System Value of Gas Storage – Intelligence rather than Steel

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A study commissioned by

INES

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System value of the German gas storage facilities

The Initiative Erdgasspeicher e.V. (INES) has commissioned enervis to determine the system value of the German gas storage facilities. In particular, it should be determined to what extent Germany would be affected by supply interruptions without German gas storage facilities and to what extent the system costs would increase without German gas storage facilities. The *storage flexibility* scenario therefore relies on the installed infrastructure in the gas market. This scenario is compared to the *flexibility import* scenario which considers gas supply without the support of the German gas storage facilities.

Storage flexibility

The *storage flexibility* scenario has been modelled along the currently installed infrastructure. The gas demand modelling has been based on a temperature trend taken from the year 2012. Gas consumption in 2012 was average, but there was a two-week cold spell in winter. In this scenario, gas supply in Germany and Europe and also in the rest of the world can be sustained. Nevertheless, significant findings arise solely from the modelling of the *storage flexibility* scenario:

- According to the model results, the structuring of gas consumption using available sources of flexibility has a cost-optimal tendency in the direction of a consumption focus on gas storage and not by providing flexibility via LNG or pipelines.
- The gas storage facilities available in Germany completely cover domestic flexibility requirements in winter. Furthermore, foreign flexibility requirements are served from German gas storage facilities, so that Germany can be regarded as a net exporter of flexibility.
- In the *storage flexibility* scenario, the existing transport capacities are already sufficiently developed. The market areas can be supplied. No network expansion between the considered regions or market areas is necessary to meet current needs.

Flexibility import

The *flexibility import* scenario differs from the *storage flexibility* scenario through the complete removal of German gas storage facilities. In this situation, Germany is dependent on structure and flexibility imports.

The following changes in comparison to the *storage flexibility* scenario arise:

- German gas storage facilities are partially offset by existing storage facilities in the EU, Russia, Belarus and the Ukraine.
- Norwegian production also provides flexibility to partially offset German gas storage facilities.
- In addition, LNG becomes a supplier of flexibility. The quantities of LNG imported into the EU double between the scenarios and are subject to a massive change in the import structure in order to partially offset the German gas reserves.
- Despite these developments, the German gas storage facilities cannot be fully compensated. As a consequence, it is not possible to maintain security of supply in Germany.
- In the *flexibility import* scenario, about 20 TWh cannot be supplied as needed to end customers in Germany. To

compensate for this, up to 2,210 GWh/d of load must be shed, especially at times of high peak loads.

- Not only are industrial customers cut off, but also protected customers are isolated by load shedding, i.e. household customers and district heating producers. Network expansion in Germany and Europe can reduce the supply restriction to 462 GWh/d.

The comparison of the scenarios makes it possible to determine the changes in load flows and to explore the limits of the European and ultimately the German gas system. Furthermore, it is possible to quantify which additional economic costs would arise in Germany without the deployment of gas storage facilities.

Central results

Gas storage facilities avoid network expansion

Thanks to their network-conducive deployment, gas storage facilities enable a uniform import of natural gas quantities. The constant full-utilisation of pipeline capacities leads to higher efficiency and avoids investments in transport capacities which are only necessary a few days a year. A close-to-demand provision of flexibility through gas storage leads to lower system costs.

Without gas storage Germany must import flexibility

Without German gas storage, Germany transforms from being a flexibility exporter into a flexibility importer. The value creation stage of provision of flexibility is shifted to other regions. The dependence on flexible production and quantities of LNG increases drastically – both Europe-wide and indirectly in Germany. Furthermore, Germany is heavily dependent on the provision of flexibility by neighbouring countries. Apart from shutting down consumers, Germany has no way to react within its borders.

German gas storage can only be partially compensated

The European natural gas infrastructure is effectively networked and also has access to large sources of flexibility outside Germany. German gas storage facilities can therefore be at least partially offset by sources of flexibility from the EU, Norway, Russia, Belarus, Ukraine and flexible LNG imports. However, this increases system costs significantly.

Without German gas storage supply restrictions arise

German gas storage facilities are crucial for security of supply in Germany. Removal of the German gas storage facilities leads to significant supply restrictions. This can be partly compensated by network expansion, but the additionally installed network capacity would only be utilised on a few days of a cold year. Furthermore, network expansion leads to higher system costs than the use of gas storage facilities.

System costs

The aforementioned changes in the production, transport, delivery and consumption structure also lead to changes in global system costs. Overall, the omission of German gas storage facilities in the year under review, taking into account further network expansion, would result in additional system costs of €2.2 billion per annum. This results out of the following aspects:

- The storage costs decrease in the *flexibility import* scenario by €66 million p.a., since the shutdown of German storage facilities is not completely offset by other storage facilities.
- As a result, however, other and longer gas transport routes will be used and flexible production of the yield sources is compelling. This leads to rising production costs of €196 million per annum.
- In addition, *flexibility import* scenario transport costs compared to the *storage flexibility* scenario increase by €557 million p.a., mainly due to increased LNG shipments from distant sources and the additional necessary liquefaction and regasification.
- The network expansion required to overcome the supply bottlenecks in the absence of German gas storage facilities amounts to costs of €1.4 billion p.a.
- Beyond that, costs for load shedding, i.e. for the shutdown of customers who depend on the use of gas, still arise in the *flexibility import* scenario; to the amount of approximately €0.1 billion p.a.

In the *storage flexibility* scenario, measures for network expansion in the modelling are not required. Only in the absence of German gas storage facilities must flexibility be imported into Germany. This would require network expansion measures. The existing German gas storage facilities therefore already avoid investments of at least €1.4 billion p.a. in transport network infrastructure. Taking production, transport and the remaining load shedding into account, the worldwide additional system costs compared to the *storage flexibility* scenario are €2.2 billion p.a.

Gas storage is an essential element to ensure security of supply. In the absence of gas storage facilities in Germany, system costs would increase significantly and customers – even those classified as worth protecting – would be shutdown.

Gas storage facilities are cornerstones of assured supply

Additional network expansion would increasingly erode the role of gas storage. However, gas storage continues to be essential and reduces system costs. While network expansion also takes place within a framework of regulatory granted returns on equity, gas storage facilities must operate in a competitive environment. This leads to a cost inefficient design of the gas system. An integrated approach to network and storage planning could raise significant cost benefits for the end customer and make a significant contribution to security of supply.

2 Mission and goal of the study

INES is an association of operators of German gas storage facilities and has its headquarters in Berlin. INES represents over 90 percent of German gas storage capacities. INES members also operate almost 25 percent of all gas storage capacities in the EU. The central task of INES is to promote public awareness of the contributions made by German gas storage facilities to energy policy goals. INES commissioned enervis energy advisors GmbH (enervis) to compile a study on the system value of gas storage facilities.

enervis was founded in 2001, is owner-managed and has its headquarters in Berlin. enervis is an independent consulting firm specialising in market modelling, with models in the electricity, heating and transportation sectors and a load flow model for modelling the gas market.

This study focuses on system costs and gas storage in Germany. Historically, gas networks and gas storage were considered integrated together, resulting in a cost-effective solution for natural gas transport and supply. Storage expansion and network expansion coexisted. Due to the unbundling of networks and storage, such a consideration without taking other factors into account is no longer possible:

- Gas networks are subject to a regulatory framework and profits are generated through guaranteed returns.
- Gas storage, on the other hand, does not receive guaranteed returns and must generate its earnings in the trading market.

These framework conditions lead to a decoupling of company-specific decisions from the economic optimum. Network operators are inclined to invest in pipelines and promote their priority utilisation in order to generate the promised returns. Gas storage operators, on the other hand, operate in a market-based environment in which essential contributions of the gas storage facilities for the energy supply, esp. the system value and the insured value are not or not fully remunerated.

In order to identify the role of gas storage facilities in Germany, two key theses will be reviewed in the study:

- Gas storage optimises infrastructure costs
- Gas storage as a source of flexibility is indispensable for security of supply

The study examines these theses using two scenarios: *storage flexibility* and *flexibility import*. The *storage flexibility* scenario is based on the current infrastructure in the gas market. In the *flexibility import* scenario, gas supply is considered without the support of the German gas storage facilities. The comparison of the scenarios serves to analyse the changes in load flows and to explore the limits of the European and, ultimately, the German gas system. In particular, it should be determined whether security of supply can be sustained in a scenario without German gas storage facilities.

The scenarios are modelled and analysed using the "GasTracks" gas flow model. The model used is a regional load flow model that maps the global gas market into regions. The model is presented in section 3. Both scenarios are explained in section 4. The key results of the *storage flexibility* scenario are presented and discussed in section 5, to enable a substantive and economic comparison with the results of the second *flexibility import* scenario in section 6.

3 Modelling as the basis of the study

In this study, the two *storage flexibility* and *flexibility import* scenarios are modelled and juxtaposed. Based on this scenario comparison, the key differences are determined in order to examine the theses formulated in section 2. The following section first describes the mode of operation of the load flow model (cf. section 3.1) and then the underlying basic parameters are explained (cf. section 3.2).

3.1 Brief description of the load flow model

GasTracks is an accounting model that tracks the balance of various linked regions on a daily basis. The focus is on the European market. Nevertheless, worldwide gas consumption and production regions are represented, as an isolated view of Europe through the existing LNG infrastructure and interdependencies via pipelines would limit the scope for investigation.

Within the model, regions are individual countries or, in the case of Germany, the existing market areas with additional distinction between H and L gas. Neighbouring countries are also divided into separate regions per gas quality.

Definition of regions:

The model has accurate to the day consumption expectations stored for each region on the basis of historical temperature years. For the present calculation, the Europe-wide temperatures of the year 2012 were used to derive corresponding consumption data in the European regions (cf. section 0).

In the appropriate gas quality, the gas production capacity to cover one's own requirements or which can be used for export is assigned to each region.

In addition, the sources of flexibility available in the region in the form of gas storage facilities are defined. Here, a distinction is made between three storage classes (slow, medium, fast) (cf. section 3.2.6).

Regional links:

Each region is linked to other regions. This is primarily via pipeline capacity. Furthermore, there are connections between regions via LNG infrastructure (liquefaction, regasification, LNG tankers). The pipeline capacities are identified as an aggregate between two individual zones and thus allow an exchange of gas quantities (cf. section 3.2.5). In the model, LNG replacement capacities are limited by the liquefaction or regasification capacities as well as the capacity and availability of tankers.

Shortfalls:

Shortfalls refer to the emergency shutdown of end customers. This can occur in the model when the capacities of the transportation pipes, storage, production sources or LNG infrastructure are exhausted. A region can then no longer be supplied with the available capacities and gas quantities. In the model, load shedding in the affected region is possible in these exceptional cases.

Due to the interconnectivity of the EU Single Market, in an emergency situation in a market, the willingness to pay primarily determines the country in which loads are to be shed. However, political influence or regulatory measures (e.g. export stoppages) can undermine market dynamics. For the modelling of the *flexibility import* scenario it is assumed that any load shedding will take place in Germany, since the capacity bottlenecks would be caused by the loss of German storage facilities. Based on this, the costs of the shed loads are evaluated (cf. 3.2.8.2).

If alternative supply options are available to the regions, these options will be prioritised by the model. In any case, load shedding represents the last resort solution for the model.

How the model works:

Figure 1 represents the key input parameters of the model in an overview.

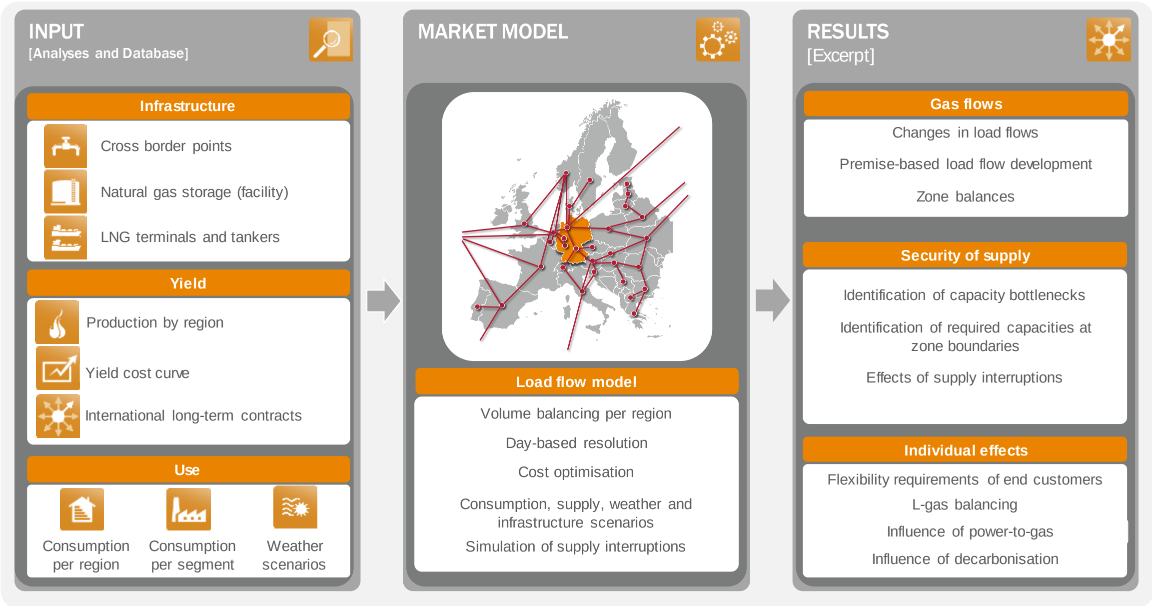

Figure 1: Overview of the GasTracks model

GasTracks optimises the deployment and utilisation of all assets (e.g. storage facilities, pipelines, LNG tankers) taking into account the respective deployment costs. The aim is to cover the given day-specific and regionally differentiated consumption.

As an additional secondary condition, a cyclic gas storage deployment is considered, i.e. the levels at the beginning and at the end of a year are identical. The initial or final level can be freely optimised by the model between 0% (no use of gas storage) and 100% (full use of gas storage).

As a result, as with all similarly constructed optimisation models, an optimal solution for the period of observation results from "perfect foresight". Perfect foresight means that the entire demand development over the period of observation is known from the outset and is therefore based on the best possible solution, i.e. the cost-optimal combination of production, transport (pipeline and LNG) and storage. In particular, this means that:

- Storage facility users know exactly when quantities will be needed in the distant coming winter. It is not necessary to stock gas in order to be able to react at any time. Storage facilities can be completely delivered.
- LNG tankers dock on time to cover just-in-time peak loads.
- All market participants are prepared, via the absolute foresight, to completely exhaust the system boundaries and cooperate with one another smoothly.

The basic parametrisation of the model is shown in the following section using Germany as the example.

3.2 Basic parametrisation of the model

3.2.1 Regionalisation of Germany

The focus of the study is Germany. While most nation states represent a region within the model, countries with different gas qualities have been split into two regions. Germany has been broken down into four regions: the two existing market areas NetConnect Germany (NCG) and GASPOOL (GPL), each of which is additionally distinguished by gas quality. In Germany, therefore, the four regions NCG L-gas, NCG H-gas, GPL L-gas and GPL H-gas arise in Figure 2 below.

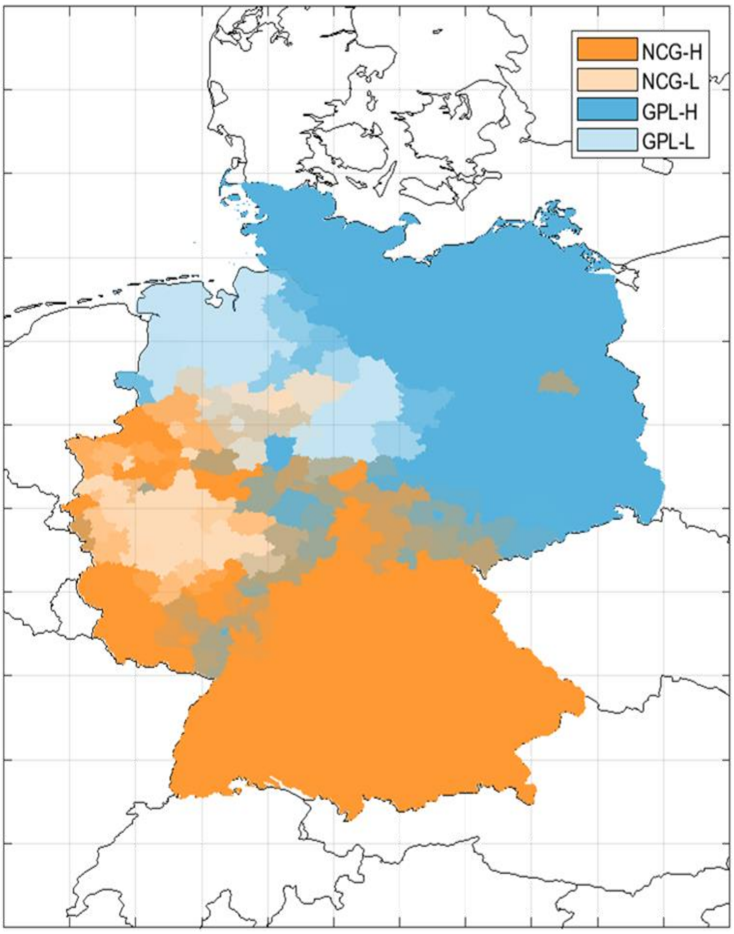

Figure 2: Depicted regions in Germany

All regions of the model are assigned gas consumption quantities, production capacities, gas storage as well as import and export capacities in the parametrisation. Details about the German regions can be found in the following sections.

3.2.2 Gas requirements of the regions

The basis for the determination of regional daily consumption loads is a weather database. The weather database contains hourly historical weather data for approx. 3,100 grid points over 29 years. The recorded weather data includes precipitation amounts, global radiation, wind speeds at different altitudes and – relevant for this study – temperatures.

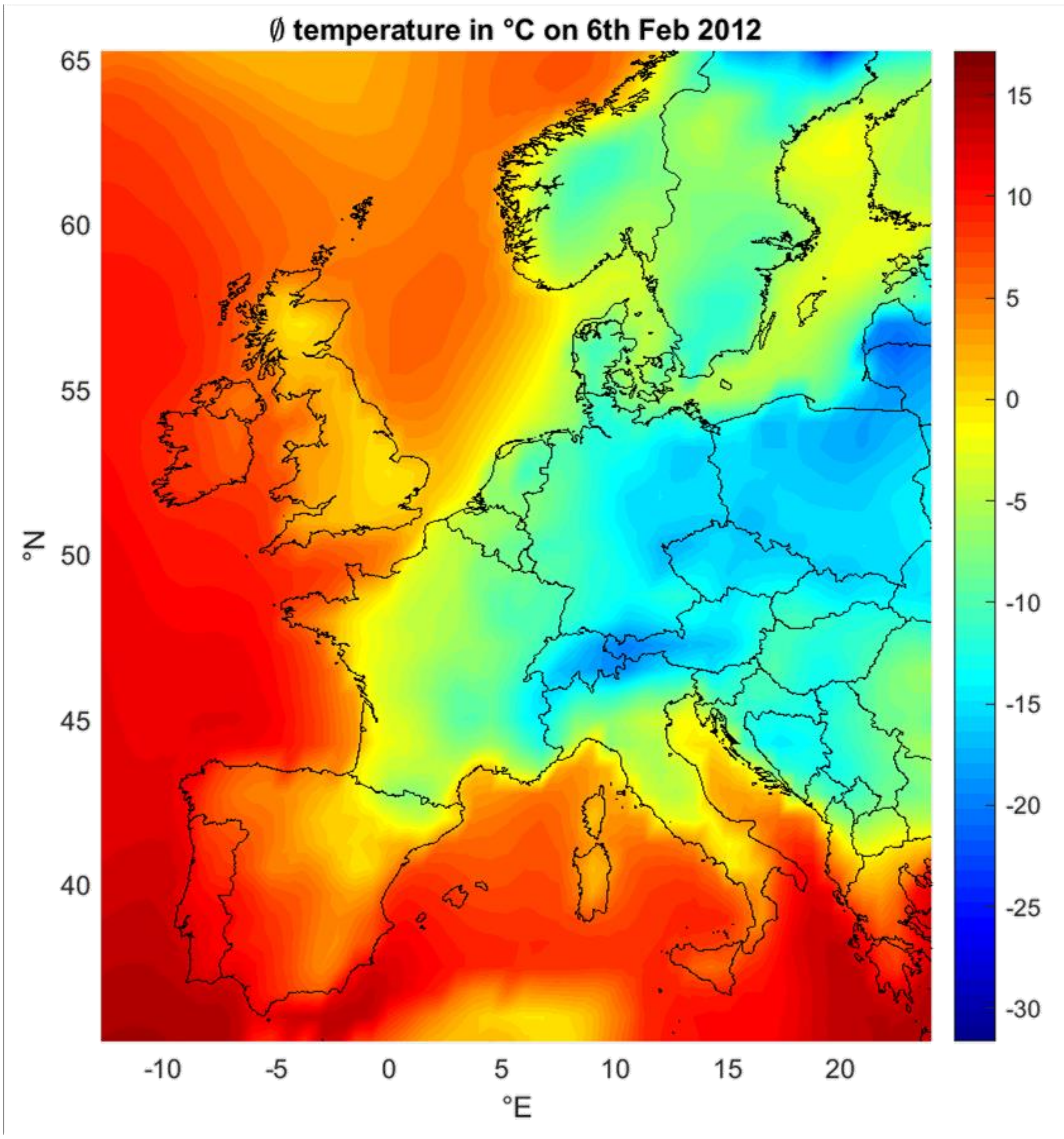

Figure 3: Exemplary day of European temperatures[1]

On the basis of this temperature data, demand load profiles are rolled out for each grid point of the weather database. Here, both temperature-dependent and largely temperature-independent load profiles are used. The proportion of temperature-dependent profiles in the respective region is derived from a historical regression with monthly-accurate consumption data[2] from each country. Using all grid points of a region, the consumption load profile of this region is then

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1 enervis presentation, base data from meteogroup weather database

2 IEA, monthly gas sales volumes

determined by averaging all the associated point profiles. This results in a consistent daily consumption data record per region.

