The Balance of Power – Flexibility Options for the Dutch Electricity Market

Final Report

Triple E

Contract details

TEC1070NL The Balance of Power – Flexibility Options for the Dutch Electricity Market

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Executive Summary

The European electricity sector is changing rapidly. A quick rise of variable renewable energy such as wind and solar in several EU countries, the emergence of decentral electricity production, and improved possibilities for storage and demand-side management that are currently under development can be seen as important successes of EU and Member State energy policies.

However, these positive developments do not come without new challenges. Incorporating the increased amount of intermittent renewable energy requires more flexibility in the electricity system as a whole. Such flexibility can be offered by existing fossil capacity, in particular gas turbines, as well as by new options such as demand side management and storage. At the same time, we see that the rise of renewables together with other current market developments such as low coal prices and a malfunctioning ETS has resulted in gas capacity being far less profitable and therefore being 'mothballed', with less flexibility in the current system as a result. This poor investment climate for conventional capacity has led in turn to a policy reaction in several Member States to introduce 'capacity mechanisms' that provide incentives to power producers to keep flexible reserves available.

Capacity mechanisms are just one of many options to increase the flexibility of a power system. It is currently debated to what extent interventions are already needed in The Netherlands. This report therefore examines in more detail what the specific requirements for increasing flexibility in the Dutch electricity sector are and when they might emerge. It also examines the specific options available to policy makers to increase flexibility in case that an intervention would be needed.

Research objectives

As a contribution to the above discussion, and in context of the ongoing market trends, this report examines the flexibility needs and options for the Netherlands. The aim of this study is to give an insight in:

1. **The specific Dutch flexibility requirements**
   What is the specific situation of the electricity sector in the Netherlands and what are balancing and flexibility needs now and up to 2023, taking into account Dutch policy objectives and developments abroad?

2. **Flexibility options available to the Netherlands**
   Which technical and regulatory balancing and flexibility options are available to the Netherlands, and which are their specific benefits and limitations?

Flexibility definition and scope

Flexibility in this report is defined as:

> ***"Flexibility expresses the extent to which a power system can increase/decrease electricity production or consumption in response to variability"***

In this report, we distinguish three simplified timescales of flexibility:

Type of flexibility	Timescale	Corresponding market
Short-term	< 15 minutes	Balancing
Mid-term	Day	Intraday/day-ahead
Long-term	Weeks/season	Future contracts

The following research scope was defined:

Geographical: The Netherlands are the geographical focus point of this research project. As the Dutch electricity market is part of a wider European electricity market (e.g. the Central West region) flexibility needs cannot be examined without establishing the links to neighbouring countries, these will be also examined. The influence of developments in Germany, but also in Belgium, Great-Britain, Denmark and Norway will be accounted for in the study.

Timeframe: The primary time horizon of the project is that of the Dutch Energieakkoord, i.e. from 2013 to 2023. An outlook will be given to the situation until 2030.

Central and decentral power generation: Focus of this report is on flexibility as an issue for a regulated, national grid within the interconnected European grid system. Central and decentral power generation are examined as giving rise to flexibility issues for such a grid. Decoupling of decentral grids and future possibilities for stand-alone local power generation are not considered.

Method and limitations

The flexibility needs and options in the Dutch power system have been examined by way of literature study and interviews. Also, an indicative modelling exercise of flexibility needs and options in the Netherlands was carried out.

The outcomes of the study have been prepared with great care, but should be also regarded within the uncertainties and limitations that apply due to the research method applied and the unpredictability of future developments in the electricity sector:

First, in this study current developments have been extrapolated for the coming ten years taking currently announced policies as a basis (Energieakkoord). That is considered feasible, because the period in the future is limited and will be determined for a substantial part by current developments. On the other hand, the electricity market is facing large challenges and major changes. Large utilities are struggling to remain profitable, whereas local actors are increasingly exploring the possibilities to produce and trade their own power. At the same time the European electricity markets are increasingly integrated, with more and more influence of neighbouring countries on national markets. This might lead to more rapid systemic changes than foreseen in this study.

Second, focus of this study is on technical flexibility of the system, and the prevention of system blackouts. The availability and cost-efficiency of various options for flexibility has been examined, as well as specific merits and limitations of application of each of these options for the Netherlands, but a full-fledged cost benefit analysis of all options was not possible within the context of this study.

Conclusions

With regard to the flexibility needs of the Dutch power system

The Energieakkoord RES targets of 2023 can most probably be realised without investments in additional flexibility beyond those already planned.

Our analysis shows that the existing potential flexibility in the Netherlands' power system is relatively diverse and high in comparison to neighbouring countries. A well-developed electricity market, a high share of CCGT and CHP plants, and interconnection capacity provide for a relatively flexible power system compared to neighbouring countries. Also, existing total generation capacity compared to demand is relatively high; such that at present a substantial overcapacity exists. Technical availability of gas turbines and interconnection capacity in the Netherlands compared to peak demand will remain good in the years to come, although profit margins of gas-fired assets are under pressure and some plants are currently closed or mothballed. The low profit margins also threaten the replacement of many CHP plants that are approaching their technical lifetime. With limited percentages of renewables to be implemented in the Netherlands compared to surrounding countries in an Energieakkoord scenario and improved predictability of wind and solar supply, there seems no absolute 'need' for specific new capacity to be implemented for flexibility reasons in the Netherlands until 2023.

A need for additional flexibility due to increasing RES penetration may emerge after 2030, timely anticipation could reduce flexibility costs.

A combination of increasing shares of RES and decreasing conventional capacity will cause a need for additional flexibility at some point in the future. The overcapacity in The Netherlands is expected to remain until around 2030, although reliable long-term predictions for the fast-changing electricity sector are difficult. Timely anticipating the future flexibility needs could reduce costs. Some flexibility options have long lead times, so timely investments could prevent a last-minute resort to more expensive solutions. Rapidly increasing system costs for integrating the variable renewables also form a powerful driver to have a critical look at the organisation of the system, in order to minimise these additional costs as much as possible.

A main systemic uncertainty is the degree to which decentral (household) electricity generation and penetration of electric vehicles will develop.

Unforeseen developments could speed up the need for additional flexibility, such as an unexpected further boom of local renewables or an increase in electricity demand due to fast penetration of electric vehicles in the market. The evolving role of decentralised power generation and demand management in the market will require a fundamental rethinking of basic design principles of the electricity system to include bottom-up considerations next to the traditional top-down orientation of dispatch of central generation capacity. This includes questions such as to what degree decentral generation can compete on a level playing field with large-scale generation in central dispatch, to what extent decentral generation could be aggregated and used for flexibility purposes on a central level and what would be consequences for the distribution grids.

With regard to the flexibility options of the Dutch power system

There is a wide variety of flexibility options available for the Netherlands, which can be roughly divided into regulatory and investment-based options.

A more flexible power system can be attained on one hand by investments in specific options in supply, demand, storage or the network, and on the other hand by regulatory interventions such as capacity mechanisms, RES curtailment, and market coupling. As such, there are many technical options as well as a broad policy portfolio available to increase flexibility in the power system.

Innovative flexibility options such as storage and smart-grid enabled demand-side management that will enter the electricity market in the future will require further technical improvements and cost reductions to be able to compete with existing flexibility options.

With increasing percentages of variable power, innovative flexibility options will enter the electricity market at some point in the future. Regulation therefore should make sure that there is equal access and a level playing field for all existing and innovative options alike. However, the exact moment of entry of these innovative options, either before or after 2030, will depend on further technological innovations and cost reductions that will make them able to compete with, and substitute the existing flexibility options.

Improving market access and RES curtailment are regulatory options that can be used relatively easily on a national level, whereas improving market coupling can serve on an international level to increase flexibility of the Dutch electricity system.

Improving market access of households and other small-scale customers, as well as other fine-tuning options such as further increasing transparency and near-real time trade, can contribute to a higher flexibility of the electricity system in the Netherlands. In case of unforeseen supply peaks that require swift action, curtailment of renewable energy can also be used as a relatively cheap and easy emergency option for system flexibility. Further improvement of coupling of European short-, medium- and long term markets increases size and diversity of the market area and as such contributes substantially to improving flexibility in The Netherlands and its neighbouring countries.

The need for capacity mechanisms as a regulatory option for the Netherlands has not been demonstrated and its introduction could also entail substantial risks for further development of low-carbon options in the future

Whereas several neighbouring countries of the Netherlands already have introduced capacity mechanisms to increase flexibility in the electricity sector, its need for introduction in the Netherlands is not evident. Moreover, opinions of stakeholders in the Netherlands on this issue vary widely. Whilst providing a possible benefit for flexibility, this regulatory option also entails substantial risks for the electricity sector. These include a potential overstimulation of conventional generation options - which interferes with emission reduction and RES objectives of the EU and the Netherlands – and barriers to the development of innovative flexibility options that could better prosper in an energy-only market.

No 'silver bullet' exists between the basic investment-based options of improving flexibility of conventional plants, smarter demand response, interconnections and storage.

Each of these four different categories of investment-based flexibility options examined has its own general and specific benefits and costs for The Netherlands associated. A proper evaluation of their relative economics would require modelling capabilities that are not yet available in the market. In general, more innovative solutions like most storage options are still too expensive to compete in electricity markets. Increasing interconnection capacity makes economic sense, even regardless of the flexibility issue. Power-to-heat and demand response are expected to become important sources for flexibility soon. With an equal regulatory access assured, private and public (in the case of grids) investors will have to evaluate technical specifications, social and political acceptance and investment and operational costs to make the case for their specific option considered.

Recommendations for further research and policy

Research recommendations

Modelling capacity for analysing flexibility needs and options needs to be improved.

Capacities of present state-of-the-art electricity sector models have shown to be too limited in this research project to model flexibility needs and options in a credible way. Improvements are needed to include the low- and medium- voltage networks (decentral) next to high-voltage grids, revenues on all electricity markets from futures to near-real time and strategic market behaviour of actors.

The consequences of the emergence of decentral generation should be further examined.

The emergence of decentral power generation might have important and so far largely unknown consequences for the organisation of the electricity system, including profound impacts on current business models of incumbent parties in the electricity sector, technical impacts on the system as well as socio-economic consequences for end-users. These need to be examined in more detail.

Policy recommendations

Assure equal market access for all options to short-, medium- and long-term flexibility markets

Basis for good functioning flexibility markets is a level playing field for all demand-, storage- and supply-side options alike. Make therefore sure that demand-reduction by small and large end-users as well as storage are valued on an equal basis to supply-side options on balancing, intra- and day-ahead markets.

Stimulate further integration of European electricity markets on all time-scales

Although one European electricity market should be realised by 2014, in practice many detailed regulatory differences still exist between national balancing-, intra-day and day-ahead markets. Improved coordination via e.g. the Pentalateral forum could help to remove these barriers. Also, best practices of the Pentalateral forum could be communicated to other Member States and vice versa.

Stimulate the further development of additional flexibility options that can contribute to meet future flexibility needs also in other EU Member States

Innovative flexibility options need to be further developed in order to be able to compete with existing flexibility options in the future. In the Netherlands there is a large variety of research ongoing in this field that can be further supported in order to develop increased flexibility for the future domestic electricity market as well as new export opportunities.

Glossary

Balancing	Restoring system frequency
CAES	Compressed air energy storage
CCGT	Combined Cycle Gas Turbine
CHP	Combined heat and power plant (cogeneration)
CRM	Capacity Remuneration Mechanisms
Curtailment	The practice of turning off wind and/or solar power generation
CWE	Central West European Region
Decentral	Non-centralised/local
Demand Response	End-use customers reducing their use of electricity in response to power grid needs
Dispatchable generation	Power plants with manageable output
DSM	Demand Side Management
DSO	Distribution System Operator (responsible for the low and medium voltage grid)
Emergency capacity	Procured by TenneT for tertiary reserve
Flexibility	The extent to which a power system can increase/decrease electricity production or consumption in response to variability
Intermittent	Or variable as used by the IEA. The word stresses the fluctuating character of the power output (due to meteorological conditions)
Investment-based flexibility options	Require financial investments either in supply, demand, storage or the network
Non-dispatchable generation	Power producers that cannot be managed as desired. Non-dispatchable producers can potentially be switched off but not switched on as desired (due to lag-time).
PLEXOS	The northwest European market model developed by DNV GL is based on the PLEXOS modelling framework and used for modelling in this study
Primary reserve	Automatically activated by the primary control system, to stabilise the system frequency after a contingency event
PRP	Programme responsible party (ENTSO-E uses the term Balancing Responsible Part BRP)
Ramping	Ramp rate is the speed at which a generator can increase (ramp up) or decrease (ramp down) generation
Regulating capacity	Procured by TenneT for secondary reserve
Regulatory flexibility options	(i.e. instruments) that require primarily regulatory intervention
RES	Renewable energy sources
Reserve capacity	Procured by TenneT for tertiary reserve
Reserve margin	The difference between reliable available capacity and load
Residual load	Or residual demand. Residual demand (t) = demand (t)– non-dispatchable generation (t)
Secondary reserve	Activated to bring the frequency back from its steady-state frequency to its nominal value within 15 minutes

SER	The Social and Economic Council of the Netherlands
Smart grid	A smart grid is an electricity network based on digital technology that is used to supply electricity to consumers via two-way digital communication
SME	Small and medium-sized Enterprises
Spot market	Power trading platform for day ahead transactions (trading today for delivery of electricity tomorrow) as well as Intraday transactions for on-the-day trading
Tertiary reserve	Activated within 15 minutes of being called, for at least 15 minutes duration, and are procured on a daily basis
TSO	Transmission System Operator (responsible for the high-voltage grid, TenneT in the Netherlands)

1. Introduction

1.1 Background

The European electricity system is on the verge of a second organisational revolution. After the start of electricity sector liberalisation in the nineties, it is now the success of European renewable energy policies that sees traditional business models in the electricity sector rapidly changing. Whereas large incumbent suppliers are gradually diversifying into renewables, their dominant position is starting to get challenged by households and independent suppliers of renewable energy that in increasing amounts offer their production to the grids. Also compounded by technological developments such as 'smarter' grids, the traditional organisation of the electricity sector is thereby changing from one-directional, i.e. from producer to consumer, into a two-directional model, in which consumers can be at the same time producers or can strategically restrict their demand to fit higher electricity system goals.

Although the changing organisation of the electricity sector can be seen as an important accomplishment of European liberalisation policies, together with the growth of renewable energy it also offers new challenges for policy makers. These concern in particular the policy goal of security of supply. Electricity systems share the specific technical characteristic that supply and demand need to be in balance at all times for the stability of the system. Therefore the increasing variability in supply and the increasing possibilities to strategically restrain demand together imply the need for a far larger flexibility in electricity grids in order to cope with increasing variability in supply and demand. At all times that renewable energy is not sufficiently available; reserve power capacity is needed to balance supply and demand. On the other hand, in times of oversupply of electricity, new ways need to be found to make an appropriate use of the surplus.

However, current market trends regarding availability of reserve power to counter undersupply are opposite to what would be needed. Gas turbines so far are often used to provide flexibility to the system, but, due to the large influxes of renewable energy low coal prices and a malfunctioning European Emissions Trading System, they can no longer make sufficient hours to remain profitable to their owners. As a consequence, new gas turbines have already been taken out of operation in various countries and are no longer available to provide flexibility. The realisation of this policy problem has already led to a reaction in many European Member States. They decided to introduce 'capacity mechanisms' that provide incentives to power producers to keep reserve power available.

In the Netherlands, such a policy decision has not been taken. Moreover, it is still an open question if in the specific situation of the Dutch electricity sector such a regulatory intervention would be needed at all. This report therefore examines in more detail what are the specific requirements for increasing flexibility in the Dutch electricity sector. It also examines what are the specific options available to policy makers to increase flexibility in case that an intervention would be needed.

1.2 Aims and scope of this project

Aims of this project

As a contribution to the discussion about solving the organisational challenges of European and Dutch electricity supply as outlined above, this study focuses on **flexibility needs and options in the**

Netherlands. Within the context of a changing organisation of the European electricity sector, it will analyse:

1. **The specific Dutch situation regarding flexibility needs**
   What is the specific situation of the electricity sector in the Netherlands and what are balancing and flexibility needs now and up to 2023, taking into account Dutch policy objectives and developments abroad?

2. **Flexibility options available to the Netherlands**
   Which technical and regulatory balancing and flexibility options are available to the Netherlands, and which are their specific benefits and limitations?

Scope of this project

In order to delineate this research project in more detail, the following limitations were set to the scope of the project:

Geographical

The Netherlands are the geographical focus point of this research project. As the Dutch electricity market is part of a wider European electricity market (e.g. the Central West region) flexibility needs cannot be examined without establishing the links to neighbouring countries, these will be also examined. The influence of developments in Germany, but also in Belgium, Great-Britain, Denmark and Norway will be accounted for in the study.

Timeframe

The primary time horizon of the project is that of the Dutch Energieakkoord, i.e. from 2013 to 2023. An outlook will be given to the situation until 2030.

Central and decentral power generation

Focus of this report is on flexibility as an issue for a regulated, national grid within the interconnected European grid system. Central and decentral power generation are examined as giving rise to flexibility issues for such a grid, with a focus on central power generation. Decoupling of decentral grids and future possibilities for stand-alone local power generation are not considered.

Scenarios

For this report, development of renewable energy policies as aimed at by the Dutch Energieakkoord up to 2023. For further developments up to 2030, an extrapolation was made of these targets.

1.3 Reading guide

Chapter 2 of this report will define in more detail what is meant exactly by flexibility in the electricity sector. It will then look in more detail into the specific electricity sector situation in the Netherlands and examine to what extent claims of a ‘need’ for increased flexibility can be substantiated until 2030. Chapter 3 will subsequently discuss what options would be available for increasing flexibility in the Dutch electricity sector. The report ends with a chapter giving main conclusions and recommendations for Dutch policy makers.

2. Flexibility requirements in the Netherlands

This chapter discusses to what extent the Dutch electricity system would require interventions to meet increased flexibility needs in the future. The timeframe regarded here is the period up to 2030, with 2023 as an important interim date – as main Dutch energy policy goals are formulated for that year.

The chapter starts with a more precise definition of the concept of 'flexibility' in electricity sectors (section 2.1). The next sections analyse how current flexibility needs are met in the Netherlands and what could be requirements up to 2030 (sections 2.2 and 2.3). Section 2.4 discusses views on flexibility needs in the Netherlands of stakeholders and experts. Section 2.5 finally gives main conclusions regarding flexibility requirements in the Netherlands.

2.1 Definition of flexibility

Currently, there are various approaches which all try to characterize the flexibility requirements of an energy system[1]. What makes it difficult is that there is no uniform definition of flexibility, nor a single indicator of a system's flexibility requirement. Given this perspective, we choose to adopt the definition of flexibility as given by the IEA, as it is most often used by academia and policy makers[2]:

> ***"Flexibility expresses the extent to which a power system can increase/decrease electricity production or consumption in response to variability"***

The flexibility issue is often confused with balancing. Though these concepts are similar, they are not the same. Balancing is defined by Mott MacDonald (2013) as: "All actions and processes through which TSOs ensure that total electricity withdrawals are equalled by total injections in a continuous way, in order to maintain the system frequency within a predefined stability range"[3]. These are operations in the time range of a few seconds to approximately one hour. This should be seen in contrast to flexibility, which covers a much broader timespan, including daily, weekly and even seasonal variations. Balancing is thus part of the flexibility issue, but it only covers the very short-term matching of demand and supply.

An increased share of variable renewables in the electricity mix might lead to flexibility challenges within different timescales, depending on the frequency or time resolution of demand and supply variations[4]. For this report, we distinguish three simplified timescales[5]:

Type of flexibility	Timescale	Corresponding market
Short-term	< 15 minutes	Balancing
Mid-term	Day	Intraday/Day-ahead
Long-term	Weeks/season	Future contracts

[1] E.g. IEA/OECD, 2014; Holttintinen, 2013; NREL, 2014; ETH Zurich, 2012; University College Dublin, 2012;
[2] International Energy Agency, 2011. Harnessing variable renewables. Technical report
[3] Mott MacDonald, 2013, Impact Assessment on European Electricity Balancing Market, March 2013
[4] Depending on whether variations are more prominent on for example an hourly or a seasonal scale.
[5] 'Generation adequacy' is sometimes used as a technical term to delineate what we call in this report 'long-term flexibility'.

For an adequate assessment of flexibility needs, it is important to examine the impact of an increased share of renewables on each of the three flexibility time-scales. Also, it should be taken into account that the policy discussion about flexibility on one hand concerns the optimal economic dispatch of available generation capacity on the short term, and incentives for investment in new generation capacity or other flexibility options on the longer term.

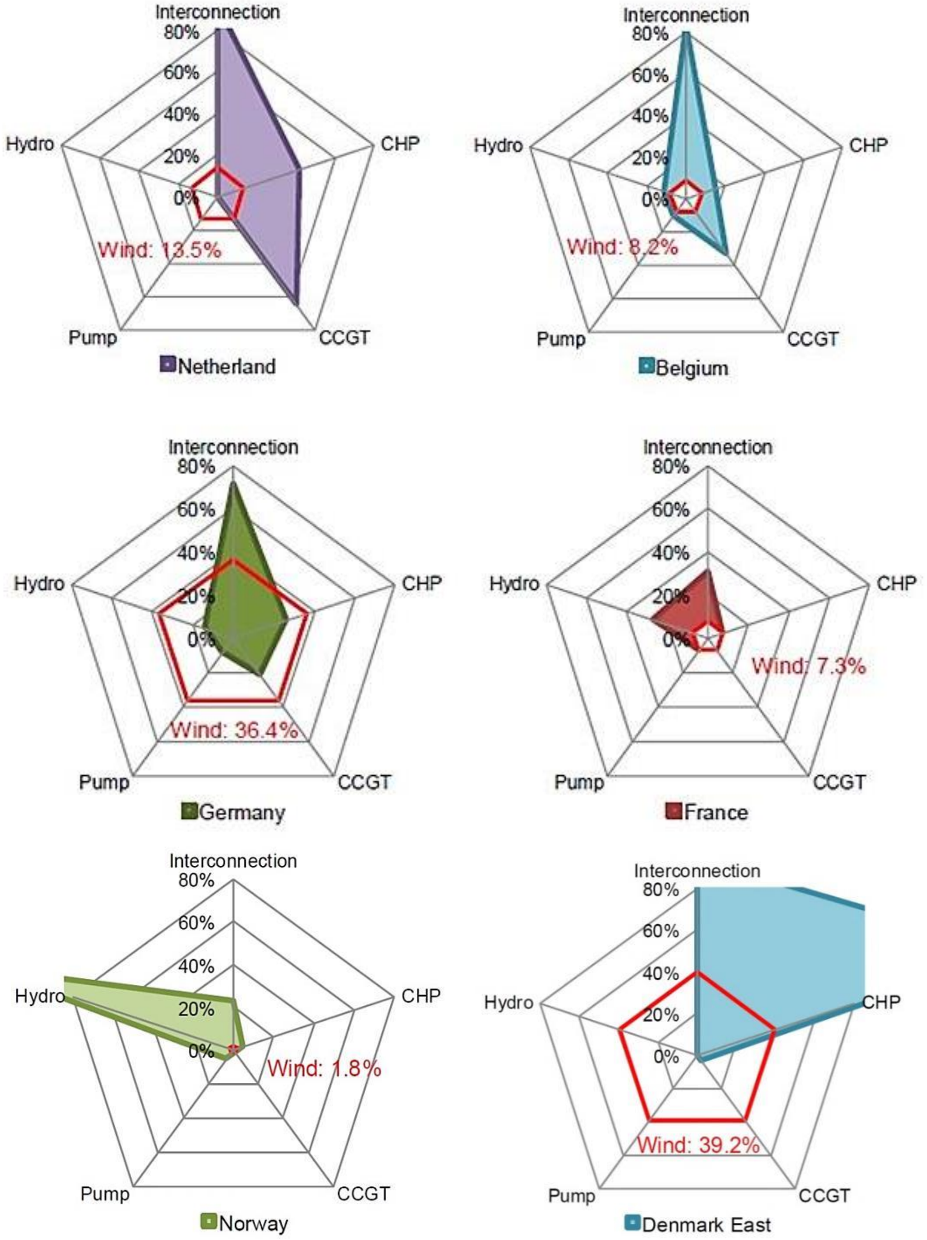
2.2 How the Netherlands currently meets its flexibility requirements

In order to deal with varying demand patterns and supply or network incidents, today's power systems already provide a substantial degree of flexibility. This flexibility is arranged and valued via markets (see Annex 1: How markets deal with flexibility). However, not all countries have equally flexible power systems and deal with varying demand and supply patterns in different ways. Some countries develop significant interconnection capacities, while others for instance focus on more supply-driven solutions (e.g. CCGTs, CHP), or on hydro capacity.

That countries have different points of departure is perhaps best depicted in figures they refer to as 'flexibility charts'[6]. These flexibility charts for The Netherlands, Belgium, Germany and France show the different degrees of potential flexibility and the main sources for each country (see Figure 2-1). As the figures show, the Dutch power system provides a substantial degree of flexibility. Contrary to the surrounding countries, the Netherlands already have three potential sources for flexibility in a substantial amount available: interconnection, CHP and CCGT. Figure 2-1 shows that interconnection capacity in the Netherlands already potentially can meet more than 80% of current peak demand, CCGT 60% and CHP 40%, whereas current installed wind capacity is low compared to other countries (13.5% of peak demand). Only Denmark has, with two large potential sources of flexibility (interconnection and CHP) a similar existing flexibility capacity. Neither are there in the current electricity system in the Netherlands signs that indicate a shortage in flexibility capacity so far (Annex 1). However, main question is if this will change in the future.

[6] Yasuda, Y, et al., 2013, Flexibility Chart: Evaluation on Diversity of Flexibility in Various Areas

Figure 2-1 Flexibility charts of NL, BE, DE, FR with wind penetration ratio (% of installed power compared to peak demand as of the end of 2011, red line signalling installed wind capacity in relation to peak demand) [7]



[7] Yasuda, Y, et al., 2013, Flexibility Chart: Evaluation on Diversity of Flexibility in Various Areas

2.3 Future flexibility requirements in the Netherlands

The extent to which future flexibility needs in the Netherlands will increase, will depend for a large part how future supply, demand and interconnection in the Netherlands will develop. These developments are described in this section.

