bid ladder analysis and ancillary services analysis so as to provide consistent results periodically for future adequacy assessments**

- **Day-ahead bid ladder analysis:** Standardise the quantitative findings from fexibility analyses with market parties in order to gain improved insights in the resources, bidding patterns and variations over seasons and years. The completeness can be improved for the day-ahead bid ladders by including flexibility resources utilised through smart bids and in intraday markets (taking care to avoid double counting). Moreover, standardising the methodology is required so as to ensure comparability.
- **Expand the coverage of the ancillary services analysis** by assessing the depth of ancillary service markets based on offered volumes from all offered/auctioned ancillary services products. In addition, the types of flexible resources underlying each offer can be registered.

**Initiate sector-specific studies into demand response, through stakeholder interaction and detailed sector studies, either with a selected set of representative individual parties, or through a sector approach with relevant sector associations.**

- This enables an improved assessment of flexibility characteristics associated with the available capacity reported as part of 2 and 3. Moreover, this is relevant to model demand response more accurately. In this way, the number of data fields in the questionnaire mentioned under 1 can be limited, thus reducing the effort required for completing this.
- These sector studies are to focus at least on horticulture, chemical industry and industries with high temperature heat based processes, mobility and the built environment. In particular, new demand response unlocked in sectors that where electrification of energy demand takes place need to be adequately addressed, besides existing demand response.

# Annex

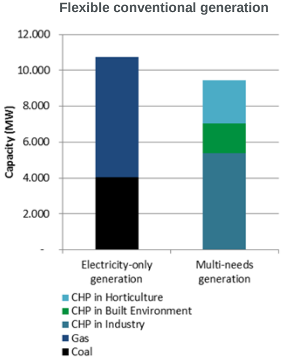
## Analyses to quantify the capacity and nature of flexibility resources.

# Flexible Conventional Generation



**This analysis of conventional generation focusses on installed and operational coal- and gas-fired power generators. It aims to quantify these flexible resources in 5 categories with specific activation price levels.**

| Category | Sub-category | Flexibility characteristics |
|---|---|---|
| Electricity-only generation | Gas-fired power plants | These are assumed to be capable of responding fully to electricity market prices, within the constraints of their technical capabilities. Flexible generation behaviour is likely due to place higher up in merit order and the absence of further operational constraints such as required heat output. |
| | Coal-fired power plants (incl. biomass) | Since these power plants focus on the single need of electricity generation, these may be assumed to respond fully to the electricity market within the constraints of their technical capabilities. Base-load operation expected. Substantial costs associated with start-up and stop decisions for these generators will influence the flexibility that these generators provide. |
| Multi-needs generation | CHP in Industry | Resources that deliver heat/steam/$CO_2$ as well as electricity, typically for industrial process or horticulture. Likely that their generation schedule is based on the need with the highest marginal value, often heat or steam demand of the core production process. |
| | CHP in Built Environment | Resources that deliver heat to a district heating system as well as electricity. It is likely that their generation schedule and optimisation is based on the need with the highest marginal value, thus often “must-run” during cold winter months with electricity as a by-product. |
| | CHP in Horticulture | Typically, the available capacity to produce electricity is operated as part of an overall optimisation for heat, $CO_2$, electricity demand for lighting, and the national electricity and gas market and grid costs. In addition, when electricity prices exceed the marginal value of the primary processes in the greenhouse or on days without heat demand these generators typically operate to serve the electricity system. A further assessment of operational options and constraints is warranted. |




**Summary of flexibility capacity found in this analysis:**

| | Generation | Demand Response | Storage | Total |
|---|---|---|---|---|
| Total | 10,750 MW *Electricity-only*<br>9,450 MW *Multi-needs* | | | |

# Market questionnaire - set up (1/3)

## The market questionnaire aims to quantify flexible resources based on information from three types of market parties:

- **Grid Connected Parties** are the owners of flexibility resources, including consumers, consumers with generating capacity, or generators. These are expected to be aware to what extend their flexible resources are operated flexibly in response to the electricity market and system.
- **Balance Responsible Parties (BRPs)** are the administrative entities that are responsible for maintaining the balance on the grid for the sum of all connections in their portfolio. Contacting BRP's could lead to a large coverage from a relatively small group of respondents.
- **Aggregators** have a core business in unlocking flexibility resources by pooling decentralised and typically smaller flexibility resources. There are specialised in flexibility and are likely to know in detail how much flexibility is available in their portfolio and how this capacity is operated. However, this category will not result in complete coverage since not all connections are covered by aggregators.

source: USEF

## Data on flexible capacity (bandwidth in MW) actively operational, including:

- Indication on technology category and electricity market segments where it is active.
- Five characteristics of flexibility as shown as the headers of the questionnaire (figure on right), as well as a breakdown between implicit and explicit flexibility.
- Additional data gave insight in the sectors with which the assets are associated, as well as the total annual electricity generated or consumed as a reference value for coverage of feedback received.