For the present study, a year with a two-week cold period in February was selected from the historical data, which forms the data base for both scenarios regarding consumption volume and structure. A comparison of the consumption data over the various historical weather years shows that 2012 has an annual consumption corresponding to a cold year with partially high peak loads (especially in February) in Germany. Europe-wide, the 2012 temperature year was only average.

Since high peak loads are fundamental for the design of infrastructures, the year 2012 was used. This ensures that infrastructure costs are not underestimated, as infrastructures must always be designed for peak loads. However, due to the otherwise average winter, the system costs derived from it can still be considered as representative. In order to test the model parametrisation and the gas consumption calculated on this basis, a comparison was made with data published, on the one hand, by the market area leader NCG and, on the other hand, included in the German Gas Network Development Plan 2016 (NDP). An excellent match for the regions GPL L-gas, NCG L-gas and NCG H-gas arises therefrom. There are no publicly available comparable figures for the GPL H-gas region for 2012. The comparison is represented in Figure 4 and demonstrates the accuracy of the modelling results.

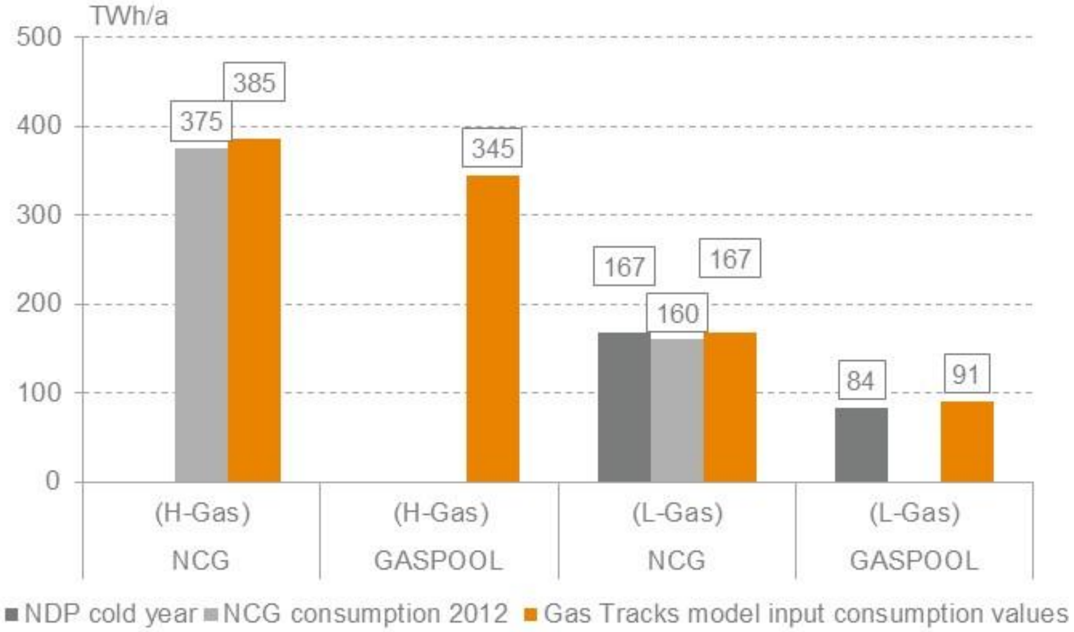

Figure 4: Checking the parametrisation based on the defined German regions

Figure 5 shows both the annual consumption and the maximum daily output for some European consumer countries. The high daily consumption in Italy – compared to Great Britain – is striking. February was much colder in parts of Italy than in the UK which is influenced by the Gulf Stream. This observation shows that, although the weather in 2012 was characterised by a cold weather situation in Europe, especially in February, gas supply was relieved by a comparatively mild weather and hence consumption situation in Great Britain. Overall, 2012 is thus an average European temperature year with a cold period, but not an extreme stress scenario for security of supply from a European perspective.

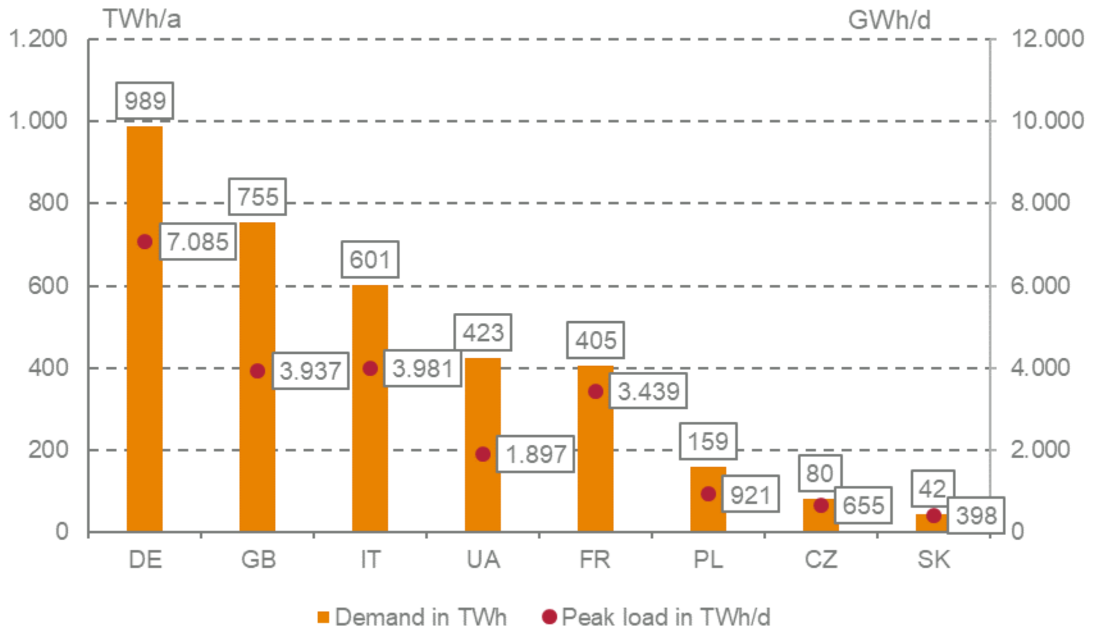

Figure 5: Modelled annual consumption and peak loads of selected European consumption countries

3.2.3 Production

The model includes worldwide production data. A maximum annual delivery amount and a maximum daily delivery amount are identified.

The production data for Europe is derived from the Ten Year Network Development Plan 2017 (TYNDP 2017) and compared with data from the NEP 2016. In particular, the production data for Dutch L-gas from the Groningen field was adjusted to the NDP assumptions in order to reflect the production restrictions imposed by the Dutch government.

3.2.4 LNG infrastructure

Data on the LNG infrastructure relate to liquefaction plants, regasification plants and LNG tankers. The daily capacity is relevant for liquefaction and regasification plants. For LNG tankers, the number, volume, speed and boil-off quantities (loss rate due to evaporation) are required. The data for the LNG infrastructure comes from the 2016 World LNG Report of the IGU (International Gas Union).

Furthermore, for each combination of liquefaction and regasification terminals, the distance by sea was determined. This matrix allows estimating how long LNG tankers will need to transport LNG from the liquefaction plant to regasification.

3.2.5 Import and export capacities

The import and export capacities between the German market areas and their neighbours are derived from the data published by ENTSO-G in 2016. Analogous to the assumptions made in the 2016 NDP, NordStream's capacity will be limited to the regulated part (OPAL restriction) and imports from Austria and Denmark will not be allowed. The NordStream/OPAL capacities, which can be directly allocated to the Czech Republic, were also directly linked to this region in the model.

The following graphics show the capacity of the import and export of German regions as determined by enervis. These figures include both cross-border points and market area transfers. Conversion capacities are not included in the illustration.

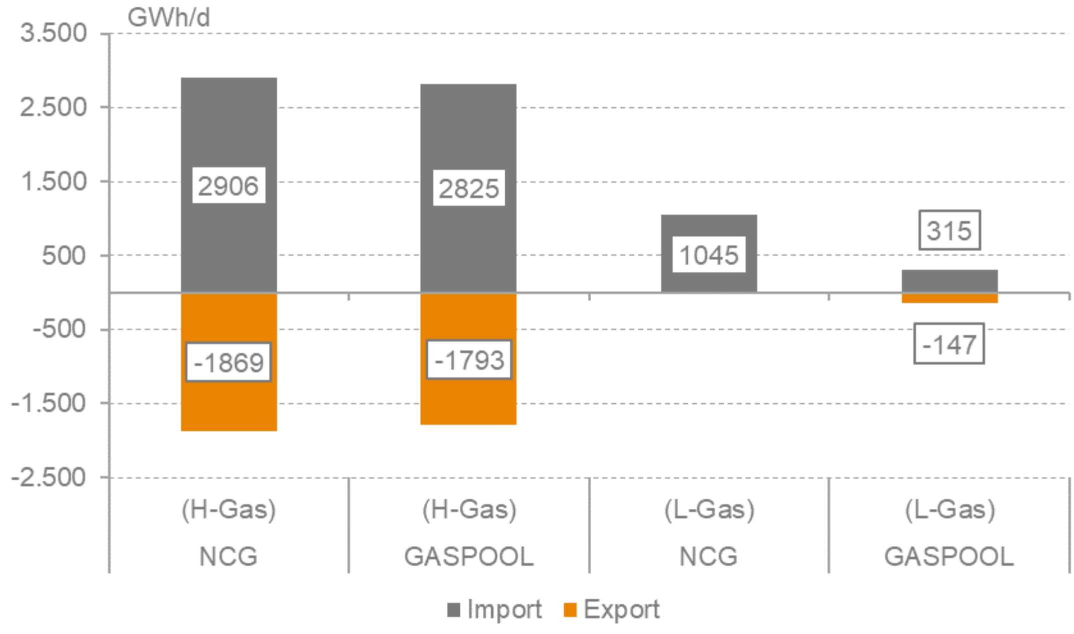

Figure 6: GasTracks import and export capacities per region of Germany

If the available import capacities per gas quality are compared with the maximum daily consumption, the peak load, there are clear differences between the H and the L gas sectors. This is clarified in Figure 7.

In the H-gas sector, without taking into account the transit volumes, sufficient import capacity is available to cover the consumption of the H-gas market, at least purely mathematically. However, as soon as transit volumes are included in this analysis, the required extraction capacity exceeds the available import capacity. Structuring by means of gas storage is therefore required.

The gas volumes that are routed through other countries are not specified in the model, but are a model result. The available capacities of each region allow gas to flow from one region to another. The model autonomously decides which transport route the volumes use. Supply of adjacent markets takes place cost-optimally over the available routes of the model.

In contrast to H-gas, the installed capacities in the L-gas sector are clearer. From a German point of view, L-gas transit volumes play no role. The supply of neighbouring countries with L-gas is ensured mainly by the Netherlands. However, the sole consideration of import capacity and peak consumption in L gas clearly shows that it is not possible to supply the peak load exclusively via the import points. The flexibility of gas storage is required.

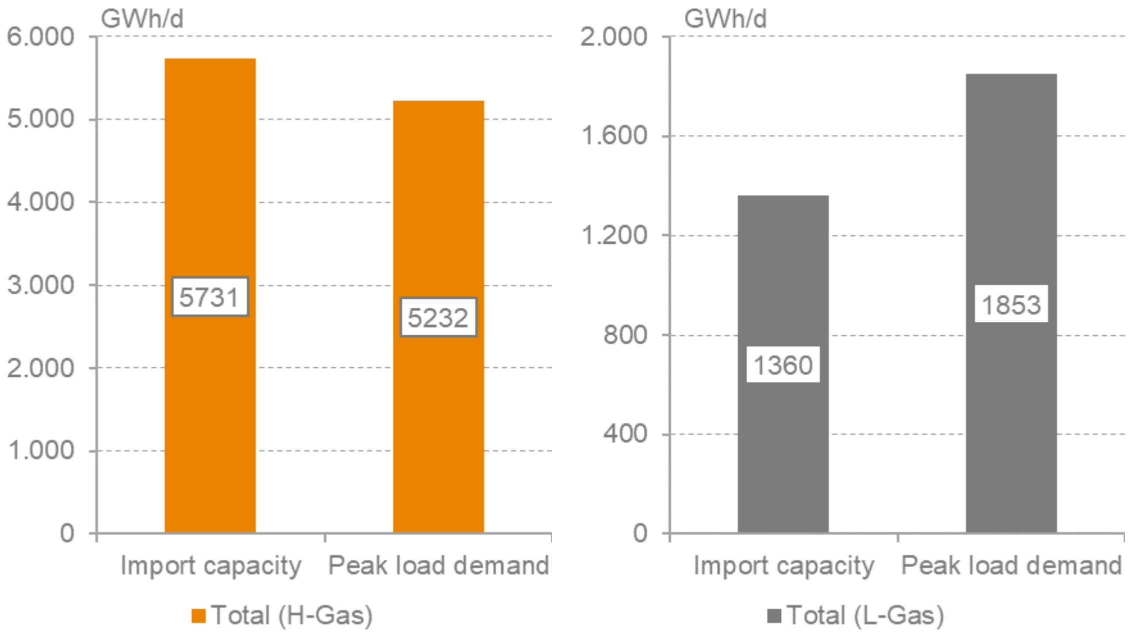

Figure 7: GasTracks - Comparison of the capacity balance of incoming and outgoing gas according to quality

3.2.6 Gas storage facilities

The storage parametrisation was based on data from the LBEG (Authority for Mining, Energy and Geology of Lower Saxony)[3] and from GIE[4]. The allocation to the German regions took place analogously to the possible injection capacities into the respective network. If storage facilities belong to several regions and no detailed information about the exact connection capacity per market area is available, the connection capacity of the storage facilities was assigned to the connected regions in equal parts.

The model depicts three types of storage: "fast", "medium" and "slow". Assignment is based on the withdrawal duration of a storage facility. Here, the necessary number of days for a complete withdrawal of the working gas volume (WGV) from a level of 100% to complete emptying, taking into account the maximum withdrawal capacity, is specified. No characteristic is used in the classification. Fast storage is classified as those that take less than 45 days for complete withdrawal. Medium storage takes less than 80 days. For slow storage, the withdrawal period is more than 80 days. The storage facilities are aggregated in each region per class and placed in the model. In Germany, the total installed working gas volume is approx. 263 TWh. Figure 8 represents the regional distribution of the storage facilities considered for Germany.

3 LBEG, Untertage-Gasspeicherung in Deutschland, 2016

4 GIE, GIE Storage Map, December 2016

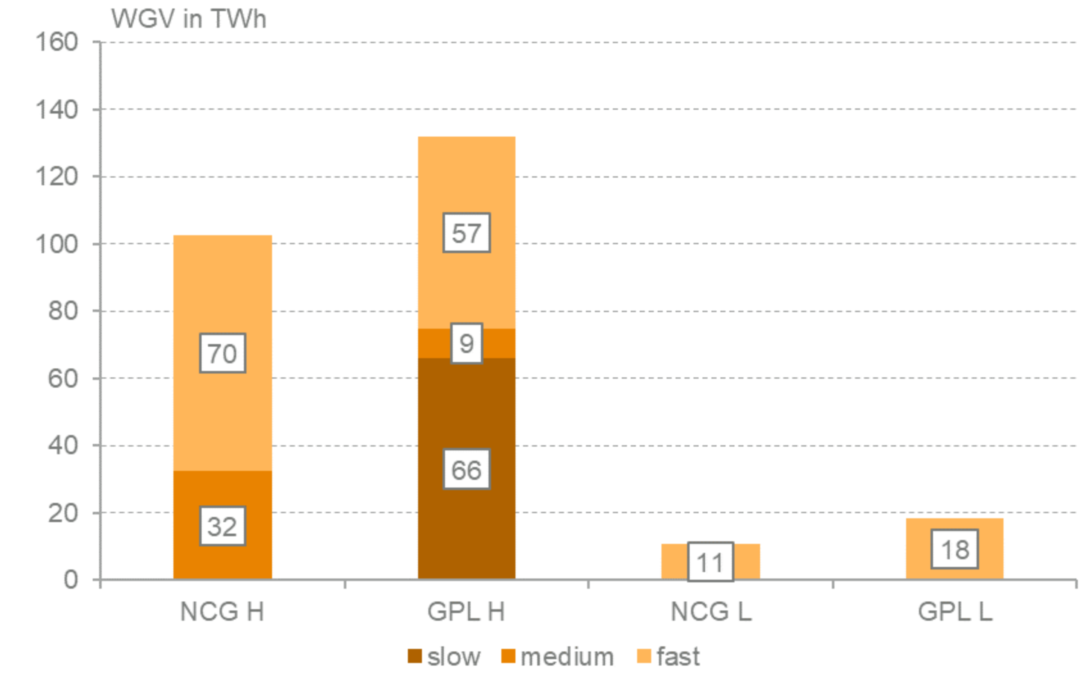

Figure 8: Storage inventory by region in TWh Working Gas Volume

The storage categories are equipped for each region with a specific injection and withdrawal capacity (IC or WC). In total, Germany has an installed gas storage withdrawal capacity of almost 7,100 GWh/d. The injection capacity reaches a maximum value of about 4,200 GWh/d. The following Figure 9 shows the maximum available injection or withdrawal capacity by region.

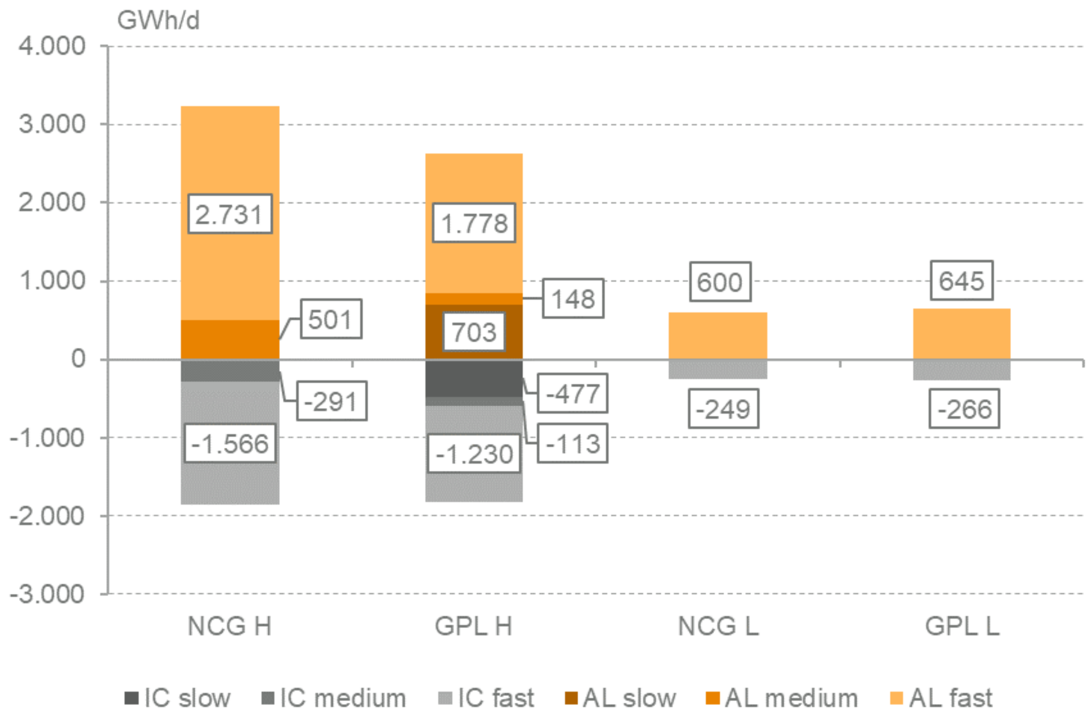

Figure 9: Maximum injection and withdrawal capacity by region in TWh/d

The actual available capacity of the storage facility depends on the respective fill level. Therefore, the storage facilities are depicted with level-dependent characteristics. The injection capacity drops as the fill level of the storage facility increases. The withdrawal capacity falls with decreasing fill level. The characteristic has been set identically for all storage categories. The following Figure 10 represents the characteristics stored in the model.