2.3.1 Supply-side developments

One of the major causes for the expected increased flexibility needs is the growth in variable RES production in the Netherlands as well as in neighbouring countries. In the Netherlands, up to 2023 a substantial growth in RES production is aimed at in the 2013 SER Agreement (Box 2.1)

Box 2.1: SER Agreement goals

For renewable energy, the SER agreement sets a target of 16% by 2023. This implies that 40% of all electricity in the Netherlands by 2023 should be generated from renewable energy sources. For comparison: in 2013, this share was only 12%.

Wind power and solar PV play a key role in the plans (Table 1.1). Onshore wind capacity will be expanded to 6 000 MW in 2020. Taking into account the necessary decommissioning and refurbishing of existing turbines, this means that some 5 000 MW of new wind capacity needs to be installed. The targets for offshore wind are equally ambitious: 4450 MW in 2023. It is foreseen that in 2019 the next offshore turbines will come online. Solar PV has to grow to about 5 000 to 6 000 MWp by 2023.

Table 2-1 Targets of the SER Agreement

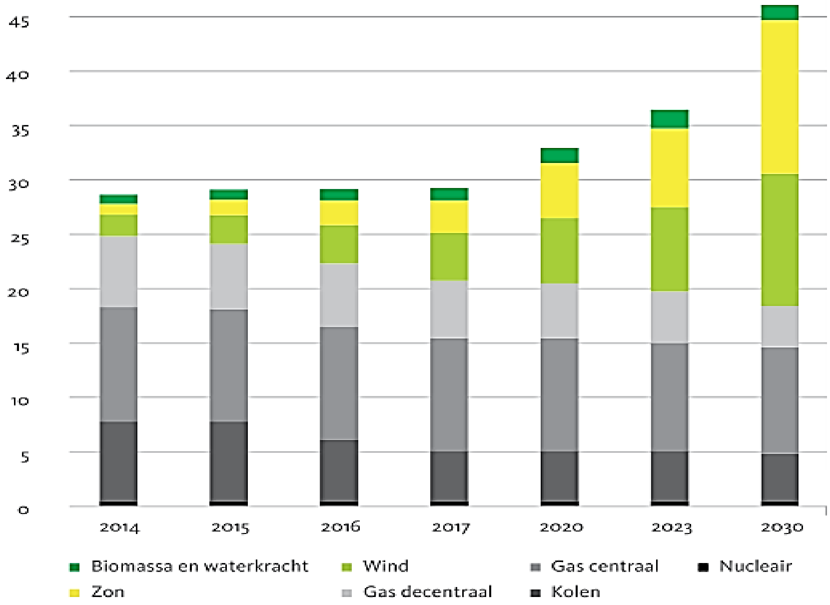
Capacity	Unit	2013	Target 2020	Target 2023
Wind (onshore)	MW	2100	6000	
Wind (offshore)	MW	228		4450
Solar PV	MWp	550	4000	5000 – 6000
Electricity production				
Share renewables	%	12	32	40
Share wind and solar PV	%	6	22	31

The potential impact of RES on flexibility needs has to be evaluated against the size and age of the current electricity generation park and in particular against developments in the two available supply-side flexibility options as indicated by Yahuda et al.: CCGT gas turbines and cogeneration plants. Also, developments in decentral power generation need to be taken into account here.

Age and size of the electricity generation park in the Netherlands up to 2030

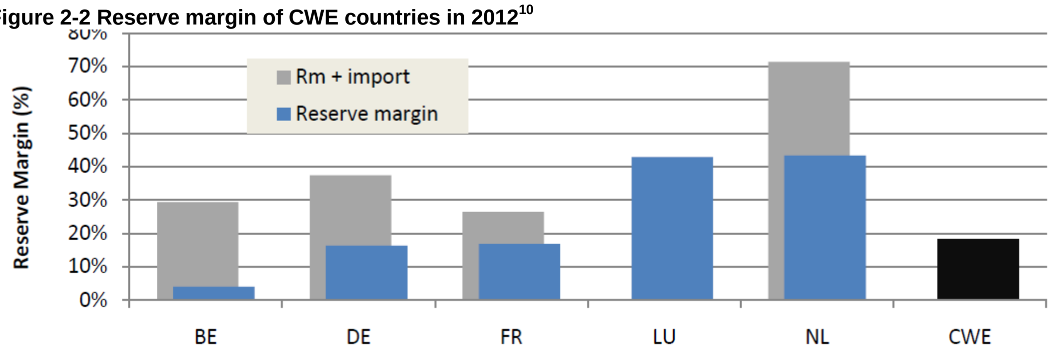
With presently announced policies, the Dutch electricity supply will change substantially up to 2030 as is depicted in the figure below.

Figure 2-1 Capacity development in The Netherlands (GW) 2014 - 2030[8]



The share of gas-fired power capacity (CCGT + CHP) will decrease which will be compensated by an increase of renewable, predominantly wind and solar PV. The share of coal fired power plants will not change significantly and remains stable from 2020 onwards. The coal fired power plants, which came in operation in the 1980s, will close down within the next two years. This will be compensated by three new coal power plants that will come online in 2014. In 2012, the reserve margin (reliable available capacity – peak load) of the Netherlands was the largest in all of the CWE countries (about 40%). In 2014, this margin further increased to 62%. TenneT expects the reserve margin to further increase to 87% by 2021[9].

Figure 2-2 Reserve margin of CWE countries in 2012[10]



After 2021, the reserve margin is expected to decrease and may even disappear around 2030 if mothballed plants are not reopened[11]. In this case, a need for additional back-up capacity would emerge around that time.

[8] ECN/PBL Nationale Energieverkenning 2014
[9] TenneT, 2014, Rapport Monitoring Leveringszekerheid 2013 - 2029
[10] Albrecht, 2014, The price of energy security in depressed electricity markets; the case of Belgium, Prof.Dr. Johan Albrecht, Faculteit Economie & Bedrijfskunde, Second Summer School Economics of Electricity Markets, 28/08/2014
[11] TenneT, 2014, Rapport Monitoring Leveringszekerheid 2013 - 2029

Developments in CCGT gas turbines up to 2030

CCGT gas turbines are seen by Yahuda et al. as one of the key potential flexibility options in the Netherlands. In that light, the recent mothballing of a brand-new CCGT in the Netherlands in February 2014 can be seen as an important event[12]. The mothballing was motivated with the reason that, according to its owner, 'it could no longer compete with cheap German electricity'[13]. In this way, it contributed to the discussion about the need or not for a capacity mechanism in the Netherlands[14]. If such a modern power plant already was mothballed, would that not indicate that such a mechanism would be inevitable to secure the future survival of gas power plants as a source for flexibility in the power system? However, the specific situation of this power plant, being situated very close to the Belgian border, already gave rise to a subsequent discussion about connection of the plant to the Belgian grid[15] – suggesting that there is also a strategic component involved in the mothballing.

Looking at the CCGT park in the Netherlands, their start of operation and regular end of lifetime, the following can be said: Low electricity prices, together with low CO2 prices and low coal prices have pushed gas-fired power plants out of the market. The share of total gas-fired electricity production in total electricity production has steadily declined from 62% in 2010 to 60% in 2011 and 53% in 2012 and 2013. In 2013 and the first half of 2014, a substantial amount of gas-fired capacity was being mothballed (3284 MW) or closed down (2559 MW) in the Netherlands[16]. Furthermore, almost all previously announced capacity investment projects for the Netherlands have been either cancelled or been put on hold[17]. ECN and PBL predict that central gas-fired power production in the Netherlands will therefore only account for 34% of total power production in 2014. This implies that gas will lose its role as dominant energy carrier in the Netherlands for the first in a very long time. Although closure and mothballing can be seen as a normal market response, it can cause serious concerns in terms of loss of flexibility if the trend will prolong. Up to 2020 gas-fired capacity is expected to decline marginally to 10,5 GW, after which the situation is to remain stable. These projections are however uncertain. For example, the role of gas-fired power plants could increase when flexibility requirements increase[18].

Table 2-1 Future development of central gas-fired power plants in the Netherlands[19]

		2014	2020	2023	2030
Production share	%	34	19	16	11
Capacity	GW	11	10,5	10	9,5

Developments in cogeneration up to 2030

Cogeneration traditionally plays a large role in Dutch electricity supply in the Netherlands (up to 30% of total electricity production[20]), at least since a boom in the nineties up to 2005. From 2010 onwards the share of CHP in the Dutch power mix has declined. Currently CHP only foresees in 20% of the final heat use in the industry and this share is expected to decline to 10% in 2020.To date CHP capacity in the Netherlands consists in particular of industrial capacity as well as of cogeneration capacity for the Dutch greenhouse sector.

[12] Financieel Dagblad (2014) Essent sluit nieuwe gascentrale, 5 February 2014
[13] Ibid.
[14] For more detail on capacity mechanisms, see section 3.1.1
[15] https://www.essent.nl/content/overessent/actueel/archief/2014/rwe-stelt-clauscentrale-beschikbaar-voor-belgische-markt.html
[16] Tennet, Market Review 2014 (First half 2014)
[17] Ibid.
[18] ECN, 2014, Quanitifying flexibility markets (to be released shortly)
[19] ECN/PBL Nationale Energieverkenning 2014
[20] PBL/ECN, 2014, Energietrends 2014

As CHP have an operating lifetime of about 15 to 20 years operators are being faced to amortise their investments and have to invest in new capacity. Electricity prices however have remained stable, or even declined, while gas prices have increased. This implies that the future of CHP, when taking into account price developments, will look gloomy. This is also stressed in the latest CHP barometer[21], which expects that the margin of gas-fired power plants will remain negative until 2016. Recent forecast as stipulated in the NEV indicate a further decline in the production share of CHP in the Netherlands, from 19% in 2014 to only 11% in 2030.

Table 2-2 Future development of decentral gas-fired power plants in the Netherlands CHP[22]

		2014	2020	2023	2030
Production share	%	19	16	14	12
Capacity (electric)	GW	7	5,5	5	3

Decentral power generation up to 2030

An important question for future flexibility needs in the Netherlands will also be how decentral power generation apart from cogeneration will develop until 2030. If decentral power would grow rapidly, it would add to intermittent RES power in particular in the form of PV.

Growth-scenarios of the TKI Solar Energy show that 20 GWp of solar PV capacity can be realised by 2030. During summer 2014 the first GWp of solar PV capacity was reached.

Table 2-3 Future development of solar PV in the Netherlands[23]

		2014	2020	2023	2030
Production share	%	0.9	4,1	5.6	11.2
Capacity	GWp	1	4	5-6	20

By 2030, PBL and DNV GL[24] calculated that the low-voltage demand peak during a typical winter day is about 8 GW. Maximum PV supply via low voltage on a summer afternoon is 18 GW. Supply peak is thus higher than the demand peak. Whether the rapid growth of solar PV is to continue will greatly depend on price and efficiency developments of solar systems. Next to this, it remains uncertain what will happen with financial support arrangements such as the Dutch "salderingsregeling", which will be evaluated in 2016.

[21] Energy matters, 2014, WKK barometer Juli 2014
[22] EU, 2014, Energy in figures - Statistical pocketbook
[23] ECN/PBL Nationale Energieverkenning 2014
[24] DNV Gl/PBL, 2014, Het potentieel van zonnestroom in de gebouwde omgeving van Nederland

Box 2.2 The role of decentralised supply and demand for flexibility

Perhaps the largest uncertainty in the development of the power system is the evolving role of decentralised actors in the market. Local actors will have an increasing influence on the power system. Currently, households and SMEs are passive consumers. They do not interact with the power system and hardly produce power. This role is slowly changing. More and more households and SMEs start producing their own power and supplying power to the grid, mainly from PV panels. The development of a smart grid will also increasingly enable consumers to respond to price signals and adjust their power consumption behaviour accordingly. In a future power system, todays passive consumers of energy could become active producers and consumers of clean energy, often referred to as prosumers.

Today, we already see the local production of energy increasing. The amount of households with PV panels is increasing exponentially in The Netherlands. There is also a boom in citizen cooperatives with the objective of local energy generation. These cooperatives struggle to find a viable business model, but when they do it could lead to a fast growth in decentralised power production.
An increase of demand for residential consumers is also expected. The increasing share of heat pumps and electric vehicles is referred to as the electrification of the heating and transport sectors.

These decentral developments can have profound implications for the flexibility challenge. The increase in local demand and supply could add to the flexibility requirements. Especially since heating and transport is not evenly distributed throughout the day, but occurs in peaks. On the other hand, a smart management of supply and demand could also increase the flexibility of the system. The development of a smart grid enables local 'prosumers' to charge their electric vehicle at times of excess power supply when prices are low. Similarly, the combined storage capacity of an electric car fleet could be used to provide capacity to the system when a demand peak occurs. This management of demand and supply could help to balance out the national grid. Supply and demand can also be matched on a local level, thus easing the strain on the high voltage grid.
A big question for policy makers and other stakeholders, such as TSOs and DSOs, is whether it is cheaper to deal with flexibility on a local scale or on a national scale. This has for instance implications for grid investments. An increase of local flexibility solutions will increase the need for low voltage grid investments and -as explained- thus decrease the need for high voltage grid investments.

2.3.2 *Demand-side developments*

Electricity demand in the Netherlands is expected to increase on average by 1 to 1.25% per year until 2030[25] . This does not seem to indicate particular needs for additional flexibility capacity at first glance. Also the recently released NEV projects that national primary electricity demand will stabilize up to 2020 (105 TWh), and only marginally increase to 2030 due to improved economic growth (115 TWh). However, for short-term flexibility needs it is of course important how peak demand patterns will develop. Here there are no main structural changes foreseen until 2030, apart from changes in demand patterns that might be induced by the development of decentral supply (reducing demand for centrally produced and distributed electricity) or changing patterns as a result of demand-side management (levelling out peaks and valleys in demand).

[25] TenneT, 2013, Kwaliteits en Capaciteitsdocument deel 1

One specific option on the demand side is the development of electric vehicles (EV), which could serve as an additional demand source by recharging them, specifically at times of oversupply in the electricity grid. The Dutch government aims at 1 million electric cars in 2025[26] (see table 2.8). This would cause an additional electricity demand of 3 TWh per year[27], adding around 2% to total demand.

Table 2-2: Development of electric vehicles and (semi) public charge points in the Netherlands
(Italics: policy targets)[28]

	01-2012	01-2013	01- 2014	10-2014	2020	2025
Electric vehicles	~4.000	7.410	30.211	42.017	*200.000*	*1.000.000*
(Semi) public charge points	~1.900	3.664	5.876	10.679	-	-

EV can bring flexibility to the electricity network through a system called Vehicle-to-grid (V2G). The vehicles communicate with the grid and apply a sell demand response service, either through delivering electricity, or simply by lowering their charging rate. The market of V2G is still in a start-up-phase, but according to the few studies available the prospects for this technology is very positive[29]. The JRC has shown, in a scenario with 10% EV in total car fleet (which could happen around 2025 in the Netherlands), EV have the potential to significantly shift load during the day, leading to peak-shaving (up to 2 GW per country) in the afternoon[30]. Peaks however will increase during the evening, and to a lesser extent during the night. Whether the 1 million electric cars will actually be on the roads in 2025 already is highly questionable. The 2015 target of 20.000 electric vehicles has already surpassed, primarily due to attractive fiscal measures, but realising 1 million electric vehicles by 2025 seems still a long way to go.

2.3.3 *Developments in interconnection capacity*

In the neighbouring countries of the Netherlands, up to 2030 installed RES capacity will also significantly increase (Table 2-1). This is important, as the Netherlands will also share in the potential detrimental or beneficial consequences for flexibility of these developments via its interconnection capacity. It is therefore also relevant to know which are up to 2030 the foreseen developments in interconnection capacity of the Netherlands with its neighbouring countries.

Table 2-3 Intermittent renewables production of total indigenous production + policy plans for RES-E in countries with direct interconnections to the Netherlands (as far as specified)[31]

Country	Wind	Solar	RES-E policy goals
Netherlands	2013: 5,6%	2013: 0,5%	
Germany	2014: 9%	2014: 6,8%	55 -60% % RES in electricity (2030) 35% RES in electricity (2020)
Belgium	2012: 2,8%	2012: 2,1%	
United Kingdom	2013: 6,6%	2013: 0,01%	
Denmark	2013: 32,7%	2012: 0,1%	50% wind in electricity (2020)
Norway	2012: 1,1%	2012: 0%	

[26] http://www.rijksoverheid.nl/onderwerpen/auto/elektrisch-rijden
[27] CE Delft, 2009, Duurzame elektriciteitsmarkt? October 2009 3.090.1
[28] RVO, 2014, Cijfers elektrisch vervoer
[29] Debnath et. al (2014) *"Energy storage model with gridable vehicles for economic load dispatch in the smart grid"*. Edith Cowan University, Joondalup, WA 6030, Australia
[30] JRC, 2013, Technology Aspects of the Energy Transition, Stathis Peteves, Head of Unit, Energy Systems Evaluation Unit, Scientific Support to the Energy Mix, 8-Nov-2013
[31] UK government, 2013; Fraunhofer, 2014, Carsten Vittrup. "2013 was a record-setting year for Danish wind power; BP, 2014; NVE, 2013

Within the timeframe up to 2030 there are several plans for new cross-border transmission capacity between the Netherlands and its neighbours. These extensions are part of the realisation of the European policy plans to establish a pan-European electricity market.

In practice, the following new interconnections are foreseen up to 2030:

- To handle the increased power flows between Germany and the Netherlands that are occurring between the Netherlands and Germany, an extra 1.300MW 380 kV connection line is to be realised in 2016 (Doetichem – Niederrhein) and TenneT is currently investigating the economic feasibility of increasing interconnector capacity between Meeden and Diele.
- It is to be expected that a fourth phase shifter in the 400 kV substation of Zandvliet (Belgium) will be installed at the Dutch-Belgium Border. This will extent the interconnection capacity by an additional 700 MW by 2016.
- A connection to Denmark, the COBRA cable, is in the design and permitting phase. The cable is planned to have a capacity of 700 MW and should become operational in 2019[32].;
- A second interconnector to Norway (700 MW capacity) is under consideration (NorNed2). At the moment there is no date foreseen but it is at least not expected to become operational before 2022.

The latest ENTSO-E scenario's indicate that that under the given assumptions the Dutch interconnection capacity will increase from 5,7 GW in 2014 to 9.8 GW in 2030 , thus increasing by 72% compared to the current situation.This equals 20% of total installed electrical capacity, both in 2014 and in 2030.

Table 2-4 Interconnection capacity of the Netherlands, 2014 and 2030[33]

Interconnection capacity of the Netherlands with	2014	2030
Belgium	1,5	2,2
Germany	2,5	3,8
Norway	0,7	1,4
United Kingdom	1,0	1,0
Denmark		0,7
Unknown yet		0,7
Total	**5,7**	**9,8**

Question is if through increased interconnection capacity not problems of overcapacity due to large percentages of RES in other countries are imported. However, even in Denmark and Germany, with much higher RES percentages as in the Netherlands, flexibility problems so far remain limited (Box 2.3). In addition, through interconnection capacity with several national electricity systems power outages can be prevented, as was the case with the NorNed cable between Norway and the Netherlands on the 11th of May 2014. In that night, from 2 to 8 a.m., the power flow in the NorNed cable was reversed (to flow from the Netherlands to Norway) in order to deal with an exceptionally high supply of wind power and low demand during those hours[34].

[32] RGI, 2013, Overview: where do we stand? What is built, what is planned?, Bergen, 27 June 2013, Theresa Schneider, Renewables Grid Initiative; TenneT, 2014, Groen licht voor 300 km lange 'groene' zeekabel tussen Nederland en Denemarken, 10 September 2014

[33] ENTSO-E, 2014, Scenario Outlook and Adequacy Forecast 2014-2030

[34] TenneT, 2014, Market Review 2014: Electricity market insights, first half 2014

Box 2.3 Technical power outages in Germany and Denmark

The German energy transition has entered its adolescence, and is much more mature than the Netherlands, which has in terms of penetration of variable renewables only reached its infancy. Nevertheless, the German grid doesn't seem to have experienced major problems in effectively integrating the increasing share of variable renewables in technical sense. On the contrary, Germany has had the most reliable grid in Europe since standardized power outage statistics (SAIDI) were released in 2006. The average power outage in Germany fell below the level of 2012 (about 15 minutes over the whole year), which was already the lowest number in Europe. In the German media, there are only a few examples to be found of near power outages. These indicate that technical failures, such as failure of a substation or malfunction in a nuclear facility, and not intermittent renewable production are the cause of the near technical blackouts.

In Denmark, the integration of wind power in the electricity system so far is a success story; no major incidents at system level have been experienced. Only a few hours per year, the Danes produce so much wind power that they have to pay other countries to import the surplus. Denmark's energy system is currently able to cope with the intermittent character of wind power due to large district-heating, interconnection and demand-side management capacity.

2.4 Views on flexibility requirements and main uncertainties

The previous section argues that, whereas most signs indicate that needs for additional flexibility capacity in the Netherlands up to 2030 will be limited, there are also many uncertainties around this conclusion. A key uncertainty is obviously the pace by which variable renewable electricity sources will be introduced in the Dutch electricity system. The recently published 'Nationale Energieverkenning', which explores possible energy futures of the Netherlands, estimates that realisation of renewable energy targets up to 2023 will lag behind schedule[35]. With even more ambitious emission reduction targets ahead for 2050, it could also be argued however, that sooner or later additional instruments will have to be introduced to accelerate the implementation speed. Another main uncertainty is the impact of the rise of decentral power generation and possibilities for demand-side management due to smart grids on system variability.

The uncertainties regarding flexibility requirements give ample room to diverging views of experts and stakeholders on the topic. For instance, on one hand the OECD/IEA in their 2014 review of the Dutch energy sector state that: 'Current power generation overcapacity in the Netherlands can serve as a flexible source to the North-West European power markets. Instead of pursuing a national approach, the Netherlands is right to promote cross-border electricity trade in the region, as it can benefit from cost and resource efficiency of the larger market. To this end, the Netherlands should further strengthen its electricity network within the country and across the borders lift congestions, while at the same time supporting the integration of renewable energy policies into electricity markets to by way of cross-border balancing, intra-day markets and system operation as well as reserve mechanisms'[36]. Implicitly the IEA therefore seems to indicate that, rather than having a flexibility problem of its own, the Netherlands by way of its interconnections could contribute to reducing flexibility problems in its neighbouring countries – at least in the years to come.

[35] ECN/PBL Nationale Energieverkenning 2014
[36] IEA, 2014, Netherlands energy sector review, Paris

For the longer future, however, Netbeheer Nederland (2014), the branch organisation of Dutch electricity and gas TSOs and DSOs, states that 'enormous fluctuations in supply and demand of electricity in 2030 will be a day-to-day reality'[37]. As a main solution, they see the need for an improved data management system that can deal with such rapid fluctuations. Also, they argue in favour of a better integration of electricity, gas and heat grids, with an important role for power to gas as a flexibility option.

For this project also various representatives of stakeholders in the Netherlands were interviewed face-to-face[38]. The opinions of these stakeholders on the need for additional flexibility options for the Dutch electricity sector were found to be likely divided. Several parties stated that Dutch electricity supply is relatively well-organised and transparent compared to other countries. In particular, the Dutch division between a programme responsible-, measuring responsible- and supply party for each connected end-user was considered as a well-functioning system. According to several respondents, due to current oversupply there are probably no new flexibility options needed now or in the near future.

Also, according to most respondents if there is any problem at all it is for sure not a technical, but rather a market related problem. As one respondent puts it: 'The root cause of the need for flexibility lies in the increasing share of intermittent power, and in Germany - with current shares of intermittent power that will be only reached in ten or twenty years in the Netherlands – we do not see substantial technical problems either.'

CIEP/PBL also argues in a recent report[39] that the flexibility challenge is primarily an economic one. Integrating large shares of variable renewables is increasingly costly as the share of variable renewables (VRE) increases, as can be observed from the increasing system costs (€/MWh) in the table below.

Table 2-5 Estimated additional system costs (€/MWh) of expanding solar and wind electricity in France, The UK and The Netherlands[40]

			Wind			Solar
VRE-share	10-15%	15-25%	>25%	10-15%	15-25%	>25%
Adequacy	3-6	3-6	4-15	5-15	10-15	10-20
Balancing	1-5	1-5	>5	1-5	1-5	>5
Network	4	7-15	15-25	10	10-15	15-40
Total	**8-15**	**11-26**	**>24-45**	**16-30**	**21-35**	**>30-65**

These increasing costs are a good reason in itself to have a critical look at the organisation of the system, in order to minimise these additional costs as much as possible. Similarly, Ecorys estimates that if costs of intermittent electricity generation in the EU was to be limited to 25 billion euro per year, no more than 40% of renewables could be integrated into the market[41].

37 Netbeheer Nederland, 2014, Actieplan duurzame energievoorziening
38 See the annexes for an overview of interview partners
39 CIEP/PBL (2014) Reflections on coordination mechanisms, The Hague
40 Ibid
41 Ecorys (2011) Assessment of the Required Share for a Stable EU Electricity Supply until 2050, Brussels

Viewpoints further diverge concerning the need or not for a capacity mechanism for the Netherlands. The Dutch regulator and TSO state that such a mechanism is not needed, as the current energy-only market in their opinion will be perfectly able to generate the needed and most cost-effective flexibility options by itself. However, other parties refer to political pressure that would make the introduction of a capacity mechanism in the Netherlands in some form or another inevitable. As one interviewee from a market party puts it:

‘In order to keep conventional power profitable in an energy-only market, as a society you will have to accept periods of electricity scarcity with high peak prices. This will motivate investors to invest in peak- or back-up power. However, in such periods the system will also become very vulnerable to blackouts. In my opinion, neither society nor politicians will accept this vulnerability. Capacity mechanisms will therefore be inevitable.’

2.5 Conclusions

Main conclusions of this chapter regarding flexibility requirements in the Netherlands up to 2030 are:

1. The current potential flexibility capacity in the Netherlands is sufficient to meet current demand for flexibility and higher than in its neighbouring countries. Contrary to the neighbouring countries, where there are generally one or two main potential sources for flexibility, in the Netherlands there are three main potential ‘conventional’ sources: interconnection, a high share of CCGT and flexible CHP.

2. Up to 2030, flexibility requirements in the Netherlands will increase due to the planned increase in VRES capacity in the Netherlands and in its neighbouring countries. Of the three ‘conventional’ flexibility sources already available to the Netherlands, interconnection capacity in relation to peak demand will remain roughly the same: although new interconnections are envisaged, demand will also increase in a similar pace. Also, CCGT capacity – based on average technical lifetimes - will remain relatively high, although actual operation of these plants will depend on economic parameters which are susceptible to change in the market place. Only CHP capacity is likely to decrease significantly, as the age of the existing park will require new investments that are not economically viable if current price developments continue. Overall, we estimate that availability of conventional flexibility options up to 2023 and probably even 2030 in relation to peak demand is most likely to be sufficient to meet flexibility requirements without investments in new flexibility capacity being required in a business-as-usual scenario (with implementation of the SER agreement and envisaged NEV policy scenario up to 2030).

