

Demand and supply of flexibility in the power system of the Netherlands, 2015-2050

Key messages of the FLEXNET project

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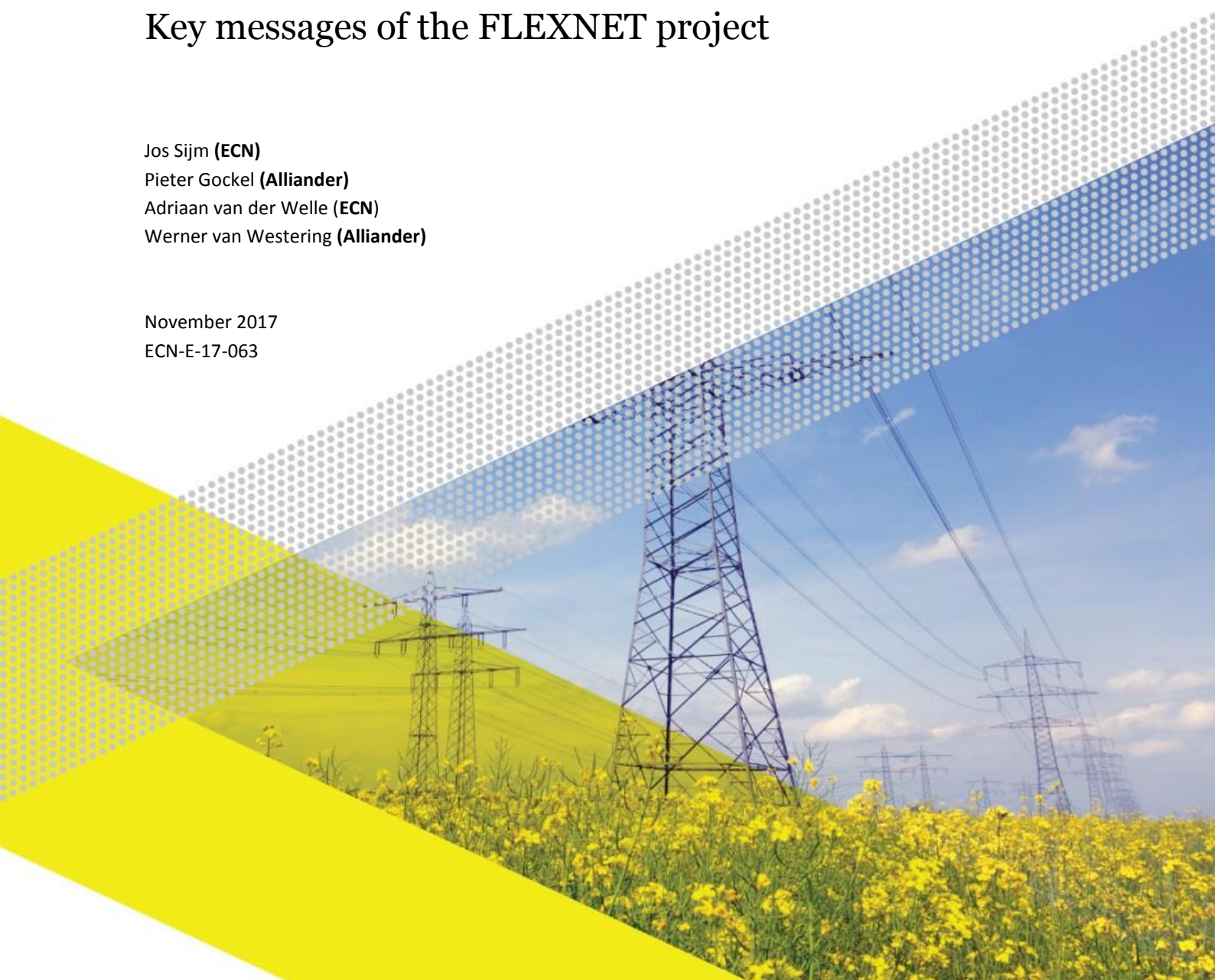
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Project consortium partners



Acknowledgement

The overall objective of the FLEXNET project was to analyse demand and supply of flexibility in the power system of the Netherlands up to 2050 at both the national and regional level.¹ The project was commissioned and funded by the Top Sector Energy (TSE) under the tender programme System Integration (NL Ministry of Economic Affairs/RVO.nl; reference number TES0114010).

FLEXNET was carried out by a consortium consisting of the Energy research Centre of the Netherlands (ECN) and several members of Netbeheer Nederland – i.e. the Dutch branch organisation of energy network operators – in particular Alliander, Enexis, Stedin, TenneT and Gasunie Transport Services (GTS). In addition, the consortium included two other partners (GasTerra and Energie-Nederland) who were involved as co-funders of the project.

Over the lifetime of FLEXNET (March 2015 – August 2017), the project was supervised by a Steering Committee consisting of the following members: Eppe Luken (ECN, chair), Frans Nillesen (RVO.nl), Erik van der Hoofd (TenneT/Netbeheer Nederland), Erik ten Elshof (NL Ministry of Economic Affairs), Tjitske Brand (GasTerra) and Walter Ruijgrok (Energie-Nederland).

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The FLEXNET project consisted of three phases, each addressing a specific main question:

- *Phase 1 ('The demand for flexibility')*: what are the flexibility needs of a sustainable and reliable power system in the Netherlands up to 2050?
- *Phase 2 ('The supply of flexibility')*: which mix of robust flexibility options can meet the predicted flexibility needs in a socially optimal way?
- *Phase 3 ('Societal framework to trade-off grid reinforcement and deployment of flexibility')*: in which situations is deployment of flexibility a more attractive option than grid reinforcement to overcome predicted overloads of the power network?