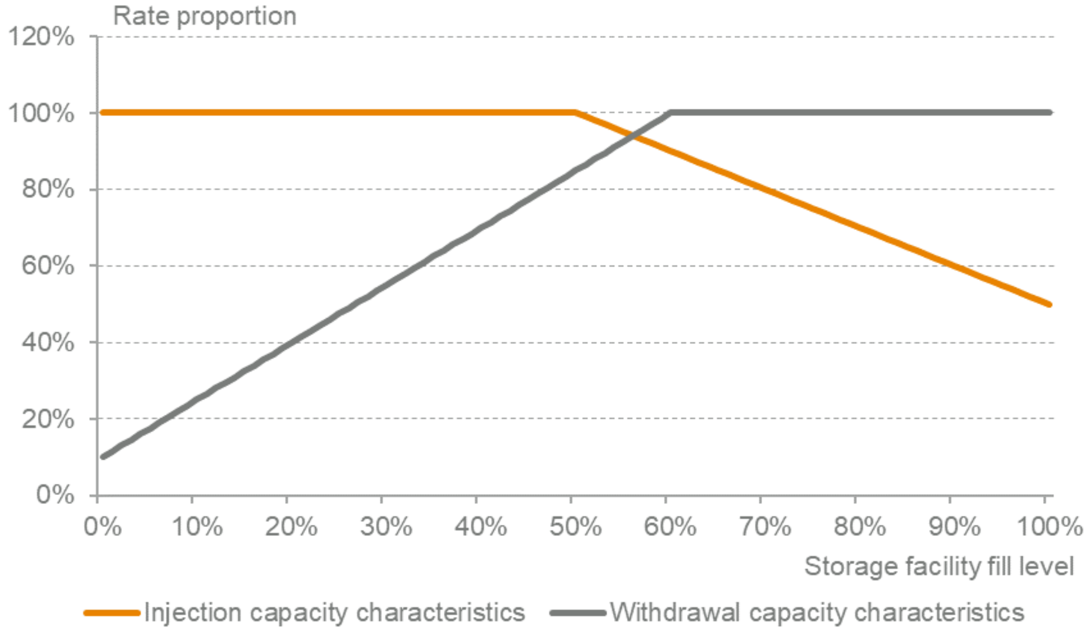

Figure 10: Injection and withdrawal characteristic of storage facilities[5]

3.2.7 Digression: Gas storage in Germany and Europe

In order to be able to classify the gas storage capacities installed in Germany compared to other European countries, Figure 11 on page 19 compares Germany's gas storage facilities with those of other European countries. On the one hand, the share of working gas volume in the total consumption of the country is depicted and, on the other hand, the share of peak output that could be covered by the maximum withdrawal capacity are shown.

The share of working gas volume in annual consumption in Germany is about 26%. Germany is thus in the midfield of the countries considered. France (FR) is at 40%, Italy at 20%.

Furthermore, German gas storage facilities, in the best case scenario, i.e. full storage, can withdraw the approximate amount of the required peak load. Other countries, such as Slovakia and Ukraine, can provide between 1.2 times and 1.7 times the peak load of their own country through storage.

Although Germany has one of the largest installed storage volumes, it is also one of the largest gas consumer markets in continental Europe. Thus, compared to other countries and the storage facilities installed there, Germany is in midfield.

5 Basis of the withdrawal characteristic curve: INES / BMWi / bbh, Möglichkeiten zur Verbesserung der Gasversorgungsicherheit und der Krisenvorsorge durch Regelungen der Speicher, S. 136, 2015; The injection curve was created on the basis of enervis empirical values and coordinated with INES.

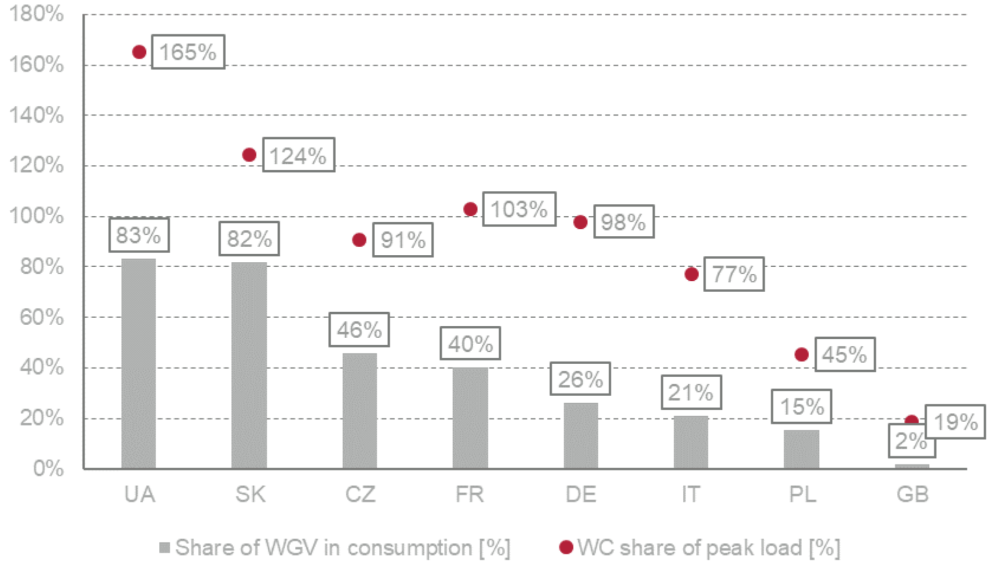

Figure 11: Consumption and peak load per respective country of the installed gas storage facilities according to Working Gas Volumen and Withdrawal Capacity depicted in the model

3.2.8 Cost assumptions

The utilisation of infrastructure for gas supply is provided in the model with corresponding variable costs. The costs are shown identically worldwide. Therefore, from the point of view of market participants, there is a free international market. The framework conditions for flexibility and transport services are identical for all infrastructure facilities. The optimisation of the model therefore takes place in an idealised free and fair competitive environment. Distortions that may exist due to different regulatory conditions in different regions are not taken into account.

In this study, variable costs were set conservatively high for gas storage and low for other infrastructure, as can be seen in the following sections. This underestimates the potentials and deployment for the provision of flexibility through gas storage (conservative approach). The costs of the model are explained below.

3.2.8.1 Transport costs

3.2.8.1.1 Pipeline capacities

There are no direct variable costs for transport capacities in the model. Rather, the transport losses (propellant gas) at the rate of 3%/Thsnd.km are used, which must be provided by production sources and, corresponding to the transport volumes and distances, require additional production.

Pipeline transport	
Transport losses	3% of the transported gas per 1,000 km

Table 1: Pipeline transport cost parameters[6]

6 International Gas Union, "Natural Gas Facts & Figures" 2012: 0.2-0.4% per 100 km

3.2.8.1.2 Expansion of pipeline capacities

Insofar as pipeline extensions are made in the model, these are assumed at a flat-rate with costs of €120,000 /(GWh/h) per kilometre.[7]

Expansion of pipeline capacities	
Costs in GWh/h per km	€120,000/(GWh/h)/km

3.2.8.1.3 LNG capacities

The LNG routes have capacities and are represented in three stages: liquefaction capacity, transport capacity (number of LNG tankers) and regasification capacity.The costs of liquefaction and regasification are stored as variable costs amounting to €/thsd. m³. The costs of sea transport are distance-dependent, variable costs in €/(thsd. m³ * km). The costs are shown identically in the model worldwide.

LNG capacity	Costs
Liquefaction + regasification	55 €/thsd. m³
Sea transport	€2.12/(thsd. m³ * 1000km)

Table 2: Parameters of LNG costs[8]

3.2.8.2 Gas storage costs

Storage costs are also variable costs in €/thsd. m³ storage or withdrawal. The costs are charged on the turnover of the storage facilities and are identical worldwide. Variable costs required in storage capacity marketing range between 0.50 and 0.80 €/MWh, i.e. between 4.50 and 8.80 €/thsd. m³.[9] For this study, the costs were set higher at €10/thsd. m³, which is a very conservative approach in the framework of this study.

Storage facility	Costs
Handling costs	€10.00/thsd.m³

Table 3: Parameters of gas storage costs

3.2.8.1 Production costs

In the model, variable production costs ranging from €80 to €90/thousand. m³ have been assumed.

	Costs
Worldwide production costs	80-90 €/thsd. m³

Table 4: Parameters of production costs

7 enervis analyses; see i.a. FNB Gas, Netzentwicklungsplan Gas 2016-2026 plus Annex „Ausbaumaßnahmen (2016 – NEP Bestätigt).

8 Liquefaction and regasification: Costs are based on the lower costs of liquefaction and regasification costs reported in various sources (e.g. EIA, "The Global Liquefied Natural Gas Market 2003: Status & Outlook" 2003, Hilmar Rempel, „Erdöl und Erdgas – Gesamtressourcen und Verfügbarkeit“, 2006), Transport costs: Tanker volume of about 160,000m³, freight rate about €86,000/day, average speed 19 knots, round trip to be paid, natural gas has 600 times the volume of LNG

9 Price sheets from various storage operators on handling costs, enervis' own experience on energy costs per MWh handled

3.2.8.2 Load shedding costs

Insofar as supply bottlenecks occur as part of the model and delivery to end customers cannot be ensured, load shedding takes place. This is equivalent to shutting down consumers and is identified by the model as a "shortfall". Subsequently, the cost of this load shedding ("value of lost load") is assessed. The basis for this assessment is an investigation by the VIK Verband der Industriellen Energie- und Kraftwirtschaft e.V. („Demand Side Management aus Industriekunden-sicht",), presented on 9th August 2016 at the "NCG-Workshop Regelenergie" in Düsseldorf). Among other things, this study compares gross value added (in billion € p.a.) to gas consumption (in TWh) of various energy-intensive industries. This results in the gross value added of these industries in €/MWh gas consumption.

	gross value-added [Bn €]	Gas consumption 2012 [TWh]	Shutdown costs [€/MWh]
Brick/building ceramics	0.93	6.84	135.96
Papermaking	3.24	22.28	145.42
Pig iron/steel	6.00	36.98	162.25
Chem. primary industry	22.41	106.58	210.26
Metal manufacturing	18.72	75.63	247.52
Glass & glassware	3.22	12.79	251.76
Chem. products	34.66	104.49	331.71
Commercial paper	9.50	28.12	337.84
Glass industry, ceramics, stones and earths	12.60	28.85	436.74

Table 5: Theoretical shutdown costs of energy-intensive industries[10]

To determine the costs of load shedding within the model, it is initially assumed that only the illustrated energy-intensive industries are affected. Resulting load shedding in the customers worthy of protection sector, such as household customers or district heat generators, are valued at the same cost.

It is further assumed that only the avoided gross value added per megawatt hour will be incurred as a cost for load shedding. This assumption is also conservative, since it is precisely in unplanned production losses that significantly higher costs can occur. For example, materials may be lost, equipment damaged, contracts breached, or any other not-included damage may occur.

Assuming constant utilisation of the various industries, a merit order curve of the load shedding costs can be generated on the basis of the available information (cf. Figure 12). Based on the load shedding reported by the model, the total load shedding costs are deduced therefrom.

10 VIK guest lecture at the "NCG-Workshop Regelenergie", August 2016

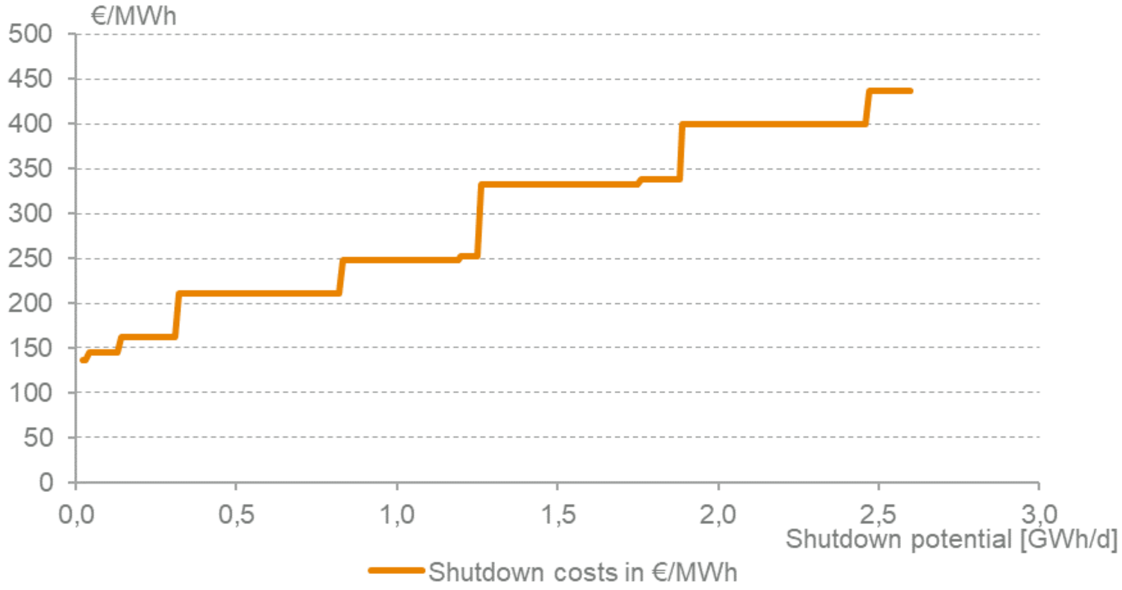

Figure 12: Merit order curve of load shedding[11]

The potential randomly surveyed and extrapolated to Germany by the VIK ("German Association of Industrial Energy Consumers") amounts to 2,500 GWh/d. An allocation of the shutdown potential to individual regions of Germany did not take place. As part of the modelling process, it is assumed for the sake of simplification that the load shedding potential across all zones in Germany is available at the illustrated amount.

11 enervis' own calculations; VIK guest lecture at the "NCG-Workshop Regelenergie", August 2016

4 Scenario design

The study compares two scenarios; *storage flexibility* and *flexibility import*. The *storage flexibility* scenario depicts the current inventory of infrastructure facilities, current expectations for natural gas demand and production capacity per region. The *flexibility import* scenario builds on the identical data. However, in this scenario, all gas storage facilities in the German regions are removed from the model.

Since no other parameters are varied between the scenarios, the effects of the elimination of all German gas storage in the current gas system can then be analysed. Due to the extensive gas exchange possibilities between the regions, the removal of German gas storage facilities not only has an effect on Germany but also triggers effects in other countries.

The considered scenarios do not represent a development over several years. Only a single calendar year with the parameters defined in the previous section is considered. In the scenarios, the levels of existing storage facilities at the beginning and end of each year are identical, so flexibility can be provided through storage, but no net supply is made over a full year, since the injection volumes correspond to the withdrawal volumes.

Figure 13 provides an overview of the design of the scenarios and describes the main parameters for the German regions exemplary explained in section 3.2.

	STORAGE FLEXIBLITIY	*FLEXIBILITY IMPORT*
Model range	• Modelling the global gas system	
Gas demand	• Modelling based on a Europe-wide average temperature year with a two-week cold period	
Production	• Production capacities of supplier countries as of 2016	
Pipeline capacities	• Depiction of the installed infrastructure as of 2016	
LNG liquefaction **LNG regasification** **LNG tanker fleet**	• Depiction of the installed infrastructure as of 2016	
Gas storage facilities	• Depiction of the installed infrastructure as of 2016	• Depiction of the installed infrastructure without German gas storage

Figure 13: Overview of the design of the scenarios

Each scenario covers one calendar year in which global optimisation of the gas flows, taking into account the set secondary conditions, occurs. The results of the model are the (exact daily) utilisation of the infrastructure elements (production, transport capacities, storage facilities, LNG infrastructure up to LNG tankers). In addition, the model excludes the costs of using the infrastructure.

In the following section 5, selected results of the *storage flexibility* scenario are provided and explained. The results of the *flexibility import* scenario are subsequently compared in section 6 with the *storage flexibility* scenario.

5 Results of the *storage flexibility scenario*

The results of the *storage flexibility* scenario are analysed in two sections. Section 5.1 depicts the results of the regions in Germany. The next section 5.2 examines the key points outside Germany. Since the model has perfect foresight and the scenarios create identical competitive conditions through the cost parameters across Europe or worldwide, load flows can partially differ from historical load flows.

5.1 Germany

The following sections evaluate the results of global gas flow modelling with regard to the German market. In the analysis, the load flows to and from neighbouring regions are examined (cf. section 5.1.1), then the German gas balance is presented (cf. 5.1.2). A more detailed investigation is then carried out for gas storage (cf. 5.1.3). The classification of the import and export balance takes place on the basis of these analyses (cf. 5.1.4).

5.1.1 Load flows in Germany

The load flows in Germany are determined by the availability of gas in the supplier countries. Furthermore, the transport capacities from the supplier countries to the target markets are relevant. Germany is a hub for gas and, with its central geographic location between supply and consumption countries, as well as the high existing transport capacity, is also responsible for the transfer of gas from production to demand priorities of other countries. Substantial quantities are therefore routed as transit quantities through Germany, respectively its regions. This is also reflected in the model results of the *storage flexibility* scenario.

Figure 14 and Figure 15 show the average utilisation of the pipelines per region, separated for L and H gas, for the months of December to February and for the months of March to November. The transparent arrows describe the technically available capacity (TAC). The solid arrows describe the average utilisation of the existing pipeline connections between the regions. The surface content and the size of the arrows describe the size of the exchange possibility for the respective neighbouring region. If the filled arrow corresponds to the transparent counterpart, the average utilisation in the period considered is 100%. The graphics give an impression of how the gas flows through the regions of Germany and which countries/neighbouring regions are supplied. Details can be found in Attachment I.1. Table 6.

H-gas regions:

The results of the H-gas regions can be seen in Figure 14.

The GPL H-gas region "DE.GPL.H" shows almost complete utilisation of import points from Russia (North-Stream) and Poland during the summer months. In addition, in summer there are also imports from Norway. In winter, on the other hand, the import points from Russia are significantly less and those from Norway hardly used anymore. Furthermore, it can be seen that the utilisation of existing export capacities in the direction of the Netherlands, Belgium and the Czech Republic increases in winter. Furthermore, the existing capacity for the NCG market area will be utilised both in summer and in winter.