3. Beyond 2030, or in scenarios of higher RES implementation up to 2030, additional flexibility capacity might be needed in the system. Given the long lead times of some flexibility options, such as grid investments, the scale and nature of these flexibility needs should be anticipated well in advance. The rapidly increasing system costs for integrating the variable renewables also form a powerful driver to have a critical look at the organisation of the system, in order to minimise these additional costs as much as possible.

4. A rapid increase of decentral options like solar or electrical vehicles might give rise to additional flexibility requirements in the future. Whereas a rapid growth of PV will cause more variability in the system, storage capacities of electric cars on the contrary could have a stabilising function, on the condition that distribution grids can cope with increased flows. Next to the uncertainties in growth rates of implementation of renewables in general, with many underlying uncertainties regarding e.g. policies and price developments involved, the development of these decentral options introduces a main systemic uncertainty in the electricity sector – as their proper integration into the system would require a rethinking of current design principles of the system from unidirectional top-down to bidirectional top-down and bottom-up.

5. Views of stakeholders regarding requirements for additional flexibility in the Dutch electricity sector are diverging and should also be seen in relation to interests involved. Whereas some parties stress the qualities of the existing Dutch system and its ability to cope with flexibility needs in the future, other parties point to the need for investments in their field, e.g. in grids. Whether or not foreseen increase and height of peak prices due to increased variability in the future electricity system will lead to a strong political pressure for regulatory intervention in the system is an important point of discussion.

3. Flexibility options for the Netherlands

In the previous chapter, it was discussed to what extent new flexibility capacity in the Netherlands is actually required in the coming years in light of existing markets and already installed flexibility options. Whereas an acute need for market intervention in the Netherlands in the coming years was not found, it is clear that announced policy plans in the European Union and Member States will lead to much higher percentages of RES capacity installed up to 2050. Also, technological developments will make that new flexibility options such as advanced storage or demand-side management will become available on the market. This chapter therefore discusses in more detail possibilities and limitations of application in the Netherlands of the main categories of flexibility options currently known.

We distinguish in this chapter between *regulatory flexibility options* (i.e. instruments) that require primarily regulatory intervention and *investment-based flexibility options* that require financial investments either on the supply side, on the demand side or in storage:

Regulatory flexibility options	Investment-based flexibility options
Capacity mechanisms	Increasing flexibility of conventional plants
Curtailment of RES	Demand-side management and smart grids
Other regulatory options	Increasing network capacity
	Electricity Storage

3.1 Regulatory flexibility options

3.1.1 *Capacity mechanisms*

In the energy only market, power plant operators generally receive revenues for every unit of electricity (MWh) sold. The price they receive for every MWh sold is set on the wholesale markets, based on marginal costs of power production. Wind and solar power require large upfront investments, but have low marginal costs. At peak production hours, the low marginal costs drive down the price of electricity. This pushes conventional plants out of the money and scares of investors as they are uncertain whether they will be able to recoup their investments.

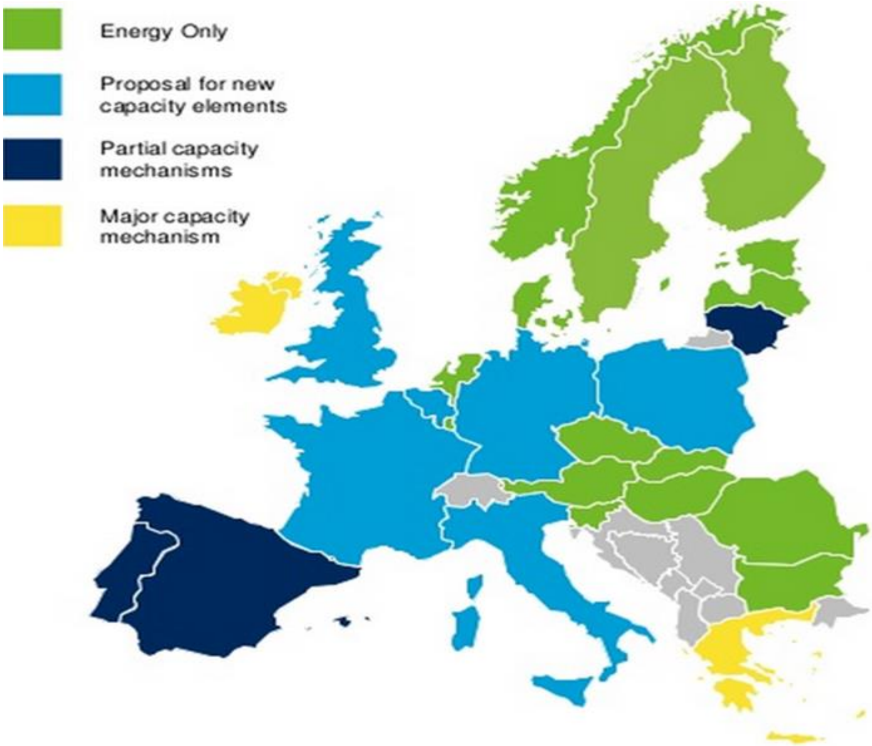
Capacity mechanisms are government interventions in the power market to ensure that electricity undertakings (often suppliers) assume the responsibility to provide or pay for generation capacity which they would not otherwise do, or at least not to the same extent, considering only their own commercial interests[42]. These capacity mechanisms can provide an additional incentive for developers and owners of generating to make their capacity available to electric markets where price signals from the energy only market alone would not.

The basis of most capacity mechanisms is that operators are not only compensated for the units of energy they produce (MWh), but also for the capacity they have installed (MW). In this way, power plants that operate only in limited hours of peak demand can still remain profitable.

[42] EC, 2012, Consultation Paper on generation adequacy, capacity mechanisms and the internal market in electricity, 11/15/2012

A number of European Member states have designed additional capacity mechanisms to create more long-term price signals for suppliers. Examples and a more detailed explanation of the type of capacity mechanisms can be found in Annex A. The figure below shows that pure energy-only markets can be found in only a few EU countries. In many other Member States there is some form of capacity mechanism introduced.

Figure 3-1 Capacity mechanisms: state-of-play in the European Union[43]



The need for capacity mechanisms is subject to intense debate. Proponents of capacity mechanisms argue that energy only markets with significant RES penetration will never be able to provide enough financial incentive for investments in sufficient back up capacity. They claim that this will over time endanger the level of reliability of supply. It can already be observed that companies such as Eon and RWE aim their investments more in areas outside of Europe. They delay investments, awaiting more certainty in the creation of new mechanisms that ensure an adequate return on investment in new conventional generation capacity. These developments already take place in surrounding countries such as Germany, France and Great-Britain. Key Dutch players such as Energie-Nederland and TenneT however believe that energy only markets result in better capital efficiency and can provide adequate incentives, if parties are informed, to invest in standby capacity. Moreover, the peak prices that will result from shortage provide technology neutral investment signals that are required for investments in the right type of flexibility options. This may not necessarily be conventional generation capacity. Capacity mechanisms tend to favour existing (conventional – mostly gas) generation capacity and are typically not technology neutral.

Capacity mechanisms have also a tendency of being national solutions, due to autarky thinking, and therefore discriminate interconnection vs. local balancing and back-up capacity[44]. Ideally, capacity mechanisms have to be arranged at transnational or even European levels such that perverse incentives

[43] DG ENER, 2015, Developments in energy policy, presentation S. Vergote
[44] Statkraft, 2013, Position paper on the design of capacity mechanisms

are avoided. This will take significant amount of time, considering the difficulties that have been experienced in harmonising the balancing regulation in Europe.

Advantages and disadvantages of application in the Netherlands

The Netherlands is relatively dependent on gas plants as a flexibility option, part of which have already been mothballed. Capacity mechanisms may provide an incentive to keep them in back up. Yet, the need for market intervention in the Netherlands in the coming years has not been demonstrated as existing flexibility capacity could be sufficient.

Table 3-1 Capacity mechanisms as a potential flexibility option for the Netherlands

	Capacity mechanisms
Main characteristics	- Regulatory (financial) stimulation of flexibility options separate from energy-only markets; - Consists of several sub-options; - Already applied in several EU Member States (Belgium, France, United Kingdom) and considered in others (Germany)
General application possibilities	- Introduces financial incentives in particular for existing peak generation capacity (gas) to remain operational and prevent mothballing.
General application limitations	- Might be supply-side biased / favour conventional capacity and hamper innovation.
Specific advantages of application in the Netherlands	- The Netherlands is relatively dependent on gas-fired power plants as a flexibility option, part of which have already been mothballed.
Specific disadvantages of application in the Netherlands	- Its need for market intervention in the Netherlands in the coming years has not been demonstrated as existing flexibility capacity could be sufficient.

3.1.2 Curtailment of renewable energy

Curtailment is a reduction in the output of a generator from what it could otherwise produce given available resources, typically on an involuntary basis[45] (See Annex B). Curtailing occasional supply peaks of wind and solar power is currently more economic than storing them. However, in the future, with more frequent and longer peaks combined with cheaper storage, this picture might change.

Curtailing renewables means that low-carbon power is effectively thrown away. Moreover, renewable energy producers are sometimes compensated for the curtailed power, which adds even more to the costs. Even though curtailment is often economically the most sensible option, from a societal point of view it might be controversial at some point. Many experts agree however, that curtailment should be considered as a serious option. Allowing for even a very small percentage of curtailment can dramatically reduce the costs of the remaining flexibility requirement.

RES curtailment can provide flexibility on all timeframes, although its use for frequency containment is limited.

[45] NREL, 2014, Wind and Solar Energy Curtailment: Experience and Practices in the United States

Advantages and disadvantages of application in the Netherlands

As current RES capacity in the Netherlands is low compared to its neighbouring countries, application of RES curtailment at this moment would mainly concern foreign suppliers.

Table 3-2 RES Curtailment

Main characteristics	- RES curtailment is the restriction of access of RES to the grid in times of high supply peaks. It has been applied occasionally in some countries.
General application possibilities	- Relatively easy to apply
General application limitations	- Might face public acceptance issues; - Could require financial compensation of RES suppliers
Specific advantages of application in the Netherlands	- Current RES capacity in the Netherlands is still relatively low
Specific disadvantages of application in the Netherlands	- None

3.1.3 Other regulatory options

Ecofys (2014)[46] mentions the following additional potential regulatory interventions that could improve flexibility without new investments in flexibility capacity being needed:

Market coupling

In market coupling, instead of explicit trading of transmission capacity between markets, total supply and demand are matched over different market areas in order to use existing grid capacity in the most efficient way. Prerequisite for this option is that markets are physically linked by way of interconnection capacity.

Market coupling can be implemented for day-ahead, in intra-day and balancing markets.

Prequalification standards

Market actors have to fulfil specific prequalification standards before they are allowed to trade on electricity markets. Especially in balancing markets, these standards comprise a number of technical characteristics that have to be met, e.g. minimum sizes of bids. Pooling of small entities opens the market to bids from additional flexibility options, including demand side options and controlled generation of intermittent renewables.

Scheduling times

Services on electricity markets are traded in defined time blocks. Shorter scheduling periods for fulfilling the contract opens the market especially for intermittent power and for bids from the demand side. RES and demand side actors often provide flexibility only for a certain time frame, e.g. in day-time. If the predefined time blocks are too long (e.g. 12 hours, or one week), these flexibility options are excluded from the market. Allowing transactions within operating periods can further reduce the need for control power and increase schedule accuracy.

[46] Ecofys (2014) Flexibility options in electricity systems, Ecofys Germany

Gate closure

The forecasting accuracy of renewable power production increases as we further approach real-time. Delaying gate closure closer to real-time includes better forecasts for VRES. With lower uncertainty, the need for balancing reserves decreases.

Transparency

Market results, such as reserve and imbalance prices, should be published as soon as possible. Time lags hinder adjustments by market actors.

General characteristic of these options is that they mainly concern fine-tuning of regulation, which is relatively easy and can be achieved at low costs in all Member States without additional investments in flexibility options being needed. Exception here is market coupling, which is often linked to necessary investments in interconnection capacity. The benefits to be obtained by fine-tuning will depend on the specific regulatory system in each Member State.

Advantages and disadvantages of application in the Netherlands

The Dutch electricity market is well developed with an intraday market and a short gate closure set one hour prior to delivery for the balancing market. A key issue for the further development of the electricity market is the further integration with neighbouring markets[47].

Table 3-3 Other regulatory options

Main characteristics	- By fine-tuning of regulatory options, as well as by increasing geographical size of markets by way of market coupling, increased flexibility can be obtained without need for additional flexibility investments.
General application possibilities	- Relatively easy to apply at low cost
General application limitations	- Specific benefits for flexibility will depend on the characteristics of each national regulatory system; - Market coupling will require close coordination and cooperation between different Member States.
Specific advantages of application in the Netherlands	- None identified.
Specific disadvantages of application in the Netherlands	- Market coupling: Surrounding countries (BE, UK, DE) are increasingly implementing capacity mechanisms, which might potentially adversely influence the Dutch internal energy market when markets are coupled. On the other hand, influxes of excess flexibility capacity from abroad could also have positive effects in the Netherlands.

[47] Eclareon, 2011, Integration of electricity from renewables to the electricity grid and to the electricity market INTEGRATION National report: Country report Netherlands, Client: DG Energy

3.2 Investment-based flexibility options

Apart from regulatory-based flexibility options, there are a variety of ways to increase flexibility in the power system that will require investments on the supply-side, the demand-side or in storage. With technological improvements that have become available in the past years and that are likely to continue in the near future, a larger number of such options will become available as costs for each of these will decrease. The pace in which this will occur, however, is hard to predict.

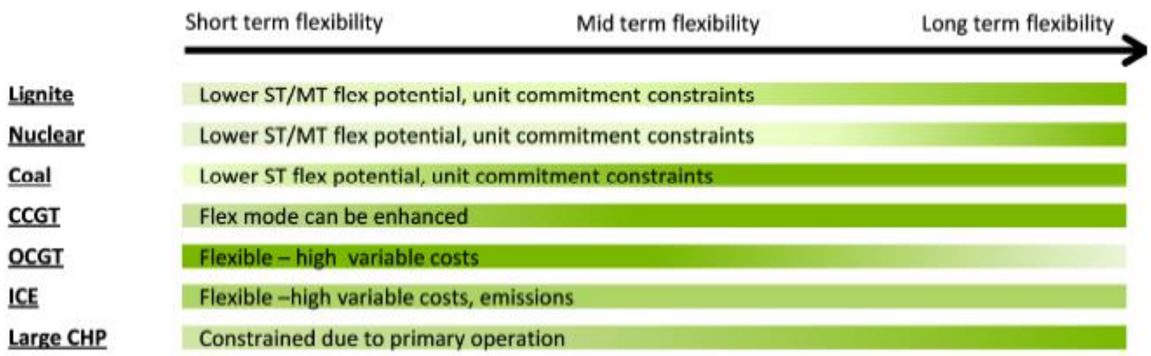
3.2.1 Increasing flexibility of conventional plants

Thus far, system flexibility is almost exclusively provided by thermal power plants. The flexibility of the current power plant fleet can be improved by retrofits of existing plants, or opting for more flexible new plants. This allows for increased load-following and thus more flexibility in the conventional power plant fleet (e.g. coal, gas, nuclear). Conventional plants can provide system flexibility by increasing or decreasing output on request.

The investment costs differ per type of power plant. Additional investment costs for modern coal plants range from 1300 – 1750 €/kW, for modern gas plants between 684 – 1250 €/kW (CCGT) and 380 – 700 €/kW (OCGT). Variable costs are highly dependent on fuel costs. Price indications for the current European market are: Coal: 22 – 30 €/MWh, CCGT: 40 – 60 €/MWh, OCGT: 60 – 76 €/MWh.

Not all power plants are equally flexible. Gas turbines and internal combustion engines are the most flexible units, while CCGT and steam turbines are subjected to more constraints. These constraints are defined by each technology's ramping capability, must-run requirements and minimum load. Technology developments in power generation and refurbishment of old units can allow increasing the flexibility of all conventional power plants. The flexibility constraints determine the type of flexibility services that the various technologies can provide, as schematically depicted below:

Figure 3-2 Flexibility of conventional power plants[48]



The figure shows that short-term flexibility (balancing) is currently typically provided by gas-fired units, which can ramp up faster and can operate at lower minimum loads than coal fired power plants. Technological advancements increasingly allow coal to play also a role in providing system flexibility.

Particularly the ability to operate at lower loads will become important in future energy systems. A reduced minimum load is particularly important at times of high generation from renewables, for example in areas where there is a high feed in from solar power during the day. At these times, the

[48] Ecofys, 2014, Flexibility options in electricity systems

remaining demand, referred to as residual load, is limited. At such times, several conventional power plants could be turned off. However, starting up a coal fired plant is costly and time consuming so they would preferably run continuously and just reduce their output. Continuous running at low load will enable back-up plants to remain connected to the grid and therefore able to move to full load more rapidly when required, at the expense of a lower overall efficiency. Cost-benefit analyses of retrofitting existing power plants to increase flexibility shows a wide range of outcomes, driven by project-specific costs[49].

The potential and deployment of this flexibility will decrease over time, with a decreasing share of fossil fuel fired power plants in the energy mix.

Advantages and disadvantages of application in the Netherlands

The Dutch power system is largely gas-fired, and thus faces relatively low investment costs in additional flexibility. The flexibility of the coal fleet in The Netherlands is already increasing as inflexible old plants are closing and more flexible new plants are under construction/coming on line.

Investments in increased flexibility of conventional power plants can increase the ability of the Dutch power system to provide also flexibility services for surrounding countries, which increasingly face capacity shortages. Belgium and the UK are already experiencing capacity shortage. Capacity shortage may also increasingly become an issue in Germany with the phase out of the nuclear power plants.

Table 3-4 Increasing flexibility of conventional plants

Main characteristics	- Investment costs are rather high, variable costs will probably only increase with fuel prices.
General application possibilities	- Depending on the technology, flexible power generation can provide flexibility services on all time-frames (short-mid-long term)
General application limitations	- Ramps and part-load operation lead to lower efficiencies and higher CO2-emissions. - Start-ups and ramps also lead to increased wear and tear on the unit components and systems. - Investments in the existing fossil fuel based infrastructure can meet public resistance.
Specific advantages of application in the Netherlands	- The Dutch power production is largely gas-fired, and thus faces relatively low investment costs in additional flexibility. - Investments in increased flexibility of conventional power plants can increase the ability of the Dutch power system to provide also flexibility services for surrounding countries, which increasingly face capacity shortages.
Specific disadvantages of application in the Netherlands	- None identified

[49] OECD/IEA 2014 The Power of Transformation Wind, Sun and the Economics of Flexible Power Systems GSE, Rome, 8 July 2014; 2

3.2.2 Demand side management

The current power system is organized so that supply resources are operated to follow demand under all circumstances, in a distributed system customer demands interact with and respond to supply conditions and capabilities[50]. The concept of demand side management is not new. The second source of flexibility of today's electricity system is demand side management, although this term is typically not used in this respect. TSOs have agreements with several industrial parties, that in times of supply shortage these industrial parties will reduce their demand and receive financial compensation in return (for more detail, see Annex A).

In the future, both industrial parties and households should be able to respond to price signals and adapt their consumption pattern accordingly. Refrigerated warehouses are often used as example. As long as the temperature of these warehouses remains in a defined range, the exact moments of cooling can be delayed to times with lower electricity prices. In a system with smart grids, such demand response dynamics can be increasingly automated, resulting for the warehouses in higher electricity consumption but in overall lower costs.

The potential of flexible capacity in demand side management is significant, and growing due to the electrification of some sectors (e.g. electric vehicles, heat pumps). The crucial question is how high the levels of financial compensation need to be for consumers to shift their demand.

Industrial demand response

Some industrial installations involve processes that allow freedom in shifting energy requirements of the process in time. Examples of such processes include electrolysis (see also paragraph 3.2.4 - power to gas), cement and paper mills, electric boilers, and electric arc furnaces[51]. Industrial demand response can involve a shifting of demand or simply cutting demand and accepting lower production. Costs of shifting demand are generally modest if the primary process is not disrupted. Costs generally relate to change of shifts in personnel, installation of communication and control equipment, and potentially additional on-site storage of intermediary products. Costs associated with reduced production can be high and are usually avoided. The potential of industrial demand response is high. To what extent the potential can be harvested depends on sufficient incentives and the regulatory framework.

Household demand response

Potential demand management technologies in the residential and services sector include air conditioning, compressing air for mechanical use or even rescheduling of washing processes in households. Another example would be delivering domestically produced energy from solar panels to the grid during periods of peak prices.
The potentials are considered to be high, but the enabling IT infrastructure and the constraints due to the primary use of controlled devices can present significant challenges, e.g. abandonment of profile based allocation[52].

[50] VTT, 2009, Integration of Demand Side Management, Distributed Generation, Renewable Energy Sources and Energy Storages State of the art report Vol 1: Main report, for IEA DSM
[51] Ecofys, 2014, Flexibility options in electricity systems, By: Dr. Georgios Papaefthymiou, Katharina Grave, Ken Dragoon, Date: 10 March 2014, Project number: POWDE14426, by order of: European Copper Institute
[52] Ibid.

Advantages and disadvantages of application in the Netherlands

For demand side management on household and SME level, smart grids are needed. Smart grids research in The Netherlands is well-developed, with several pilots under way. These research can help to kick start the development of a smart grid.

Electric vehicles are often mentioned in relation to smart grids and residential demand response, due to their storage capacity (see also section 2.3 on electric vehicles). The development of an electric vehicle infrastructure and the penetration of EVs in the Dutch market are relatively advanced.

The largest potential for demand response is in heavy industry (e.g. metals), which is increasingly phased out in The Netherlands. Still, significant potential remains, typically at lower cost than residential demand response.

Table 3-5 Demand-side management

Main characteristics	Investments: see networks for smart grid investments (~€5.8 billion[53]) Variable costs increase with demand. Mainly useful for short-term and mid-term flexibility
General application possibilities	Short-term and cost-efficient solution, additional potential for complete shut-down in minutes, but at much higher costs (value of lost load)
General application limitations	Development of potential relies on electricity cost sensitivity and on price spreads in the electricity market. In The Netherlands however, current overcapacity prevents price peaks. In most of the industrial entities, the high organisational effort is not worth the cost savings by shifting demand to low price hours. Potential barriers for DSM can be uncertain potential, quality losses in products, short period of shifting, structure of demand (efficient usage of production capacity). Many technologies with high DSM potential, such as electric vehicles and heat pumps, have hardly entered the market.
Specific advantages of application in the Netherlands	Smart grids research in The Netherlands is well-developed. The development of an electric vehicle infrastructure and the penetration of EVs in the Dutch market are relatively advanced.
Specific disadvantages of application in the Netherlands	The largest potential for demand response is in heavy industry (e.g. metals), of which the future in the Netherlands and Europe is far from certain.

[53] Ministerie van Economische Zaken, 2010, Op weg naar intelligente netten in Nederland. Conclusies en aanbevelingen van de Taskforce Intelligente Netten

3.2.3 *Increasing network capacity*

The power transmission and distribution networks can form a constraint to matching supply and demand. Power system transmission and distribution networks thus are a key enabler of flexibility in the system. Network strengthening is relevant for short-term, mid-term and long-term flexibility. Strengthening the network reduces congestion by allowing netting or offsetting changes in generation over larger geographic areas. Netting can be done on a local, regional, national or international level. Netting on a local level reduces the need for investments in high voltage lines and vice versa. There is a debate ongoing about the economically optimal geographical level of netting.

In general, demand response is seen as an economically sound option to deliver flexibility on the long term. According to the European Commission's Roadmap 2050, demand response can save 30-40% on required back up capacity[54]. To realise 60% RES in Europe, the required back up capacity would be 205 GW without demand response and 120 GW with DSM, a difference of 85 GW[55]. This corresponds to about 2.5 GW of back up (gas) capacity in The Netherlands.

Distribution networks (low/medium voltage)

On a local level, investments would be needed to allow for demand response, thus creating a 'smart grid'. Although there does not seem to be a clear definition of 'smart grids', its most important characteristic is a two-way flow of electricity and information enabling the capability to monitor everything from power plants, to sun and wind forecasts, to electricity meters and individual appliances. A smart grid incorporates digital communications to deliver real-time information thereby enabling the balance of supply and demand.

The estimated investments required in to enable a smart grid are[56]:

- Low voltage network €2.8 billion
- Medium voltage network: €1 billion
- Glass fibre network: €1 billion

These numbers are indicative, higher estimates are also seen[57].

High voltage transmission lines

When it comes to the high voltage transmission lines, cross-border lines are particularly interesting for adding flexibility to the system. This improves or creates a connection with adjacent power markets with different power mixes and thus different dynamics, thus providing good opportunities for netting. A cable to Norway, a country with huge hydro storage reservoirs, is even more interesting for bringing flexibility and reliability to the system. For this reason, the Dutch and Norwegian TSOs have already constructed the so called NorNed cable. A second cable, NorNed2, is seriously considered but not expected to be built before 2022[58]. The investment costs of this 700 MW cable are estimated at €600-650 million.

[54] EC, 2011, 'Energy roadmap 2050' (COM(2011) 885 final of 15 December
[55] Ministerie van Economische Zaken, 2010, Op weg naar intelligente netten in Nederland. Conclusies en aanbevelingen van de Taskforce Intelligente Netten
[56] Ministerie van Economische Zaken, 2010, Op weg naar intelligente netten in Nederland. Conclusies en aanbevelingen van de Taskforce Intelligente Netten
[57] EPRI, 2011, Estimating the Costs and Benefits of the Smart Grid A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid, EPRI, Palo Alto, CA: 2011
[58] http://www.energeia.nl/preview/1422-Statnett-herziet-strategie-interconnectoren-Norned-2-op-de-lange-baan.html

Grid investments are capital intensive. Overhead lines (OHL) are the cheapest transmission technology with the lifetime cost estimates varying between 2m€/km and 4m€/km per kilometre. Underground cable (UGC), direct buried, is the next cheapest technology after overhead line, with the lifetime cost estimates varying between 10 m€/km and 20 m€/km[59]. The investments in the high voltage transmission lines needed to enable a smart grid are estimated at €1 billion[60].