The current report presents the key messages of the FLEXNET project, based on the on the three extensive background reports of each phase of the project as well as the Summary Report of the FLEXNET project as a whole. In particular, these reports include:

¹ FLEXNET is an abbreviation that stands for “**FLEX**ibility of the power system in the **NET**herlands”.

- *The demand for flexibility of the power system in the Netherlands, 2015-2050*, Report of phase 1 of the FLEXNET project;
- *The supply of flexibility for the power system in the Netherlands, 2015-2050*, Report of phase 2 of the FLEXNET project;
- *Societal framework to trade-off grid reinforcement and deployment of flexibility*, Report of phase 3 of the FLEXNET project (published in Dutch: 'Maatschappelijk afwegingskader voor de inzet van flexibiliteitsopties in elektriciteitsnetten).
- *Demand and supply of flexibility in the power system of the Netherlands, 2015-2050*, Summary report of the FLEXNET project.

These reports can be downloaded for free at: <https://www.ecn.nl/flexnet/>

At ECN, FLEXNET is administered under project number 53626. For further information, you can contact the project leader: Jos Sijm (sijm@ecn.nl; tel.: +31 6 1048 4843).

Abstract

The current report presents the key messages of the FLEXNET project. The overall objective of the FLEXNET project was to analyse demand and supply of flexibility in the power system of the Netherlands up to 2050 at both the national and regional level. The current report is based on the summaries of the three extensive background reports of FLEXNET, each covering one of the three phases of the project. These phases include (i) the demand for flexibility (phase 1), (ii) the supply of flexibility (phase 2), and (iii) societal framework to trade off grid reinforcements versus deployment of flexibility (phase 3).



Summary of key messages

Introduction

The Netherlands is aiming at a more sustainable, low-carbon energy system. For the power system this implies (i) a larger share of electricity from variable renewable energy (VRE), in particular from sun and wind, (ii) a larger share of electricity in total energy use due to the increasing penetration of demand technologies such as electric vehicles (EVs), heat pumps (HPs), power-to-gas (P2G), etc., and – as a result of these two trends – (iii) a higher need for flexibility and system integration.

In this study we have developed several scenario cases up to 2050 which show the increase in flexibility needed in the electricity system (phase 1). We distinguish between three sources ('causes') of the demand for flexibility, i.e. due to (i) the variability of the residual load, (ii) the uncertainty ('forecast error') of the residual load, and (iii) the congestion (overloading) of the power grid (where residual load is defined as total power demand minus VRE power supply from sun and wind). The analyses in this study are based on hourly power demand and supply profiles for a 'normal' ('representative') year, although we also consider some extreme hours and some extreme situation in particular.

Subsequently, in phase 2 of the study, we have explored various options that can be used to provide flexibility such as, for example, storage, demand response or cross-border power trade. Our analysis provides insights in the importance of the different options in the future energy system, given their technical characteristics and economic costs. The analyses in phase 2 are conducted within an EU-wide power trade setting, assuming similar (correlated) weather patterns across EU countries.

Finally, in phase 3 of the study, we have described a societal framework that can be used to make well-informed decisions with regard to the trade-off between grid reinforcement and the deployment of flexibility options.

The study has been conducted at both the national level and the regional network level. The major key messages of the different phases of the study at the study at these levels are outlined below.

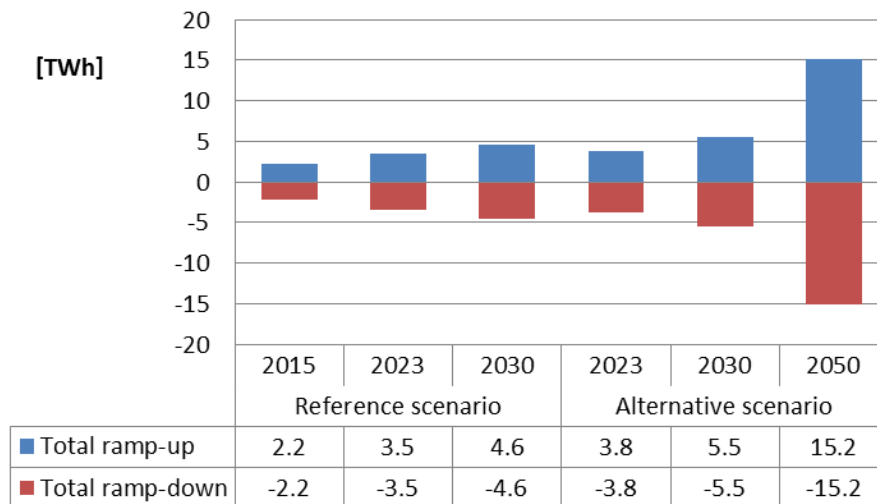
Phase 1: the demand for flexibility

National level

Increasing flexibility needs due to increasing variability of residual power load, in particular beyond 2030

Over the years 2015-2050, the variability of the residual load in the Dutch power system increases strongly, mainly due to the increase in power generation from variable renewable energy (VRE), in particular from sun and wind, but also partly due to the increase in total load, notably resulting from the increase in electric vehicles (EV), heat pumps (HPs) and other means of additional electrification. As a result, the total annual demand for flexibility more than doubles between 2015 and 2030 and increases even further – by a factor 3 – between 2030 and 2050.