**Market Questionnaire**

| FlexType | Technology | Flexibility Capacity / Power Offered / Contracted: Min (MW) | Max (MW) | Day/night pattern significant influence on MW flexible capacity | Weather pattern significant influence on MW flexible capacity | Markets where flexible capacity was offered in or responded to: Long term | Day-ahead | Intraday | Passive balancing | FCR (primaire reserve) | aFRR (regel vermogen) | mFRR (reserve- en noodvermogen) | Contingency power for BRP portfolio | Congestion management TSO | Congestion management DSO | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EXPLICIT<br>Dispatch of flex according to the needs of BRP, TSO or | | | | * enter 'y' if applicable | | * enter 'y' *if applicable* | | | | | | | | | | |
| DemandResponse | Low temperature Heat (Pow… Heat) | | | | | | | | | | | | | | | |
| Storage | | | | | | | | | | | | | | | | |
| Generation | | | | | | | | | | | | | | | | |
| IMPLICIT<br>Exposed to an… | | | | * enter 'y' if applicable | | * enter 'y' *if applicable* | | | | | | | | | | |
| DemandResp… | | | | | | | | | | | | | | | | |
| Storage | | | | | | | | | | | | | | | | |
| Generation | | | | | | | | | | | | | | | | |

Technology drop-down list:
- Low temperature Heat (Power2Heat)
- High temperature Heat (Power2Heat)
- Cooling
- Electrochemical processes
- Electric Motor Driven Systems (EMDS)
- Lighting, ventilation or air conditioning systen
- Conversion (a.o. Power2Gas, Power2Produc
- Smart charging of electric vehicles

## Adding up results from all types of market parties would result in double counting. Instead, the set with the highest reported flexible capacity is used.

- A single connection/flexible resource can be covered by all three market parties at the same time.
- For example, a small industrial consumer (Connected Party) can partner with an aggregator to unlock its flexibility. It will also have a connection that is part of a BRP portfolio.

# Market questionnaire - results (2/3)



### The questionnaire data shows a lower value for the available flexible capacity due to an incomplete response, its distribution over electricity market segments and sectors.

- While a significantly higher response rate is desirable, anecdotal evidence suggests that the parties that did respond are the most active with flexibility and may leverage the highest flexible capacities.
- Therefore, these results are only partial and the actual flexibility in the Dutch market is likely to be higher.

### 370 MW Renewable generation flexibility is already active in the Dutch market.

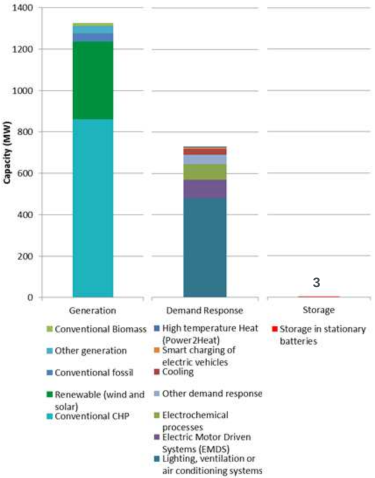
- While this is only a small percentage of installed capacities (some 8 GW wind and solar at the time of writing), this demonstrates that the market model provides the incentives to do so.
- Qualitative response indicates that this flexibility is used for many purposes: sold long-term, in the day-ahead market, and is part of a portfolio for mFRR and in real time for voluntary contribution to (passive) balancing.

### 730 MW Demand Response available in industry (heat, electrochemistry) and horticulture.

- Response from aggregators provided most insight in ‘Demand Response’.
- The technologies and processes that deliver the Demand Response obtained from the questionnaire are similar to some technologies and processes listed in the Berenschot 2015 and CE Delft 2016 studies *(pages 28-29)*.