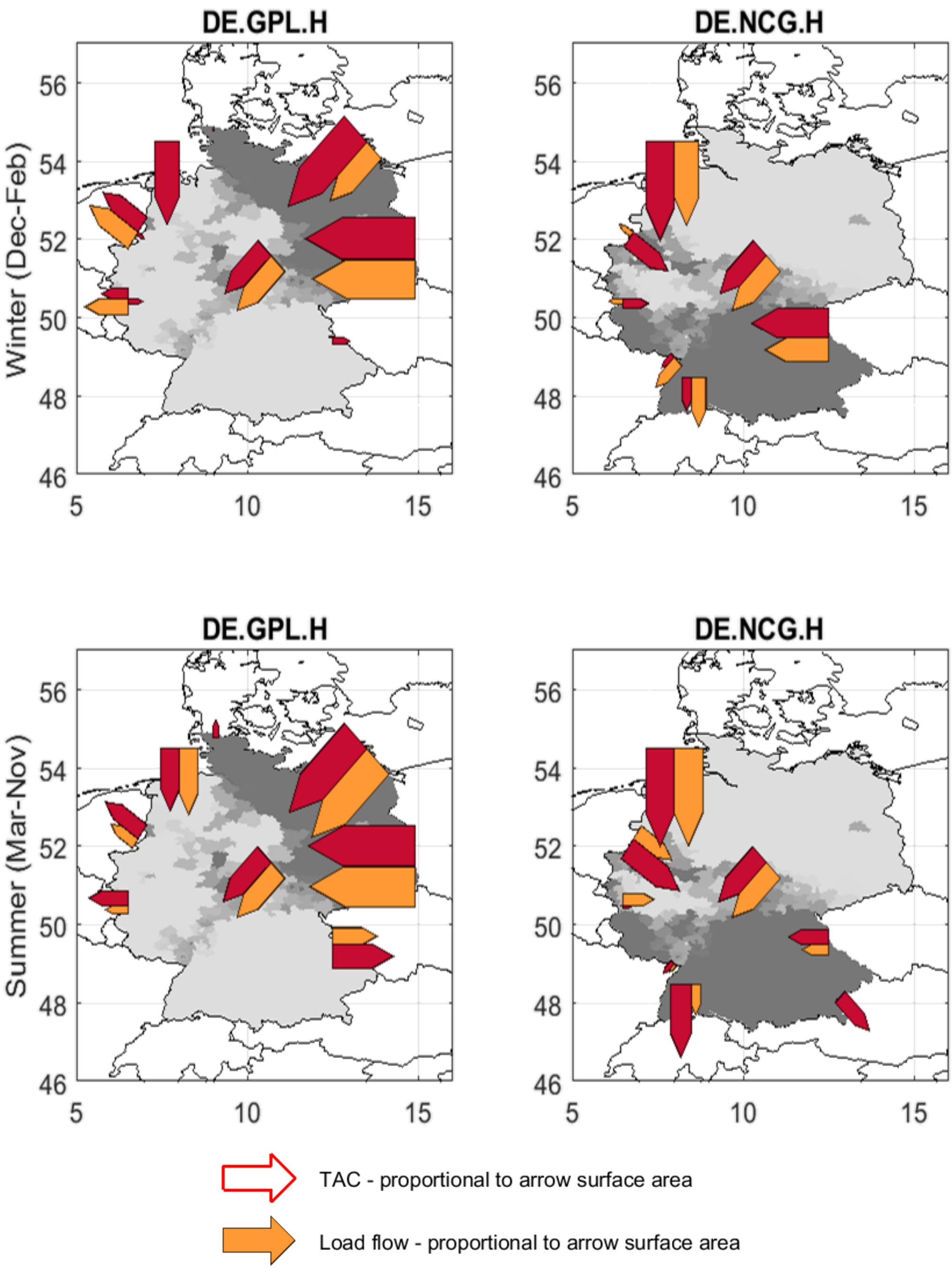

Figure 14: Average capacity utilisation of the German H-gas regions to the neighbouring regions in the *storage flexibility scenario*

In the NCG H-gas region "DE.NCG.H", the import capacity from Norway is also fully utilised during the summer. In addition, volumes are sourced from the Netherlands and Belgium in the summer and, to a lesser extent, from the Czech Republic. In winter, the utilisation of Norway's import capacity declines, while the volume of imports from the Czech Republic increases. Otherwise, quantities are exported to the Netherlands, Belgium and France in winter. At the same time, exports to Switzerland rise. The sourcing of GPL H-gas volume is the same in summer and winter.

Basically, it can be stated that Germany relies on imports of H-gas in the absence of larger H-gas production capacities. These are shipped from Norway, Poland and directly from Russia via North Stream in the summer, and are mainly imported into the GPL market area. GPL serves partially as a transit market area, which transfers large volumes to NCG. At the same time, German exports are low in summer. In winter, the situation changes: import volumes fall and export volumes rise. This is only possible because the German H-gas storage facilities provide flexibility for the neighbouring countries in the west. However, part of this flexibility also comes from the Czech Republic (and its upstream regions Slovakia and Ukraine), as seen from the Czech Republic's stronger load flows to Germany in the winter.

A bottleneck in transport capacity cannot be determined in this consideration based on the temperatures of 2012.

L-gas regions:

The L-gas regions are also characterised by imports. The results can be seen in Figure 15 on page 27.

The GPL L-gas "DE.GPL.L" region has production facilities. In addition, the region is supplied with converted gas volumes from the "DE.GPL.H" region. This explains a comparatively low utilisation of the available import capacities from the Netherlands. In the winter months, exports to the NCG L-gas neighbouring zone are made.

The NCG L-gas region "DE.NCG.L" (without own production) relies heavily on imports from the Netherlands. In the winter months, there are additional gas purchases from the GPL L-Gas region.

Overall, the behaviour of the L-gas areas differs from that of the H-gas areas. In winter, more has to be imported than in summer – the L-gas storage facilities don't have the capacity to compensate for the additional consumption in winter.

Capacity utilisation:

The modelling optimally controls the deployment of available flexibility sources from supplier countries, such as the use of gas storage facilities. This network-conducive operation of gas storage means that there are no capacity bottlenecks and thus there is no need for additional capacities between the regions mapped in the model.

5.1.2 German gas balance

In the gas balances, the quantities needed, i.e. the end-consumer consumption, the export quantities and the injection quantities are compared with the corresponding yield volumes, i.e. imports, production and withdrawal. If there are bottlenecks in the supply of the region, this is characterised by shortfalls. The individual German regions are explained below.

Here, the gas balance is visualised for each inner German region, allowing a more detailed overview of the origin and use of the gas. Furthermore, insights into the origin of flexibility can be gained in this analysis. The demand quantities are shown as negative values in the graphics and include both the consumption within the region as well as export and injection quantities. Yield sources, i.e. production, import and withdrawal, are depicted as positive values. The colour of the respective area shows from which adjacent region the gas originates or into which region the gas is delivered.

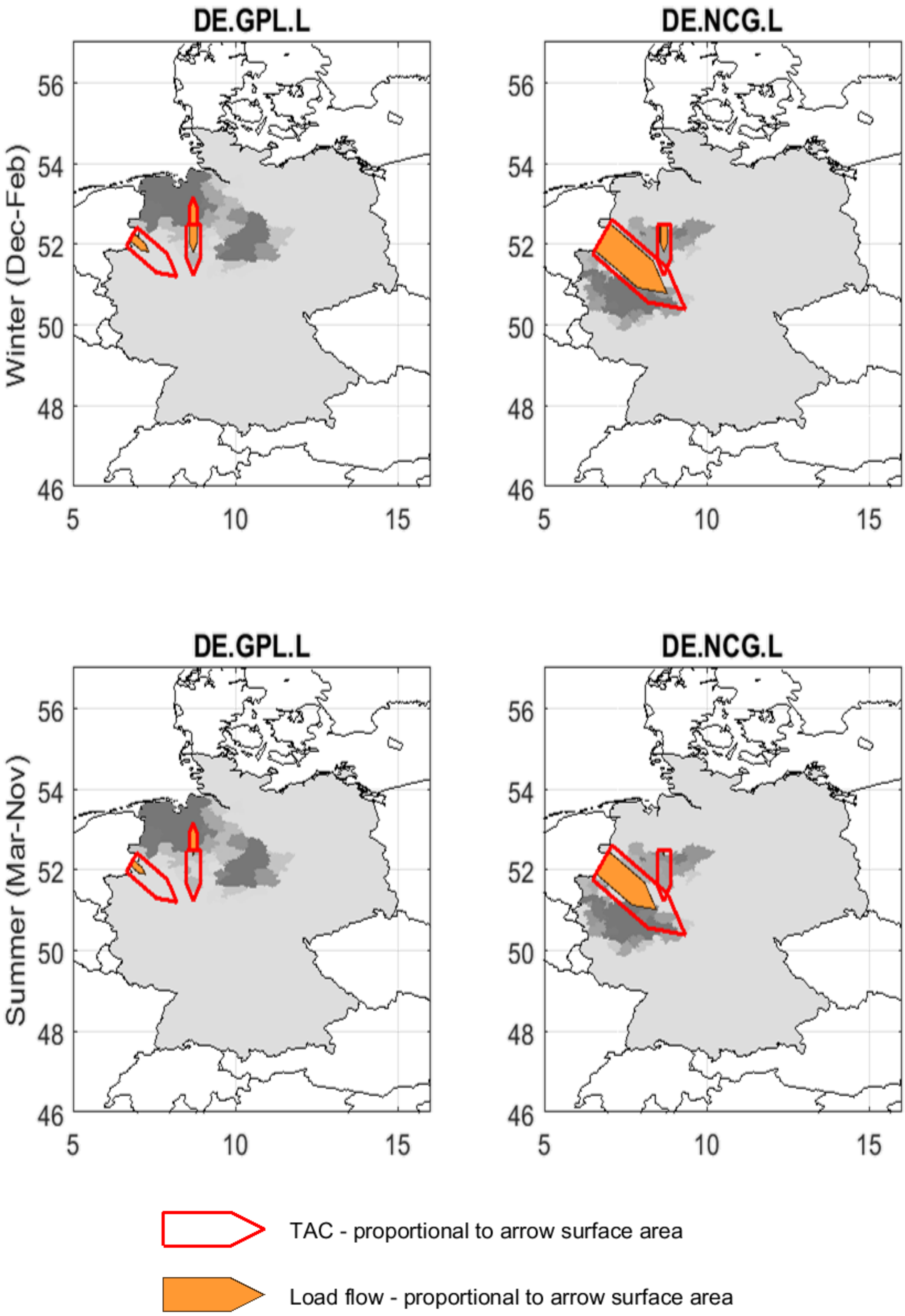

Figure 15: Average capacity utilisation of the German L-gas regions to the neighbouring regions in the *storage flexibility scenario*

5.1.2.1 GPL H-gas region

The natural gas balance in the GPL H-gas region is shown in Figure 16. The graph shows the flow of gas yield and usage on a daily basis over the calendar year of the *storage flexibility* scenario.

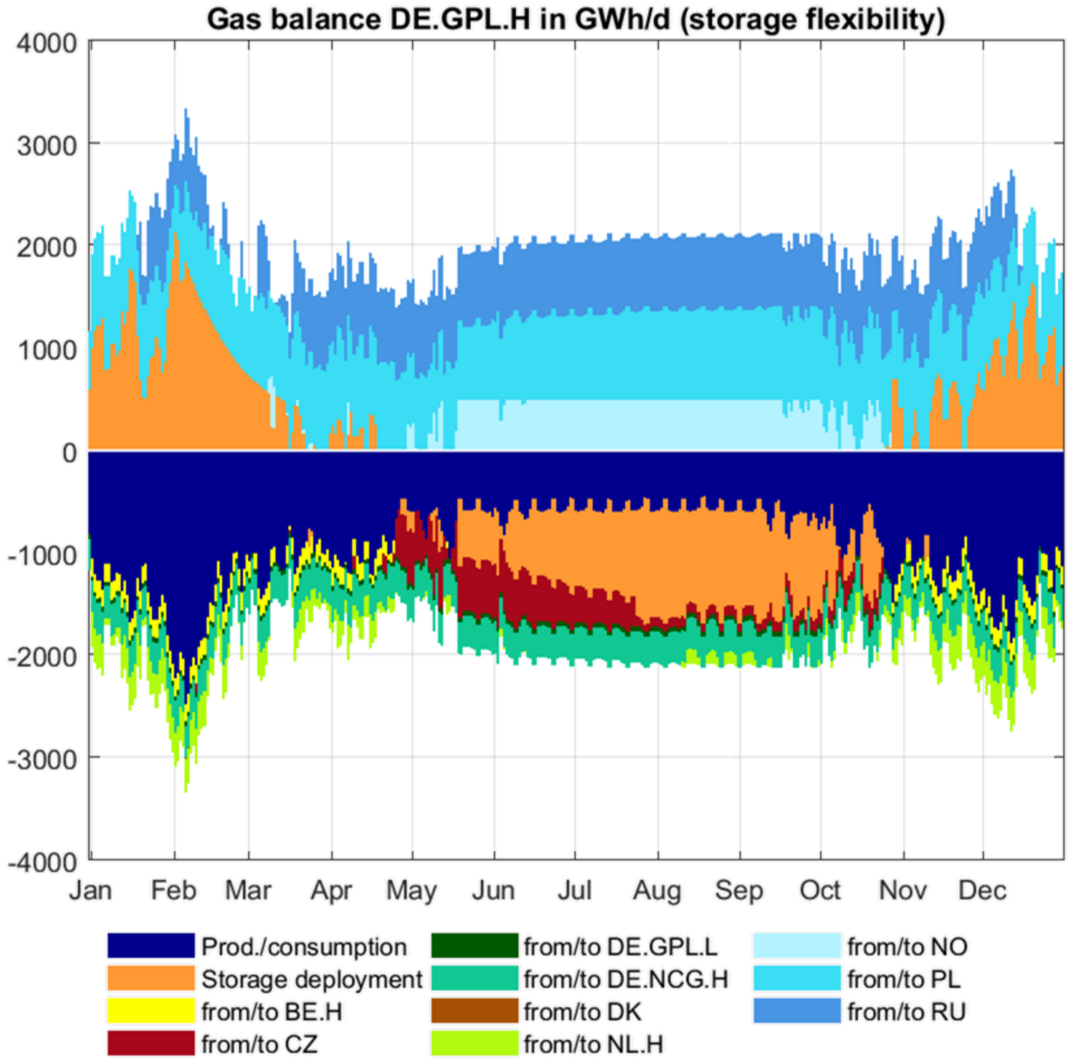

Figure 16: Gas balances of the GPL H-gas region in Germany[12]

Demand side

The demand volumes are driven by domestic consumption and exports to other regions.

Consumption volumes show a strong seasonal demand. The peak demand is retrieved in the winter months, whereas demand in the summer drops significantly.

12 Abbreviations not explained in the text: BE - Belgium, NL - Netherlands, DK - Denmark, Stor - Storage (facilities), Prod - Production, Cons - Consumption; The suffix "H" in a region indicates that only the H-gas share of the region is taken into account here.

Furthermore, additional exports to the Czech Republic can be observed during the summer months. In the winter months, increasing exports to the Netherlands are recorded. Quantities are forwarded to the NCG H-gas region throughout the year.

The injection of gas volumes takes place during the summer months in the GPL H-gas region "DE.GPL.H".

The model has no load shedding. The system can be supplied by the available sources of supply.

Yield side

The yield side in the GPL H-gas region is characterised by imports from Russia (RU), Norway (NO) and Poland (PL). However, the imports reported as Polish volumes are also of Russian origin.

The seasonal configuration is mainly provided by the injection and withdrawal from gas storage facilities. The structuring is done close to the consumption areas. The use of gas storage facilities for structuring is preferred to the import of flexibility. This means that, in the optimisation model system costs can be reduced by using gas storage that is close to consumption, even though the handling costs of the storage facilities were conservatively set high (cf. section 4.2.8.2).

5.1.2.2 NCG H-gas region

The natural gas balance of the NCG H-gas region is depicted in Figure 17 on page 30. GPL H and NCG H have very similar balances.

Demand side

Consumption volumes in the NCG H-gas region are also highly seasonal, with the result that winter consumption increases sharply compared with the summer months.

In the winter months, additional gas is supplied to France, the Netherlands and Belgium to cover peak loads.

Injection in the gas storage facilities takes place over the summer months.

There is no load shedding in the DE.NCG.H area in this scenario.

Yield side

The NCG H-gas region is supplied with gas through imports from Belgium (BE), the Netherlands (NL), the Czech Republic (CZ), Norway (NO) and GPL H-Gas. The imports reported as Czech volumes are of Russian origin.

In the NCG H-gas area, too, the seasonal flexibility is supplied by the gas storage facilities close to consumption areas. The use of gas storage for structuring is preferred over other options. Consequently, deploying gas storage that is close to consumption, the optimisation model also reduces system costs in the NCG H-Gas area, despite a conservative cost approach for storage deployment (see Section 4.2.8.2).

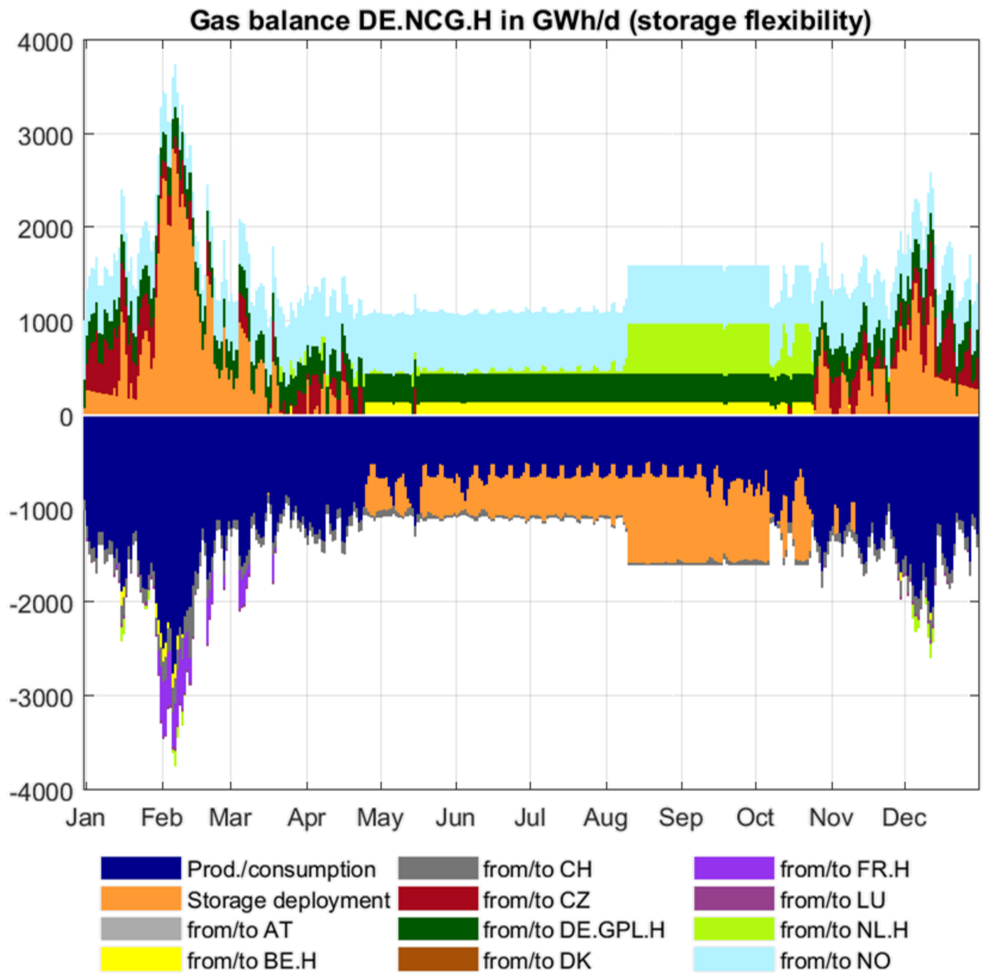

Figure 17: Gas balances of the NCG H-gas region in Germany[13]

5.1.2.3 GPL L-Gas-Region

The natural gas balance of the GPL L-gas region is depicted in Figure 18 on page 31.

Demand side

Demand volumes in the GPL L-gas region are almost entirely consumption-based and only a few are exported to the NCG L-gas region during the winter months.

L gas consumption volumes are also seasonal. The peak demand is retrieved in the winter months, whereas demand in the summer drops significantly.

The gas storage facilities are filled in the summer months.

The supply of L-gas in the *storage flexibility* scenario is not exposed to load shedding. The system is fully supplied by the available yield sources.

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13 Abbreviations not explained in the text: BE - Belgium, AT - Austria, LU - Luxembourg, DK - Denmark, Stor - Storage (facilities), Prod - Production, Cons - Consumption; The suffix "H" in a region indicates that only the H-gas share of the region is taken into account here.

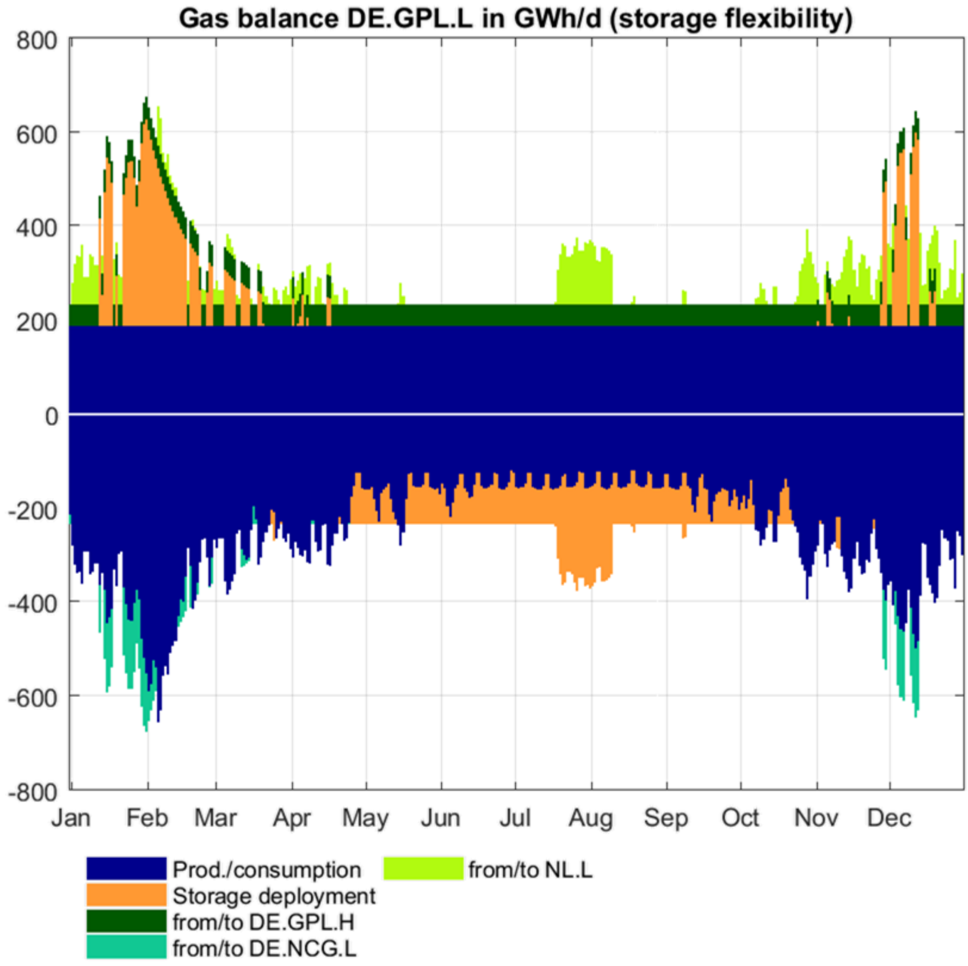

Figure 18: Gas balances of the GPL L-gas region in Germany[14]

Yield side

In contrast to the H-gas areas, there are L-gas production sites, in particular in the GPL L-gas area, which help supply the L-gas areas.