As explained in section 2.2, each country uses its own strength in providing flexibility to its electricity system. Very few regions possess enough cheap potential to provide the amount of flexibility that is needed. Therefore it will be prohibitively expensive if the flexibility issue would be solved at a local or national level because new and expensive technologies would be needed. In contrast, sharing existing flexibility resources among regions and countries can help to buffer variable renewable electricity generation in a cost-efficient manner.

A recent paper by Steigenberger & Grotewold explains how increased interconnection is crucial for the integration of variable renewables in the EU power system[61]. Connecting the countries not only allows efficient use of flexibility options but also reduces the need for flexibility. Both demand and supply will be netted to some extent. Weather patterns are not the same all over Europe. When wind blows at the Atlantic coast, it might be calm in Hungary; when the sun is shining in the South, it might be cloudy in the North. The ability to trade electricity between regions allows us to mobilise and better use the resources in all parts of Europe. Tapping into the Eastern European biomass potential, for instance, or shifting loads in industrial centres in order to reduce peak demand can be efficient measures to stabilise the system. The abundant hydro capacity in Scandinavia and the Alps could play an important role in balancing continental European power supply.

Furthermore, the total amount of capacity needed to ensure system reliability can be reduced by cooperation. Because people in Spain, Poland and The Netherlands sleep, work and cook at different times and because power systems function under different conditions, load curves vary between regions. Therefore, cumulated peak demand is lower than the sum of national peak demands, which means that ensuring the secure supply of electricity at any time becomes easier and cheaper when countries cooperate.

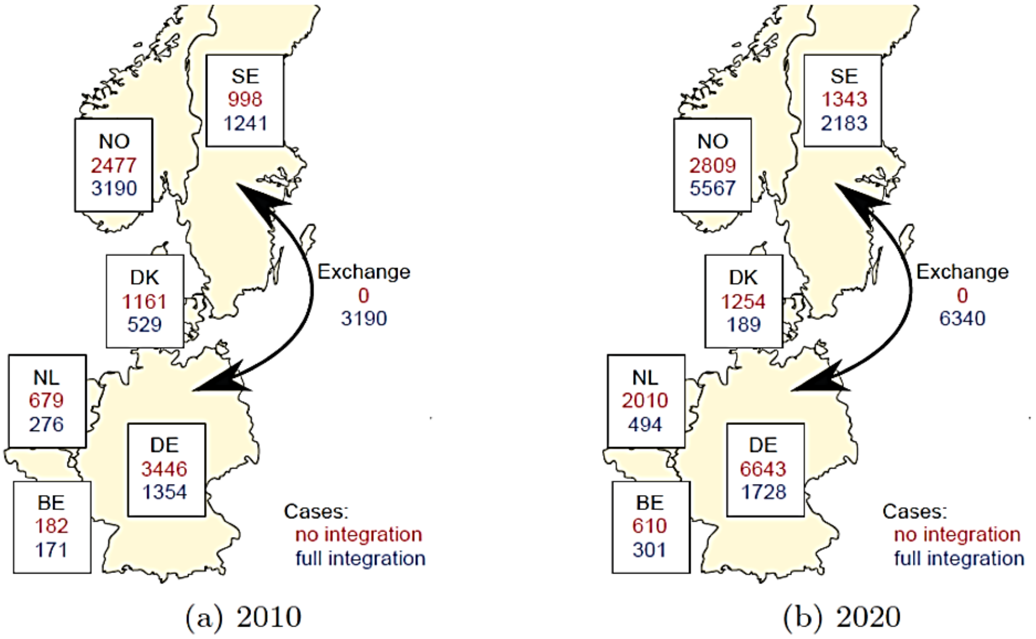
The figure below shows the required balancing reserves (GWh/yr) in 2010 and 2020, in a situation without (red) and with (blue) integration of the energy markets around the North Sea basin.

[59] Parsons Brinckerhoff, 2012, Electricity Transmission Costing Study - An Independent Report Endorsed by the Institution of Engineering & Technology

[60] Ministerie van Economische Zaken, 2010, Op weg naar intelligente netten in Nederland. Conclusies en aanbevelingen van de Taskforce Intelligente Netten

[61] Steigenberger & Grotewold, 2014, Why Germany's Energiewende Reminds Us of the Virtues of Cooperation, Markus Steigenberger of Agora Energiewende, Lars Grotewold of Stiftung Mercator, Global Policy Volume 5. Supplement 1. October 2014

Figure 3-3 Country wise annual balancing reserve allocation[62]



Cooperation makes the energy transition easier and cheaper, expanding the transmission grid is thus critical[63]. Investments in interconnection are already needed and planned to foster the EU's Integrated Energy Market (IEM). Hence, the business case for additional interconnection from a flexibility perspective is very strong, since the investments are already accounted for.

Advantages and disadvantages of application in the Netherlands

The Netherlands has no specific objectives as to specifically required grid reinforcements or expansions to accommodate further growth of renewable energies. What is worse, grid operators in The Netherlands are not allowed to pre-invest anticipating on accelerated development of RES installations. They are therefore inevitably lagging behind with the adaptation of the grid to the new circumstances, since lead times of grid investments are much longer than RES projects[64]. The consequence of the delayed grid development process without counteraction can be insufficient grid capacities.

Grid investments can enable electricity exports and provide flexibility services to countries surrounding The Netherlands. Belgium and the UK are already experiencing capacity shortage[65]. Capacity shortage may also increasingly become an issue in Germany with the phase out of the nuclear power plants. In times of shortage (and thus high prices) in these countries, the excess Dutch capacity can serve as back up.

Interconnection investments can also enable cheap electricity imports from mainly Germany in times of excess electricity production. The existing and planned interconnection to Norway allows The Netherlands to tap into the vast Norwegian (pumped) hydro potential.

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[62] Graabak, H., 2014, Norwegian hydropower for balancing of intermittent renewables, potential and market aspects, Ingeborg Graabak, SINTEF Energy Research, conference on Intermittent Renewables, Balancing Power and Electricity Market Design, Hardingasete, Norway 25-27 August 2014

[63] Steigenberger & Grotewold, 2014, Why Germany's Energiewende Reminds Us of the Virtues of Cooperation, Markus Steigenberger of Agora Energiewende, Lars Grotewold of Stiftung Mercator, Global Policy Volume 5. Supplement 1. October 2014

[64] Eclareon, 2011, Integration of electricity from renewables to the electricity grid and to the electricity market INTEGRATION National report: Country report Netherlands, Client: DG Energy

[65] Although particularly in Belgium this is not related to RES

Overhead transmission lines often face public resistance. This has caused a recent decision of the Dutch government that overhead lines are no longer allowed near residences. This forms a complicating factor for some high voltage grid investments. Investment costs of underground cables are a factor 5 higher.

The current tariff structure for electricity networks does not incentivise smart behaviour and investments[66]. Some argue that a market for transport capacity could help to alleviate congestions. Instead of fixed transport fees, the tariffs then vary with the degree of grid congestion. This then provides an incentive to grid users to change their transport needs accordingly.

The current Dutch grid is functioning well without too serious congestions, although there are already situations where a concentration of heat pumps leads to power outage on a local level. Significant investments are not immediately needed, but given the long lead-times of these projects it is essential to start planning the required grid investments[67]. Large parts of the grid are scheduled to be replaced in the medium (10 years) and long term (10-30 years). In scheduled construction or deep renovation projects, there is a choice between grid reinforcement or investing in smart distribution networks. The second option will be slightly more expensive, but will yield more benefits[68].

Table 3-6 Increasing network capacity

Main characteristics	- Overhead Line (OHL) 2-4 m€/km Underground cable (UGC) 10-20 m€/km - Smart grid investments[69]: High voltage grid: €1 billion Medium voltage grid: €1 billion Low voltage grid: €2.8 billion - Grid investments on all levels (low-medium-high voltage) are a key enabler for flexibility on all timeframes (short-mid-long)
General application possibilities	- Interconnection investments allow coupling of power markets: day-ahead, intra-day, balancing. - Investments in the internal grid (low-medium and high voltage) allow for the development of a smart grid and thus enable demand side management.
General application limitations	- High upfront costs and no efficient market based cost allocation.
Specific advantages of application in the Netherlands	- The Netherlands is surrounded by countries where capacity shortage is expected on the short term (BE, UK) or medium term (DE). Grid investments can enable electricity exports and provide flexibility services to our surrounding countries. - Interconnection investments can enable cheap electricity imports from mainly Germany in times of excess electricity

[66] Ministerie van Economische Zaken, 2010, Op weg naar intelligente netten in Nederland. Conclusies en aanbevelingen van de Taskforce Intelligente Netten
[67] Ministerie van Economische Zaken, 2010, Op weg naar intelligente netten in Nederland. Conclusies en aanbevelingen van de Taskforce Intelligente Netten
[68] CE Delft (2012) Maatschappelijke kosten en baten van intelligente netten
[69] Ministerie van Economische Zaken, 2010, Op weg naar intelligente netten in Nederland. Conclusies en aanbevelingen van de Taskforce Intelligente Netten

	production. - Interconnection to Norway allows The Netherlands to tap into the vast Norwegian (pumped) hydro potential.
Specific disadvantages of application in the Netherlands	- Grid operators in The Netherlands are not allowed to pre-invest anticipating on accelerated development of RES installations leading to capacity shortages. - A complicating factor for some high voltage grid investments might be the recent decision of the Dutch government that overhead lines are no longer allowed near residences. Investment costs of underground cables are a factor 5 higher.

3.2.4 Storage

As explained in the introduction, energy storage can bring both additional supply and additional demand into the system, allowing the time-shifting of energy between periods of over- and under supply from variable renewables.

Pumped storage

Pumped hydro stores energy mechanically by using electricity to pump water from a lower reservoir to an upper reservoir. Subsequently energy can be recovered at any desired moment by allowing the water to flow back via turbines, thereby producing power in a similar way as traditional hydro power plants. With 129 GW of installed capacity worldwide and 42 GW in the EU, pumped hydro storage (pumped storage) is the most prevalent and mature energy storage technology. Initial investment costs tend to be high, however operational costs are low.

Hydropower contributes to grid stability by providing flexibility, as spinning turbines can be ramped up more rapidly than any other generation source. Hydropower can also provide other grid services, including “black start” capability when grid-wide black-outs occur[70]. From the storage options, today, only pumped hydro is able to facilitate grid scale RES integration[71].

The Netherlands is connected to the vast hydro reservoirs of Norway with a 700 MW cable, called the NorNed cable. The seasonal inflow of water and the peaks in wind production appear to match perfectly (see figure below).

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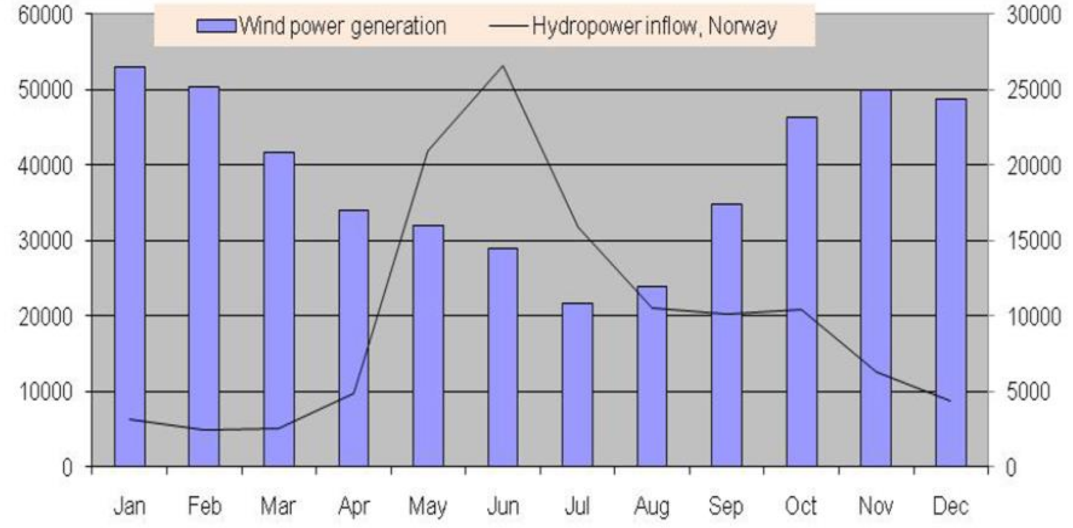
[70] IRENA, 2012, Renewable Power Generation Costs in 2012: An Overview.
[71] JRC, 2013, Technology Aspects of the Energy Transition, Stathis Peteves, Head of Unit, Energy Systems Evaluation Unit, Scientific Support to the Energy Mix, 8-Nov-2013

Figure 3-4 Monthly variability of wind power production in the North Sea (left axis) compared to energy inflow in Norway (right axis)[72]



The capacity in the Norwegian hydropower system can be increased from 30 GW to 50 GW in the future. The increase requires no increase in reservoir capacity[73].
However, the option is politically and socially difficult. Whereas a connection to Norway would decrease electricity costs in The Netherlands (see modelling results), electricity costs in Norway might increase. Moreover, most hydro reservoirs are located in the north of Norway. Increased connection with The Netherlands thus requires more high voltage lines through the Norwegian landscape.

Traditional pumped storage is not possible in The Netherlands due to a lack of elevation in the terrain. By connecting to Norway, the Dutch power system can benefit from the Norwegian hydro reservoirs. An alternative was presented in 1981 by an engineer called Lievense. The plan, known as Plan Lievense, consists of an artificial 8km by 4km island in the North Sea, which will comprise a 40m-deep open pit that will be enclosed by a ring of dykes. Up to 500MW of wind turbines could be installed on these dykes, as well as other renewable energy sources. The installed capacity of the pumped storage would amount to 1500MW and the storage capacity of the lake would top 20GWh. The investment costs are estimated to be 2.45 b€[74].

CAES

In compressed air energy storage (CAES), energy is stored by running electric motors to compress air into enclosed volumes. The electrical energy is recreated when the stored compressed air is fed into the let of a combustion turbine. The combustion turbine consumes some fossil fuel in its operation, but the compressed air at its inlet reduces the work of the combustion turbine that can generate almost three times the energy of a similarly sized conventional gas turbine. Key barriers to the technology are its efficiency, high capital costs and the specific siting requirements needed.

Abandoned gas reservoirs and particularly salt caverns are suitable for installing CAES facilities. The Netherlands has many of these suitable locations. Conventional CAES is currently reaching maturity; more advanced varieties like adiabatic CAES are still in the development and piloting phase.

[72] Graabak, H., 2014, Norwegian hydropower for balancing of intermittent renewables, potential and market aspects, Ingeborg Graabak, SINTEF Energy Research, conference on Intermittent Renewables, Balancing Power and Electricity
[73] Ibid.
[74] http://www.we-at-sea.org/wp-content/uploads/2010/06/Day-2-session-3b-Energy-Island.pdf

Batteries

Batteries refer to electrochemical energy storage technologies that convert electricity to chemical potential for storage and then back to electricity. Batteries can be broken down into three main categories:

- **Conventional** batteries that are composed with cells which contain two electrodes (e.g. lead acid, lithium ion);
- **High temperature** batteries that store electricity in molten salt (e.g. NAS);
- **Flow** batteries that make use of electrolyte liquids in tanks (e.g. Zn/Br Redox, FE/Cr Redox).

Few battery technologies are currently commercially available for flexibility services. Batteries are currently only economically interesting for short-term flexibility/balancing, for which there is hardly an additional need. However, the share of fossil fuel powered generation, which currently provides balancing services, will decrease in the future energy mix. Batteries might become an interesting replacement at that point for providing balancing services.

Power to gas

Power to gas is the functional description of the conversion of electrical power into a gaseous energy carrier (e.g. hydrogen or methane). The procedure consists of two steps: Electricity (usually assumed to come from 'excess' production of intermittent power sources like wind or solar) is used in a electrolyser to split water into hydrogen and oxygen. Hydrogen is combined with carbon-dioxide to create methane. Methane is the main constituent of natural gas and therefore can be injected (up to a certain amount, estimates range between 0 – 10%) to the existing infrastructure for natural gas (grid and storage). The high storage capacity of the gas grid could then be used for medium- and long-term storage purposes. The formed synthetic gas can be used not only in the power and heating systems but also as fuel in the transportation sector after being further converted to methanol or butanol[75] or as input in the chemical industry[76].

In the Netherlands there are some small-scale pilot projects ongoing[77]. Most research takes place in Germany where a 6 MW German plant began operation in 2013. Joint multinational initiatives like the North Sea Power-to-Gas Platform[78] also exist. Key strength of chemical storage over some of the other technologies is its high energy density compared to most of the other technologies and its high shifting period. Other benefits of this technology are the possibility to use the existing natural gas grid infrastructure, the possibility to use the end products in different sectors, the opportunity to recycle large amount of CO2 in an alternative way than Carbon Capture and Storage (CCS)[79]. For example, by using output CO2 from factories for the formation of the methane. Key barriers are the low efficiency, assumption of 'cheap' electricity, and high CAPEX. Alternatives to the thermochemical methanisation process are also investigated, claiming lower capital and operating costs[80]. Although costs are thus still high, technological learning is expected to bring these down in the future. The expectation is that the

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[75] Deutsche Welle (2014) 'Power-to-gas' may solve renewables storage challenge, http://www.dw.de/power-to-gas-may-solve-renewables-storage-challenge/a-17754416

[76] Fraunhofer ISE (2014) Power-to-gas http://www.ise.fraunhofer.de/en/business-areas/system-integration-and-grids-electricity-heat-gas/research-topics/power-to-gas/power-to-gas; in addition a good presentation as was given by Prof. Dr. Sterner, a renowed Power-to-Gas (PtG) expert. He recorded his presentation for the SCOT "CO2-to-fuel" workshop (13th of February 2015). The presentation can be found here: http://www.power-to-gas.de/mp4/Talk_PTG_Sterner.mp4

[77] For example in Rozenburg (as done by Stedin and DNV GL)

[78] The platform's goal is aims to explore the viability of power-to-gas in the countries surrounding the North Sea area - http://www.northseapowertogas.com/about-us

[79] Sunfire (2014) Power-to-gas http://www.sunfire.de/en/produkte/fuel/power-to-gas-methanisierung

[80] http://www.electrochaea.com/

application of power-to-gas in the chemical sector will continue to grow, driving down costs. At some point, costs will have decrease while the need for flexibility has increased. At this point, power-to-gas may become economically attractive to provide medium to long term flexibility services. This is not expected before 2030.

Power to heat

One possibility to increase the flexibility of demand is the conversion of an excess of electricity generation into heat energy. This allows for a partial uncoupling of production and consumption through heat storage. This process is called 'power-to-heat'. Combining thermal storage with electric heat has the potential to substantially increase the flexibility of the power system.

There are several ways to convert power into heat. One option is direct resistance heating: an electric current through a resistor converts electrical energy into heat energy. Heat pumps offer a more efficient technology to convert electricity to heat. Heat pumps effectively move heat energy from a source (e.g., ambient air) to the end use or storage. In a reversed form, heat pumps are used in refrigerators or rooms (air conditioning) to remove heat and thus effectively cool these spaces. Flexibility is provided by selectively energizing heaters and storing the generated heat for later use.

The IEA concludes in a 2014 study that the addition of energy storage capacity to co-generation plants can provide an added level of flexibility to regulate electricity and heat outputs while minimising energy losses[81]. The supplementing of a CHP plant with a district heating storage system or heat accumulator enables the operation of a CHP plant to be more efficient and flexible. Heat accumulators are normally atmospheric hot water based vessels, dimensioned according to the size and needs of the district heating network. A fast dispatching CHP plant can be operated to counter variations in the production of renewable power. In wind power intensive systems, where electricity prices might even turn negative, e.g. during nights with high wind speed, and there is overproduction in the electrical system, electric boilers can be an excellent complement to charge the heat accumulator. Such a system enables optimal operation in varying market conditions at a total efficiency of over 90%[82]. The size of the thermal storage typically allows for mid-term flexibility services.

In Denmark, a country with a high share of wind power, thermal power stations are already equipped with 325MW of combined electric heating capacity[83]. A 2011 study found that installing 900 MW of heat pumps and a further 1500 MW of electric heaters can reduce Danish power exports on an annual basis from 2.9 to 0.8 TWh. "In other words, the CHP systems can absorb a significant part of the variations of the wind power"[84].

Compared to the often discussed Power-to-Gas technology, Power-to-heat is already available at comparably low costs[85]. The Power-to-heat technology is well-suited for the provision of balancing power. According to a German study, Power-to-heat plants can pay back investment costs in less than one year by just providing negative secondary reserve.

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[81] OECD/IEA 2014. Linking Heat and Electricity Systems
[82] Wärtsilä, 2012, Smart Power Generation – District heating solutions Authors: Niklas Haga, Veikko Kortela, Anders Ahnger
[83] http://www.energienieuws.info/2013/10/kansen-voor-wkk-en-warmte-op.html
[84] Bach, P., 2011, Wind Power and District Heating: New business opportunity for CHP systems: sale of balancing services: http://pfbach.dk/firma_pfb/forgotten_flexibility_of_chp_2011_03_23.pdf
[85] Böttger, M., et al., 2014, Potential of the Power-to-Heat Technology in District Heating Grids in Germany, Diana Böttger, Mario Götz, Nelly Lehra, Hendrik Kondziella, Thomas Bruckner, Energy Procedia 46 (2014) 246 – 253

Advantages and disadvantages of application in the Netherlands

The most mature and economically interesting storage option at this point, pumped hydro, is not applicable in The Netherlands in its traditional form due to geographical (elevation) constraints. Alternative plans such as the infamous ‘Plan Lievense’ proved not economic.

There are several sites in The Netherlands where CAES could be implemented, mainly salt caverns but also empty gas reservoirs. CAES is a potentially interesting storage option for the more distant (beyond 2030) future.

The Dutch CHP plants in the horticulture and residential sectors provide good opportunities for use of power-to-heat to provide flexibility. Moreover, the largest share of CHP capacity is located near the western shore, where also the largest offshore wind parks are planned[86]. A Danish author concludes that the use of CHP for flexibility could inspire a re-evaluation of the future role of the Danish CHP plants, which face –like the Dutch CHP plants- increasingly tough competition in the electricity market. “Otherwise, there is a dual risk that due to further growth in wind power Danish CHP plants will face closure and the country’s electricity system will become extremely dependent on international balancing services”[87], the author writes.

The well-developed gas infrastructure and industry in The Netherlands could prove an asset in the future, when costs of power-to-gas have decreased and demand for flexibility has increased.

Table 3-7 Storage

Main characteristics	- Storage options range from very costly (advanced batteries) to relatively cheap (pumped hydro) - For each flexibility timeframe there is one or more matching flexibility option.
General application possibilities	- Storage can be used in times of excess supply and in times of excess demand. - Pumped hydro and potentially CAES can provide the majority of required flexibility services. Balancing needs may in the future be covered by batteries (or flywheels).
General application limitations	- The most economically viable storage options are limited by geographical constraints. Pumped hydro needs differences in altitude and CAES needs suitable reservoirs for the compressed air. - Grid investments threaten the business case for storage. The Dutch internal grid and cross border connections are well developed and will improve in the future.
Specific advantages of application in the Netherlands	- There are several sites in The Netherlands where CAES could be implemented, which is a potentially interesting storage option for the more distant (2030) future. - The Dutch CHP plants used for horticulture and district heating offer good potential for using power-to-heat to

[86] http://www.government.nl/news/2013/12/20/government-designates-new-areas-for-offshore-wind-farms.html
[87] Bach, P., 2011, Wind Power and District Heating: New business opportunity for CHP systems: sale of balancing services: http://pfbach.dk/firma_pfb/forgotten_flexibility_of_chp_2011_03_23.pdf, p.4

	provide flexibility. Moreover, the glasshouses are mostly located near the western shore, where also the largest offshore wind parks are planned. - The well-developed gas infrastructure and industry in The Netherlands could prove an asset in the future, when costs of power-to-gas have decreased and demand for flexibility has increased.
Specific disadvantages of application in the Netherlands	- The most mature and economically interesting storage option at this point, pumped hydro, is not applicable in the Netherlands in its traditional form due to geographical (elevation) constraints.

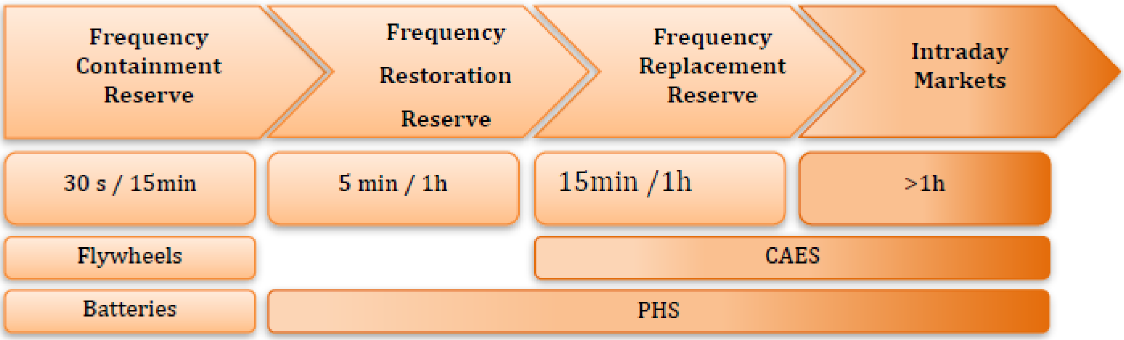
3.3 Comparison of flexibility options

After discussing the merits of each flexibility option individually, we will put them in broader perspective in this section, comparing costs, revenues and potential.

3.3.1 *Technical capabilities*

The various flexibility options provide different services, depending on their characteristics such as response time, ramping rate and capacity. Some flexibility options could provide balancing services, whereas others cannot. The figure below demonstrates that flywheels and batteries are storage technologies that can provide primary (referred to as frequency containment in the figure) reserve, but they are not useful for the secondary and tertiary reserve. CAES can provide tertiary reserves, but is not suited to provide secondary balancing services.