### 3 MW Storage is active and focussed on balancing ancillary services (FCR).

**Results market questionnaire**




*These results represents flexibility assets in a portfolio that covers only 4-12% of annual production or consumption. Based on 5 respondents.*

**Summary of flexibility capacity found in this analysis:**

| | Generation | Demand Response | Storage | Total |
|---|---|---|---|---|
| **Total** | 1,320 MW (370 MW renewable) | 730 MW | 3 MW (↑↓) | |

# Market questionnaire - insights (3/3)

## A limited coverage of the market was achieved due to a low response rate.

1. **Connected Parties** questionnaire had 14 respondents which covered 12% of the market. Notwithstanding this low response rate, it is essential to cover this adequately due to their large role and integrated energy-flexibility propositions.
2. **BRP's questionnaire** had 5 respondents and roughly 7% coverage in terms of the number of parties. This low response rate and the fact that connections can switch portfolio's, will make it hard to compare results over time.
3. **Aggregators** questionnaire had 5 respondents, with the sum value pointing to the highest flexible capacity of the 3 sets.


## The day-ahead market plays a key role, with highest flexible capacity reported active here.

- This underlines the relevance of the day-ahead bid ladder analysis (page 22) in quantifying flexible capacity.
- Secondly, the real-time balancing market (passive balancing) in which flexibility operators provide voluntary contributions to system balancing. This supports the relevance of the analysis of flexibility in voluntary balancing (pages 25-26).

## Of particular interest are the flexibility from variable renewable resources actively used by some parties, and the types and sector distribution of demand response and storage capacity.

- This highlights the relevance of tracking the growth of these 'new flexibility resources' as part of the adequacy assessment.
- Response was low when it came to flexibility from conventional generation. However, this is well covered by the dedicated analysis on page 18.

*sources: creative commons icons used: Davo Sime, Krisada, P Thanga Vignesh, iconsphere, Arthur Shlain; and USEF icons*

# Day-ahead bid ladder analysis (1/2)

## The day-ahead bid ladder analysis aims to quantify the total flexible volume supplied to the day-ahead market (DAM) by focussing on the price-sensitive volumes bid in this market.

- Individual bids of market parties are aggregated and considered as a proxy for capacity of flexibility resources available.
- Minimum and maximum price per bid is set by the exchange (EPEX) at respectively -500 €/MWh and 3.000 €/MWh.
- Cross border trade volumes are inserted in the price insensitive part of the demand curve or offer curve when the Netherlands is exporting or importing respectively.

## Price Sensitive Bids (PSB) reflect flexible volumes offered in the day-ahead market.

- PSB is the sum of bid volumes in the demand curve at a price <3.000 €/MWh and the offer curve > -500 €/MWh.
- The bid price provides a threshold value where these are scheduled differently above or below this bid price. Therefore, these bids can be considered to be associated with flexible resources.
- In contrast, the volume of bids in the market at 3.000 €/MWh and -500 €/MWh are inflexible.

## Market Response (MR) reflects the response during periods of high prices, and can be used as a proxy for Demand Side Response (DSR).

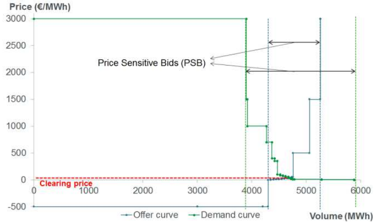
- Market Response volume is the total volume of Price Sensitive Bids (PSB) minus the PSB volume <150 €/MWh.
- This is likely to exclude generation-backed bids, as marginal generation costs of these tend to be <150 €/MWh

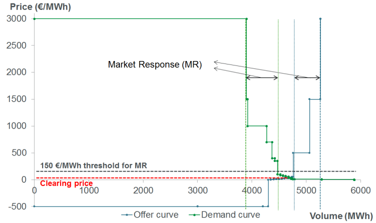
## Some potential flexibility was missed, as smart orders could not be included in this analysis.

- Impact on MR volumes is likely to be limited since volumes of smart orders in this price range are likely very limited [19].
- Bid ladder analyses are expected to also show bidding behaviour that is not necessary associated with flexibility but results from other dynamic behaviour in the market. This could not be assessed based on the available data.