At peak load times, volumes to cover consumption are imported from the Netherlands. In the summer months, gas is also imported to fill the gas storage facilities.

There is little available gas storage volume in the L-gas regions. In the GPL L-gas region, the storage facilities can only provide part of the seasonal structure. The storage facilities are primarily used in the model because of the cost-optimal decision. However, further structuring is needed, which is imported via the Netherlands.

14 The suffix "L" of a region indicates that only the L-gas region of the region has been identified.

5.1.2.4 NCG L-gas region

Figure 19 contains the L-gas balance of the NCG L-gas region.

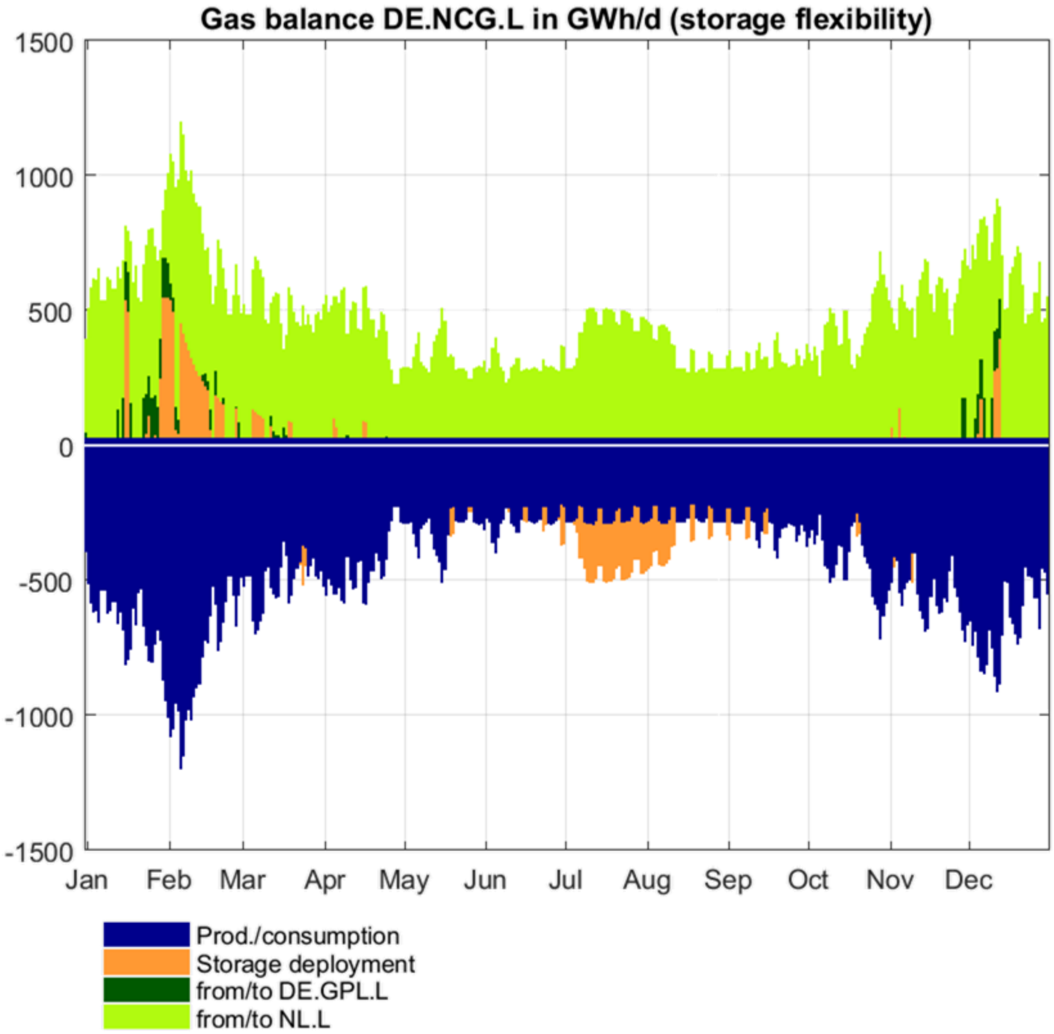

Figure 19: Gas balances of the NCG L-gas region in Germany[15]

Demand side

The demand in the NCG L-gas region is characterised exclusively by consumption and few injections.

Consumption volumes show the typical summer and winter structure.

During the summer months, the few existing gas storage facilities are filled.

The supply of L-gas in the *storage flexibility* scenario is not exposed to load shedding. The system is fully supplied by the available yield sources.

Yield side

15 The suffix "L" of a region indicates that only the L-gas region of the region has been identified.

The NCG L-gas region does not have production facilities. Therefore, the NCG L-gas region relies entirely on imports from the Netherlands and the GPL L-gas region.

Furthermore, there are only small gas storage capacities that are insufficient to meet flexibility demands.

Therefore, considerable quantities are imported from the Netherlands, which at the same time provide the necessary flexibility and are used for injection in the summer months.

5.1.3 Description of the storage utilisation

Storage facilities provide the essential source of flexibility in the regions. Alternatively, the gas can be flexibly produced and then transported to the demand region.

Already in the previous section it was presented in detail that storage facilities are used within the German regions. The gas storage facilities are preferred by the optimisation model over consumption-distant structuring. The production sources are utilised as uniformly as possible by the model. The existing transport capacities are also optimally operated within the framework of the possibilities. The close-to-consumption provision of flexibility enables the model to minimise system cost.

The utilisation of storage facilities in each region is depicted in Figure 20. The graphs show the level of gas storage over the calendar year under consideration.

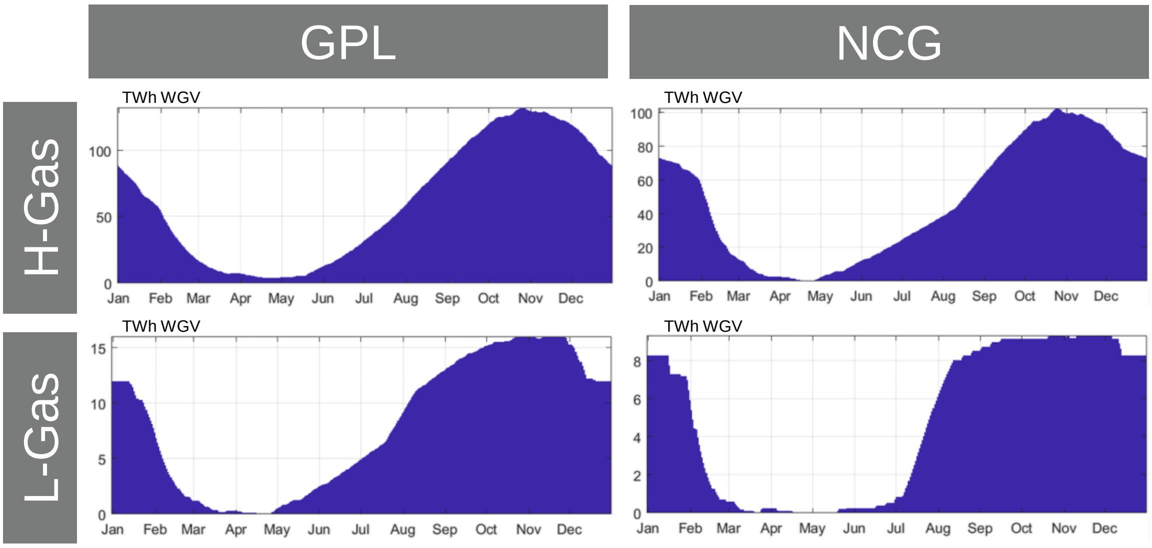

Figure 20: Utilisation of the German gas storage facilities per region (level in TWh Working Gas Volume)

In all German regions, the storage facilities are almost completely utilised, i.e. they are almost completely emptied after having started from a filling level of almost 100%. This type of utilisation can only come about because the model optimises the gas flows over the entire period of observation assuming perfect foresight. In practice, a perfect forecast for a weather year is completely impossible, which is why, usually, volume reserves must be held back for potential cold periods.

In historical situations, it has been possible to observe high levels of utilisation of the storage facilities, but in Germany the fill levels have not fallen below 14%.[16]

16 AGSI, historical German storage data, retrieved on 11th September 2017

5.1.4 Description of the import and export balance

Germany is heavily dependent on natural gas imports. Furthermore, quantities are exported to neighbouring countries. Germany receives gas acyclically as there are sufficient storage facilities for structuring. The storage facilities can be filled through early import. The withdrawals during the winter months make it possible to cover the domestic demand as well as provide the option to export flexibility to other regions.

Figure 21 shows the resulting import and export quantities as well as the balance. Germany provides flexibility to neighbouring markets. This is executed on the one hand via direct export, but also via the acyclic import quantities. Germany is thus a net exporter of flexibility. Section 5.2.1, using the example of Norway, shows how production quantities not exported to Germany can be used in other regions.

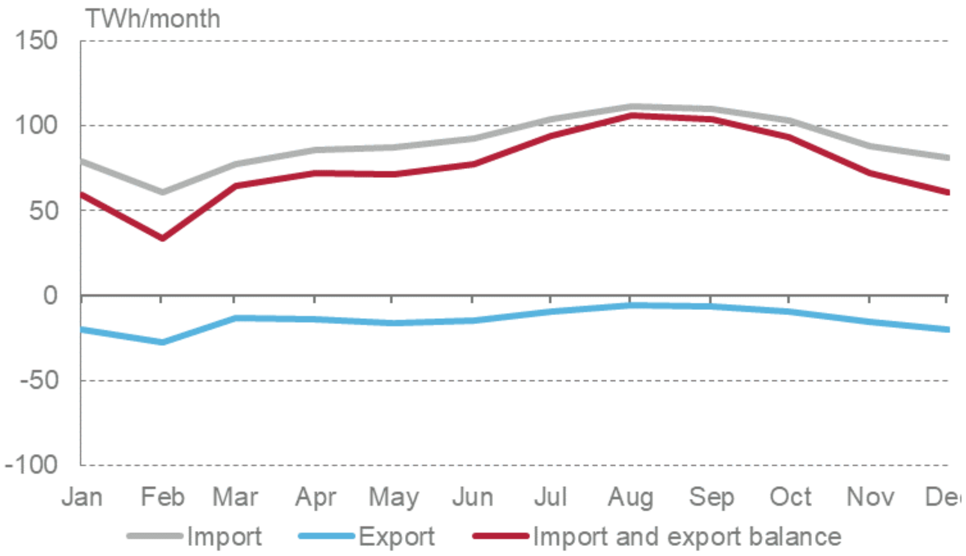

Figure 21: German import and export balance on a monthly basis

The model makes it possible to use the infrastructure in this way, since perfect foresight allows for full storage utilisation.

5.2 Developments outside Germany

Germany is supplied with gas from various regions. The European gas network has many options for gas exchange. In order to analyse the effects of the removal of German gas storage facilities, the main alternative sources of flexibility are presented below. This includes production volumes, LNG employment and storage utilisation outside Germany.

5.2.1 Production capacity

Production in the model tends to a steady utilisation, so that in most cases a linear band-shaped utilisation arises. Nevertheless, flexibility in other regions can be arise by varying the exports from this linear band structure, as illustrated by an example.

Norwegian production in the *storage flexibility* scenario is band-shaped. Due to Germany's acyclic, summer-intensive imports, the UK can import more during the winter months and reduce its import of gas in the summer months, as the following figure illustrates.

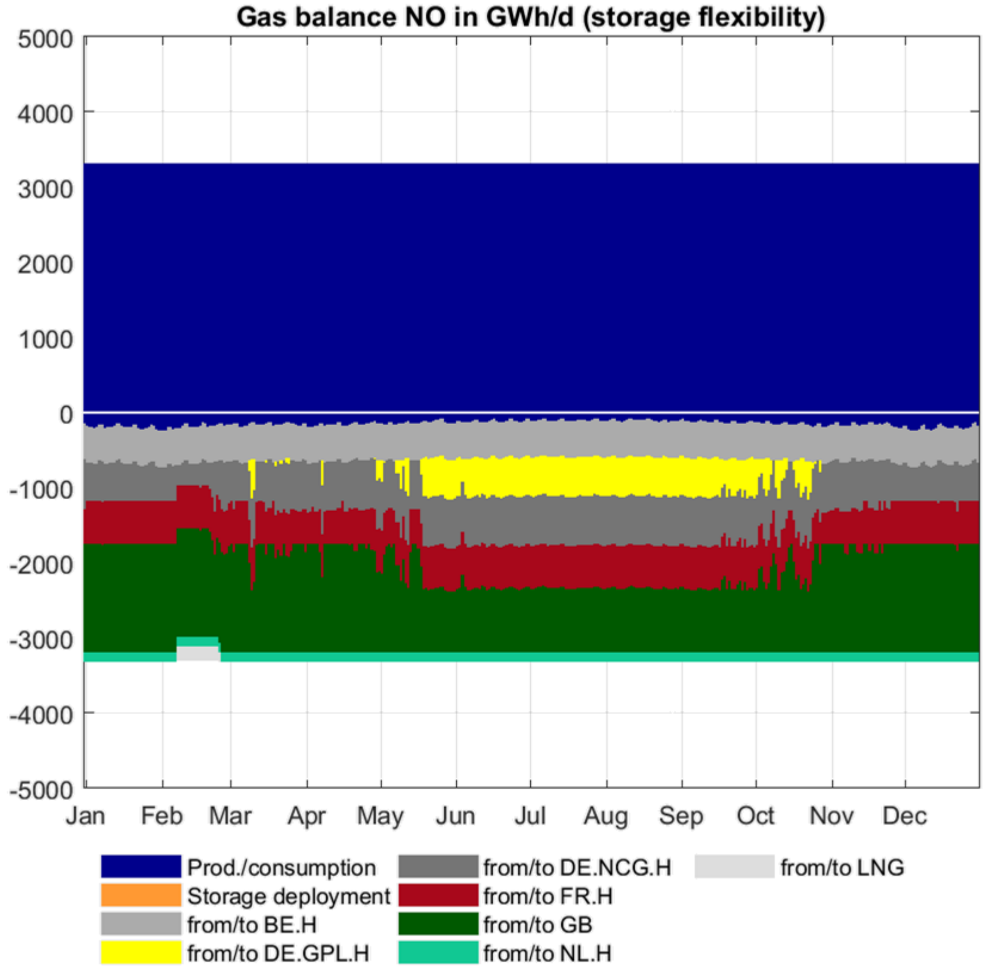

Figure 22: Example Norwegian production and exports

5.2.2 Description of LNG capacity utilisation

In the following considerations, aggregated regions are considered to reduce complexity. The designations of the aggregated regions are to be understood as follows: "DE" covers the German market regions, "NO" corresponds to Norway, "RU" includes Russia, Belarus and Ukraine. The "EU" covers all European market regions (excluding DE, NO, RU). The aggregated region "Rest" contains the other world-wide regions depicted in the model.

The provision of LNG has largely uniform utilisation worldwide. Europe mainly imports during the summer months, which provides additional structure in other parts of the world, as illustrated below.

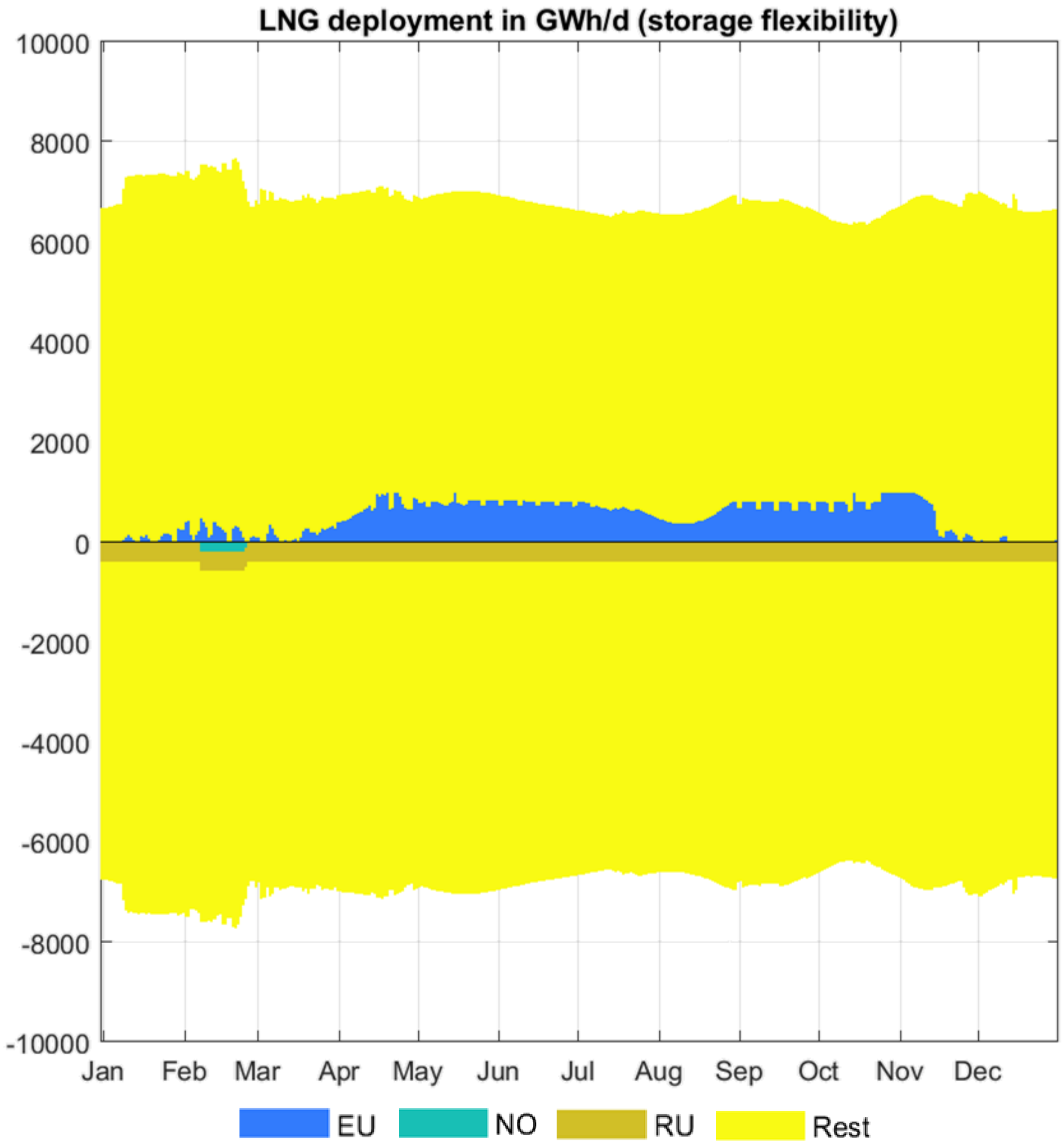

Figure 23: LNG usage in Europe and the rest of the world

Compared to other parts of the world, the use of LNG in relation to the entire gas market currently plays a minor role in Europe.

5.2.3 Storage balance: Europe and Russia

The storage facilities in the EU and RU aggregated zones will also be used to provide flexibility close to consumption, thereby structuring gas supplies. The use of storage facilities follows the optimised method of deployment: gas quantities are withdrawn in winter and injected in summer, as depicted in Figure 24. Production thus enables compliance with a largely band-shaped structure. In addition, existing transport pipelines are utilised more uniformly and are subsequently optimally managed.