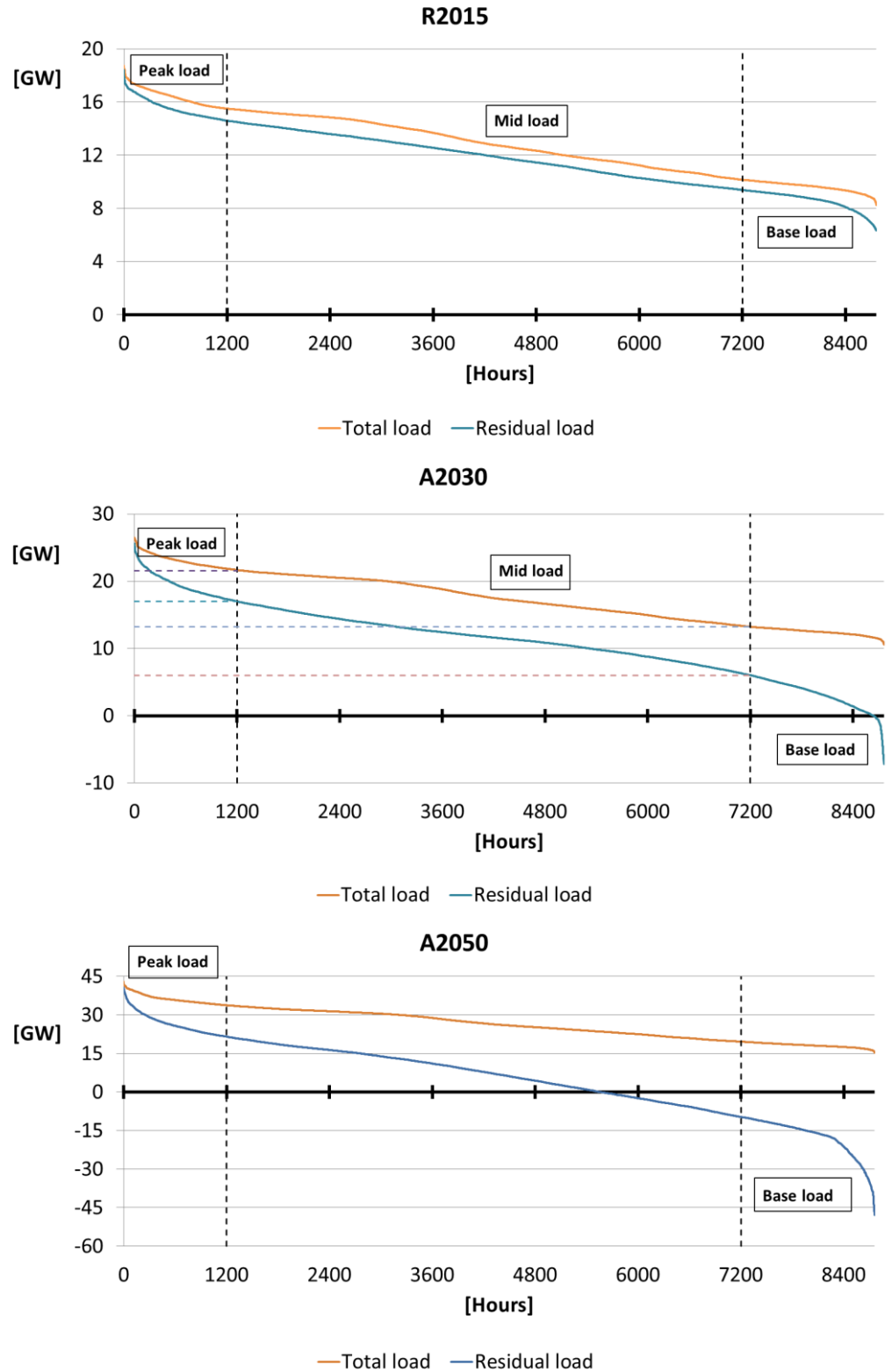
Figure 1: Total annual demand for flexibility due to the variability of the residual power load in the Netherlands, 2015-2050



Increasing need for flexible peak load capacity

Mainly due to the increase in power supply from VRE sources, the need for residual *peak* load capacity increases substantially over time, whereas the need for residual *base* load capacity decreases significantly (and even becomes zero in A2050). Peak load capacity, however, has to be rather flexible as it covers less than 1200 hours per annum spread throughout the year. Notably, the number of peak hours with relatively high levels of residual load is relatively small in A2050 (and A2030), i.e. it is usually even much smaller than 1200 hours. Therefore, capacity investments in (flexible) power generation – or other (flexible) power supply options – to meet these high residual load levels have to be recovered in a relatively small number of running hours (as further explored during phase 2 of the study).

Figure 2: Duration curves of total load and residual load in three scenario cases



Note: for visibility reasons, the scale of the Y-axis differs between the three pictures. As a result, the slope of the residual load duration curve is actually much steeper in A2050 – compared to R2015 – than suggested in the figure. Moreover, the difference between the total load and residual load duration curves is actually much wider in A2050 – compared to R2015 – than suggested in the figure.

Increasing number of hours with a VRE surplus

As the share of VRE generation in total load increases significantly over the period 2015-2050, both (i) the number of hours with a VRE surplus (i.e. a 'negative residual load'), (ii) the maximum hourly VRE surplus, (iii) the total hourly VRE surplus per annum, and (iv) the maximum number of consecutive VRE surplus hours increase as well. This raises both new challenges and opportunities in terms of flexibility demand and supply in the power system. For instance, the incidence and alternation of (large) hourly VRE shortages versus (large) VRE surpluses enhances the issue how to deal with these fluctuations in residual load (and the related fluctuations in hourly electricity prices). On the other hand, these fluctuations create also opportunities in terms of energy storage and demand response.

Wind (on sea) is the main driver of the increasing need for flexibility

The main driver of the increasing demand for flexibility is the increase in electricity production from VRE power sources, in particular from wind (on sea) and – to a lesser extent – from sun PV. Another, less important driver – at least in a direct sense – is the increase in the additional load due to the further electrification of the energy system, notably due to the hourly variations in the additional load for passenger EVs rather than in the additional for household HPs or other means of electrification. In an indirect sense, however, the increase in electrification is an important driver of the demand for flexibility if it is assumed that the resulting additional load is largely met by electricity from VRE power sources.