*source: the day-ahead bid ladder analysis was inspired by Elia's research on Market Response which is repeated annually since 2017. The same definition and methodology to extract MR from the aggregated curves is used.*

| | Buy / demand curve | Sell / offer curve |
|---|---|---|
| Generation | Buy back sold electricity | Sell electricity to be generated |
| Demand | Buy electricity to be consumed | Resell bought electricity |



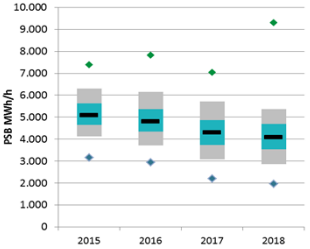



# Day-ahead bid ladder analysis (2/2)

**Flexibility capacity found in the Price Sensitive Bids (PSB) analysis and the Market Response (MR) analysis are plotted. 2018 values and a 5% - 95% percentile range are adopted in the summary.**

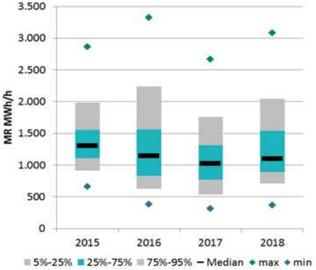
## Capacity in Price Sensitive Bids (PSB) is in the range of 2.800 MWh/h to 5.300 MWh/h.

- This range shows that in 95% of all 2018 hours there was at least 2.800 MW of flexible price sensitive capacity offered in the day-ahead market. And in 5% of all hours this was at least 5.300 MW.
- A decreasing trend for PSB can be observed between 2015 and 2018. This can likely be explained by the introduction of smart block bids. It does not necessarily mean a decrease of flexibility in the market, but does point to the limitations of this analysis.
- Market parties indicated that these better match technical constraints, while limiting risk of imbalances. This is important for Market Parties since imbalances can be costly due to risk of very high imbalance prices.
- Other factors contributing to decreasing PSBs are the growing volume of intraday trades and a growth of netting of price independent orders and reduced price dependent orders due to netting of the price dependent orders portfolios.




## Capacity in Market Response (MR) is in the range of 700 MWh/h to 2.000 MWh/h.

- In 95% of all 2018 hours there was at least 700 MW of flexible price sensitive capacity available in the day-ahead market with a price above 150 €/MWh. And in 5% of all hours this was 2.000 MW above 150 €/MWh.
- Most likely, this reflects demand response bids, more specifically demand reduction bids. However, flexible demand increase (at low prices) is not reflected by these figures.
- Market Response does not show the decreasing trend seen in PSB.




## 700 MW demand response is adopted as a conservative estimate (95% percentile value).

- It is in line with 730 MW reported in the market questionnaire and the 1.000 MW operational demand response from the 2004 Deloitte demand response study (page 28).

**Summary of flexibility capacity found in this analysis:**

| | Generation | Demand Response | Storage | Total |
|---|---|---|---|---|
| Day-ahead market | | 700 MW – 2,000 MW (↑) | | 2,800 MW – 5,300 MW |

# Flexibility in ancillary services

## The Ancillary Services analysis quantifies and characterise the flexible resources that deliver balancing services to TenneT. It focusses on the balancing products FCR and FRR.

## TenneT contracts these balancing ancillary services from Balancing Service Providers (BSPs).

- **Frequency Containment Reserves (FCR)** are flexible resources contracted that deliver power activated in response to frequency deviations, providing a constant ratio between frequency change and power change within a maximum of 30 seconds. The aim of FCR is to stabilise frequency disturbances in the entire (Continental Europe) high-voltage grid, regardless of the cause and location of disruptions.
- **Frequency Restoration Reserves (FRR)** are flexible resources contracted that deliver power that is activated to correct the real-time power imbalance. FRR contracted capacity is mainly based on historical imbalances and the largest imbalance that can result from an instantaneous change of active power of a single power generation module, single demand facility or single HVDC interconnector, or from a trip of an AC circuit within the balancing area.

## In recent years 'new flexibility' has entered the FCR market, including 30 MW batteries.

- As ancillary services are procured on a technology-neutral basis, TenneT does not have complete insight in the technologies.
- Historically, FCR was supplied with conventional power plants that maintained a spinning reserve capacity.