The depiction has removed German gas storage facilities in order to enable a later comparison of the storage modes in the EU and RU aggregated regions.

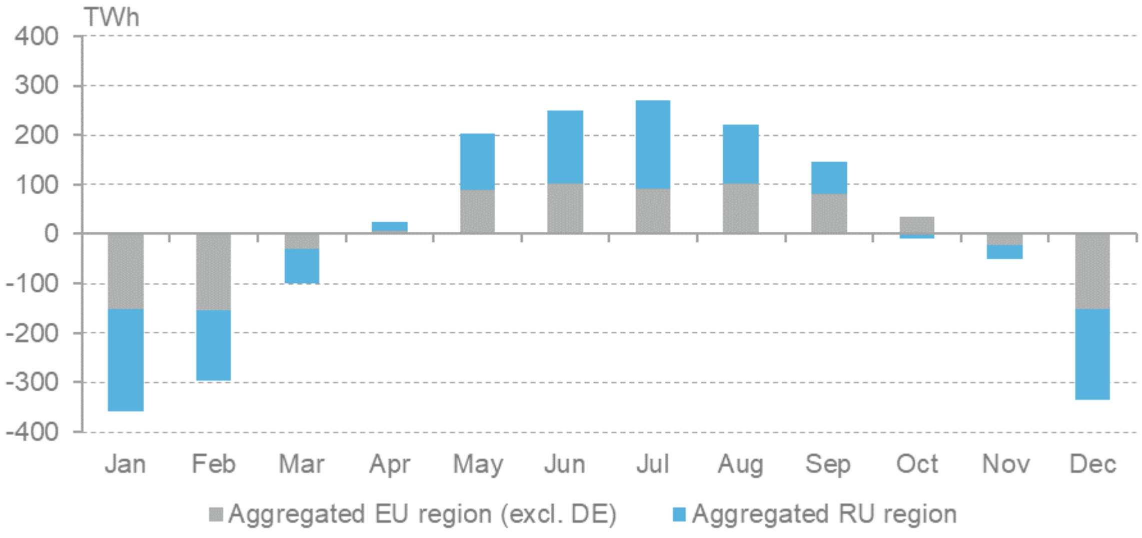

Figure 24: Storage balance in the EU and aggregated regions RU (neg. withdrawal, pos. injection)

5.3 Interim conclusion on the *storage flexibility scenario*

In the considered *storage flexibility* scenario, all regions can be supplied with the existing production, transport, LNG and storage capacities. There is no load shedding and therefore no network expansion at the borders of the regions is necessary. The storage inventory is also sufficiently dimensioned to cover the assumed weather scenario without interrupting the supply. It should be noted that all systems are optimally deployed using perfect foresight.

Germany has high H-gas import capacities through which Norwegian and Russian gas can be imported. Furthermore, it is possible to pass on transit quantities to neighbouring regions. In the L-gas market, Germany depends mainly on the Netherlands and its own production volumes.

The deployment of the systems and infrastructures is cost-optimised in the model. As a result, it can be stated that storage is deployed predominantly, before the flexibilisation of production and transport is utilised. The decision to prioritise storage reduces the subsequent need for transport capacity at the regions' borders. One can speak of a network-conducive deployment of storage facilities. Simultaneously, no capacity bottlenecks have been identified in the model. In order to control the load flow situation in the weather year used, the model does not require any expansion of capacities between the regions, as long as the gas storage facilities are deployed network-conducively.

Germany is able to export flexibility to other regions through its existing storage infrastructure. Furthermore, Germany's storage stock enables higher imports in the summer months, which in turn allows producing countries to deliver more winter volumes to other regions while still maintaining consistent production capacity utilisation.

6 Scenario comparison: storage flexibility vs. flexibility import

In this section the *storage flexibility* scenario will be compared with the *flexibility import* scenario. In the *flexibility import* scenario the gas storage facilities in Germany were removed from the model. Thus, these are no longer available to the market.

The focus of the study is on Germany. The evaluation of the German market is therefore given special significance. Yet, global gas infrastructure is interconnected through existing pipeline links, gas storage facilities, LNG, and production facilities, resulting in the exchange of flexibility between regions. In this system of "communicating pipes", effects outside of Germany are to be expected if the German gas storage facilities are no longer available.

In the following analysis, direct comparisons, and emerging differences in particular, between the two *storage flexibility* and *flexibility import* scenarios, are employed and presented in detail.

6.1 Germany

The effects on Germany are analysed in this section. In section 6.1.1, the load flows of the German regions in the *flexibility import* scenario will be linked with the load flows in the *storage flexibility* scenario. Subsequently, the natural gas balances of the four German regions are examined in detail and differences to the *storage flexibility* scenario depicted (cf. section 6.1.2). At the end of this section, the changes in the German import and export balance between the *flexibility import* and *storage flexibility* scenarios will be explained (see 6.1.3).

6.1.1 Shifts in load flows in Germany

H-gas regions:

In Figure 25 on page 39, the load flows of the German H-gas regions in the *flexibility import* scenario and load flows of the *storage flexibility* scenario are compared (cf. section 5.1.1).

The red arrows represent the load flows of the *flexibility import* scenario, the orange ones of the *storage flexibility* scenario. The arrow surface size indicates the strength of the load flow between regions. Insofar as shifts in the load flows have occurred due to the removal of the storage facilities from the energy system, the respective arrow of the *flexibility import* scenario is larger or smaller than in the *storage flexibility* scenario.

Contrary to the results of the *storage flexibility* scenario, the import capacities in the GPL H-Gas region are utilised much more in the *flexibility import* scenario. In particular, the additional import via Norway and Russia is apparent. At the same time, export capacities towards the Netherlands and Belgium are less heavily utilised during the winter months but, in contrast, increase during the summer months.

The NCG H region depicts similar tendencies. Import capacity is also being exploited to a greater extent in both the summer and winter months. Simultaneously, exports to neighbouring regions are reduced in the winter months and increased in the summer months.

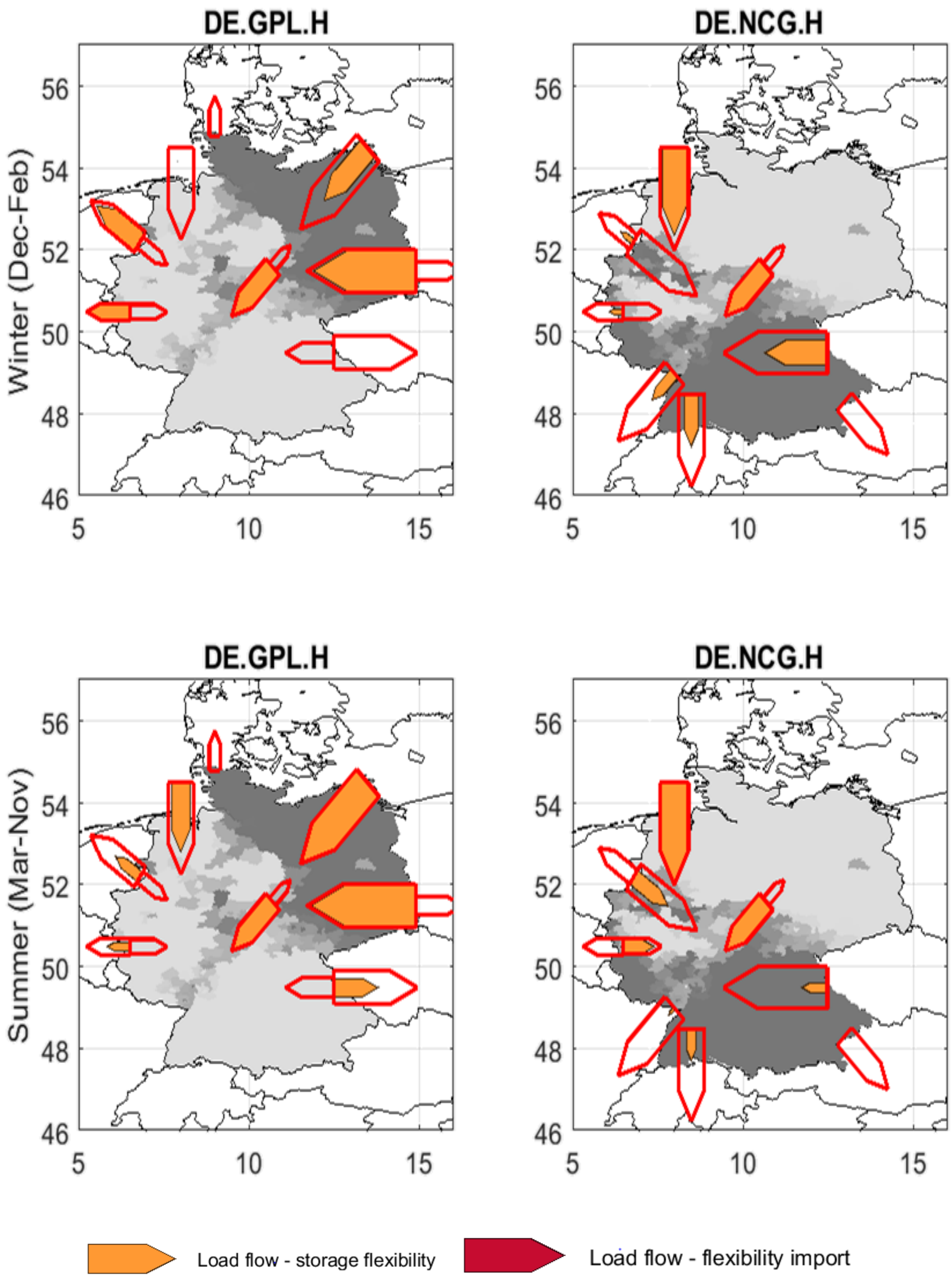

Figure 25: Average capacity utilisation of the German H-gas regions to the neighbouring regions

In this context, it is interesting to consider the transit of NCG H-Gas to Switzerland: in the *storage flexibility* scenario, large quantities are forwarded to Switzerland in the winter and small quantities in summer. This behaviour reverses in the *flexibility import* scenario. In winter, only small, in summer, however, large quantities are transmitted. Due to the lack of gas storage in Germany, the export to the south can no longer be structured with the main emphasis in winter.

It can be stated that Germany is structured in both H-gas regions via the control of import and export.

If both regions GPL H-gas and NCG H-gas are considered together, another effect can be observed: In the winter, a significantly higher utilisation of import capacities from the Netherlands and Belgium in the NCG H-Gas market area can be seen. This is done to return volumes to the NCG H gas region that were previously exported from GPL H gas. The background is an utilisation of intra-German capacities between the market areas, which are compensated by imports and exports via the Netherlands and Belgium.

The capacity situation is significantly more tense in the *flexibility import* scenario. Both imports and exports show high capacity utilisation between regions. There are still routes that have unutilised capacity. However, these cannot be utilised because these markets can no longer provide additional flexibility via the transport chains.

L-gas regions:

The L-gas regions characterised by imports also exhibit changes in the *flexibility import* scenario. The results are depicted in Figure 26.

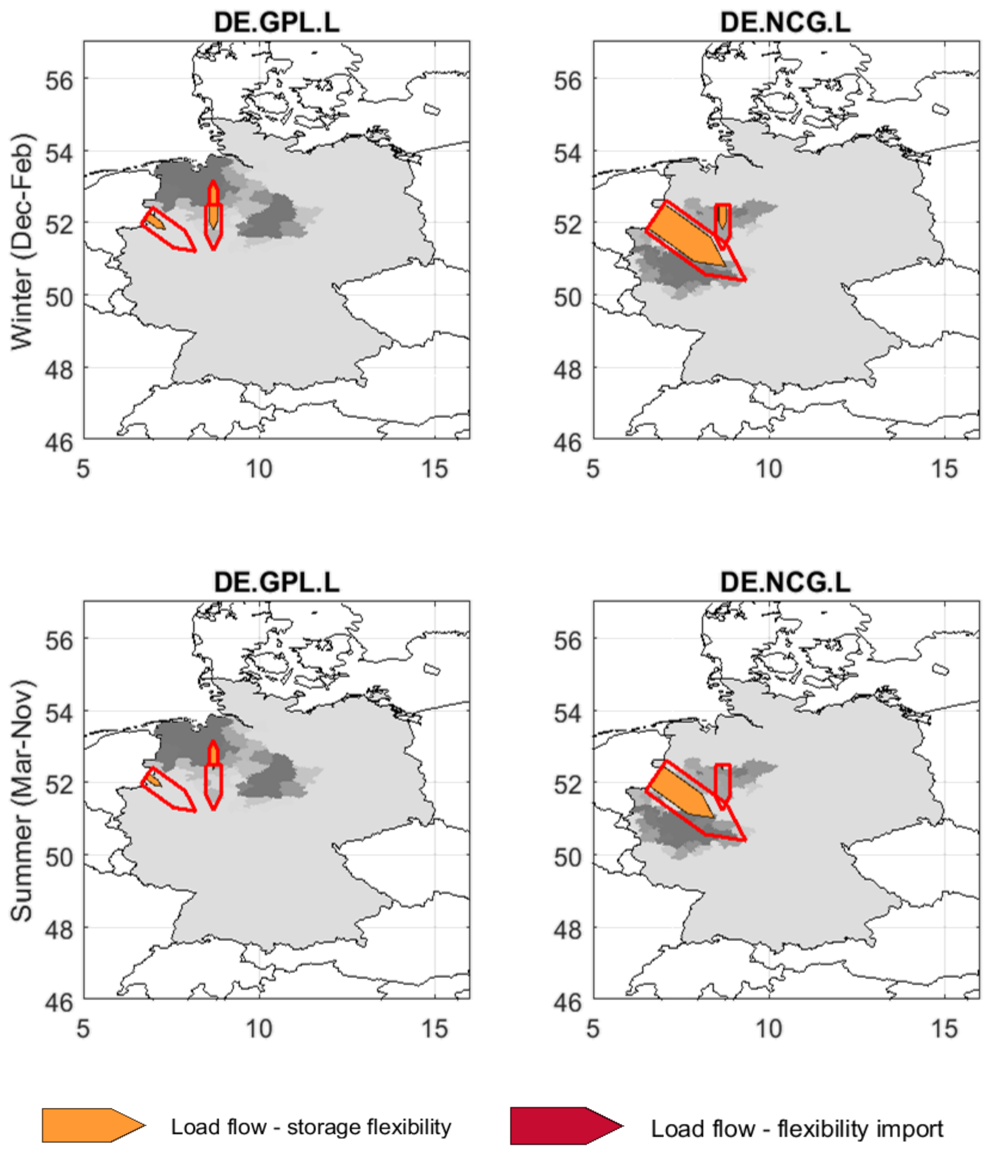

Figure 26: Average capacity utilisation of the German L-gas regions to the neighbouring regions

The GPL L-gas region has production facilities that can meet some of the demands. Nevertheless, import from the Netherlands must be increased significantly, especially in the winter months. This is understandable in the absence of gas storage. Consequently, a provision of flexibility takes place from the Dutch side.

In the *storage flexibility* scenario, the NCG L-Gas region was already reliant on imports from the Netherlands. In the *flexibility import* scenario only smaller shifts of imports arise. There are still unutilised import capacities available. However, they cannot be utilised because the Netherlands has to supply both Dutch domestic demand and the L-gas zones in Belgium and France – ultimately, there is a lack of L-gas output to cover peak loads in this under-diversified region.

The following tables show the capacity utilisation of the pipeline connections between the aggregated regions described above for both scenarios. The "Others" aggregated region includes Turkey, Algeria and Libya. The four German regions are also aggregated and depicted under DE.

Storage flexibility

From \ To	GE	EU	Other
GE		14%	
EU	40%		0%
NO	70%	89%	
Rest		70%	
RU	83%	51%	100%

Flexibility import

From \ To	GE	EU	Other
GE		↗ 32%	
EU	↗ 46%		↗ 29%
NO	↗ 82%	↘ 82%	
Rest		↘ 54%	
RU	↗ 98%	→ 49%	↘ 93%

Figure 27: Capacity utilisation between aggregated regions (annual average)

In the *flexibility import* scenario, the capacity utilisation of the pipelines connecting Germany with the rest of Europe in particular increases. This effect is caused by the seasonal structuring of German demand, which must now take place outside Germany.

6.1.2 Changes in the German gas balance

The German gas balance and every single sub-region is characterised by the loss of storage facilities. Imports and exports have shifted significantly compared to the balance of the *storage flexibility* scenario.

First, the effects on the GPL and NCG H-gas regions are outlined below (Figure 28 and Figure 29 on pages 42 and 43). Then a focus is placed on the L-gas regions (Figure 30 and Figure 31 on pages 45 and 46).

The left part of the graphics shows the gas balances already presented in section 5.1.1 for the *storage flexibility* scenario. The right part of the graphic contains the new gas balances of the *flexibility import* scenario in which no gas storage exists in Germany. Both scenarios are then directly compared with one another using the graphics.

H-gas regions:

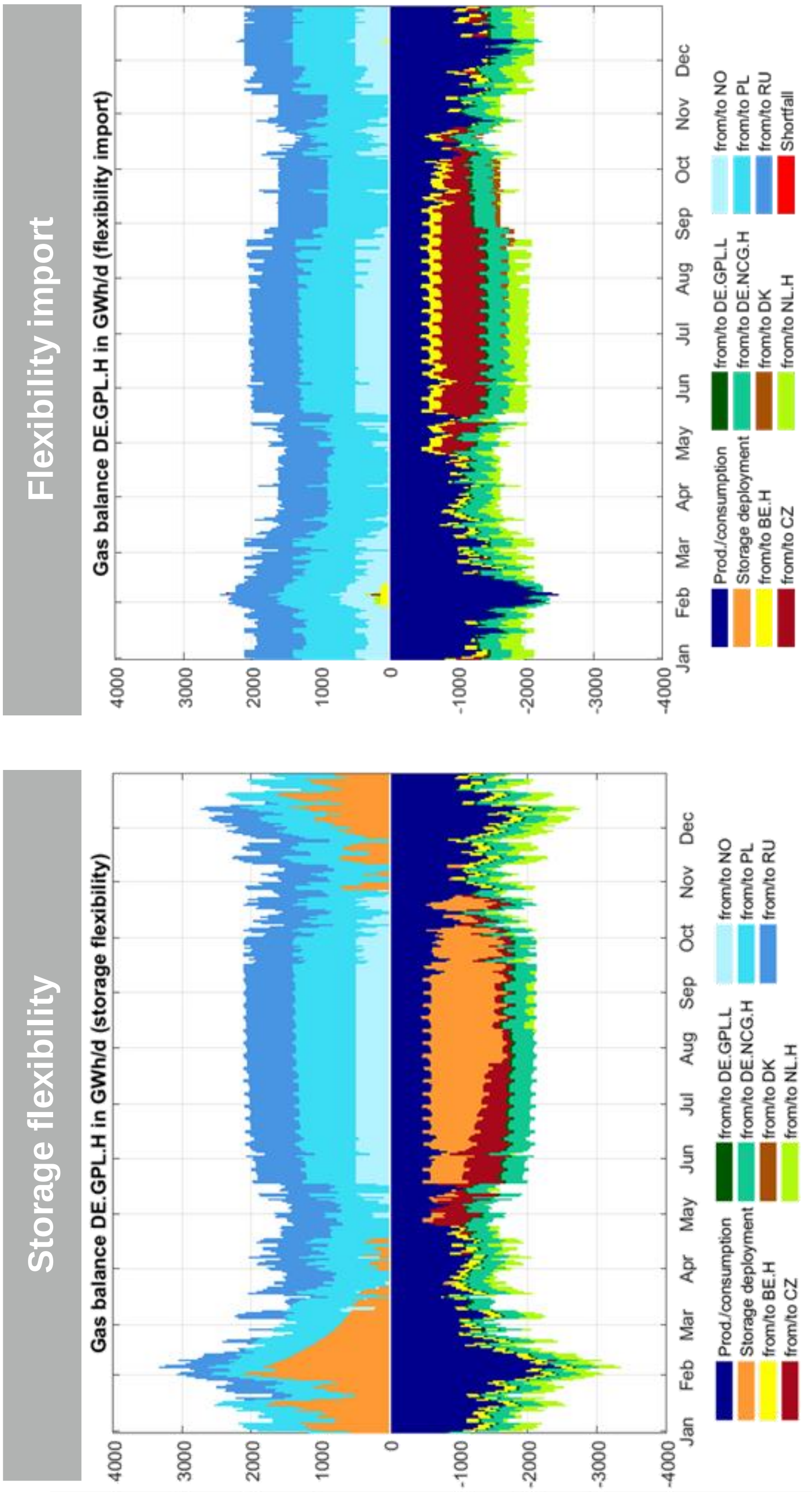

Figure 28: Gas balances of the GPL H-gas region in Germany in comparison (*storage flexibility* scenario and *flexibility import* scenario)