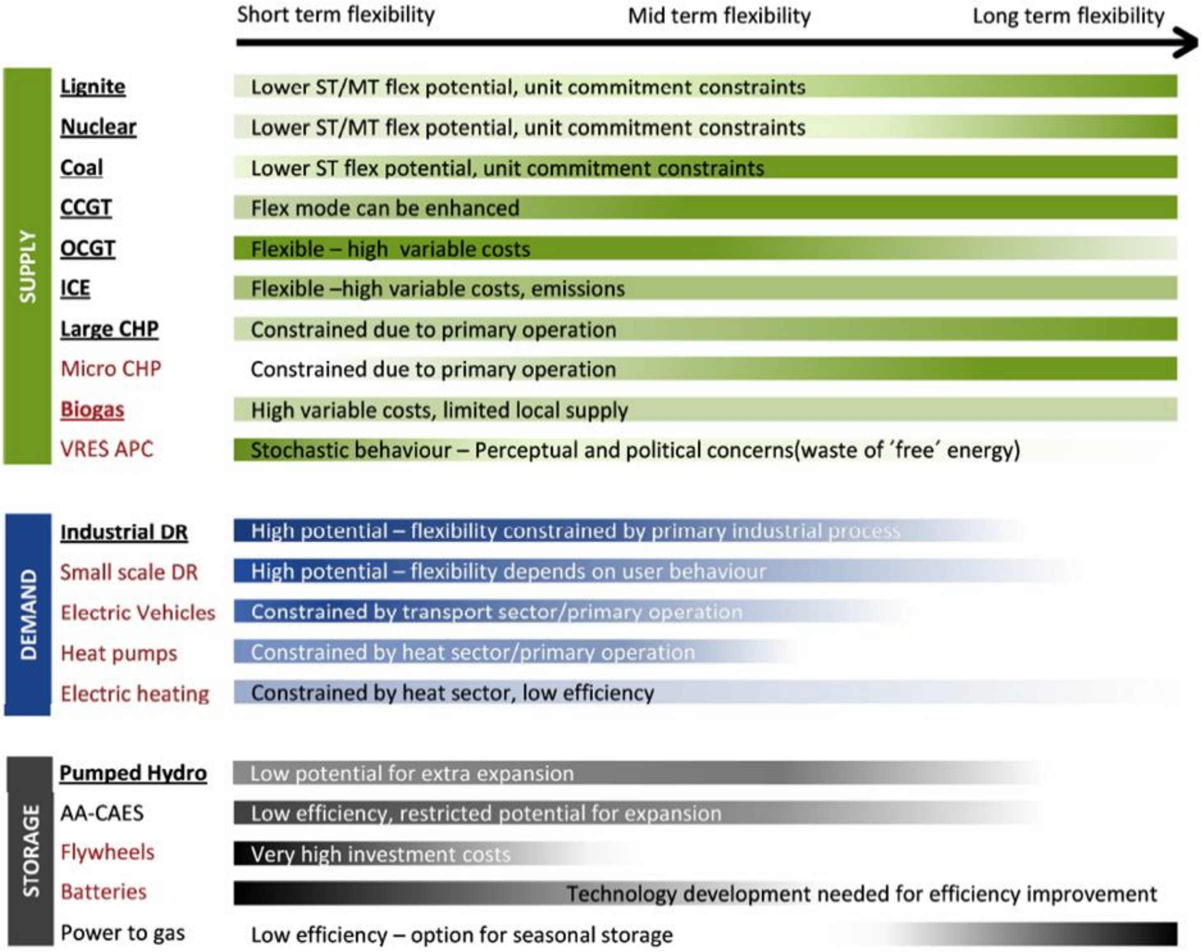
Figure 3-5 Balancing services linked to typical storage technologies[88]



The figure below indicates for a range of flexibility options the ability to provide flexibility services in different operational timeframes: short term flexibility (balancing markets with a timeframe of up to one hour), mid-term flexibility (spot markets - up to days), and long term flexibility (future contracts – seasonal variations). The degree of shading indicates the suitability of the technology to provide flexibility in that timeframe.

[88] JRC, 2013, Assessing Storage Value in Electricity Markets: A literature review

Figure 3-6 Comparative assessment of the characteristics of flexibility options in different operational timeframes (bold/underscore technologies are mature)[89]



The above figure does not include RES curtailment and network strengthening. RES curtailment can provide flexibility on all timeframes, although its use for frequency containment is limited. Network strengthening is a key enabler for many of the flexibility options and is thus relevant for short-term, mid-term and long-term flexibility.

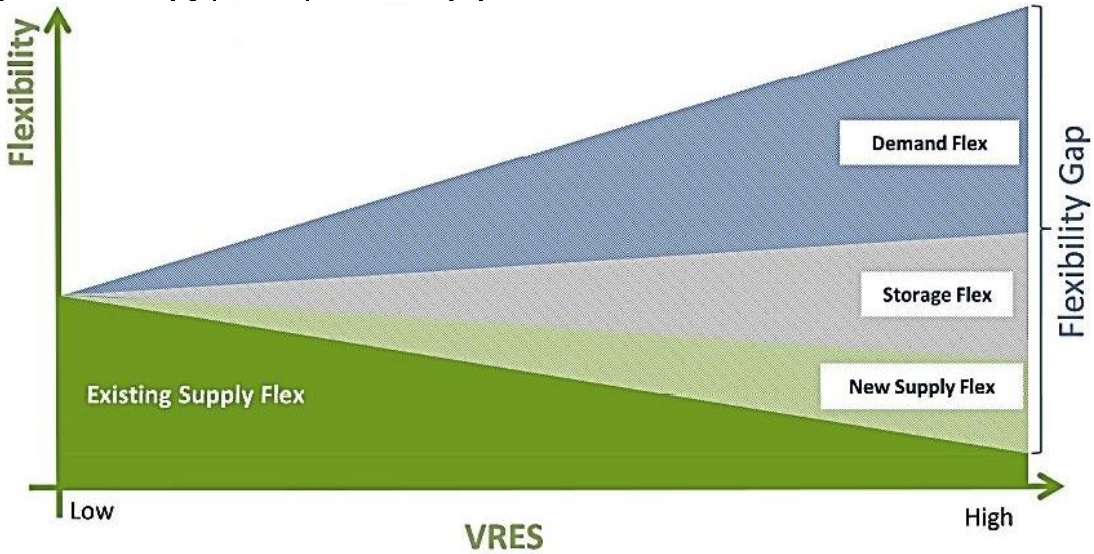
The potential of the flexibility options varies according to geography, resources and the structure of the economy[90]. The potential of pumped storage in The Netherlands for instance is limited by the capacity of the NorNed cable (700 MW). Also, the sites where CAES could be installed are not infinite, though readily available in The Netherlands with abundant salt caverns. The potential of demand response is arguably close to infinite, since virtually any consumption of energy could be bought off against a high enough price.

It is clear from the analysis of the individual options that none of the flexibility options can provide the solution on its own. A recent OECD/IEA study (2014) concludes that "neither opting for the cheapest

[89] Ecofys, 2014, Flexibility options in electricity systems
[90] Steigenberger & Grotewold, 2014, Why Germany's Energiewende Reminds Us of the Virtues of Cooperation, Markus Steigenberger of Agora Energiewende, Lars Grotewold of Stiftung Mercator, Global Policy Volume 5. Supplement 1. October 2014

option nor pursuing only the option with the best cost-benefit performance will suffice"[91]. While the different resources can substitute for each other under many circumstances, certain integration issues may only be addressed by some of them. A few examples: Large offshore wind parks can only be integrated with investments in transmission infrastructure, but integrating small scale decentralised renewables asks for distributed options such as customer-side demand response or small scale storage. Flexible plants can step in when wind or solar power is not available, but cannot avoid RES curtailment once net load becomes negative while storage can. Curtailment of renewables can help to reduce situations of generation surplus, but it does not help resolving situations of very low wind power and solar PV output. These examples underline that all types of flexibility options are needed to meet the future flexibility requirements, as illustrated in the figure below:

Figure 3-7 Flexibility gap in European electricity systems with different shares of VRES[92]



3.3.2 *Costs and revenues*

The options and associated costs to increase flexibility are very system-specific[93]. The costs of increasing flexibility of the existing power plant fleet depend strongly on the current energy mix. Increasing the flexibility of the primarily nuclear based French power plants will for instance prove much more costly than increasing the flexibility of the largely gas-fired Dutch power plant fleet. Installing pumped storage in the French Alps is much cheaper than an artificial pumped storage reservoir in The Netherlands.

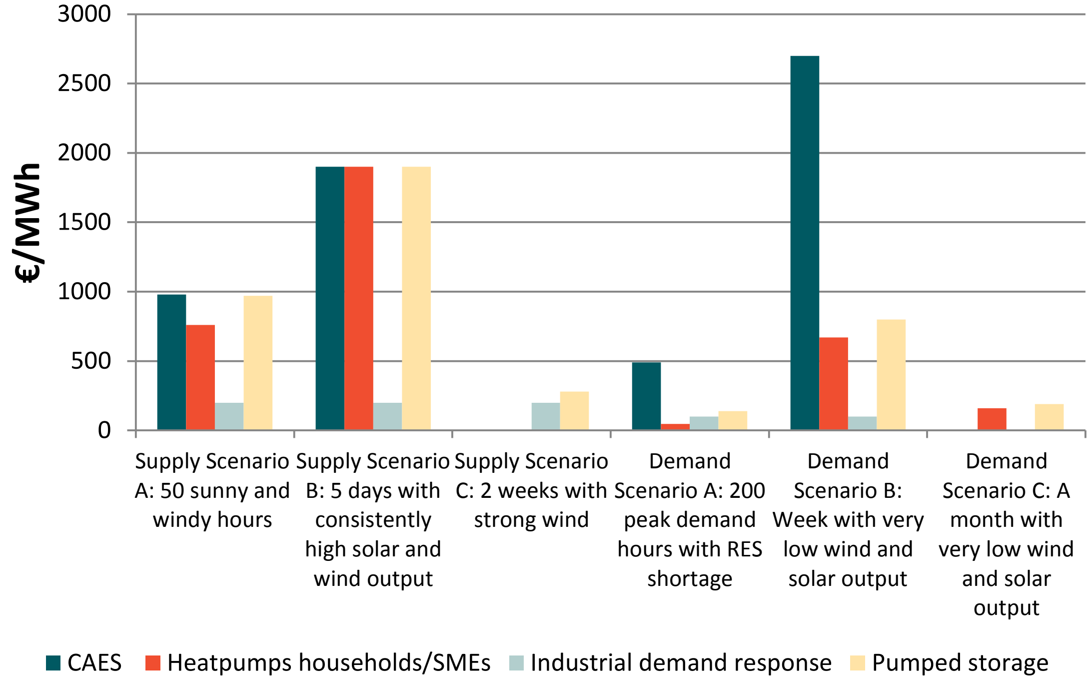
Moreover, one should be cautious with a one-on-one comparison of costs. Because the various flexibility options provide different services, as explained in the previous paragraph, they have thus different revenue streams. A MWh of electricity sold in the balancing market may yield much more revenues that a MWh sold in the day-ahead market. Electricity prices tend to be more volatile and higher on average when zero hour approaches.

More costly options are therefore not necessarily less economic under the condition that they can yield revenues from the imbalance markets. Different scenarios with different flexibility needs (hourly/daily/weekly/seasonal) will thus lead to different economics of the flexibility options. CE Delft

[91] OECD/IEA, 2014, The Power of Transformation - Wind, Sun and the Economics of Flexible Power Systems, February 2014, 238 pages, ISBN PRINT 978-92-64-20802-5 / WEB 978-92-64-20803-2
[92] Ecofys, 2014, Flexibility options in electricity systems
[93] NREL/21CPP 2014 "Flexibility in 21st Century Power Systems", 21st Century Power Partnership. 14 pp.; NREL Report No. TP-6A20-61721

demonstrated this in a simulation of the Dutch electricity market in 2025[94] for various demand and supply scenarios. The results in the following diagrams illustrate how the costs of flexibility options vary with the scenarios:

Figure 3-8 Flexibility costs (in €/ MWh) comparison for 4 options in 6 scenarios[95]



Bearing in mind that costs are very system-specific, it is still interesting to provide an indication of how the costs of the various flexibility options roughly compare. Since cost ranges are wide, the NREL only provides relative costs. These are presented in figure 3-9.:

[94] Assuming full implementation of the SER Energieakkoord/energy covenant

[95] CE Delft, 2014, Match van vraag en aanbod - Globale verkenning van oplossingen, kosten en markt - Notitie, Delft, april 2014, Opgesteld door: F.J. (Frans) Rooijers A. (Ab) de Buck H.J. (Harry) Croezen B.E. (Bettina) Kampman

Figure 3-9 Relative costs of flexibility options. Relative costs are illustrative, as actual costs are system dependent[96]

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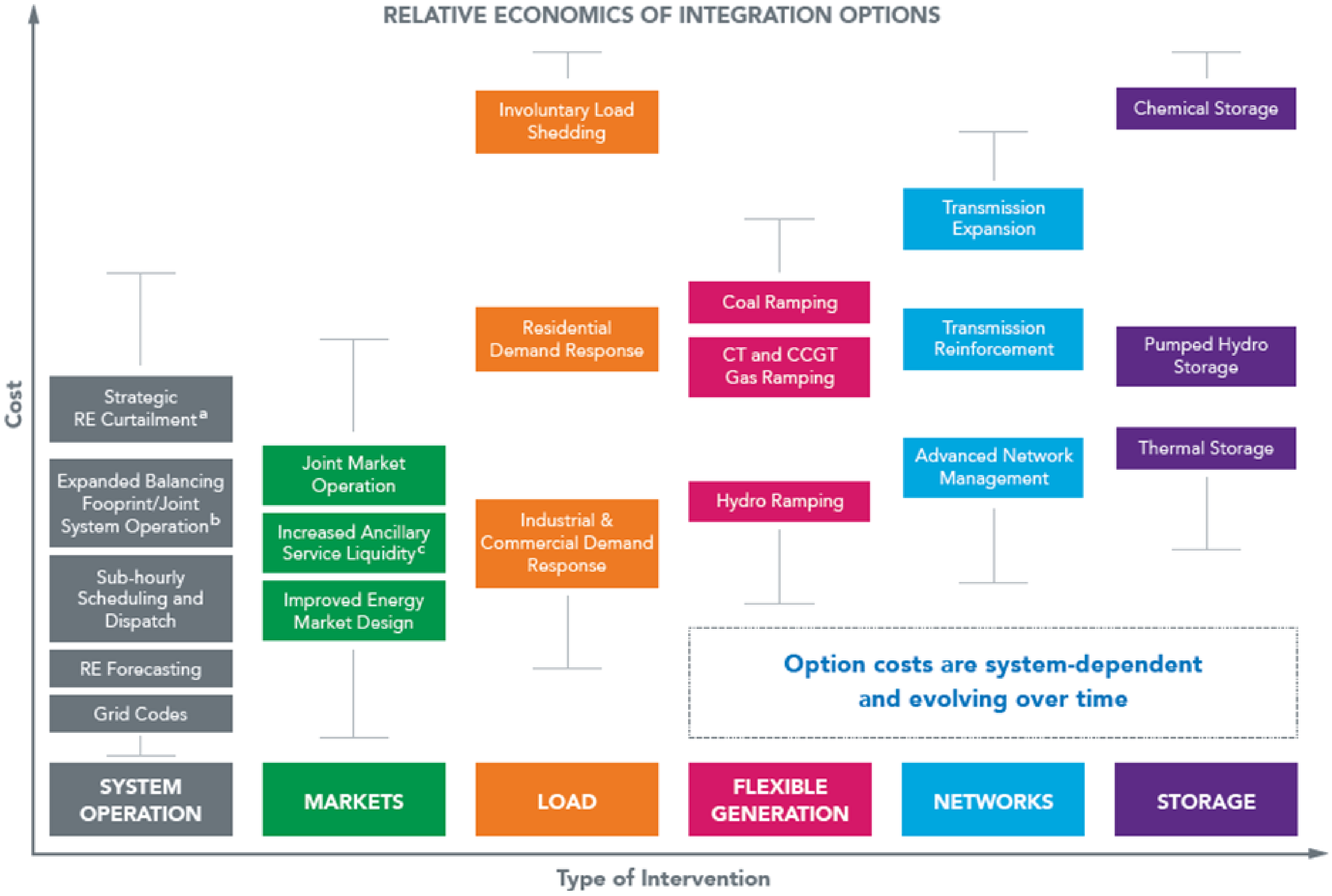

[96] NREL/21CPP 2014 “Flexibility in 21st Century Power Systems“, 21st Century Power Partnership. 14 pp.; NREL Report No. TP-6A20-61721

Although, as mentioned, costs are very system-specific, figure 3-9 shows that in general tools that help access existing flexibility through changes to system operations and market designs are cheaper than those that require investments in new sources of flexibility. Though generally cheaper, these changes may be much more difficult to implement. Changing market design, joint system operation and joint market operation entail changes to institutional relationships which are typically not easily made.

Storage can currently only be profitable in a situation with significant grid congestion. In a situation with significant local grid congestion (and constraints on reinforcing or extending the grid) power storage can become an option if it were able to benefit from extra grid related revenues, e g. from solving potential congestion constraints or from avoiding grid related wind curtailment[97]. Large scale stationary storage is negatively affected by grid extensions that smooth power prices over time and between regions and countries. However, if such grid extensions (on regional, national or international level) do not happen, storage can be an economic option to avoid wind curtailment[98].

A recent (September 2014) German study[99] finds that up to a share of 60% of renewable energy sources in the energy mix, the German energy transformation can do without new electricity storage facilities, as there are cheaper options to provide the flexible electricity input needed in view of the intermittent nature of renewables. For the time being, cross-border power trade, demand management and intelligent steering of fossil-fired power plants can ensure flexible electricity flows at less money. For the moment, adding storage to the system would only increase overall system costs. For Germany, integrating storage units into the power-transmission network would increase annual costs by as much as 2.5 billion euros in 2023 and up to 3.3 billion euros in 2033. Only in a best-case scenario with 90 percent renewable power, storage might save as much as 2.3 billion euros a year in Germany. These RES shares are not expected before 2050.

A notable exception may be Power-to-heat. Compared to the often discussed Power-to-Gas technology, Power-to-heat is already available at comparably low costs[100]. The Power-to-heat technology is well-suited for the provision of balancing power. According to a German study, Power-to-heat plants can pay back investment costs in less than one year by just providing negative secondary reserve.

3.3.3 *Modelling flexibility options*

The complexities of comparing costs, revenues and potential of flexibility options are explained in the previous paragraph. An adequately comparison of flexibility options in a given system under a given scenario requires modelling. The functioning of the electricity system is simulated by a variety of models. Modelling is the only way to assess the complex interplay of the flexibility options with the electricity system and with each other.

Modelling flexibility options poses a new challenge to modellers. Part of this study was an attempt to compare the flexibility options using the northwest European market model developed by DNV GL, based on the PLEXOS modelling framework. Due to limited time and model limitations, the outcomes

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[97] Frontier Economics, 2010, Study on flexibility in the Dutch and NW European power market in 2020, A report prepared for EnergieNed, April 2010
[98] Ibid.
[99] Agora, 2014, Stromspeicher in der Energiewende - Untersuchung zum Bedarf an neuen Stromspeichern in Deutschland für den Erzeugungsausgleich, Systemdienstleistungen und im Verteilnetz, Agora Energiewende, 050/10-S-2014/DE, September 2014
[100] Böttger, M., et al., 2014, Potential of the Power-to-Heat Technology in District Heating Grids in Germany, Diana Böttger, Mario Götz, Nelly Lehra, Hendrik Kondziella, Thomas Bruckner, Energy Procedia 46 (2014) 246 – 253

could not be used for this study. A more detailed description of the modelling efforts can be found in Annex C: Modelling exercise.

This section will discuss the implications of modelling flexibility options in general, and with the DNV GL model in particular.

Modelling with PLEXOS for Power Systems™ (“PLEXOS”)

The northwest European market model developed by DNV GL, based on the PLEXOS modelling framework, is widely employed for the simulation of electricity markets with dispatchable generation units. This study aimed to employ the model for the simulation of flexibility options in a market with an increasing share of variable renewables. The experiences with modelling flexibility options in general, and with PLEXOS in particular, are limited. When electricity market models were designed, flexibility options were not yet an issue. The models have only very limited provisions to deal with the complex revenue streams and interactions of flex options in electricity markets.

Despite their limitations, the existing market simulation models such as DNV GL’s market model are the best available for this type of simulations for the moment. Within The Netherlands, DNV GL’s market model is arguably the most extensively applied model for electricity market simulations.

DNV GL’s market model can provide insight in load and demand patterns. More volatile prices are an indicator for larger differences between demand and supply, and can thus serve as a proxy for flexibility needs. However, the model cannot provide detailed insight in the type of flexibility needed.

A complicating factor is that PLEXOS is an optimisation model with so-called ‘perfect foresight’. This means that the model in advance knows what amounts of intermittent capacity it will have to deal with and there is no uncertainty. In practice, TSOs may be faced with unexpected peaks in demand and supply. The required regulatory and reserve capacity is an input to the model, rather than an outcome.

The results from our literature review, stakeholder consultations and preliminary modelling however suggest that there are no technical flexibility needs in the foreseeable future in the sense that the current system could not cope with the flexibility requirements. There will increasingly be an economic window of opportunity for flexibility services. Modelling these flexibility options might provide more insight in their potential deployment and economic viability.

The unit commitment and dispatch modelling in PLEXOS is typically done for power generation units, but could also include flexibility options. Short-term planning is used to obtain insight in the optimal dispatch of a given generation mix, potentially including flex options. The optimal dispatch is based on the marginal generation costs of each unit. A model run covers typically not more than one year.

PLEXOS is not able to model very short-term flex, i.e. flex with timescale shorter than 1 hour. This includes additional flex in conventional plants.

Modelling discussion

One of the aims of this study was to model the economics of various flexibility options in different scenarios. Yet, the market model employed for this study appeared to have its limitations in adequately comparing the economics of the different flexibility options and the exercise did not result in satisfactory answers to this question. A further exploration of other modelling attempts revealed that the limitations are not unique to the model employed in this study. A review by Foley et al. (2010) of existing electrical system models concludes that “a clear challenge for electricity systems models is the proper consideration of ancillary services, the grid and energy storage systems”[101]

The US National Renewable Energy Laboratory (2010) similarly concluded that the challenge of simulating energy storage in the grid, estimating its total value, and actually recovering those value streams continues to be a major barrier[102]. These value streams concern particularly the operational benefits such as ancillary services. Accurately including the revenue streams and feedback effects of flexibility options in an electricity market is extremely challenging. Particularly demand response is hard to model. Özdemir et al (2014) conclude that “including demand response and generation co-optimisation helps planning models more realistically model the economics of investment. But due to the complexity and computational burden that those features add, they are frequently excluded from models, potentially distorting cost estimates and investment recommendations[103].

Current models are built to simulate an electricity system as it has existed for the last 20-30 years. These models are not (yet) capable of simulating new emerging realities and are therefore not sufficiently capable of calculating correctly potential business models for the various options. The Argonne National Laboratory, the U.S. Department of Energy's national laboratory for science and engineering research, notes that “the implicit assumption of a centralized decision-making process built into many of the global optimization and equilibrium-based power systems analysis tools developed over the last two decades limits their ability to adequately analyze the forces prevalent in today’s emerging markets”[104].

Power markets (and thus also models) need to deal with a changing reality. The old system, with centralised dispatchable units, moves towards a system with variable generation and more local actors. Whereas flexibility is currently managed by the TSO in the high voltage system, in the future an increasing role is foreseen for local and regional actors in managing their demand and supply to provide flexibility to the system.

An adequate model to simulate a future electricity system should thus include not only the centralised actors and the high voltage grid, but also the medium voltage with regional actors, and the low-voltage grid with local actors. Such a model should be able to determine the optimal mix of investments to increase flexibility. This mix might include:

- Large decentralised storage
- Local storage (e.g. in electric vehicles)
- Industrial demand response
- Residential demand response
- High voltage transmission grid extension
- Improved (smart?) distribution network

Such a comprehensive model does not exist currently.

[101] Foley at al., 2010, “A strategic review of electricity systems models,” Energy, no. 35, pp. 4522-4530, 2010.
[102] NREL, 2010, The Role of Energy Storage with Renewable Electricity Generation, Paul Denholm, Erik Ela, Brendan Kirby, and Michael Milligan, Technical Report, NREL/TP-6A2-47187, January 2010
[103] Özdemir, Ö., et al., 2014, Economic Analysis of Transmission with Demand Response and Quadratic Losses by Successive LP, (2014) Submitted to the IEEE Transactions on Power Systems, July 21, 2014
[104] http://www.dis.anl.gov/projects/emcas.html

Current power market models typically simulate the high voltage grid and the larger centralised generation units. Such a model would have to be extended with models that cover the medium and low voltage grids. These models exist, but have themselves great difficulty in dealing with the new reality which asks for two-way communication and bi-directional power flows (smart grids) as opposed to the current situation where flows go only from the centralised power units to the decentralised consumer. Accurately modelling load flows in the current system is already extremely challenging. The smart grid development will only add to this challenge. If it were possible to couple these models it would lead to an extremely complex and heavy model that no computer today could possibly run. On top of this, the model would probably be so complex that interpreting the results would become nearly impossible.

The above described complexities hold for all types of models currently used, such as simulation, optimisation or agent-based models. The difficulties of modelling three grid levels accurately are irrespective of the type of model employed. The changing reality asks for an extension of these models, without making them overly heavy and complex. The models are thus incomplete, and not fundamentally flawed since the basic layout of the system (the wholesale power market) is not expected to change fundamentally. It is merely expanding to include more actors on different levels.

3.4 Views on flexibility options

The stakeholders in the Dutch electricity sector that were interviewed in this project proposed various options that could help to increase flexibility in the Dutch electricity sector in the future. These included one physical investment suggested, and several potential regulatory improvements.

The physical investment option to improve flexibility discussed by interviewees was a second cable to Norway. The large potential of hydro in Norway offers to various respondents an interesting possibility to provide more flexibility for the Dutch system, and according to one of them ‘a good business case anyhow’. Nevertheless, it was also remarked that there is internal resistance in Norway against such a cable. Not only will the overland connection to the cable have consequences for the landscape in Norway, but it might also lead to higher electricity prices in Norway itself. In Norway, planning of the cable was postponed from initially between 2015-2017 to after 2021[105].

Regulatory options spontaneously proposed by interviewees were better prediction of wind and solar power generation, better pricing of balancing power, integration of decentral power in balancing markets and better coordination of regulation between Member States in electricity-only and in capacity markets:

- **Better predictions of wind and solar power** over more time ahead will also reduce the need for balancing options in the future, according to one respondent.

- There are several improvements possible regarding the **pricing of balancing power in Europe** according to interviewees. Regarding Norway, for instance, the value of pumped water storage needs to be better accounted for. In practice it is often unclear who is the owner of pumped storage for balancing. Also, different regulatory arrangements in existing pricing zones in Europe are an issue to consider for future regulation.