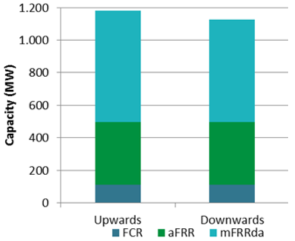
## Some 1,800 MW unique flexibility resources were contracted for FRR, over the 2018 bid periods.

- FRR capacity can be offered based on a portfolio (mix) that may include a range of resources (demand response, renewable generation). For example a BSP with a portfolio of gas-fired power plants and wind generation can ramp up and down with a certain amount of gas-fired generation, but can also do so based on wind farms at time when this is more cost effective.
- Results from the market questionnaire show renewable generation capacity in mixed portfolios are already utilised for FRR.

**Summary of flexibility capacity found in the ancillary services analysis:**

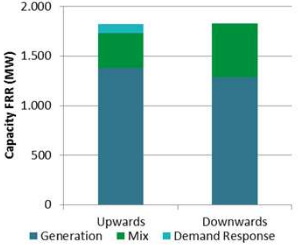
| | Generation | Demand Response | Storage | Total |
|---|---|---|---|---|
| **Ancillary services** | 1,380 MW – 1,730 MW (↑)<br>1,280 MW – 1,830 MW (↓) | 90 MW ↑ | 30 MW ↓↑ | 111 MW ↓↑ FCR<br>1,800 MW ↓↑ FRR |

**Dimensioning Ancillary Services TenneT NL**




** Dimensioning Q3+4 2019*

**Unique technology mix of FRR capacity 2018**



# Voluntary balancing - BRP behaviour

| | G | DR | S | T |
|---|---|---|---|---|
| DAM | | | | |
| AS | | | | |
| VB | | | | |
| T | | | | |

## Voluntary Balancing analysis focusses on the behaviour of BRP portfolios in response to imbalance price signals.

- Using the actual measured net balancing position (MWh) over 15 minute Imbalance Settlement Periods (ISP) and the settlement programme, the deviation between the two is the BRPs imbalance position.
- Each ISP a BRP may be supporting the system imbalance by having a BRP imbalance that has an opposed direction than the system imbalance (Positive Contribution (PC)) or be contributing to the system imbalance (Negative Contribution (NC)).
- However, it is unknown what part of each deviation between the actual measured net position of the BRP and the settlement programme can be attributed to an intentional voluntary contribution.

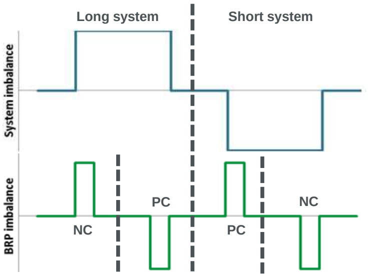
## In broad terms, a BRP actively contributes to system stability voluntarily if the PC/NC ratio is >1 and if it increases with an increasing imbalance price.

- This was analysed by categorising each ISP per BRP as PC or NC for the years 2016 and 2017.
- PC/NC ratio is based on the number of PC quarters by the number of NC quarters per BRP.
- This second step is repeated for all quarters that had an imbalance price delta above a certain threshold value in order to see the development of this ratio above certain price thresholds.

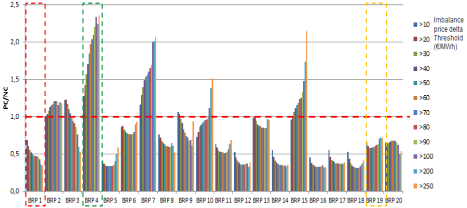
## The results show different behaviours among BRPs, including some that typically provide a positive contribution:

- **BRP 1** = example of a BRP for which the ratio PC/NC is below 1 and decreasing when price incentives increase. This suggests no positive contribution, but aggravating the system imbalance.
- **BRP 4** = example of a BRP for which the ratio PC/NC clearly increases when the price incentive increases. This suggests an active voluntary contribution.
- **BRP 19** = example of a BRP for which at lower price level the ratio PC/NC is decreasing, however, at high imbalance prices it slightly increases.

**Definition positive contribution (PC) and negative contribution (NC)**




**BRP's PC/NC ratio at several imbalance price delta thresholds**



# Voluntary balancing - events analysis



## A next analysis focussed on infrequent episodes where a high imbalance price persists over some time and considers the change in imbalance position per BRP in response.

- The resulting measure is a proxy for the flexible capacity that each BRP is able to mobilise in such circumstances.
- 82 Events in upward regulation direction and 20 events in downward direction were studied over a 2 year period.