Flexibility needs due to the uncertainty of the residual load also increase strongly

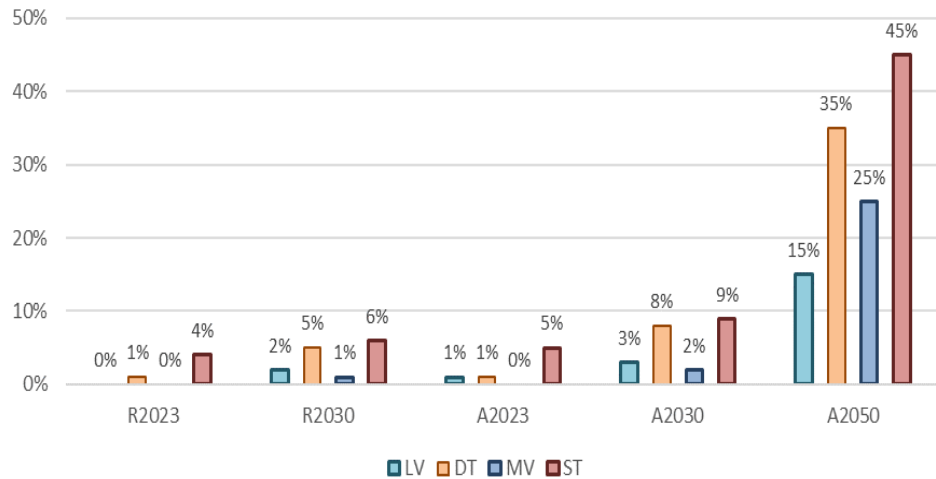
The demand for flexibility due to the *uncertainty* of the residual load is also expected to increase rapidly up to 2050, in particular due to (i) the uncertainty – or lower predictability ('forecast error') – of power from wind, in combination with (ii) the large (dominant) increase in installed wind capacity over the years 2015-2050. The size of this type of flexibility demand, however, depends highly on the extent to which improvements in reducing the forecast error will be effectuated up to 2050.

Regional grid level

The expected percentage of overloaded assets as a result of the adoption of EV, HP, PV seems limited until 2030 relative to the conclusions of previous studies

The ANDES modelling analysis of the implications of the FLEXNET scenario cases for the load profiles of the Liander distribution grid indicates that the incidence of overloaded assets due to the increasing adoption of PV, EV and HP is limited, at least until 2030 (<10%). In A2030, about 8% (± 3000) of the distribution transformers and 9% (about 40) of the substation transformers will be overloaded. The percentage of overloaded cables is even lower at 2-3% (± 1500 km of LV cables and ± 700 km of MV cables). As a conclusion it can be said that most assets of the grid, especially cables, will have sufficient capacity to facilitate the increased loads for at least the next 15 years.

Figure 3: Percentage of overloaded assets per scenario case at different levels of the distribution grid



Note: LV = Low voltage cable; DT = Distribution transformer; MV = Medium voltage cable; ST = Substation transformer

In absolute numbers, the overloads will lead to a significant amount of work and will become a serious challenge for the grid operator. Investments in the grid need to take into account future load increase to prevent “double” work (returning to the same asset for reinforcement during the operational lifetime of an asset). If not, this might endanger the achievement of the work assignment of the network operator, i.e. to maintain, reinforce and replace the network infrastructure.

Despite a limited total number of overloaded assets the regional distribution grids face great challenges in the form of large numbers of new connections for EV charging points, local congestion due to local concentrations of EV, PV and/or HP, a large increase of connections for medium size solar and wind farms, and the phase out of gas in the built environment that creates the need and natural moment to adapt the electricity grid.

Beyond 2030, the incidence of grid overloads is more significant, but most likely not alarming with the right investment strategy

According to the result of the ANDES model, 35% of the distribution transformers and 45% of the substation transformers are expected to be overloaded in the A2050 scenario case. Although these overload percentages are significant, they are not per se alarming. Due to asset ageing, many of the assets indicated as overloaded in 2050 will most likely have been replaced with larger capacity assets before becoming overloaded. The additional costs of installing assets with larger capacities are marginal, as most of the costs are caused by the required work, not the material. The model therefore assumes the investment strategy takes into account future load increase. Moreover, several ‘smart solutions’ are expected to become available within this time span. Therefore, the actual number of grid overloads is potentially lower than indicated by the ANDES modelling results. Again, most concerning to the grid operator will most likely be the achievement of the work assignment.

Most overloads are expected to arise in city centres

Geographically, most overloads are expected to arise in city centres, because of relatively old networks. The fact that the adoption of PV, EV and HP is lower in the city centres is offset by the density of the urban population, resulting in a larger increase of power load in urban areas than in non-urban areas.

Apparent need for trade-off between grid reinforcement and deployment of flexibility

From both a socioeconomic and a (regional) grid load perspective, there appears to be a clear need for weighing network reinforcements versus deployment of flexibility options, notably in the period beyond 2030 (when the incidence of grid overloads increases significantly). This trade-off, however, is also important in the coming years to use the efficiency potential of flexibility solutions and to deal with less predictable grid load increases where flexibility can be a good temporary solution till grid reinforcement is carried out. This issue has been further analysed in both the second and third phase of the FLEXNET project (see below).