[105] http://www.energeia.nl/preview/1422-Statnett-herziet-strategie-interconnectoren-Norned-2-op-de-lange-baan.html

- The growth of decentral power is another issue discussed in the interviews. One remark is that small end-users that are producers so far are ‘free riders’ in the system in terms of participation in balancing costs. A future system would have to take the **responsibility of decentral producers regarding balancing power** into account. Specific for the Netherlands is the situation of cogeneration, of which the share in the Netherlands is relatively high compared to other countries. A respondent notes that the business case for many of the older cogeneration capacity does no longer hold. This flexibility option therefore might well disappear over time in the Netherlands if no further measures are taken.

- **Better coordination between European electricity markets** in various ways is suggested by interviewees as an additional option to provide flexibility in the system. ‘One coordination centre for the TSOs would solve many problems, as then there would be only one captain on the ship’, according to one respondent. For instance, one of the coordination problems yet to be solved is the lack of integration of bidding procedures in intra-day markets. Whereas in the Netherlands and Belgium bidding is limited to one hour in advance of real time, in Germany this is one quarter. This distorts current markets.

- Also, **national capacity markets should be coordinated on a European level** according to respondents. In the present situation, lack of such coordination can result in undesired outcomes due to electricity flows from one country to another. At least, market parties should get the right to participate across borders in capacity markets of another country. Coordination and cooperation between countries is already the case in the NORDIC system and to a lesser extent there is also integration in the ‘Pentalateral forum’ between Germany, France and the Benelux countries. This should be further expanded.

3.5 Conclusions

From the analysis of flexibility options for the Netherlands, the following conclusions can be drawn:

1. For the fulfilment of any additional flexibility needs in the Netherlands in the future, a distinction can be made between regulatory-based options, that do not require investments in new flexibility options, or investment-based options, that stimulate investments in new flexibility capacity to be built.

2. Increase in wind and solar capacity affects mostly mid-term and short-term flexibility requirements. The balancing needs (very short term) are expected to increase only slightly. Primary and secondary reserve will be hardly affected by increasing share of wind and solar, tertiary reserves to some extent. This holds even more as predictability of wind and solar radiation patterns is still expected to increase in the future.

3. Flexibility options provide different services and thus have different revenues. This makes a one-to-one cost-based comparison not useful. Costs and revenues of flexibility options in the market can only be adequately assessed by models. However, this project has shown that current models are not yet capable of adequately modelling flexibility options. They were never designed for the emerging flexibility options and are tailored to centralised power systems, whereas decentralised solutions become increasingly important. Expanding those models will be an important element in the evaluation of flexibility options in the future. The main improvements needed are to include

low- and medium- voltage (decentral power) next to high-voltage power, revenues on all electricity markets from futures to near-real time and strategic market behaviour of actors.

4. The fact that flexibility options provide different services also means that no single flexibility option can provide the answer to the flexibility challenge; there is no 'silver bullet'. A mix of flexibility options will be needed. Based on the observations in this chapter, however, some prioritisation of flexibility options can be made:

   – A logical first step would be to use the existing flexibility potential to its maximum. The current systems in neighbouring countries like Germany and Denmark have proven much more flexible than expected. At the same time, the current flexibility regulation could be fine-tuned at low costs and with limited risks involved. Fine-tuning includes improving market access, transparency and near-real time trade. Another simple measure would be increasing RES curtailment, which is politically sensitive but often much cheaper and easier to implement than alternative flexibility measures.

   – A next step to improve regulation would be to improve system operations and market design. Although costs of flexibility are very system-specific, in general tools that help access existing flexibility through changes to system operations and market designs are cheaper than those that require investments in new sources of flexibility. Though generally cheaper, these changes may be much more difficult to implement. Changing market design, joint system operation and joint market operation entail changes to institutional relationships and transnational arrangements which are typically not easily made.

   – Besides improved regulations, investments in 'hardware' at some point will be necessary to allow for additional flexibility. Here, several options have to be evaluated against each other:

     Increasing flexibility of conventional plants
     Cost-benefit analyses of retrofitting existing power plants to increase flexibility shows a wide range of outcomes, driven by project-specific costs. For gas-fired plants, investment costs are substantially lower than for coal fired plants. The largely gas-fired Dutch power system can thus be made more flexible at relatively low cost. These Investments in increased flexibility of conventional power plants can increase the ability of the Dutch power system to provide also flexibility services for surrounding countries, which increasingly face capacity shortages.

     Demand Response
     Demand response is a technical option that will become more and more available in the coming years and that is widely considered to be inevitable in a system with more variable renewables. The technical potential of demand response is huge, but uncertain is at what price consumers are ready to shift their demand. Whatever the price is, it will arguably come down over time when actors find shifting their loads easier than initially expected. The relatively strong position of The Netherlands in smart grids and use of electric vehicles provide a solid base for residential demand-side management.

Grids

Investments in the grid provide the strongest business case for investment based solutions. At the international level, the European Integrated Energy Market (IEM) calls for increased interconnection. These interconnections will also be essential for cross-border balancing and flexibility services. Moreover, connections to surrounding countries with (imminent) capacity shortage allow for export of expensive electricity at peak demand hours in those countries. For the Netherlands, an additional cable to Norway is economically sound (PBP~5yr) just on the basis of integrating both markets. The flexibility services provided by the hydro reservoirs will only add to the business case. On the local and regional level, investments in the medium and low voltage grid are inevitable since large parts of the network reach their technical lifetime and need to be replaced. Replacement of these distribution lines with a network that allows for two way communication and transport, a smart grid, would be more expensive but this additional investment will pay off by allowing for demand response.

Storage

Besides network investments and demand response, storage provides an additional investment based option for flexibility services. However, the only storage option that is currently able to provide flexibility to the system is pumped hydro, which is not available in The Netherlands due to geographical constraints. Storage options, besides pumped storage in for instance the Alps or Norway, are still far from a positive business case. Even in the future, batteries or CAES will probably need revenues beyond the spot market, for instance from the balancing market. Grid investments are currently cheaper than storage, but also threaten the storage business case. Storage can currently only be profitable in a situation with significant grid congestion. As the price of storage will go down and the need for flexibility will increase, storage may become profitable over time.

This does not mean that there will be no development of storage options in the near future. New storage technologies like batteries, power-to-heat or power-to-gas are expected to grow regardless of the need for flexibility, due to rising demand from the transport, heat and chemicals sectors. Of these options, power to gas at this moment is still too expensive. It might provide a promising option for the longer term. Compared to the often discussed power-to-gas technology, power-to-heat is already available at comparably low costs. The power-to-heat technology is well-suited for the provision of balancing power. The Dutch CHPs in horticulture and district heating networks provide excellent conditions for power to heat deployment, provided that in particular heat is properly priced. Many CHPs in horticulture are approaching their technical lifetime and renewal of the CHP plants is not evident, given the increasingly tough competition in the electricity market. Flexibility could inspire a re-evaluation of the meaning of CHP for the Dutch electricity sector.

4. Conclusions and Recommendations

This report has examined the needs and options for additional flexibility in the Dutch electricity sector in the light of the anticipated large increase in variable renewable energy sources in the near future. It is clear that there are still many uncertainties regarding this issue, which give rise to a variety of views of stakeholders and experts. Also, conclusions and recommendations of this report should be seen in the light of the uncertainties that arise due to the applied research method and the possibility of more rapid systemic changes in the electricity sector than foreseen. Three main limitations of the study outcomes are apparent.

Uncertainties and limitations of the study outcomes

First, outcomes should be seen in the light of the main research method applied, i.e. literature study and interviews. Modelling flexibility in more detail turned out to be not feasible within the limited context of this study. The conclusions therefore are of a mainly qualitative character.

Second, in this study current developments have been extrapolated for the coming ten years taking currently announced policies as a basis (Energieakkoord). That is considered feasible, because the period in the future is limited and will be determined for a substantial part by current developments. On the other hand, the electricity market is facing large challenges and major changes. Large utilities are struggling to remain profitable, whereas local actors are increasingly exploring the possibilities to produce and trade their own power. At the same time the European electricity markets are increasingly integrated, with more and more influence of neighbouring countries on national markets. This might lead to more rapid systemic changes than foreseen in this study.

Third, focus of this study is on technical flexibility of the system, and the prevention of system blackouts. The availability and cost-efficiency of various options for flexibility has been examined, as well as specific merits and limitations of application of each of these options for the Netherlands, but a full-fledged cost benefit analysis of all options was not possible within the context of this study.

Nevertheless, the analysis in this report leads to conclusions regarding flexibility needs and options that together give sound indications for designing and implementing flexibility policies in the Netherlands. The chapter first presents conclusions regarding flexibility needs and options in the Netherlands (sections 4.1 and 4.2). Finally, it presents recommendations for research and Dutch policy (section 4.3).

4.1 Flexibility needs in the Netherlands

The Energieakkoord RES targets of 2023 can most probably be realised without investments in additional flexibility beyond those already planned.

Our analysis showed that the existing potential flexibility in the Netherlands' power system is relatively diverse and high in comparison to neighbouring countries. A well-developed electricity market, a high share of CCGT and CHP plants, and interconnection capacity provide for a relatively flexible power system. Also, existing total generation capacity compared to demand is relatively high such that at present a substantial overcapacity exists. Technical availability of gas turbines and interconnection capacity in the Netherlands compared to peak demand will remain good in the years to come, although profit margins of gas-fired assets are under pressure and some plants are currently closed or

mothballed.The low profit margins also threaten the replacement of many CHP plants that are approaching their technical lifetime.
With limited percentages of renewables to be implemented in the Netherlands compared to surrounding countries in an Energieakkoord scenario and improved predictability of wind and solar supply, there seems no absolute 'need' for specific new capacity to be implemented for flexibility reasons in the Netherlands until 2023.

A need for additional flexibility due to increasing RES penetration may emerge around 2030, timely anticipation could reduce flexibility costs.
A combination of increasing shares of RES and decreasing conventional capacity will cause a need for additional flexibility at some point in the future. The overcapacity in The Netherlands is expected to remain until around 2030, although reliable long-term predictions for this fast changing sector are difficult (see next point).
Timely anticipating the future flexibility needs could reduce costs. Some flexibility options have long lead times, so timely investments could prevent a last-minute resort to more expensive solutions. Rapidly increasing system costs for integrating the variable renewables also form a powerful driver to have a critical look at the organisation of the system, in order to minimise these additional costs as much as possible.

A main systemic uncertainty is the degree to which decentral (household) electricity generation and penetration of electric vehicles will develop.
Unforeseen developments could speed up the need for additional flexibility, such as an unexpected boom of local renewables or an increase in electricity demand due to fast penetration of electric vehicles in the market. The evolving role of decentralised power generation and demand management in the market will require a fundamental rethinking of basic design principles of the electricity system to include bottom-up considerations next to the traditional top-down orientation of dispatch of central generation capacity. This includes questions such as to what degree decentral generation can compete on a level playing field with large-scale generation in central dispatch, to what extent decentral generation could be aggregated and used for flexibility purposes on a central level and what would be consequences for the distribution grids.

4.2 Flexibility options for the Netherlands

There is a wide variety of flexibility options available for the Netherlands, which can be roughly divided into regulatory and investment-based options.
A more flexible power system can be attained on one hand by investments in specific options in supply, demand, storage or the network, and on the other hand by regulatory interventions such as capacity mechanisms, RES curtailment, and market coupling. As such, there are many technical options as well as a broad policy portfolio available to increase flexibility in the power system.

Innovative flexibility options such as storage and smart-grid enabled demand-side management that will enter the electricity market in the future will require further technical improvements and cost reductions to be able to compete with existing flexibility options.
With increasing percentages of variable power, innovative flexibility options will enter the electricity market at some point in the future. Regulation therefore should make sure that there is equal access and a level playing field for all existing and innovative options alike. However, the exact moment of

entry of these innovative options, either before or after 2030, will depend on further technological innovations and cost reductions that will make them able to compete with, and substitute the existing flexibility options.

Improving market access and RES curtailment are regulatory options that can be used relatively easily on a national level, whereas improving market coupling can serve on an international level to increase flexibility of the Dutch electricity system.

Improving market access of households and other small-scale customers, as well as other fine-tuning options such as further increasing transparency and near-real time trade, can contribute to a higher flexibility of the electricity system in the Netherlands. In case of unforeseen supply peaks that require swift action, curtailment of renewable energy can also be used as a relatively cheap and easy emergency option for system flexibility. Further improvement of coupling of European short-, medium- and long term markets increases size and diversity of the market area and as such contributes substantially to improving flexibility in The Netherlands and its neighbouring countries.

The need for capacity mechanisms as a regulatory option for the Netherlands has not been demonstrated and its introduction could also entail substantial risks for further development of low-carbon options in the future

Whereas several neighbouring countries of the Netherlands already have introduced capacity mechanisms to increase flexibility in the electricity sector, its need for introduction in the Netherlands is not evident. Moreover, opinions of stakeholders in the Netherlands on this issue vary widely. Whilst providing a possible benefit for flexibility, this regulatory option also entails substantial risks for the electricity sector. These include a potential overstimulation of conventional generation options - which interferes with emission reduction and RES objectives of the EU and the Netherlands – and barriers to the development of innovative flexibility options that could better prosper in an energy-only market.

No 'silver bullet' exists between the basic investment-based options of improving flexibility of conventional plants, smarter demand response, interconnections and storage.

Each of these four different categories of investment-based flexibility options examined has its own general and specific benefits and costs for The Netherlands associated. A proper evaluation of their relative economics would require modelling capabilities that are not yet available in the market. In general, more innovative solutions like most storage options are still too expensive. Increasing interconnection capacity makes economic sense, even regardless of the flexibility issue. Power-to-heat and demand response are expected to soon become important sources for flexibility.
With an equal regulatory access assured, private and public (in the case of grids) investors will have to evaluate technical specifications, social and political acceptance and investment and operational costs to make the case for their specific option considered.

4.3 Recommendations for further research and policy

Research recommendations

Modelling capacity for analysing flexibility needs and options needs to be improved.
Capacities of present state-of-the-art electricity sector models have shown to be too limited in this research project to model flexibility needs and options in a credible way. Main improvements are needed to include low- and medium- voltage (decentral power) next to high-voltage power, revenues on all electricity markets from futures to near-real time and strategic market behaviour of actors.

The consequences of the emergence of decentral generation should be further examined.
The emergence of decentral power generation might have important and so far largely unknown consequences for the organisation of the electricity system, including profound impacts on current business models of incumbent parties in the electricity sector, technical impacts on the system as well as socio-economic consequences for end-users. These need to be examined in more detail.

Policy recommendations

Assure equal market access for all options to short-, medium- and long-term flexibility markets
Basis for good functioning flexibility markets is a level playing field for all demand-, storage- and supply-side options alike. Make therefore sure that demand-reduction by small and large end-users as well as storage are valued on an equal basis to supply-side options on balancing, intra- and day-ahead markets.

Stimulate further integration of European electricity markets on all time-scales
Although one European electricity market should be realised by 2014, in practice many detailed regulatory differences still exist between national balancing-, intra-day and day-ahead markets. Improved coordination via e.g. the Pentalateral forum could help to remove these barriers. Also, best practices of the Pentalateral forum could be communicated to other Member States and vice versa.

Stimulate the further development of additional flexibility options that can contribute to meet future flexibility needs also in other EU Member States
Innovative flexibility options need to be further developed in order to be able to compete with existing flexibility options in the future. In the Netherlands there is a large variety of research ongoing in this field that can be further supported in order to develop increased flexibility for the future domestic electricity market as well as new export opportunities.

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Annex A: How markets deal with flexibility

This annex describes how electricity markets are arranged to value flexibility. To understand this, the role and workings of each of the subsequent electricity markets are outlined below.

The energy-only market

Flexibility in power systems is inherently tied to the regulatory and market rules that help shape operations[106]. As the value of flexibility is revealed through the market, the typical planning stages in markets need to establish prices that correctly reflect the perceived scarcity of the commodity at that (future) point in time.

Market timeline

The Dutch electricity market operates as an energy-only market. Simplified, this means that generators get paid for the energy they deliver, and not for their delivering a specific amount of installed capacity. To cope with the challenge of flexibility, power markets (e.g. forward, day-ahead, intraday, and balancing) provide incentives to ensure that the stability of the system is maintained. Figure A-0-1 gives an overview of the market timeline, delineating the roles of both market players and the Transmission System Operator (TSO).

Figure A-0-1: The role of generators and traders in the electricity markets

	Generators and traders	TSO
Forward *Years, quarters, months, weeks*	✓ Sale/purchase decisions ✓ Scheduling of power plant maintenance ✓ Offer TSO primary, secundary reserves	✓ Procuring primary and secundary reserves ✓ Allocates 1700 MW cross-border capacity (1300 MW year ahead, 400 MW month ahead)
Day-ahead *D-1*	✓ Sale/purchase decisions ✓ Create operating schedule for power plants ✓ Offer TSO tertiary reserves	✓ Procuring tertairy reserves ✓ Allocates 2850 MW cross-border capacity
Intraday *Within 24 hours, up to 1 hour*	✓ Sale/purchase decisions ✓ Reschedule generation with updated forecasts ✓ Send re-nominations to TSO	
Balancing *< 15 min.*	✓ Provide ancilliary reserves as requested by TSO	✓ Balance (variable) generation forecast errors by activating operating reserves

By participating and trading energy in the subsequent markets, traders consequently reduce their risk in iterative time steps. As the market gets closer to real-time, trading decision get more operational (e.g. physical, technical) instead of strategic (e.g. economic, commercial). As trade happens closer to real-time, prediction accuracies for both consumption and generation increase and therefore the energy traded in the different subsequent trading options is optimised. The next paragraphs outline each of the electricity markets (forward, day-ahead, intraday, balancing) in more detail.

[106] NREL/21CPP, 2014, "Flexibility in 21st Century Power Systems", 21st Century Power Partnership. 14 pp. NREL Report No. TP-6A20-61721

Forward market

The majority of electricity trade takes place in the forward market[107]. The forward market operates (approximately) on a continuous basis up to three years to one week ahead of the implementation date and is significantly less volatile compared to other power markets. Trade decisions are predominantly taken based on strategic and commercial issues, such as the evolution of the prices of natural resources (natural gas, coal, uranium, CO_2 emission rights). During this timeframe power generating companies decide on the scheduling of their power plant maintenance. In the forward market, future (base load) blocks of electricity are sold (e.g. years, quarters, months). One month ahead of implementation date supply and demand forecasts can be fine-tuned to include more accurate weather forecasts and availability of power plants.

Day-ahead market

The Central West region day-ahead market is fully integrated. In the Netherlands, about 20% of electricity trade takes place in the day-ahead (auction based) market. As traders of electricity get closer to the week or day of execution, their predictions for consumption and generation will improve in accuracy and they have more exact knowledge about their short-term trading needs and possibilities. Consequently they have to adjust their trading with respect to what they have traded in advance in bilateral agreements. They do so by trading on an hourly basis for the next day to sell or buy any foreseeable excess or shortage of production. In the day-ahead markets, each trader can make anonymous auction bids for selling and buying energy. The bids have to be sent to a market operator that aggregates all bids and determines and returns both the Market Clearing Prices (MCPs) and Market Clearing Volumes (MCVs) for each trading period by maximizing wealth. In some day-ahead markets (such as the APX in the Netherlands), block bids, that span over a number of trading periods can also be made which have the advantage that start-up costs can be spread over a larger number of trading periods.

Intraday market

Getting closer to real-time, predictions of load and generation improve further and deviations from earlier predictions will arise, thus creating the necessity for a near real-time market to exchange power. Intraday markets are an option for traders to continuously and last-minute (up to an hour before delivery) respond to latest unanticipated changes in the portfolio. At the Intraday market, created in 2006, participants have the opportunity to continuously trade power products in hourly intervals (like day-ahead) as well as freely definable block orders up to 5 minutes prior to delivery. Until close to real-time traders can send their bids for buying and selling to the operator of the intraday spot market. The liquidity in intraday spot markets will be lower than in other markets as traders only use this market to adjust their trades they have already made before.

Balancing market

In the Netherlands, TenneT (the national TSO) is the responsible entity to maintain the power balance. The power balance can best be regarded as a flywheel which rotates with a frequency of 50 Hz and is accelerated by generation and slowed down by consumption (load). Power imbalances can occur as a result of several factors, such as events of mechanical failures of generation or due to forecast errors in power generation or demand. The TSO monitors the system imbalance in real-time and, if needed, calls bids every 15-minutes for operating reserves to restore the system balance.

[107] ECN, PBL, 2014, Energietrends 2014

Market-based provision for operating reserves

For the provision of operating reserves TenneT organises and operates the balancing market for balancing services where market parties place bids for different operating reserves. The ENTSO-E defines operating reserves for balancing actions in three categories: primary, secondary and tertiary reserves.

Box A-1: Primary, secondary and tertiary reserves explained

Primary reserves are activated automatically to stabilise the system frequency after a contingency event (loss of 3000 MW). The maximum possible outage is deemed to be 3000 MW, which is rounded off above to the loss of two of the biggest power plants in Europe. The primary reserve capacity is activated by the primary control system. The primary control system is installed per generation unit, entirely automated, and fully operational with a response time of less than thirty seconds. The minimum size of the primary reserve is determined by the ENTSO-E regional group for continental Europe as in proportion to the total production volume in the areas controlled by the TSOs. In the Netherlands this amounts to 101 MW in 2014. From 2014 onwards TenneT has the obligation to procure the primary reserve in a market oriented way. This was meant to align the level playing field with neighbouring countries, i.e., Germany, Belgium and France, where the procurement of primary reserves was already part of a market mechanism. Procurement takes place every week.

After primary control has stabilized the grid frequency, **the secondary reserves** are activated to bring the frequency back from its steady-state frequency to its nominal value within 15 minutes. The secondary reserves are activated within 5 minutes of being called, for 15 minutes to 1 hour duration, and are procured on a weekly basis.

Tertiary reserves are to be activated within 15 minutes of being called, for at least 15 minutes duration, and are procured on a daily basis. Apart from regulating, also emergency capacity is contracted by TenneT to cope with uncertainties during significant contingency events, ca. 300 MW of load shedding which can be utilised in total for 40 hours per year and with a maximum of 8 hours for a single call

As can be seen in Figure A-2, three different balancing capacities are procured for the trading of secondary and tertiary reserves: regulating, reserve and emergency capacity. For secondary reserve TenneT contracts annually a specified amount of regulating capacity (i.e. 300 MW, 133 k€/MW/yr[109]). For tertiary reserves both reserve and emergency capacity is procured.

[108] https://www.regelleistung.net/ip/action/static/ausschreibungPrlNl

[109] Lampropoulos et al, 2012, Analysis of the market-based service provision for operating reserves in the Netherlands

Figure A-2: Main characteristics of the operating reserve capacities in the Netherlands[110]

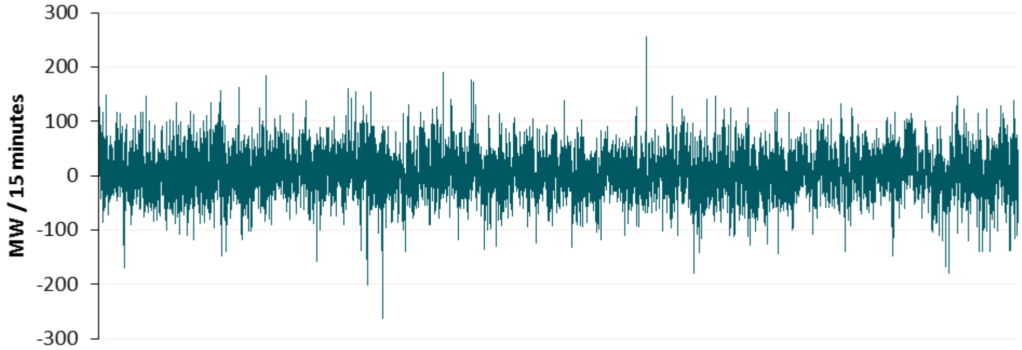
Capacity	Type	Bid size	Activation	Ramp rate	Min. step	Duration
Regulating capacity	Secondary	≥ 5 MW	Automatic	≥ 7% / min	1 MW	≥ 4 sec
Reserve capacity	Tertiary	≥ 5 MW	Automatic/ Manual	≥ 100% / 15 min	full	≥ 15 min ≤ 1 h
Emergency capacity	Tertiary	≥ 20 MW	Manual	≥ 100% / 15 min	full	≤ 15 min

Portfolio balancing: Programme Responsible Parties

Although TenneT is responsible for maintaining power balance, TenneT transfers part of this responsibility to market participants by implementing a system of programme responsibility. Each market party connected to the grid has a Programme Responsible Party (PRP)[111] whose job is to keep its energy programmes balanced for each settlement period (15 minutes). Via the imbalance prices, the PRPs are incentivized to keep the predicted production and consumption figures as close to their real production figures for each settlement period (each 15 minutes[112]). PRP's have to submit these production figures to the TSO for the next day right after the clearing of the day-ahead market[113]. These programmes specify how much electricity the connected party expects to take from and feed into the grid on the next day and may be modified up-to an hour before real-time. In practise, this implies that a PRP in practise does not have a portfolio that consists only of variable renewables, as then there would be too much uncertainty involved in predicting generation adequately.

To help PRPs to balance their portfolio, TenneT provides them with appropriate and real-time metering information regarding total system imbalance as well as estimates of individual PRP imbalances as close to real-time as possible. The sum of all transactions entered into by each PRP is the E Programme. TenneT checks all E Programmes for consistency. Ex-post, the regional system operators then notify TenneT of the amount of electricity that each PRP has actually consumed and/or supplied. The difference between the amounts recorded in the E Programme and the total of the actual measured values of each PRP is called the imbalance. As can be seen from Figure A-3, imbalance volumes typically fall within a margin of +/-100 MWh per 15 min. Throughout January - September 2014, the average imbalance volume (in both directions) was 27 MW / 15 minutes.

Figure A-3: Imbalance volumes in the Netherlands (01/01/14 – 29/09/14)[114]



[110] Lampropoulos et al, 2012, Analysis of the market-based service provision for operating reserves in the Netherlands
[111] Or Balance Responsible Party (BRP). In the Netherlands they are referred to as Programma Verantwoordelijke (PV)
[112] Also known as the programme time unit or PTU
[113] The sum of all transactions entered into by each PRP is the "E Programme".
[114] Calculated with system and transmission data from TenneT

Imbalance settlement

During operation, each PRP can be subjected to imbalance (difference between actually allocated values and as submitted in the e programme). An imbalance charge is imposed per imbalance settlement period on the PRPs that are not in balance. In case an imbalance occurs, TenneT uses the operating reserves to restore the system frequency. To operate this, there is a bid ladder in which TenneT receives bids for different classes of balancing capacity which TenneT can call in real-time in case of any imbalance.