## Method and criteria used for imbalance event analysis:

- An imbalance price delta of + / - 90 €/MWh persisting for 1 hour or more (ISPs 1, 2, 3, 4, 5, 6) defines a substantial and persistent imbalance events.
- The BRP response during each event was quantified as the difference in its average portfolio balance position between the hour before the start of the episode (ISPs -3, -2, -1, 0) and all ISPs during which the episode persisted after the first hour (ISPs 7, 8, 9, ….).
- The resulting set of events were plotted both in a scatter plot and in a histogram and an estimate was made what the "typical bandwidth" of response in MW capacity occurred. This step acknowledges that a BRP may not always find itself in the position that it can respond. Moreover, the resulting "BRP response" values are subject to substantial noise in the data due to unrelated events in a BRP portfolio such as unforeseen increases or decreases of consumption in their portfolio.

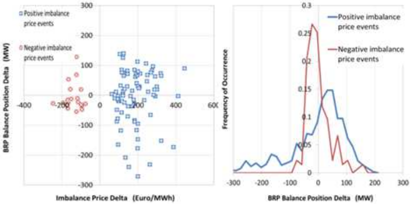
For example, the BRP vii histogram can be interpreted as follows:

- Typically this BRP provides a positive contribution in case of positive imbalance price delta, mostly in the range of 40 MW (peak histogram) to 70 MW (right flank of histogram, at indicative level of 80% of peak). In rare cases, a negative contribution occurs – possibly events where this BRP is part of the cause of the system imbalance.
- Typically provides a small contribution in case of negative imbalance price delta, mostly in the range of 20 MW (peak of histogram) to 40 MW (left flank of high histogram, with 80% of peak used as indicator).

**Summary of flexibility capacity found in this analysis:**

| | Generation | Demand Response | Storage | Total |
|---|---|---|---|---|
| Voluntary balancing | | | | 180 MW – 380 MW (↑)<br>80 MW – 160 MW (↓) |

**Example imbalance price events and behaviour for one BRP (#vii)**




**Summary for most active BRPs: range of observed voluntary balancing.**

| | Short system Flexible Capacity (MW) | | Long system Flexible Capacity (MW) | |
|---|---|---|---|---|
| | Lower range | Upper range | Lower range | Upper range |
| BRP i | 20 | 30 | | |
| BRP ii | 0 | 5 | | |
| BRP iii | 7 | 15 | | |
| BRP iv | 70 | 150 | -50 | -80 |
| BRP v | 0 | 20 | | |
| BRP vi | 20 | 50 | | |
| BRP vii | 40 | 70 | -20 | -50 |
| BRP viii | | | -10 | -30 |
| BRP ix | 20 | 40 | | |
| Total | 180 | 380 | -80 | -160 |