Phase 2: the supply of flexibility

National level

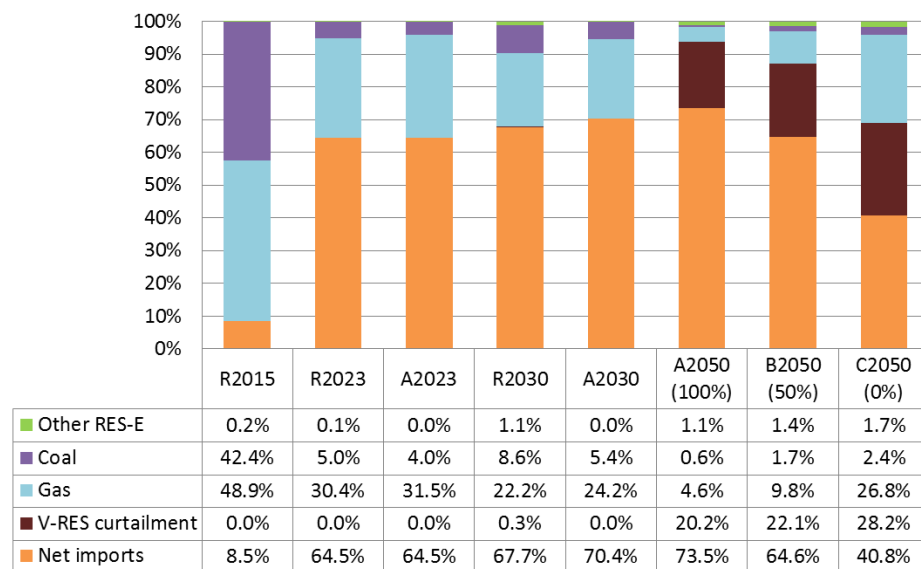
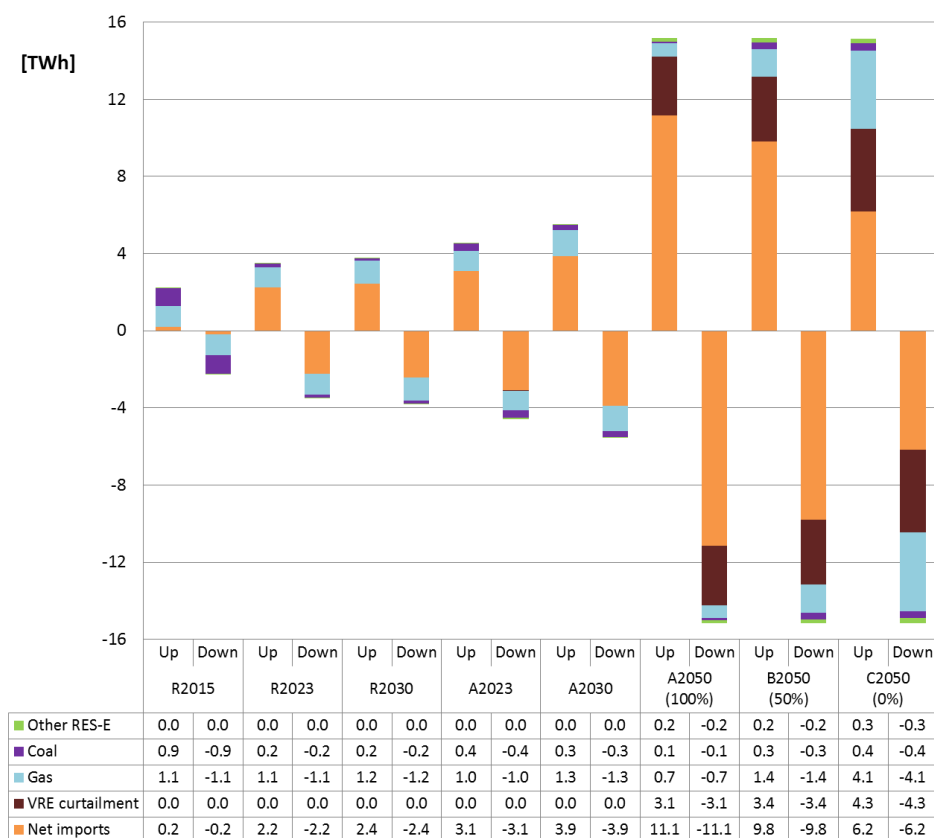
Cross-border trade becomes dominant flexibility option in future years but its size depends on available interconnection capacity as well as on the available potential and costs of alternative, domestic flexibility options.

In order to meet the rapidly growing demand for flexibility due to the variability of the residual load of the power system in the Netherlands up to 2050, cross-border power trade becomes the most important flexibility option in the coming years (decades), with shares ranging for this option from 65% to 74% of total annual flexibility needs in the period 2023-2050. As a result, power trade has a major impact on the business case of other, domestic options to meet the demand for flexibility by the Dutch power system, including the impact of (hourly variations in) power trade volumes and the related hourly fluctuations of domestic electricity prices. Due to these related volume and price effects of power trade, the business case and, hence, the size (share) of other, domestic flexibility options is lower accordingly (depending on the available potential and costs of these options). This impact, however, depends in particular on the assumptions made with regard to the optimal interconnection capacities across European countries, notably between the Netherlands and its neighbouring countries. However, even under more (very) restrictive interconnection assumptions, however, the share of power trade in total annual flexibility demand still amounts to approximately 40-65% in 2050.

Non-VRE power generation becomes less important to meet future flexibility needs but gas-fired units may remain important as back-up capacity

In the current situation (scenario R2015), power generation from conventional, non-VRE sources is the most dominant flexibility option to meet total annual flexibility needs due to the variability of the residual load of the Dutch power system (estimated at 2.2 TWh, aggregated per annum), in particular by (hourly changes in) power generation from gas (49%) and coal (42%), while the remaining share of these needs is addressed by (hourly variations) in power trade (9%). In the coming years (decades), however, the shares of these conventional power generation sources in the (rapidly growing) demand for flexibility declines steeply. Already in 2023, the share of gas falls to about 30% and

Figure 4: Total annual supply of flexibility options to meet total annual demand for flexibility, either upwards or downwards, in all scenario cases, 2015-2050 (COMPETES modelling results)



of coal even to 5% (while the share of power trade increases to 65%). Under ‘optimal’ (i.e. ‘least-cost’) interconnection conditions, the share of gas in total annual flexibility needs in 2050 (estimated at about 15 TWh, aggregated per annum) declines further to less than 5% and of coal to less than 1% (while the share of power trade rises to 74%). Under very restrictive interconnection conditions, however, the share of gas becomes

about 27% in 2050 and of coal some 2.4% (while the share of power trade becomes approximately 41%).