Being responsible for the balance management within a control area, the TSO uses an imbalance settlement system to call different types of balancing resources to restore the balance. Each of these balancing resources has properties concerning amongst others activation speed, duration, and minimum bid size. The resources, which are available to the TSO, are offered by market parties and are mostly being placed in a merit order bidding ladder. Whenever imbalance in the system occurs, the TSO uses the bidding ladder to select bids to restore the balance. When bids are selected to provide balancing resources they will receive their bid price. In systems where passive balancing is allowed, parties are also rewarded when they contribute to restoring the system balance without explicitly being selected by the TSO.

Summary

As the market gets closer to real-time, trading decisions get more operational (e.g. physical, technical) instead of strategic (e.g. economic, commercial). When trade is happening closer to real-time, prediction accuracies for both consumption and generation increase and therefore the energy traded in the different subsequent trading options is optimised. Flexibility requirements therefore can be better deducted from what is happening in markets that operate closer to real-time.

The balancing market has the function to provide last-minute flexibility (up to 15 minutes). TenneT is the responsible entity to maintain the power balance between supply and demand. Although TenneT is responsible for maintaining power balance, TenneT transfers a large part of this responsibility to market participants by implementing (the Dutch) market system of programme responsibility. Each market party connected to the grid has a Programme Responsible Party (PRP) whose job is to keep its energy programme balanced for each balancing settlement period (15 minutes). In addition, the TSO procures three different operating reserves to market parties as needed for secondary and tertiary reserves: regulating, reserve and emergency capacity. The imbalance price provides PRPs with an economic incentive to help the TSO maintain the system balance.

Annex B: Are there already signs of inflexibility in the Dutch power markets?

This annex assesses, based on historical data, whether there are already economic or technical signs of inflexibility noticeable in Dutch power markets. When data for the Netherlands was lacking, data from neighbouring countries were used.

The market signs of inflexibility discussed in the subsequent paragraphs include:

- **use of operating reserves** by the TSO (technical indicator)
- **curtailment** of wind and/or solar production (technical indicator)
- occurrence of **negative market prices** (economic indicator)
- **price volatility** (economic indicator)[115]
- **imbalance volumes and imbalance prices** (technical and economic indicator)
- **volume traded in intraday markets** (economic indicator)

Use of operating reserves

If TSO's experience more difficulty in balancing demand and supply, this should be reflected in a more frequent use of primary, secondary reserves, tertiary reserves, to compensate any deviations from the system frequency. This assumption also seems to be endorsed by 90% of the Dutch Programme Responsible Parties (Table B-1), who expect that TenneT will need to contract more operating reserves by 2020.

Table B-1: Dutch PRP responses to general balancing issues[116]

	Yes	No
Do you expect to fundamentally change the manner you balance your portfolio by 2020?	58%	42%
Do you feel the current balancing framework is sufficiently robust to keep the system balanced with the expected increase of variable renewable energy sources?	33%	67%
Do you expect to add more bids to the common merit order of regulating and reserve capacity used by TenneT for system balancing by 2020?	70%	30%
Do you expect that the need for TenneT to contract reserves will have increased by 2020?	90%	10%

However, looking at Table B-1, the use of operating reserves (expressed in total number of PTUs in per year capacity was activated divided by total number of PTUs per year) has remained more or less stable over the last eight years. If there would be something like a trend perceivable, both regulating and reserve capacity usage rates and volumes have gone down and not up. This would seem to indicate that TenneT, so far, does not experience more difficulty with balancing supply and demand in the Netherlands.

[115] Volatility of prices as such is an important market signal that can stimulate investors to invest. End-users can insure themselves against such volatility. However, too high volatility might lead to political intervention
[116] TenneT, 2013, Results BRP survey Balance responsibility RES-E

Table B-2: Usage rate of operating reserves by TenneT (total volumes expressed in MW)[117]

	Regulating capacity				Reserve capacity				Emergency capacity	
	Up		Down		Up		Down			
	Use %	Volume	Use %	Volume	Use %	Volume	Use %	Volume	Use %	Volume
2007	59,9%	331.631	70,5%	440.995	1,22%	6.136	0,29%	1.719	0,24%	2.743
2008	65,0%	364.993	70,2%	418.424	1,17%	6.679	0,17%	738	0,15%	1.978
2009	60,8%	303.880	73,9%	470.178	0,57%	5.226	0,27%	1.467	0,13%	988
2010	60,5%	351.316	69,4%	448.202	0,51%	2.752	0,17%	422	0,19%	2.144
2011	63,8%	352.807	71,0%	425.263	0,42%	3.608	0,23%	2.293	0,21%	2.264
2012	55,9%	234.207	64,2%	292.418	0,40%	2.828	0,16%	810	0,21%	2.630
2013	61,9%	249.723	61,4%	242.580	0,32%	1.319	0,04%	341	0,21%	1.750
*2014**	*52,0%*	196.824	*53,6%*	196.547	*0,00%*	1.074	*0,12%*	1.013	*0,13%*	1.516

* 2014 data only includes the period 01/01/2014 – 30/09/2014

Curtailment of renewable energy

Curtailment is a reduction in the output of a generator (typically a wind farm), usually on an involuntary basis. For example a TSO can decide to curtail wind power, meaning that it did not allow the wind farm to put power on the grid for balancing reasons. So although the resources were available, the wind farm was not dispatched.

Curtailment can be a good indicator of overall system efficiency and the associated cost. By reducing the frequency of curtailments, system flexibility improves and creates a more stable investment climate for new generation. One remark should however be made; the frequency of curtailment is very much linked to the size of the region. The smaller a region is defined, the bigger the potential relative impact of curtailment.

With respect to time, curtailment most often occurs when generation is not needed or for long periods (e.g., nights, seasonally) due to excess supply. Curtailment nowadays most often occurs with wind power. To date, there is no data available on curtailment in the Netherlands. For this reason the geographical scope is expanded to two neighbouring countries with a relative high penetration of wind power and available data on curtailment: the UK and Germany.

As the data in Table B-3 shows, the occurrence of curtailment is reasonably rare in the UK and seems to be falling. This could be due to lower forecasting errors of wind energy as the problem of accurately forecasting wind energy has received a great deal of attention in recent years. Table B-3 also shows that how smaller the region, how bigger the influence of curtailment can be.

Table B-3: Estimated volume of wind farm curtailment in GWh in the UK (relative to total production between brackets)[118]

	Apr - Sep 2011	Oct 2011 - Mar 2012	Apr - Sep 2012	Oct 2012 - Mar 2013
North-West Scotland region	28 (3.9%)	137 (10.7%)	41 (5.7%)	15 (1.4%)
Remainder of Scotland	29 (1.9%)	13 (0.4%)	8 (0.5%)	10 (0.4%)
England	0	0	0	0

[117] Calculated with system and transmission data from TenneT
[118] The UK National Grid Winter Outlook 2013/2014

In Germany, a country with high penetration of variable renewables, curtailment issues do not seem to be an issue, and have actually decreased in 2012. The Bundesnetzagentur actually states that "*The idea that the increase in decentralised power generation had a significant effect on the quality of energy supply can be ruled out for 2012*[119]". In 2012 only 0.33% of the total of renewable electricity has been curtailed, compared to 0.41% in 2011. This implies that curtailing energy is actually done less, not more, compared to 2011. This could for example be due to improved forecasting of variable production. Most of the renewable electricity curtailed in Germany (94%) is wind power, with solar only accounting for a few percent. The reason behind this is that solar power is easier to take up because power demand is usually higher around the afternoon, when most solar power is produced. Typical wind power production profiles are more or less constant throughout the day, also when demand is low. It is hard to compare Germany's or the UK's performance to what's happening in other countries as data is lacking for countries elsewhere in North-West Europe. For example, figures on wind energy curtailment in the Netherlands are currently not available. This is also related to the lack of a high penetration of wind power in the Dutch electricity mix. DNV GL, together with PBL, has recently published a study on the potential of solar energy in the Netherlands, including comments on possible curtailment issues with increasing (peak) capacity growth. They indicate that, with 23 GWp of solar power installed, solar PV needs to be curtailed, but this would also result in 2-3% energy losses as curtailment only happens a few hours per year in times of peak production[120]. That said, their study didn't take into account where or how the extra flexibility needed would come from.

Negative market prices

Negative market prices are a signal on the power wholesale market that occurs when a high inflexible power generation meets low demand. Inflexible power sources can't be shut down and restarted in a quick and cost-efficient manner. Sustained negative prices, such as can occur in systems with generators that cannot turn down to low outputs, reduce the attractiveness of investments in new generation (conventional or renewable).

Although negative prices do happen occasionally, there are a fairly rare, as several factors have to happen at the same time[121]. In Germany negative prices have occurred during 56 hours on 15 days with negative prices were observed on the day-ahead market in 2012. On the intraday market, negative prices occurred during a total of 41 hours spread over 10 days in 2012[122].

Negative prices are almost non-existent in the Netherlands[123]. If negative prices do occur, they are only modest. This is because Dutch RES subsidies, unlike those in Germany, are linked to market prices. This implies that Dutch renewable power producers have an incentive to cease or limit production levels whenever market prices are low. In Germany subsidy levels per production unit is fixed, leading to more moments of negative pricing (up to -49 euro / MWh)[124].

[119] Bundesnetzagentur, 2013, Monitoringreport 2013
[120] DNV GL, PBL, 2014, Het potentieel van zonnestroom in de gebouwde omgeving van Nederland
[121] Negative prices generally occur on very windy and or windy, low-demand, non-working days, such as summer sundays or Christmas
[122] EPEX, 2014, http://www.epexspot.com/en/company-info/basics_of_the_power_market/negative_prices
[123] FD Energie Pro, 2014, Gratis? of negatief geprijsd?
[124] http://www.powerhouse.nl/nieuws-archief-artikel/items/gas-storm-leidt-tot-negatieve-elektriciteitsprijzen-in-duitsland.html?utm_source=www.google.nl&utm_medium=organic&utm_content=/

Price volatility

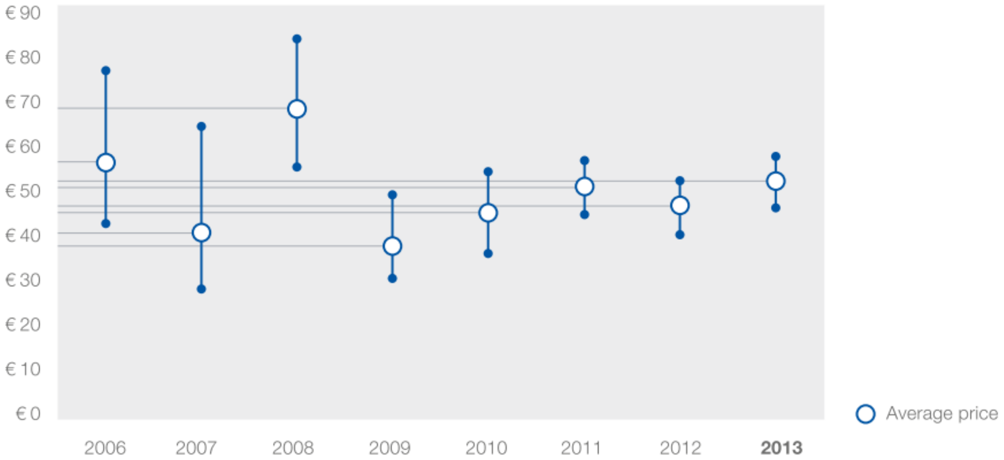
Price volatility is a measure of the variation of electricity prices over time. As such, volatility of prices is not negative, as it gives important signals to the market whether or not investments are desirable. Still, too high volatility of electricity prices can disrupt investments or lead to political intervention to protect real or assumed consumer interests[125].

Price volatility is mostly measured in standard deviation, which reflects the amount of variation from the average price. The lower the standard deviation, the more stable the price. Inevitably, as one could argue[126], with wholesale prices increasingly driven by short term weather patterns, market price volatility increases (both in the day-ahead market and even more in the intraday market)[127]. Greater penetrations of variable renewable energy could therefore lead to more frequent and magnified price swings. In that respect, oil analysts have become replaced by meteorologists, as it will be more important to predict temperatures, wind speeds and cloud coverage.

In the Netherlands, price volatility has actually decreased over the years, as is shown in Figure B-1 TenneT recently indicated this is due to the[128]:

- lack of volatility factors (e.g. low level of renewables and low level of electrical heating)
- strong presence of stability factors (e.g. CHP, interconnectors and market coupling to four independent markets)

Figure B-1: Volatility of daily average wholesale price in the Netherlands (in €/MWh)[129]

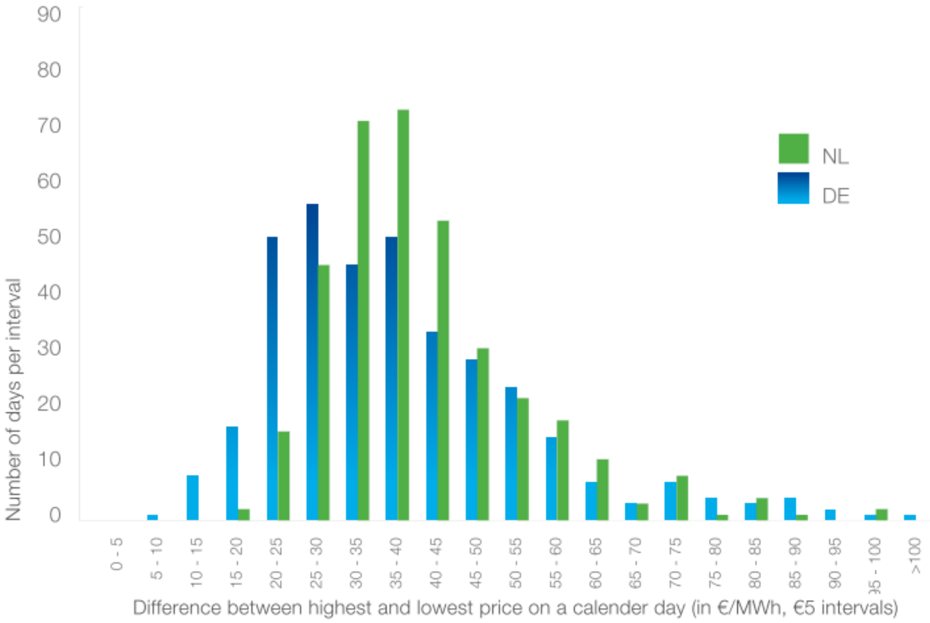


In markets with a higher penetration of variable renewables, such as Germany, we do see higher daily price variability in Germany compared to the Netherlands, but in fact lower daily spreads (e.g. price changes over the course of the day). This means that, although price volatility is lower in the Netherlands, the daily profile is more pronounced. This indicates that the fluctuating production of wind and solar in Germany does not translate into higher fluctuation in hourly prices on normal days[130].

[125] In practice, consumers can protect themselves against volatility by long-term contracts. However, if this is not done by the majority or by some main consumers and these suffer negative consequences of volatility, this might lead to political pressure for intervention.
[126] As is done in: Poyry, 2011, The challenges of intermittency in North-West European power markets
[127] Note that, price variability is not bad or good. For example for standby capacity to be in-the-money, high price volatility may be required, as it may be what is needed for cost recovery to develop a business model for arbitraging using flexibility instruments.
[128] TenneT, 2014, Market Review 2014 (Q1, Q2)
[129] Tennet, 2013, Market Review 2013
[130] Ibid

This daily spread could be the driver for investment in flexibility options such as storage or demand response, but these levels of price volatility provide (for the moment) too little incentive for market parties to invest.

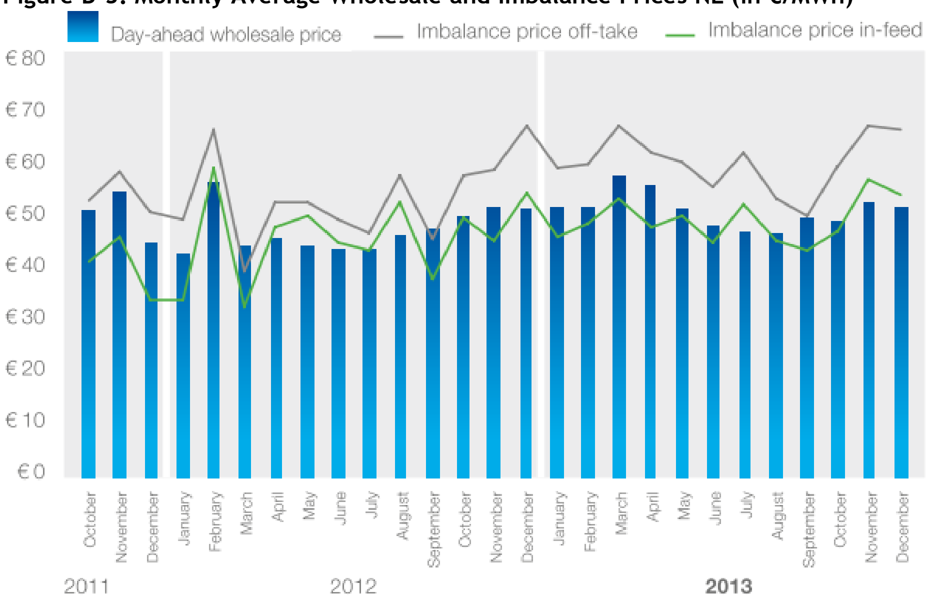
Figure B-2: Daily spreads in the Netherlands and Germany in 2013[131]



Increased imbalance prices and volumes

Imbalance prices alone do not reflect an imbalance on the market, for that data on imbalance volumes are needed as well. Given this perspective, Figure B-3 indicates that the monthly average imbalance prices (off-take and in-feed) have remained more or less stable over the last three years in the Netherlands. A similar conclusion can be drawn when interpreting the historical imbalance data of TenneT as shown in Figure B-2.

Figure B-3: Monthly Average Wholesale and Imbalance Prices NL (in €/MWh)[132]



[131] TenneT (2013) Market Review 2013
[132] Ibid

Table B-4 Descriptive statistics: Dutch imbalance volumes in MW[133]

	Average	Max	Min	# > |50| MW	# > |100| MW	# > |150| MW	# > |200| MW
2007	24,4	148,9	-176,1	3958	371	48	4
2008	25,3	154,1	-156,7	4203	322	19	0
2009	26,1	156,3	-187,7	4691	486	54	2
2010	28,0	187,0	-237,2	5434	646	86	24
2011	27,5	216,6	-184,8	5194	707	116	15
2012	28,7	204,6	-333,8	5713	569	86	27
2013	26,5	153,7	-178,7	4800	366	42	3
2014	27,0	256,1	-181,3	4845*	391*	40*	9*

* Based on 01/01/2014 - 30/09/2014 data and multiplied by 12/9

The average imbalance volumes in the Netherlands have gone up slightly from 24.4 MW (per 15 minutes) in 2007 to 27 MW (per 15 minutes) in 2014. This is a modest increase of 10.7% over the last seven years. Similarly, the frequency of spikes in imbalance volumes does not seem to show an upward trend. Based on the trend in imbalance volumes and imbalance prices one could argue that there are no prominent signs of inflexibility in the market. As can be seen from Table B-5, the majority of PRPs in the Netherlands do expect that both the imbalance volumes up and the imbalance price deviation from day-ahead prices will go up between now and 2020. This trend however has yet to take place.

Table B-5 Dutch PRP responses to imbalance situation in 2020[134]

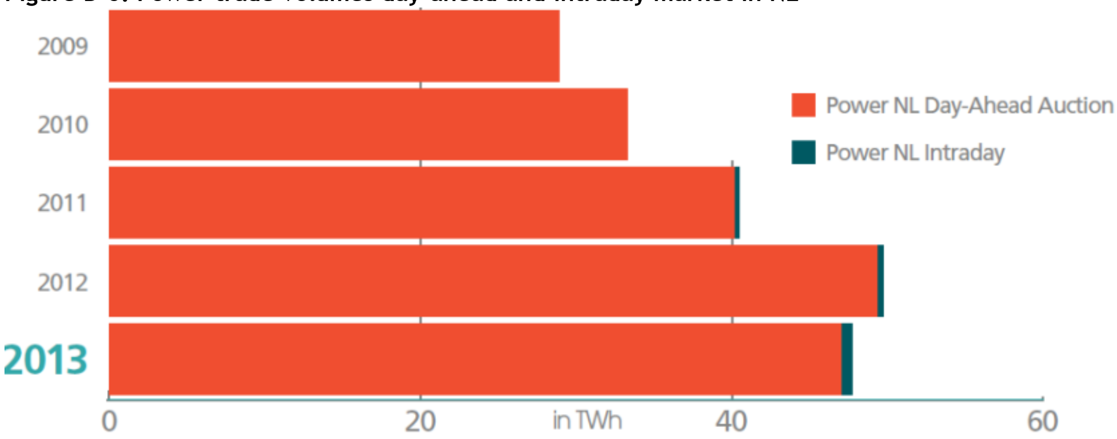
	Larger than today	Smaller than today	Similar to today
Imbalance price deviation from D-1 prices	83%	8%	8%
Imbalance volumes	75%	17%	8%

Volumes traded on day-ahead and intraday markets

A growing share of wind and solar generation sources in supply increases the uncertainty about power production in day-ahead and intraday predictions. As can be seen in Figure B-6, the volumes traded on the Dutch intraday market are hardly noticeable compared to the volumes of the day-ahead market. In 2012 the volumes traded on the intraday market represented only 1% of the total volumes traded in the day-ahead auction market. Although the volumes traded on the intraday market have increased 60% from 2012 to 2013 (from 453GWh to 725GWh), they still represent only 2% of the volumes traded on the day-ahead market.

[133] Calculated with system and transmission data from TenneT
[134] TenneT, 2013, Results BRP survey Balance responsibility RES-E

Figure B-6: Power trade volumes day-ahead and intraday market in NL[135]



A well-functioning intraday market is vital for a significant integration of intermittent renewables because these energy sources are susceptible to forecast errors[136]. Stimulating a further integration of the intraday market (market coupling) is therefore going to be a hot topic for the next few years. A further increase in the variable input of renewable energies makes it necessary to balance this out during the day by means of intraday trading. In the Netherlands we also see this happen as volumes traded on the intraday market increased 60% from 453 GWh in 2012 to 725 GWh in 2013.

Summary

To date, as the table below indicates, there are no major signs which indicate a lack of flexibility in the Dutch power system (or surrounding countries when data was lacking). Higher intraday volumes however give a clear indication that there is an increased need to balance power production during the day.

Table B-7: Signs of inflexibility, main findings

Market	
Use of operating reserves	Slightly declined within the period 2007-2014.
RES Curtailment	Occurrence is only marginal and seems to be decreasing in Germany.
Negative market prices	If they occur, which is rarely, negative prices are modest in Dutch markets (0,01- 0.08 € / MWh)
Price volatility	Showed a decreasing trend within the period 2006 - 2013
Imbalance volumes	Increased by 10,7% within the period 2007 - 2014
Imbalance prices	Remained stable within the period 2011 - 2013
Intraday volumes	Increased substantially: 60% in 2013 compared to previous year

[135] APX Group, Annual Report 2013
[136] Tennet, 2014, Market Review 2014

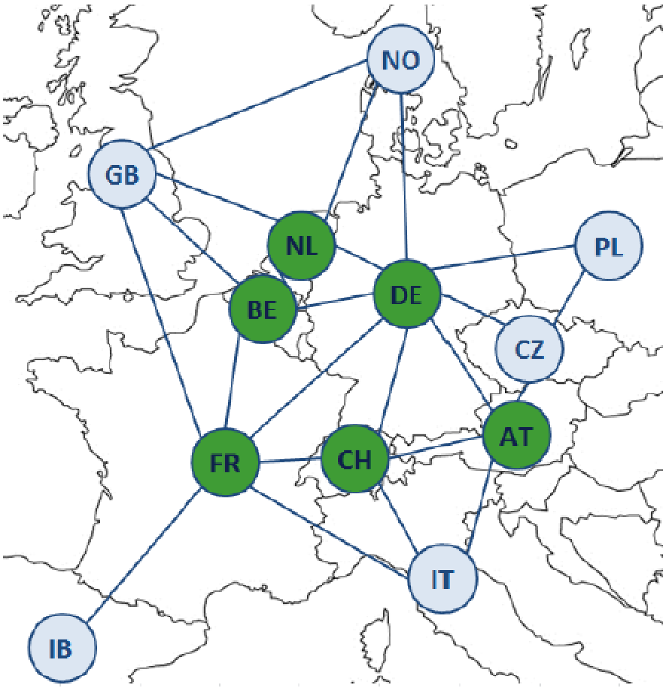
Annex C: Modelling exercise

The northwest European market model developed by DNV GL, based on the PLEXOS modelling framework

There are a limited number of models in the EU that can simulate electricity markets. Such simulations not only require a sophisticated model, but also a comprehensive database of all power plants in the area under study and their characteristics. A model that is extensively used for simulations of the Dutch electricity market (and beyond) is the North West European Market Model by DNV GL.

The Netherlands and surrounding key countries (see figure below) are modelled in detail. This means that all electricity plants larger than 50 MW are modelled individually; smaller units are modelled on an aggregated level. Units in satellite countries are aggregated per generation type.

Figure C-1 Key (green) and satellite (blue) countries in NW European market model



Source: DNV GL

Further key characteristics of the model are:

- The balancing reserves in the system and its characteristics are an input to the model.
- Interconnection capacities are based on the Net Transfer Capacities (NTC) as reported by ENTSO-E.
- Strategic behaviour (e.g. strategic bidding) is not modelled.
- The model runs with an hourly time resolution.
- The model simulates price on the day-ahead market. Intra-day and balancing markets are not included.

PLEXOS provides a short term optimisation for the dispatch of power plants, based on a minimisation of variable system costs. Those variable system costs include fuel- and emission costs, start-up costs and variable O&M costs.

The electricity price is based on the short-run-marginal costs of the price-setting plants, which is the dispatched plant with the lowest marginal costs that can increase its generation. The model concerns the day-ahead spot market.

Questions to be answered by modelling

Main aim of this research project is to examine what are potential consequences of the SER agreement for the stability of the Dutch electricity system, and which flexibility options fit best with the flexibility needs.