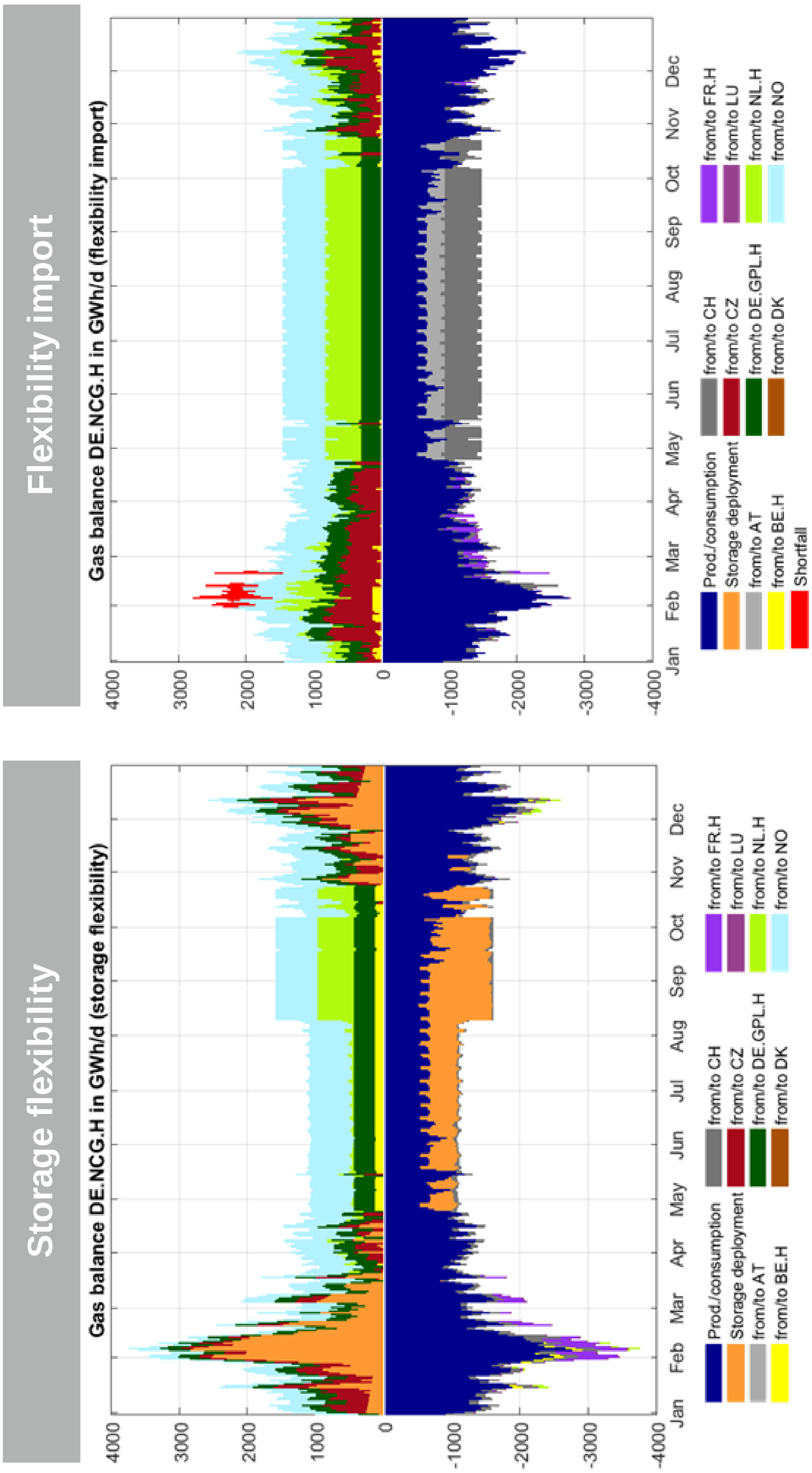

Figure 29: Gas balances of the NCG H-gas region in Germany in comparison (*storage flexibility* scenario and *flexibility import* scenario)

The omission of storage in the *flexibility import* scenario is clearly visible in both regions. Large amounts of the flexibility previously provided by storage must be offset by importing and exporting to other regions. However, this is not possible in every case. In both H-gas areas, a supply shortage ("shortfall") occurs. The demand of end customers can no longer be met. Flexibility sources in neighbouring regions are no longer sufficient and/or the import and export capacity is exhausted. The system is already overloaded. In the model, this situation is marked by load shedding at peak load times. Customers in these areas are no longer supplied with the necessary quantities and shut down. Load shedding only occurs on one day in the GPL H-gas market region. In the NCG H-gas market area, a significantly longer period of time is affected by considerably heavier load shedding. At these times, the neighbouring European countries are ultimately no longer able to cover the seasonal structuring for Germany.

L-gas regions:

The situation in the L-gas market regions is even more dramatic, as shown in the following figures. On some days in the DE.NCG.L area, the complete load must be shed. In the DE.GPL.L region, domestic production can partially maintain the supply. Nevertheless, high load shedding occurs. The load shedding would affect all consumers, including household customers and district heating producers. These customers are considered "protected customers"[17], Gas utilities are required to take appropriate precautions to supply these customers with gas in various supply scenarios. The supply cases defined in Art. 8 Para. 1 of the Natural Gas Supply Security Regulation (EU Regulation No. 2017/1938 on measures to ensure safe gas supply) can no longer be guaranteed without the existence of German gas storage.

In the *flexibility import* scenario, supply shortfalls – despite cross-regional, worldwide optimisation with perfect foresight – can no longer be avoided. This results in load shedding, which at its peak comprises 2,210 GWh/d. It has already been pointed out that perfect foresight and perfect cooperation are not to be expected in the real world. Therefore, the resulting load shedding amounts are conservative – the situation would very likely lead to significantly more drastic consumption restrictions.

17 EU Regulation 994/2010, Article 2 paragraph 1, 12.11.2010 (also SoS Regulation); BMWi, Notfallplan Gas für die Bundesrepublik Deutschland, December 2016

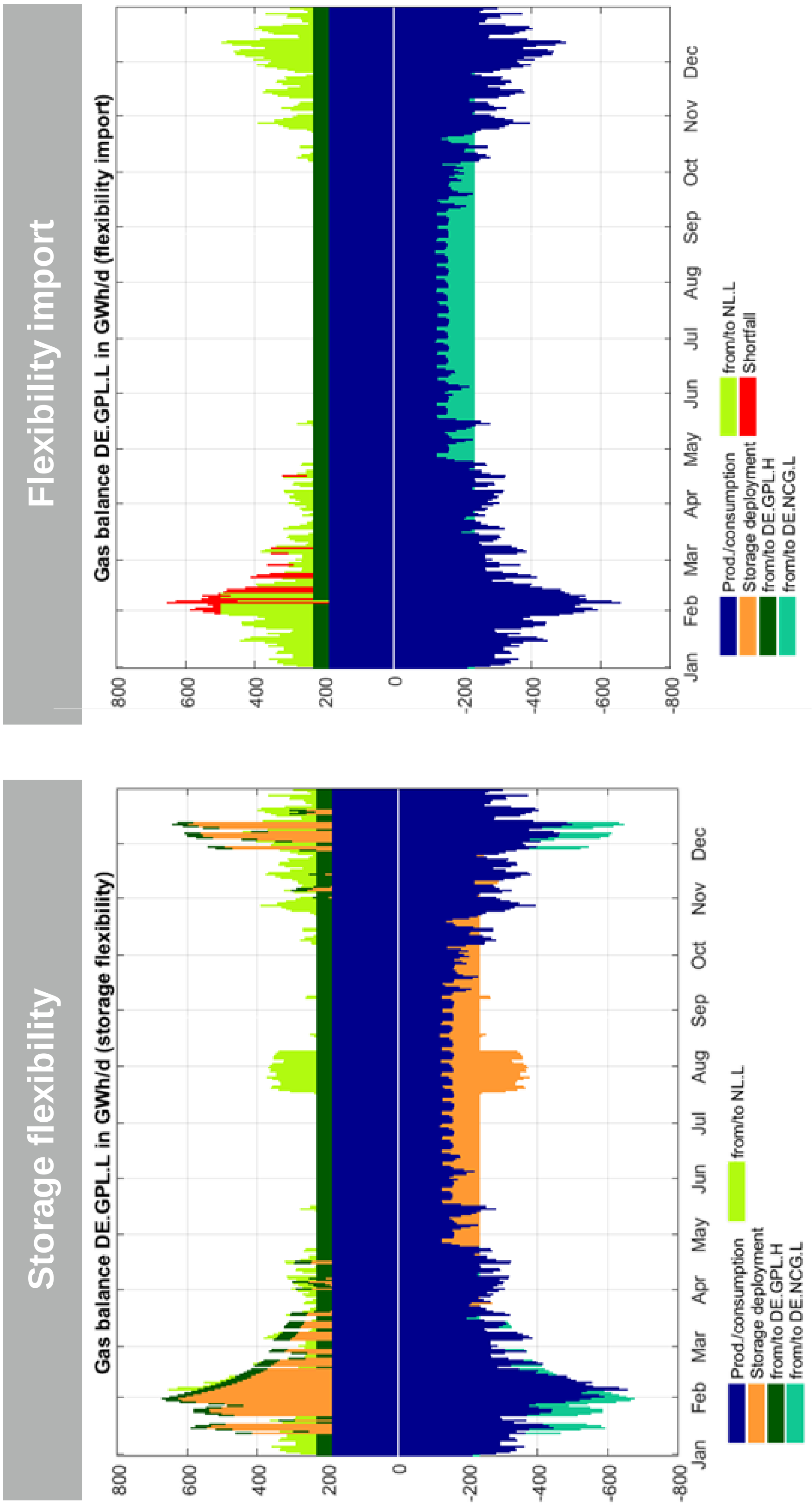

Figure 30: Gas balances of the GPL L-gas region in Germany in comparison (*storage flexibility* scenario and *flexibility import* scenario)

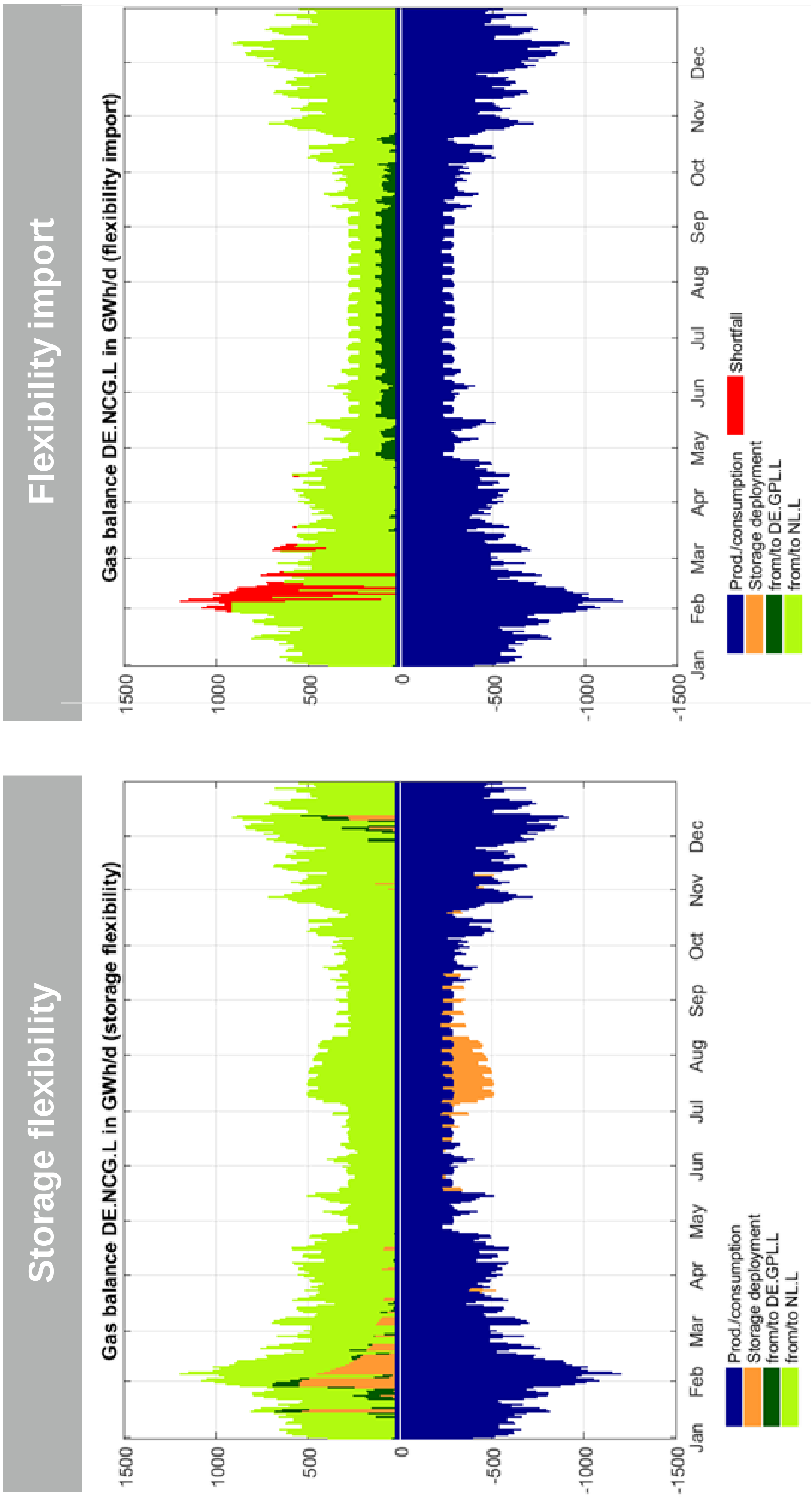

Figure 31: Gas balances of the NCG L-gas region in Germany in comparison (*storage flexibility* scenario and *flexibility import* scenario)

6.1.3 Changes in import and export balance

In section 6.1.1 a massive shift in imports and exports has already emerged. The following figure shows the shifts of the import/export balance.

The basic import requirement for gas supplies to supply Germany doesn't change. In the *storage flexibility* scenario, Germany could still act as a flexibility exporter. The storage capacities are sufficient to provide flexibility to other regions as well. The elimination of storage capacities in the *flexibility import* scenario, however, leads to significant upheavals in gas supply. In addition to the necessary gas volume, flexibility must be imported to supply end customers. The imports become clearly winter-biased. Exports are executed primarily in the summer months. This leaves a typical demand profile in Germany, which can be used to supply customers.

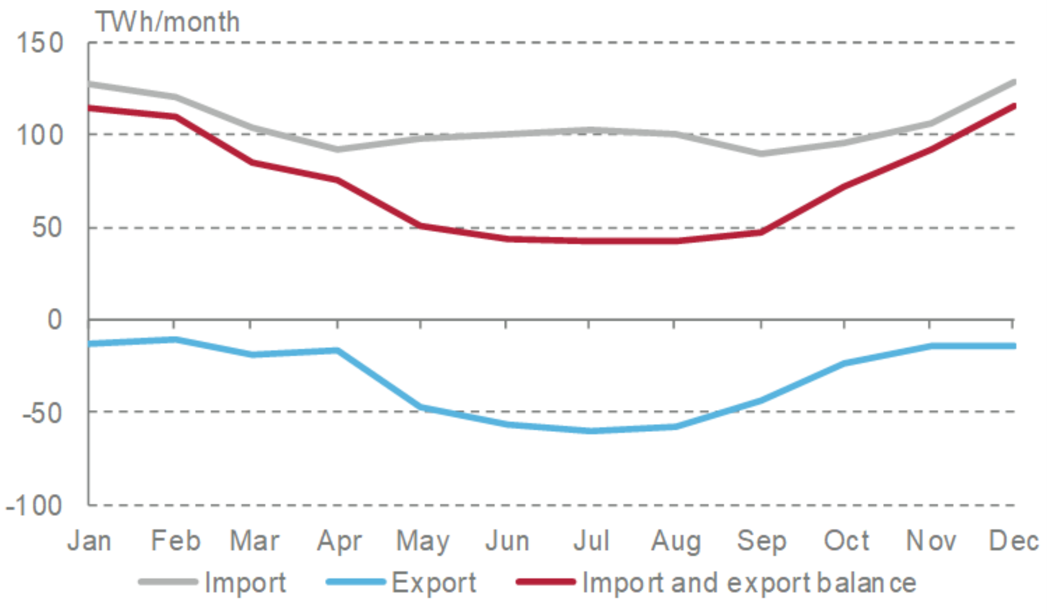

Figure 32: German import and export balance on a monthly basis (*flexibility import* scenario)

This effect becomes clearer if the import and export balances of both scenarios are compared on a daily basis. Figure 33 on page 48 shows the high load peaks that must be imported during winter months. The significant reduction in the summer months to adjust the gas volume to the low gas demand is also evident.

Germany transforms from a flexibility exporter into a flexibility importer. The value creation stage of provision of flexibility is shifted to other regions. The dependence on flexible production and quantities of LNG increases drastically, both in Europe and indirectly in Germany. Furthermore, Germany is extremely dependent on the provision of flexibility from neighbouring countries. Apart from switching off consumers, Germany has no opportunity to react within its own borders.

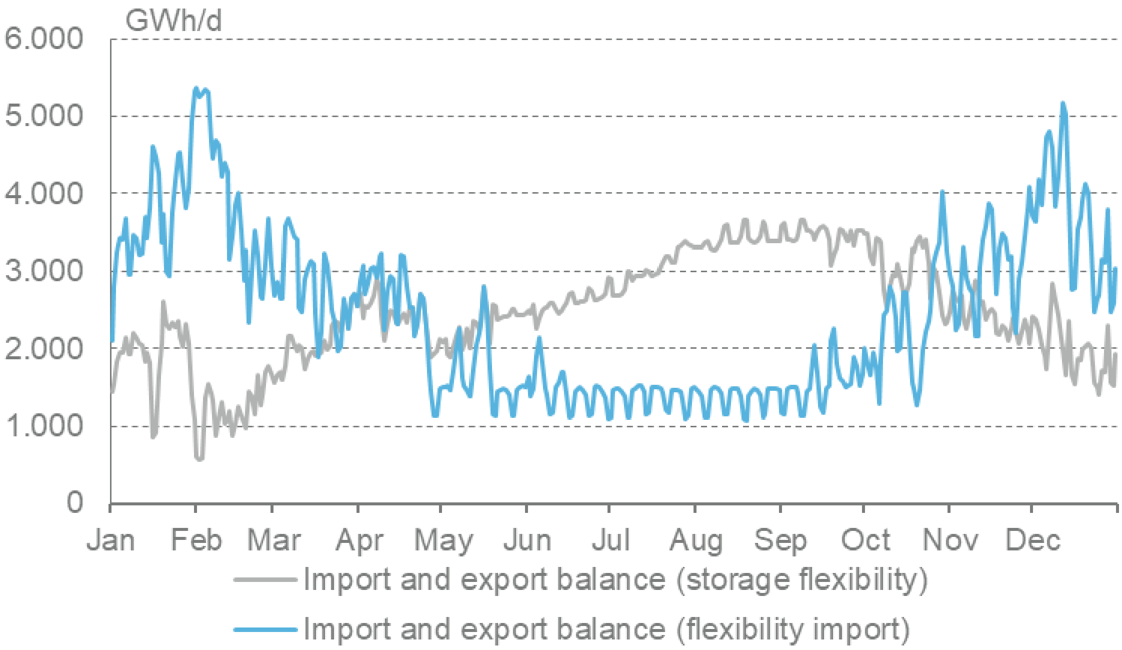

Figure 33: Import and export balances of the scenarios on a daily basis

6.2 Developments outside Germany

The effects of the loss of German gas storage facilities are therefore also felt in neighbouring regions. Production process, storage utilisation, LNG delivery quantities and structure are affected. The effects are explained in the following sections.

6.2.1 Changes in production utilisation

In order to provide flexibility, it is above all "consumer-oriented" supplier countries that adapt their production. However, effects on global production have not been evidenced. A "drill down" observation shows that the production in Norway, in contrast to the *storage flexibility* scenario, has a seasonal production pattern which partially compensates for the omission of German gas storage. Figure 34 shows Norway's regional production per scenario. In the *flexibility import* scenario, Norway increases production capacity within the framework of available capacities and correspondingly lowers production volumes during off-peak periods (see also section 5.2.1).

However, these measures are not sufficient to offset the omitted German gas storage in the *flexibility import* scenario. Rather, further steps are required.