Curtailment of VRE power generation becomes a major flexibility option only far beyond 2030 depending to the availability of alternative options (in particular power trade and demand response)

Up to 2030, there is hardly or no curtailment of power generation from VRE sources (sun/wind) needed to balance (hourly) power demand and supply as the share of VRE output in total power demand is still manageable in almost all hours of the year. In 2050, however, - with a large share of potential VRE output in total power demand (80%) and a large number of hours (>3200) with a (large) VRE surplus – VRE curtailment becomes a major flexibility option. In that year, total VRE curtailment is estimated at about 26 TWh per annum, i.e. approximately 16-17% of total realised VRE power production. Under optimal (least-cost) interconnection conditions, the share of (hourly variations in) VRE curtailment in total annual flexibility needs due to the variability of the residual load amounts to some 20%, while under very restrictive interconnection conditions this share increases to approximately 28%.

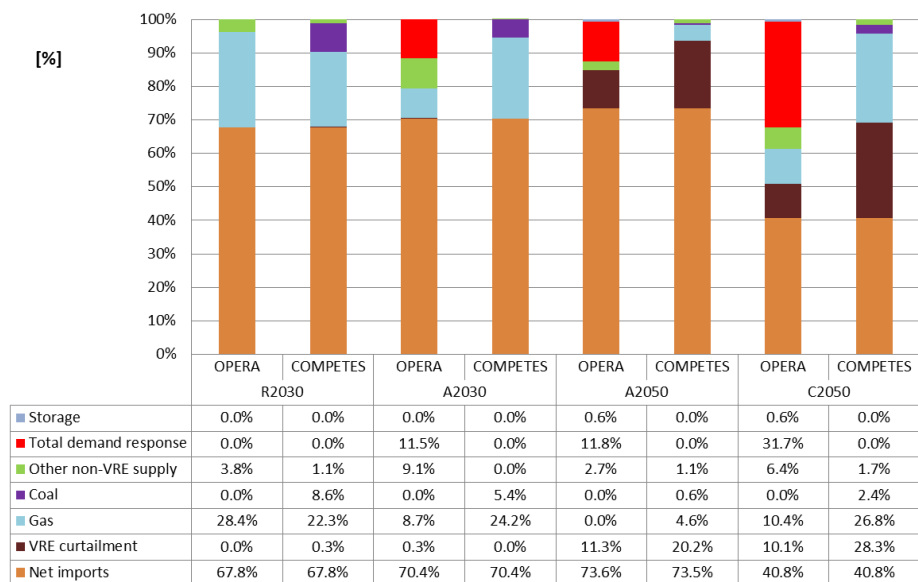
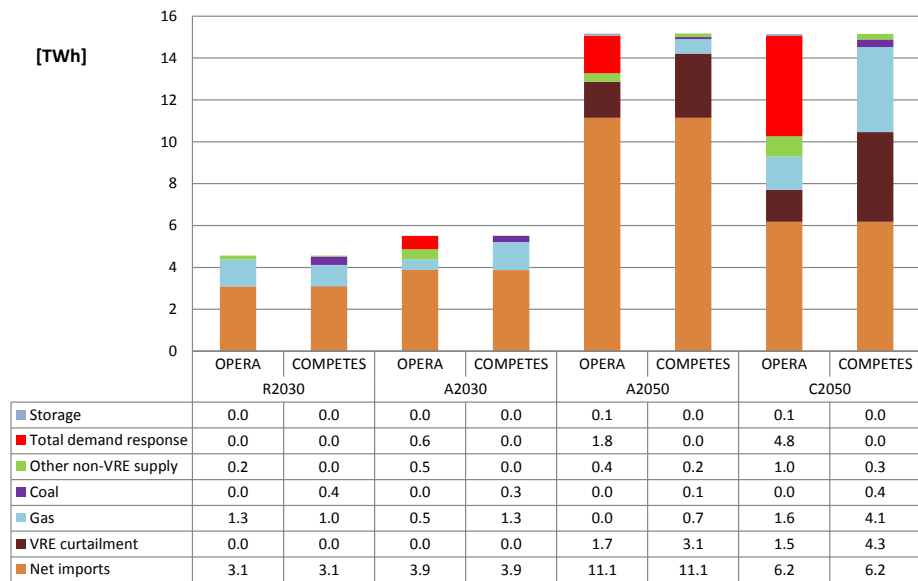
Demand response has a large potential to meet future flexibility needs, but the role of demand curtailment is negligible

In general, there seems to be a large potential to meet future flexibility needs of the Dutch power system by means of demand response, i.e. *shifting* part of (peak) power demand in a certain hour to another hour of the day, week, month, etc., either forwards or backwards. This applies in particular to (industrial) power demand functions that are expected to grow rapidly in the coming decades, such as power-to-gas (P2G), power-to-heat (P2H) or power-to-ammonia (P2A) but also to power demand by means of more smart (flexible) charging of electric vehicles (as all explored in the current study). In addition, there may be a substantial potential for demand response by other power demand functions in other sectors such as services or households (as explored at the regional network level; see below). This potential, however, may be harder to realise depending on the role of aggregators, price incentives, human behaviour, etc. On the other hand, the role of *demand curtailment* – i.e. *limiting* (peak) power demand in a certain hour (and, hence, demand is lost) – as a flexibility option is negligible, at least in the present study in which the value of lost load (VOLL) is set at a relatively high level of 3000 €/MWh.