The table below shows which sub questions can be (partially) answered by using the PLEXOS model, given its above described limitations and possibilities.

Sub question	Model contribution
1. How are short-term and long-term electricity balancing and flexibility presently regulated in the Netherlands, in surrounding countries and on a European level?	None
2. What are the potential regulatory changes currently discussed, including current discussions about ‘capacity mechanisms’?	None
3. How are the flexibility needs in the Dutch electricity system expected to develop, compared to the current situation, taking into account in particular the scenario in which the objectives of the Dutch Energieakkoord are realised, as well as scenarios with an even higher penetration of renewable energy in the Netherlands and abroad?	Modest
4. Which technical and regulatory balancing and flexibility options in theory are available to the Netherlands, and what are their technical, economic and social characteristics?	None
5. What is, based on modelling of technical and economic parameters of the flexibility options identified, the priority order of dispatch of these options in various scenarios? What would this mean for investment decisions of potential investors in flexibility options?	Strong
6. Which roles could the Netherlands play in relation to the flexibility issue in a Northwest European context?	Requires heavy modelling. The number of model runs is however limited.

The sub questions that allow for modelling can be translated into the following modelling questions.

Sub question	Modelling question
3. How are the flexibility needs in the Dutch electricity system expected to develop, compared to the current situation, taking into account in particular the scenario in which the objectives of the Dutch Energieakkoord are realised, as well as scenarios with an even higher penetration of renewable energy in the Netherlands and abroad?	In a given scenario, what developments can be observed in: - Price volatility? - Peak price frequency? - Low price frequency?

5. What is, based on modelling of technical and economic parameters of the flexibility options identified, the priority order of dispatch of these options in various scenarios? What would this mean for investment decisions of potential investors in flexibility options?	What is the dispatch order of several flexibility options in a particular scenario? How much flexibility capacity of a certain type could be economically absorbed in the system?
6. Which roles could the Netherlands play in relation to the flexibility issue in a Northwest European context?	How much flexibility capacity of a certain type could be economically absorbed in the wider Northwest European system?

Model runs: Exploring future flexibility needs

Model input

Scenarios

Two model runs have been carried out in order to get more insight into flexibility needs in the future. Two scenarios have been modelled thus far:

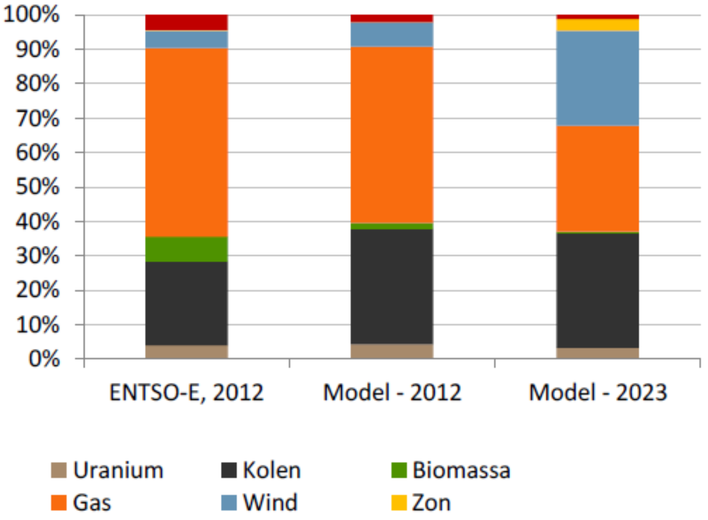
1. 2012
2. 2023 – SER energy covenant

The 2012 scenario serves as a reference point for the other modelling outcomes. The scenario run also provides insight in the adequacy of the model outputs, as it can be compared to actual data.

The 2023 – SER energy covenant scenario run provides insight in the load and demand patterns in case the energy covenant would be implemented as it is envisaged.

The figure below shows the energy mix in The Netherlands for 2012 (model and ENTSO-E data) and 2023. The difference in coal capacity between the model and ENTSO-E data can be explained from the fact that the model counts biomass burned in coal plants as coal capacity.
The key difference that can be observed in the energy mix between 2012 and 2023 is a strong increase in wind generation.

Figure C-2: Energy mix in The Netherlands, 2012 and 2023



Source: DNV GL

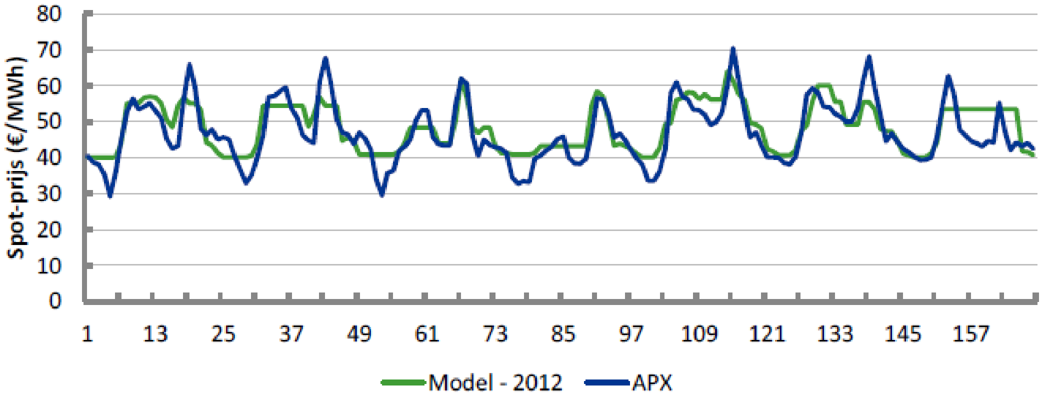
Modelling Results

2012 scenario – week run

A sample week in 2012 was modelled and compared to the actual observed (APX) power prices. The graph shows that the power prices generated by the model are of the same order of magnitude, and show the same pattern, as the APX prices that have been observed in reality. The figure also shows that the observed actual prices are more volatile than the modelled power prices.
This may be caused by the fact that the model has perfect foresight, and it does not include strategic bidding behaviour.

More volatile prices reflect larger differences between demand and supply, and can thus serve as an indicator for flexibility needs.

Figure C-3: Model run for sample week (12-19 January 2012)



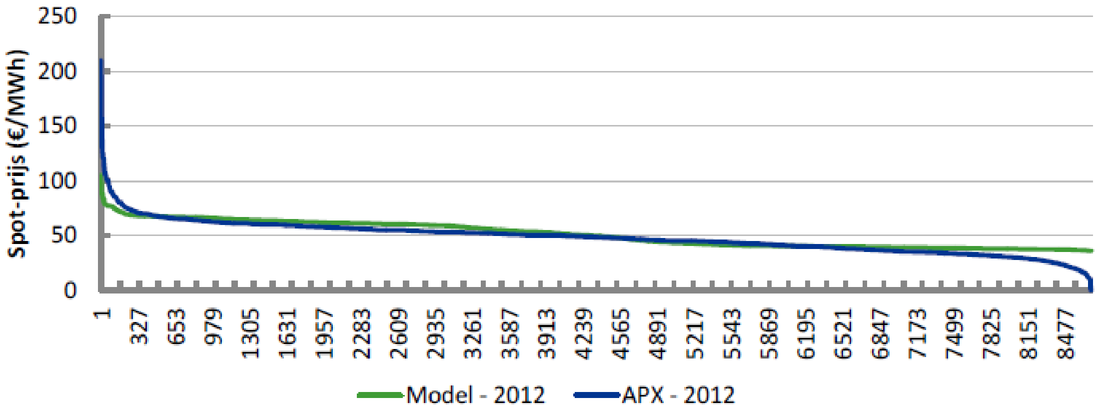
Source: DNV GL

Electricity price duration curve (EPDC)

The electricity price duration curve shows the proportion of time for which the spot market price exceeds a certain value.

The modelling results for 2012 show a rather flat curve, with the vast majority of spot market prices between around 30-75 €/MWh. Also, the results show that the biggest price extremes that have been observed on the APX for this year are not seen in the modelling results due to the reasons mentioned earlier.

Figure C-4: EPDC spot market price 2012

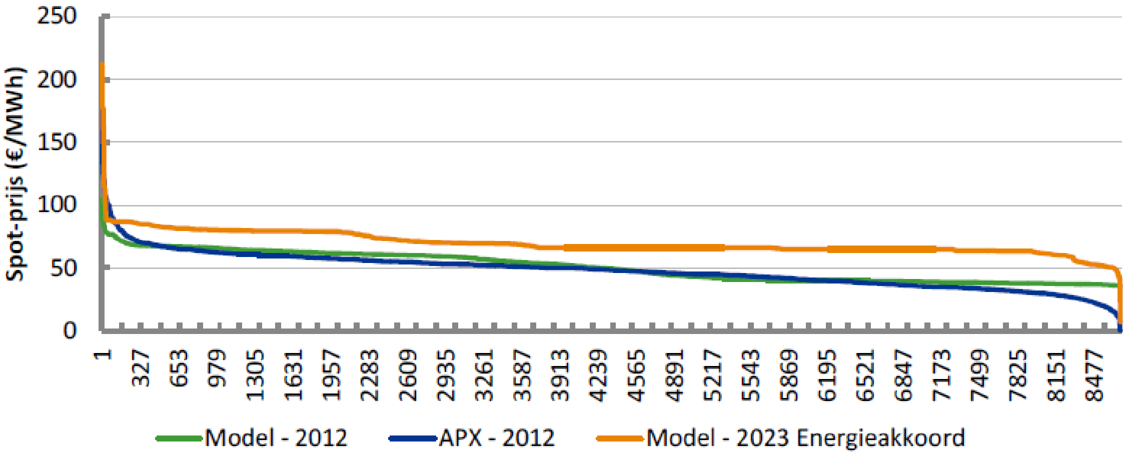


Source: DNV GL

Plotting the modelling results for the EPDC curve of the 2023-Energy covenant scenario in the figure shows that the spot market price is higher on average, but demonstrates also stronger extremes. Yet, the curve is again rather flat and price extremes, either high or low, seem to occur rather infrequently.

But, as the 2012 scenario curve demonstrates, the model consistently underestimates the frequency of price extremes.

Figure C-5: EPDC spot market price 2012 and 2023 - Energy covenant



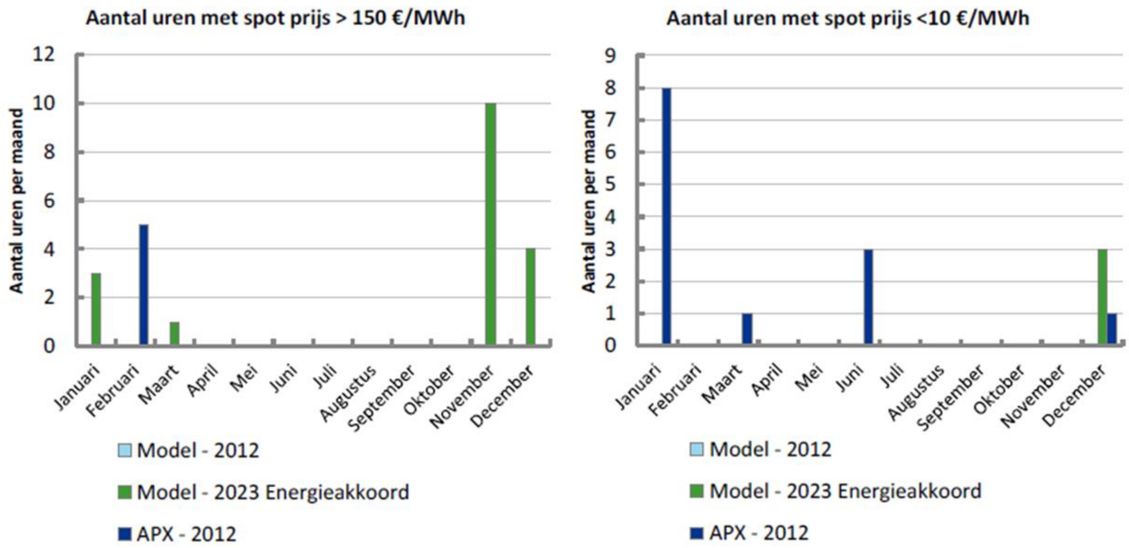
Source: DNV GL

Spot market price – Extremes

The price extremes for 2012 and 2023 have been plotted separately in a diagram. The results provide better insight in what was already observed in the EPDC graphs above. The frequency of price extreme occurrence will increase. Also, the diagrams again show that the model underestimates the frequency of price extremes. Whereas the dark blue bars show that price extremes have occurred several times in 2012, the lack of light blue bars demonstrates that this is not reflected in the modelling results for the

same year. Therefore, one may expect that the increase of price extremes in 2023 is even stronger than the green bars in the diagrams below demonstrate.
The left diagram below shows that the peak prices are mainly expected to occur in the winter, with low solar radiation. At the same time, demand is higher due to longer dark periods and increased heating requirements.

Figure C-6: Price extremes in hours/month, >150 €/MWh (left) and <10 €/MWh (right), 2012 & 2023



Source: DNV GL

The model seems to particularly underestimate the occurrence of low (<10 €/MWh) prices, as can be observed in the right hand diagram. This can probably be explained by the German feed-in tariff, which is not modelled. This feed-in tariff provides an incentive to power producers to sell their power in times of zero or even negative spot market prices, because they are compensated by the feed-in tariff.

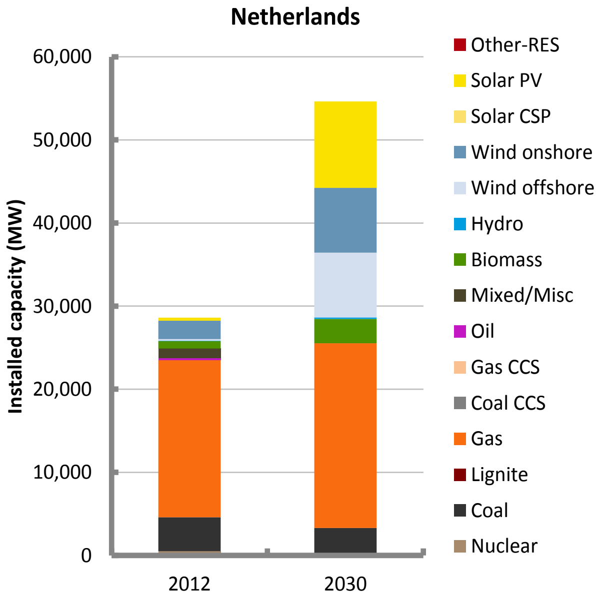
Modelling flexibility options

Model input

The model was run for the flexibility needs in 2023 (Energieakkoord, 16% RES). The need for additional flexibility solutions in this scenario appeared to be modest. For an economic comparison of flexibility options, we need to define a scenario with a higher share of variable RES.

For this reason, the Vision 3 “Green Transition” of ENTSO-E's Scenario Outlook & Adequacy Forecast (SO&AF) for 2030 was selected as a basis. The RES share of this scenario was increased with 30%. The input electricity mix is provided in the figure below:

Figure C-7: Electricity mix Netherlands, ENTSO-E Green Scenario



Source: DNV GL

For each of the flexibility options, technical and economic parameters have been gathered to enable modelling in the PLEXOS model. These parameters include:

- Ramp up rate (MW/min)
- Ramp down rate (MW/min)
- Variable costs (euro / MWh)
- Capacity (MW)
- Pump capacity (MW)
- Storage capacity (GWh)
- Pump efficiency or cycle efficiency

The required balancing capacity is an input to the model. According to a rule of thumb, the tertiary reserve is 10% of installed capacity, and the secondary reserve 4%[137].

The following options have been modelled:

- No Flex (reference)
- CAES (300MW)
- Pumped Hydro (plan Lievense) (1500 MW)
- Increased interconnection (NorNed3) (700 MW)
- Industrial demand response

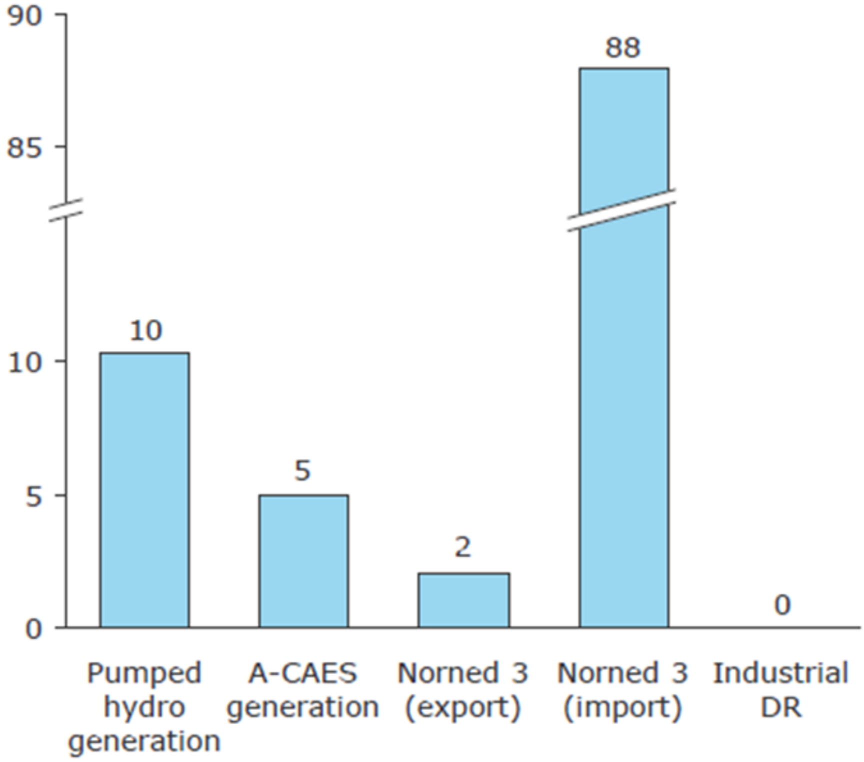
Results

The modelling results show the dispatch and effects of the flexibility options in a future electricity mix with a high share of variable renewables.

The first figure shows the utilisation of the different options throughout the year, also referred to as the capacity factor.

[137] DNV GL

Figure C-8: Utilisation/capacity factor (%)

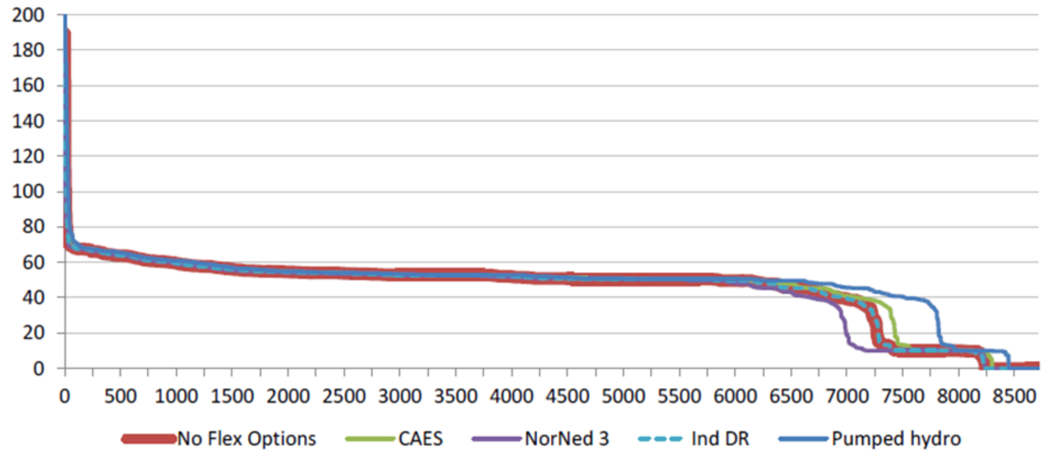


Source: DNV GL

No less than 88% of the NorNed3 cable capacity is used throughout the year, mainly for import of cheap hydropower to The Netherlands. A-CAES has a capacity factor of 5%, this is lower than the 10% for pumped hydro, due to its limited flexibility. Compared to the pumped hydro, the CAES is less flexible because of the minimum up and down times and has lower cycle efficiency (70% vs. 75%).

The price duration curve below shows the proportion of time for which the electricity price exceeded a certain value. The results show a very limited amount of hours with high prices (>70€/MWh), whereas the high share of variable renewables is expected to cause frequent price peaks due to supply fluctuations. The comparison of the scenario week run with real-world prices already demonstrated that DNV GL's market model underestimates price peaks. The results below suggest that this underestimation is quite dramatic.

Figure C-9: Price duration curve in € / MWh, output PLEXOS

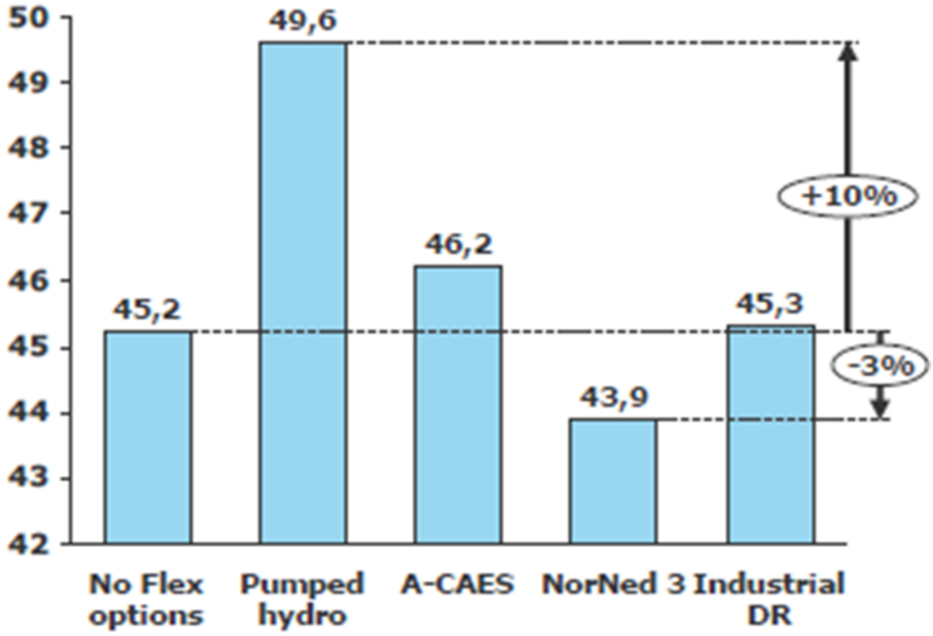


Source: DNV GL

Industrial demand response appears to have no influence on the electricity price at all. This is due to the price of 400 €/MWh from ENTSO-E, which appears to be on the very high end of the range of price estimates. The results also show that NorNed 3 increases the number of hours with low electricity due to the additional import of low cost electricity from Norway. The storage options have slightly less hours with low electricity prices as they utilize these periods to fill their storage, increasing the demand and hence price of electricity (feedback-loop).

This increase of average electricity price is depicted clearly in the following figure:

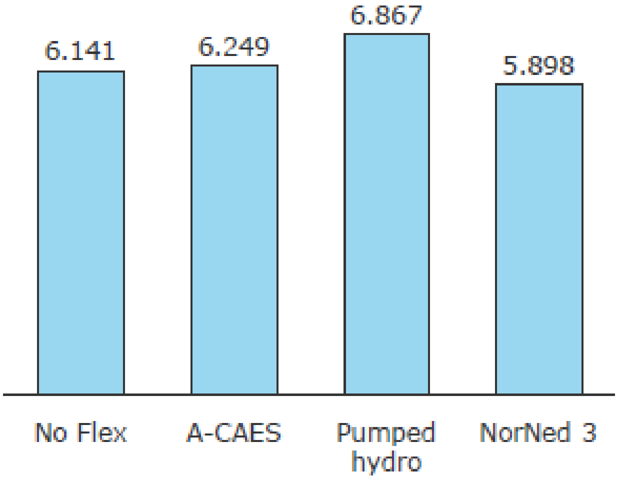
Figure C-10: Average electricity price (€/MWh)



Source: DNV GL

This average electricity price is also reflected in the total electricity costs for consumers (see figure below)

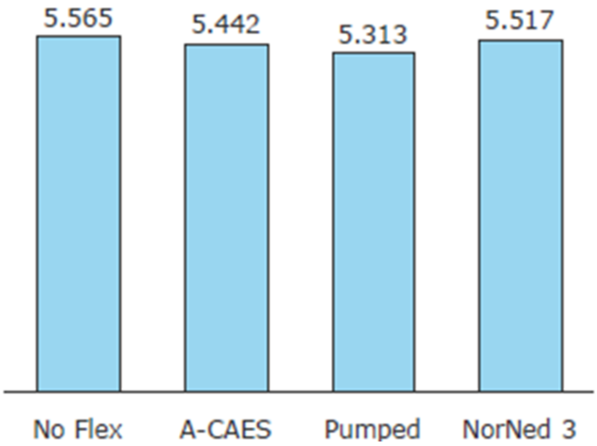
Figure C-11: Total electricity costs for consumers NL (M€)



Source: DNV GL

The next figure shows how the total generation costs of electricity change under influence of the flexibility options. The decrease of overall generation costs for CAES seems to decrease dramatically and imply that the investment of around 270m€ would be paid back within 2.2 years.

Figure C-12: Total generation cost NL (M€)



Source: DNV GL

Modelling conclusions

In the first place they show that price extremes, and thus flexibility needs, increase between now and 2023. The increase will be even stronger than the modelling results suggest, as PLEXOS is known to underestimate price extremes. Price peaks, reflecting periods of high demand and low supply, can be observed mainly during winter when solar PV production is low whereas demand is relatively high. The modelling results seem to confirm findings from other studies, that even in (very) high RES scenarios, the system remains surprisingly stable. This may be caused by the facts that ENTSO-E scenarios are used, which assume sufficient fossil back-up capacity, therefore never driving the system to shortage.

Annex D: Overview stakeholder interviews

The following organisations and persons were interviewed for this report:

Organisation	Persons interviewed	Date
TenneT	Erik van der Hoofd, Jan-Willem Meulenbroeks	14-05-2014
Powerhouse	Robert Willemsen	15-05-2014
Statkraft Markets	Paul Giesbertz	15-05-2014
Energie Nederland	Walter Ruijgrok, Ruud Otter	20-05-2014
Netbeheer Nederland	Andre Jurjus, Marijn Artz, Kirsten Wilkeshuis	27-05-2014
Ministry of Economic Affairs	Peter Aubert	05-06-2014
Autoriteit Consument en Markt	Geert Moelker, Matthieu Fransen	26-06-2014

In addition to the stakeholder interviews, independent expert Annelies Huygen (University of Amsterdam / TNO) was interviewed (03-06-2014).

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