# Annex

## Literature Review

# Literature review (1/2)

| Source | Main Findings |
|---|---|
| **Benutting vraagrespons in de geliberaliseerde elektriciteitsmarkt – Deloitte 2004** | This study focussed on the available and the utilised demand response potential and the need and opportunities to increase demand response potential. The analysis was based on quantitative modelling of energy consumption and added value in various sectors. Results were subsequently validated through interviews with companies in key sectors. It found:<br>1. Demand response potential: 1.730 MW — 1.200 MW in industry (enterprises with non-energetic energy consumption: 800 MW, enterprises with 'low occupancy rate': 400 MW); 425 MW in Horticulture lighting; 80 MW in Mineral Extraction (mainly gas storage); 25 MW in 'Transport and storage' (Cooling industry)<br>2. Utilised potential: 1.000 MW: — 350 MW with consumers that act by themselves; 650 MW in switch-off contracts (industry: 425 MW, mineral extraction: 80 MW, and horticulture: 120 MW)<br>3. Emergency power supply — 1400 MW potential based on cost benefit analysis, of which 700 MW installed |
| **Technical demand response potentials of the integrated steelmaking site of Tata Steel Ijmuiden – Feta et al. 2018** | The DR potential that can be provided to the Dutch national grids by the integrated steelmaking site of Tata Steel in IJmuiden is assessed, using a linear optimisation model subject to the technical constraints of Tata steels generators that generate electricity from its works arising gases (WAGs).<br>• 10 MW for two PTUs of positive DR capacity (demand reduction) with an 97% availability rate (20 MW with an availability rate of 65%).<br>• 20 MW for three PTUs of negative DR capacity (demand increase), (four PTUs with doubling of blast furnace gas storage capacities) |
| **Power to Products – Over de resultaten, conclusies en vervolgstappen – Berenschot, CE Delft en ISPT 2015** | The study assesses how (technical, operational and organisational), at what costs and under which conditions the process industry can flexibilise its electricity consumption. Five business cases were developed: three on flexible deployment of Power-to-Heat, one 'peak shaving', and one electrifying an industrial process. Results suggest a potential up to 10 GW of technologies to respond to surpluses, and up to 3,5 GW to respond to shortages by 2030:<br>• Electrical steam boiler: Surplus response of ~2.500 MW<br>• $H_2$ production from electrolysis: Surplus response of ~2.000 MW<br>• Electrical and electrode boiler: Surplus response of ~2.000 MW<br>• Industrial heat pump, 100-150 ºC low pressure steam: surplus response of ~1.300 MW<br>• Low temperature industrial heat pump: surplus response of ~900 MW<br>• Steam compression: surplus response of ~400 MW<br>• Converting NaCl to NaOH, $Cl_2$ and $H_2$: surplus response of ~300 MW and a shortage response of ~250 MW<br>• Hot air drying: surplus response of ~300 MW<br>• Repowering with an aero derivative gas turbine: shortage response of ~1.750 MW<br>• Jenbacher 9,5 MW gas engines (as peak load unit): shortage response of ~1.000 MW<br>• Compressed Air Energy Storage: ~500 MW |

# Literature review (2/2)

| Source | Main Findings |
|---|---|
| **Markt en Flexibiliteit – CE Delft 2016 [5]** | Potential flexibility volumes were identified in the Dutch electricity market for 2023, based on several technology specific analyses. Findings:<br>• Electricity sector: Steam and gas turbines: shortage support < 8.200 MW, power for 1.500 hours highest residual demand. CAES: shortage and surplus support of 300 MW. Power-to-heat (district heating): surplus support of 500 MW<br>• Horticulture: Power-to-heat: surplus support 1.600 MW<br>• Large consumers / industry: additional demand response industry: shortage support 500 MW. Increasing flexibility in CHPs: surplus support 1.000 MW. Power-to-heat: surplus support >3.000 MW. Hydrogen production: surplus support 2.000 MW<br>• Residential / SME: Interruptible demand EVs: shortage support <400 MW; surplus support <600 MW<br>• Demand response heat pump: shortage support 500 MW; surplus support 500 MW |
| **Demand response en $CO_2$ emissiereductie – Movares 2017** | Analysis of demand response effects in the cooling industry, without a quantitative assessment of potential. Main research question: Does an increase in flexibility (demand response) in the cooling industry lead to a decrease of national $CO_2$ emissions.<br>The study finds that consumption needs to be stimulated at low prices in order to reduce CO2 emissions with demand response. |
| **Demand response – kansenverkenning onder enkele MJA sectoren – Movares 2014**<br><br>**and**<br><br>**Introductie industriële demand response – Movares 2016** | An exploration of demand response potential in five MJA (Meerjarenafspraken Energie-efficiency) sectors in the context of an increase in installed wind and solar generation (Movares 2014). And a study toward the opportunities of flexibility for the same MJA sectors (Movares 2016). The analysis was based on interviews with companies of the five sectors and specific sector analyses. Sectors with a good potential for demand response:<br>• Refrigerated storage industry, represented in sector organisation NeKoVri.<br>• Electric pumping stations for water management, represented by sector organisation Unie van Waterschappen (UvW). Good opportunities for flexibility in electricity demand, in both water management and treatment.<br>• Large scale flour factories represented by sector organisation NEBAFA. Although limited availability since most electricity consumption is related to the primary process.<br>Sectors with limited potential for demand response:<br>• Rubber and plastic sector and surface treatment sector |
| **Market Response study – Elia 2017 and 2018** | Study aims at assessing all Market Response (MR) volumes from the day-ahead hourly aggregated curves, which are not already included in the adequacy assessment. Findings show average MR values above 150 €/MWh of:<br>• 596 MW over the period 2015 – 2017<br>• 615 MW over the period 2015 - 2018 |

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