Energy storage plays generally a limited role in meeting future flexibility needs of the power system (due to its relatively high costs) but in specific cases it may be more significant

The role of energy storage is generally limited to meet future flexibility needs (or at least generally less than what is sometimes expected or suggested in the literature). This applies in particular to longer-term, single ('pure') storage functions to address flexibility needs due to the variability of the residual load on the day-ahead market or, at the regional grid level, to using battery systems purely for congestion management reasons (see also below). The main reason is that the costs of these storage functions are generally high compared to alternative, amply available options such as power trade, demand response, VRE curtailment or – at the regional network level – grid reinforcement.

Figure 5: Comparison of OPERA versus COMPETES modelling results on the total annual supply of upward flexibility options to meet total annual demand of upward flexibility due to the hourly variations ('ramps') of the residual load in selected scenario cases, 2030-2050



In specific cases, however, the role of energy storage to meet flexibility needs may be more significant. This applies, for instance, notably for providing short-cycle storage functions to meet flexibility/balancing needs due to the uncertainty ('forecast error') of the residual load on the intraday and balancing markets, in particular to provide primary/secondary power reserves (although on these markets storage also has to compete with alternative options while power reserve markets are usually relatively small, illiquid and/or uncertain).

In addition, energy storage becomes more attractive (profitable) if it is not the only – or primary – function of a technology and could be combined with providing other (more important) functions so that its costs can be shared or even covered primarily by these

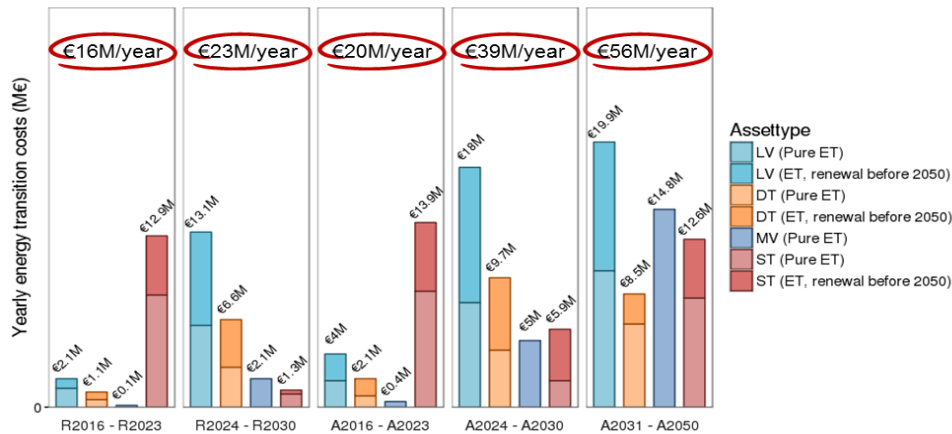
other functions and its benefits and revenues are broader and higher. Examples may include storage options such as power-to-gas (aimed primarily at reducing CO₂ emissions) or using EV batteries for storage functions (although the potential of these options to provide flexibility to the power system is likely higher through demand response than by energy storage).

Regional grid level

The net benefits of deploying large-scale flexibility options purely for congestion management in the Liander area are, *in general*, limited

In order to prevent overloads (congestion) in the Liander grid due to the increased deployment of sun PV, electric passenger vehicles (EVs) and household heat pumps (HPs) – as laid down in the FLEXNET scenario cases – *additional* investments in grid reinforcements are required of 2 to 5% per year up to 2030 and about 7% per year in the period from 2030 to 2050. Given current annual grid investments in the Liander service area of, on average, € 750 million in 2012-2016, this corresponds to a cumulative grid reinforcement investment of € 1.0-1.5 billion up to 2050 scenario.

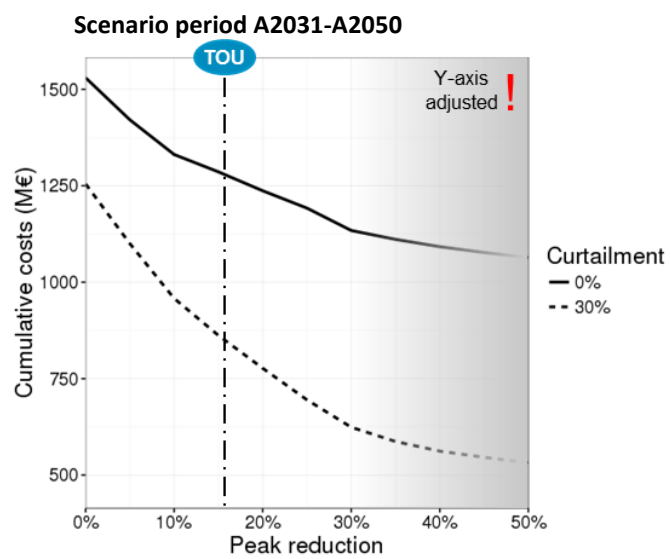
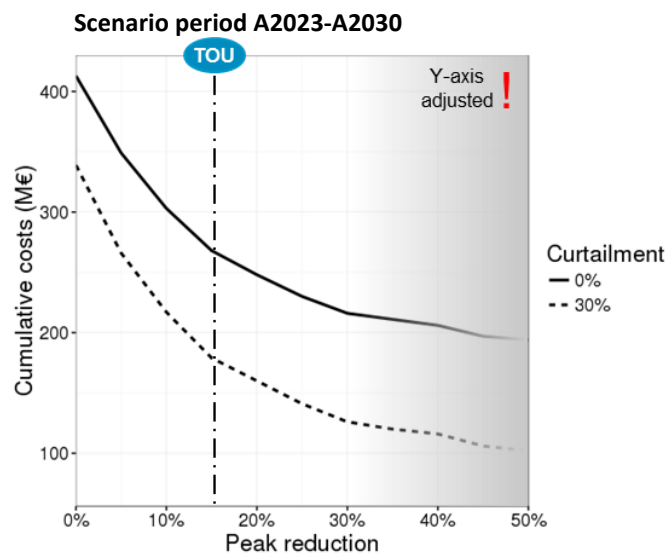
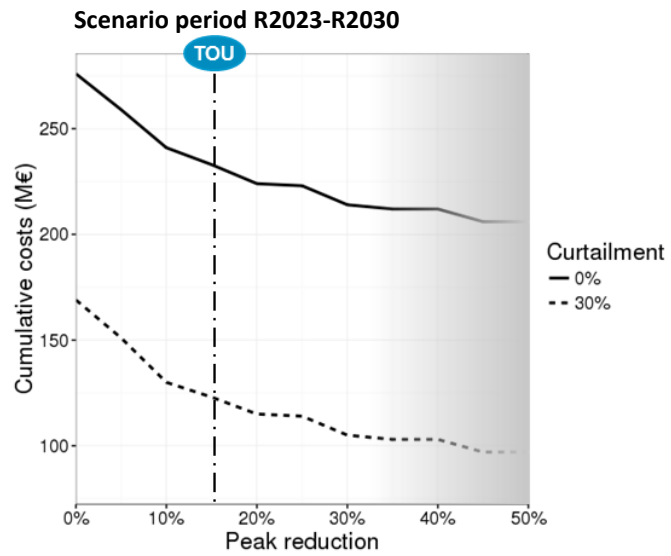
Figure 6: Increase of average network investments due to the energy transition (phase 1 results)



In terms of capital investment savings (CAPEX), it is estimated that a mix of flexibility-based measures to mitigate grid overloads – notably deploying PV curtailment and demand response pricing mechanisms – can save up to about € 700 million (cumulative) in energy transition related grid investments up to 2050. This amount of € 700 million is an indication of the value of flexibility for network investment planning by Liander.

The amount of € 700 million mentioned above, however, does not yet include additional costs required to implement and operate the flexibility-based measures to mitigate grid overloads, such as lost PV revenues, additional grid losses, additional smart metering costs, higher risks, etc. Hence, the net benefits of deploying flexibility as an alternative for grid reinforcements are significantly lower. Moreover, flexibility could have a higher value for purposes such as portfolio and investment planning optimization or system balancing. Flexibility providers should be aware that generally flexibility has relatively a limited scope and limited net benefits for DSOs, implying no large payments for flexibility can be expected from network operators. Therefore, distribution systems operators (DSOs) should be cautious in claiming flexibility for congestion management purposes as, *in general*, the scope and benefits of deploying flexibility for congestion management seems to be limited.

Figure 7: Reduction of cumulative grid investment costs during different scenario periods



It should be noted that the results have been calculated based on the current perspective on the future. Because of the many variables and assumptions, the rapid changing context and ever increasing complexity, modelling should become an integrated part of strategic decision making of the distribution system operators. This will enable a DSO to rapidly adjust their strategy based on the latest insights. In *specific* situations, however, deploying flexibility may offer a significant potential with a relatively high value and is therefore an important capability for any DSO

In specific situation (e.g., locally and/or temporarily), the deployment of flexibility measures to prevent or mitigate grid overloads – and, hence, to avoid or reduce investment costs in grid reinforcements – may offer a significant potential and relatively high value for DSOs, resulting in a concomitant high value of flexibility and associated benefits for flexibility providers. Other applications and opportunities besides congestion management which could be a reason for a DSO to deploy flexibility options include among others: local voltage support, system balancing, synergies groundwork with other infrastructural companies, black-out recovery. Moreover, a rough comparison of the Liander modelling results with modelling outcomes of DSO Stedin indicates more overloads in the Stedin service area and, therefore, a higher demand for flexibility in this area and, perhaps, a higher value (net benefits) of deploying flexibility as an alternative for grid reinforcements.

Energy storage: benefits of using battery system purely for congestion management do not outweigh costs

For energy storage at the regional grid level, the benefits of the use of a battery system for mitigating overloads do not outweigh the costs. Relatively large battery capacities are required to mitigate overloads of distribution transformers (DTs). Given (i) the accompanying cost of a battery system, (ii) the required operational expenditures (OPEX), (iii) the additional energy losses, and (iv) the added complexity and, therefore, the higher operational risks, it is safe to assume that the use of a battery system at the distribution transformer (DT) level in comparison to DT reinforcement purely for the purpose of mitigating an overload is only economically feasible for a very limited number of cases at most. The use of a battery system might be more profitable in case the same system could provide other services such as for instance voltage support, energy trading, frequency support, or resilience/back up power.

Phase 3: Societal framework to trade-off grid reinforcement and deployment of flexibility

Societal framework essential

A societal framework for analysing the trade-off between grid reinforcement and the deployment of flexibility is essential due to the effects of such a trade-off on generators, consumers, network operators and other social actors.

Indices CBA or indicative CBA preferred

Depending on the size of the grid expansion investments that can be temporarily or permanently avoided through the deployment of flexibility and the available information to determine effects, the report shows that an indices or indicative CBA would be the most appropriate form.

Relevant factors in the decision to quantify an effect are the expected size of the effect, the required effort and the social support it generates

Modify requirement to only temporarily apply congestion management

Of course, to be able to devise an adequate societal framework for the trade-off between grid reinforcement and the deployment of flexibility, the legal and regulatory limitation (in the Electricity Act and the Grid Code) that congestion management may only be temporarily deployed will have to be modified.

Implementation of the societal framework in legislation and regulations will benefit uniformity

The aforementioned analysis steps can be used in the investment plans of network operators and be prescribed in a Ministerial Regulation, such as currently exists for Quality and Capacity Documents (KCDs). Policymakers will then be able to ensure more uniform implementation of the societal framework by the network operators.

The societal framework can also provide more insight into the social value of flexibility in specific situations

To better understand the value of flexibility for congestion management, it will be important to conduct further studies to analyse in which specific situations flexibility has the greatest value, for both network operators and society as a whole, by implementing the proposed societal framework in practice.



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