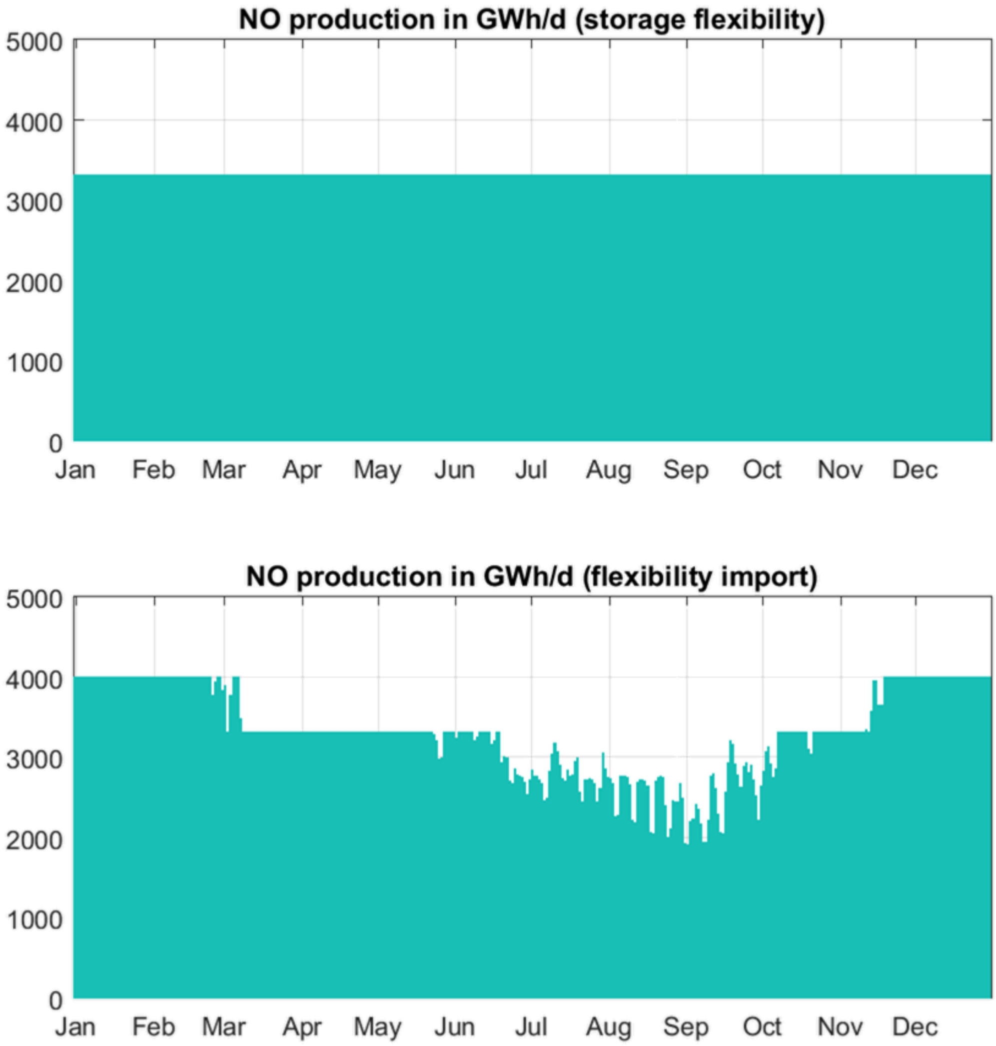

Figure 34: Norwegian production in the scenario comparison

6.2.2 Changes in LNG capacity utilisation

The additional employment of LNG imports is necessary. LNG employment therefore changes significantly between scenarios. Using LNG, it is possible to provide quantities and ultimately flexibility in the scenarios under consideration. The existing LNG infrastructure can also access remote sources of flexibility. The *flexibility import* scenario makes use of this possibility, especially in the winter months, as the Figure 35 shows.

Positive values stand for regasification (gas import into the aggregated regions), negative values for liquefaction. In the *storage flexibility* scenario, global LNG production and utilisation are predominantly band-shaped. In the *flexibility import* scenario, on the other hand, there is a clear seasonal structure. Import to Europe is visible through the contrasting colour (blue area). It can be seen that the seasonal utilisation structure of the LNG terminals in the *flexibility import* scenario is driven by a seasonal use of European LNG regasification.

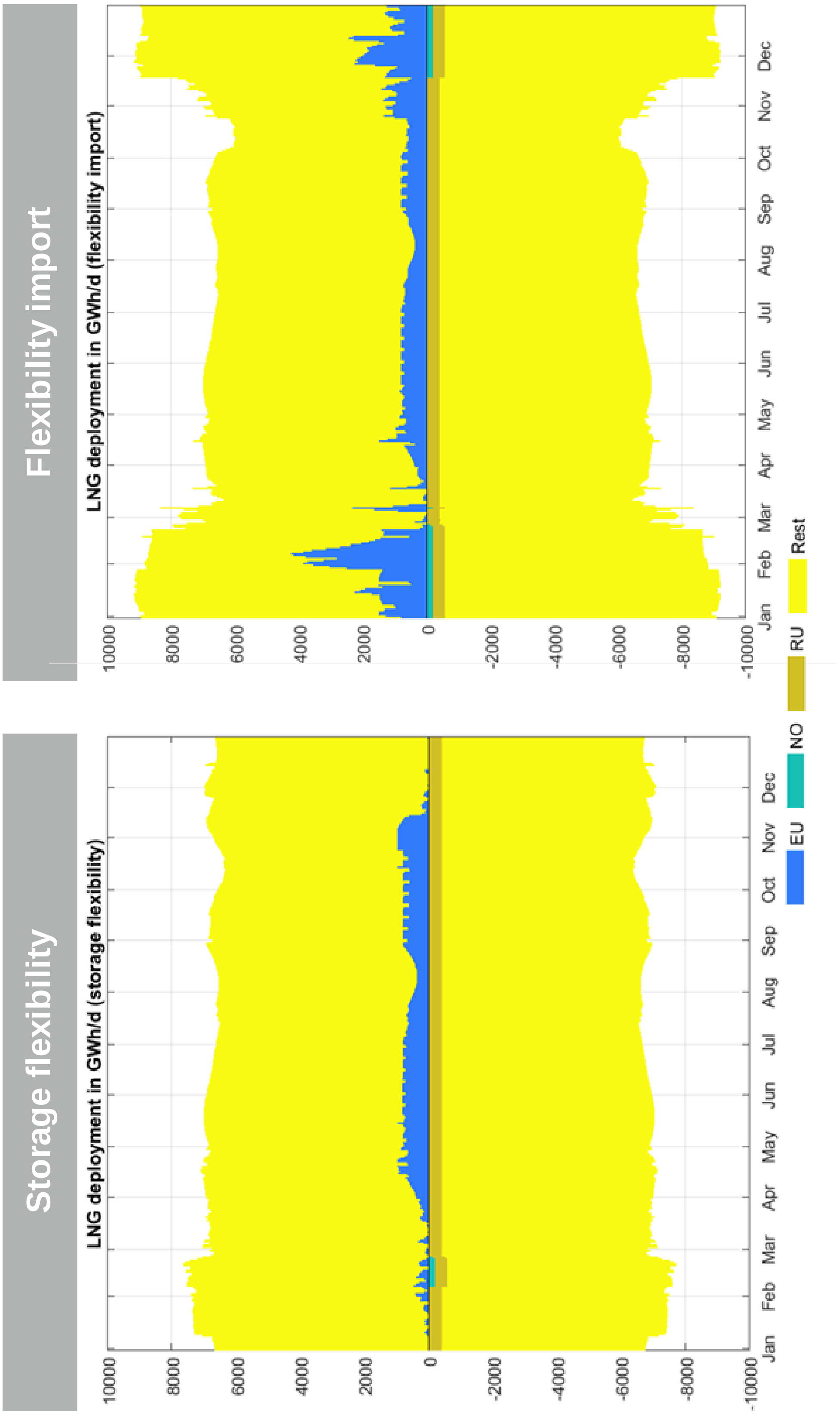

Figure 35: LNG production and imports in scenario comparison

Overall, more LNG is transported in the *flexibility import* scenario than in the *storage flexibility* scenario. The quantities to be imported into the EU almost double between scenarios.

Especially the examination of the LNG area shows distinctly once again how a cross-regional system optimisation with perfect foresight portrays regional effects (such as the removal of German gas storage facilities) internationally, in order to achieve an efficient and cost-minimised result. However, just-in-time delivery of LNG and its associated contribution to security of supply is only possible through assumed perfect foresight. The uncertainties in weather forecasts and the long shipping times between the liquefaction and regasification plants make these results highly optimistic.

6.2.3 Changes in storage deployment: Europe and Russia

In addition to changes in production and LNG imports, further flexibility potential needs to be harnessed. For this purpose, a consideration of the storage use of the regions makes sense. Already in the *storage flexibility* scenario, for example, storage facilities close to consumption locations were preferred, so in the *flexibility import* scenario no significant changes in Germany's immediate neighbouring countries are to be expected. Nonetheless, more remote regions have more storage potential that can be utilised.

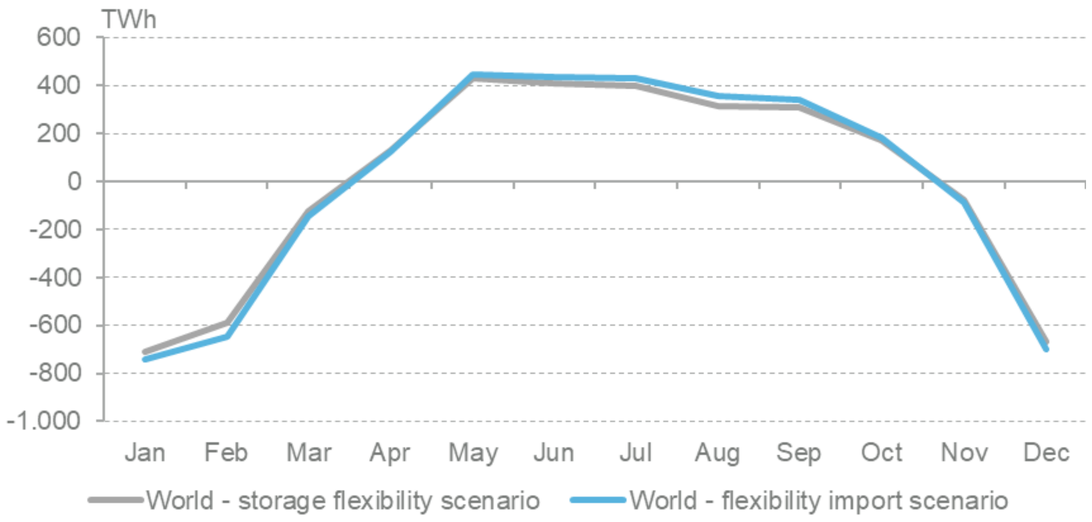

Figure 36: Worldwide change of storage utilisation

The change in global storage utilisation can be seen in Figure 36. Gas injection in the summer months and withdrawal in the winter months increases slightly. Although these differences in the scenarios are recognisable, they are of secondary importance in the global marketplace.

Only on closer inspection of the aggregated region EU (excluding Germany) and the aggregated region RU can it be ascertained that, particularly in these regions, an increase in storage utilisation can be observed (see Figure 37 on page 52). The regions' storage facilities are used to supply gas, especially in January, November and December. For this purpose, additional quantities are stored in the summer months. This is necessary to compensate for the elimination of German storage facilities in the *Flexibility import* to be offset and supply of the aggregated EU region and ultimately Germany that has to be ensured.

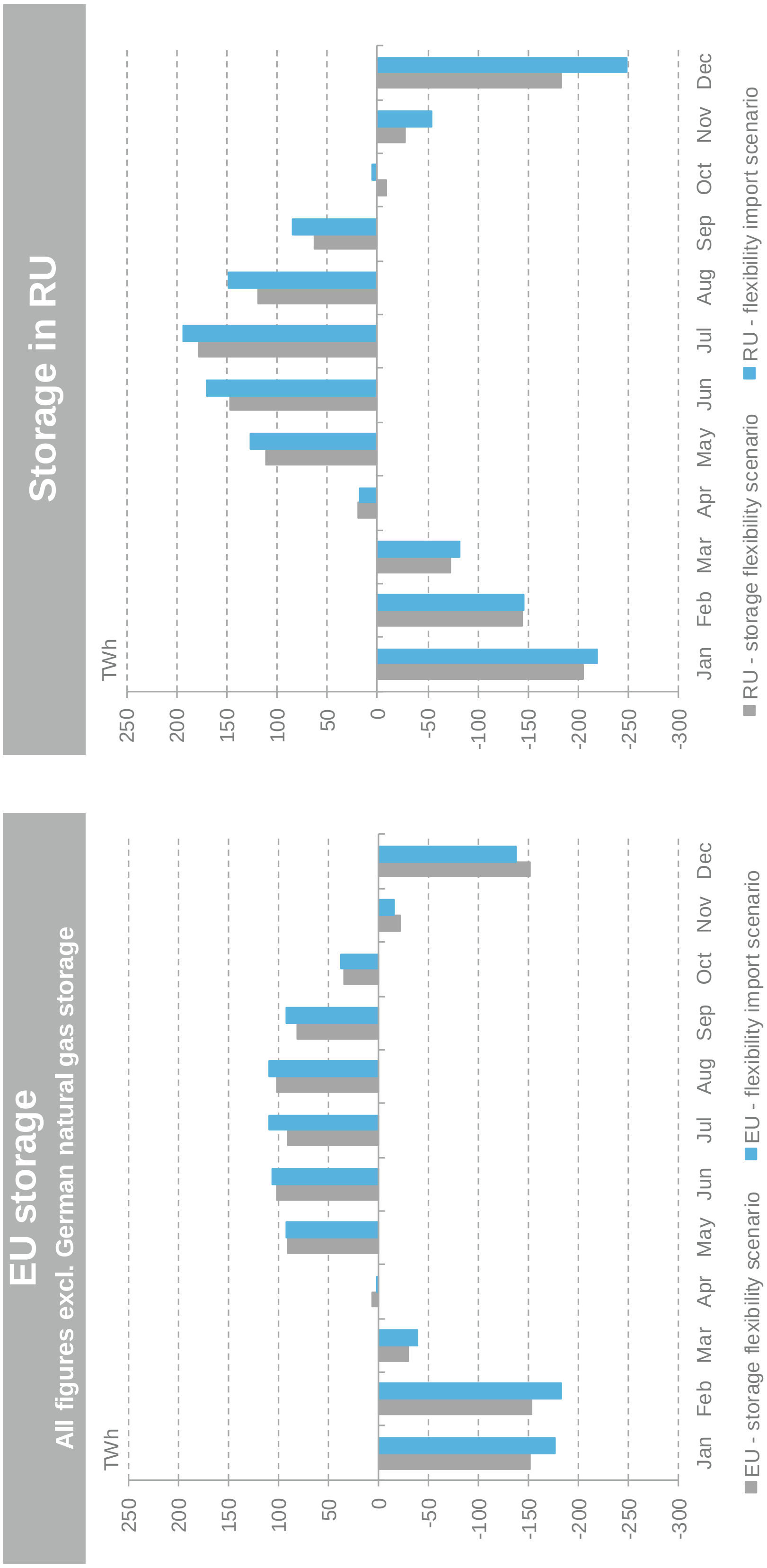

Figure 37: Change in storage utilisation in the EU and RU aggregated regions

6.2.4 Origin of flexibility

In Figure 38 below, the changes in the German import and export balance between the two scenarios which compensate the original storage utilisation in the *storage flexibility* scenario are shown. It can be clearly seen that Belgium, the Netherlands, the Czech Republic, Norway and Russia provide additional flexibility, but other neighbouring regions also make their contribution.

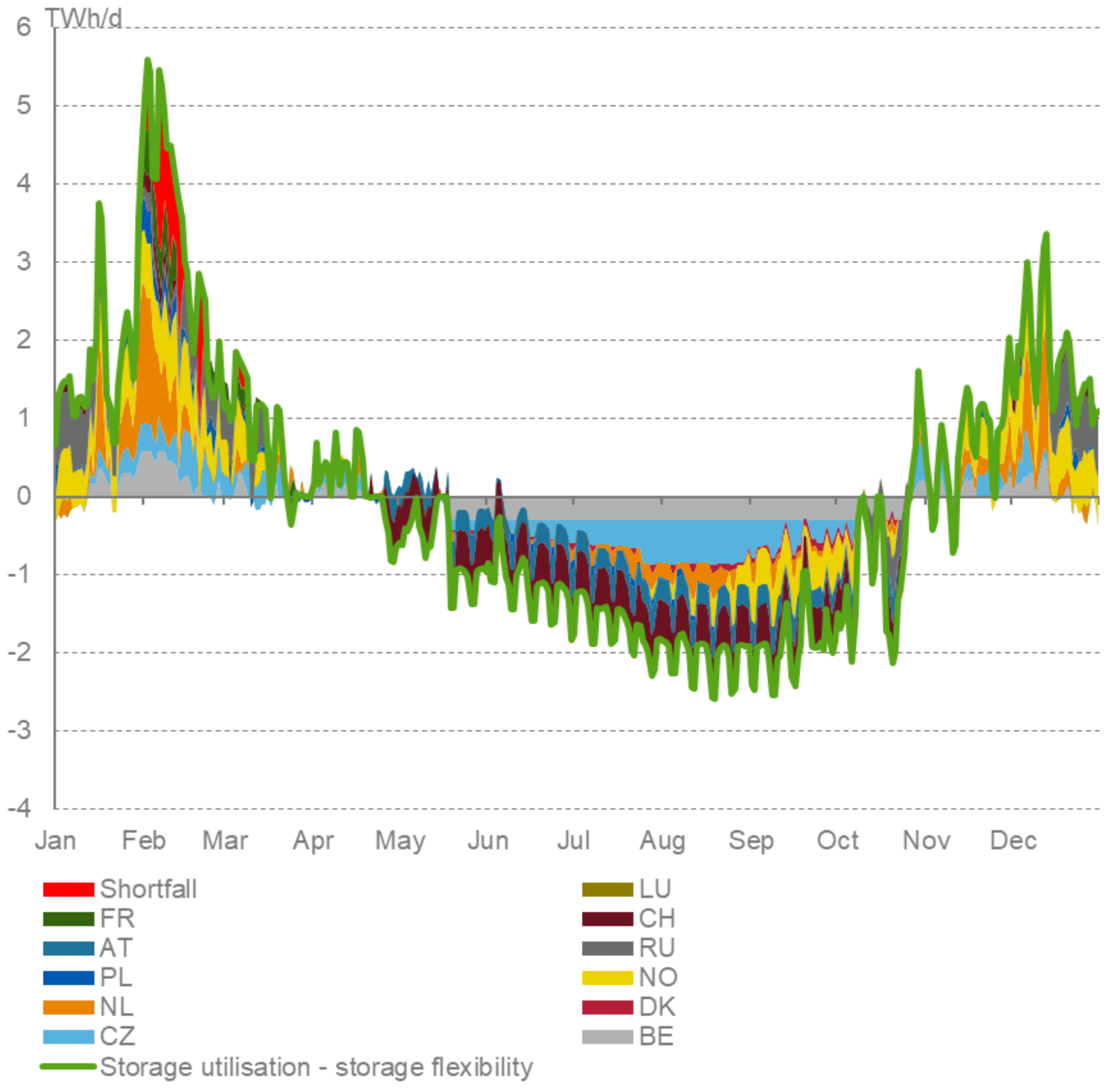

Figure 38: Suppliers of flexibility in the *flexibility import scenario*

It should be noted that flexibility is also provided indirectly via other countries and is only channelled through those regions that are directly linked to Germany. This will be explained with two examples.

Example 1: On the one hand, Russia can provide flexibility directly to Germany via the Nord Stream pipeline. On the other hand, structure can also be provided via the land transport route (YAMAL pipeline via Belarus and Poland). In the latter case, the provision of flexibility in the above consideration would not be assigned to Russia, but to Poland, since the transfer takes place at the German-Polish border.

Example 2: Additional LNG will be delivered to Italy. This delivery displaces pipeline gas, e.g. from Switzerland or Austria. The flexibility gained in this way can be supplied to Germany via other transport routes, e.g. from Russian sources.

The assignment of flexibility to individual countries can therefore not be clearly performed.

The source of flexibility can only be explained via the utilisation of the entire infrastructure described in the preceding subchapters: production, pipelines, LNG and storage facilities. Therefore, at least the types of transport can be identified, i.e. how flexibility is provided. A precise assignment of the supplied flexibility to individual regions is not possible. However, to ensure a representation of the source of flexibility, the aggregated EU region has been considered at its borders: imports were separated according to LNG import, pipeline gas and EU's own storage and production facilities. The result can be seen in the following graphic.

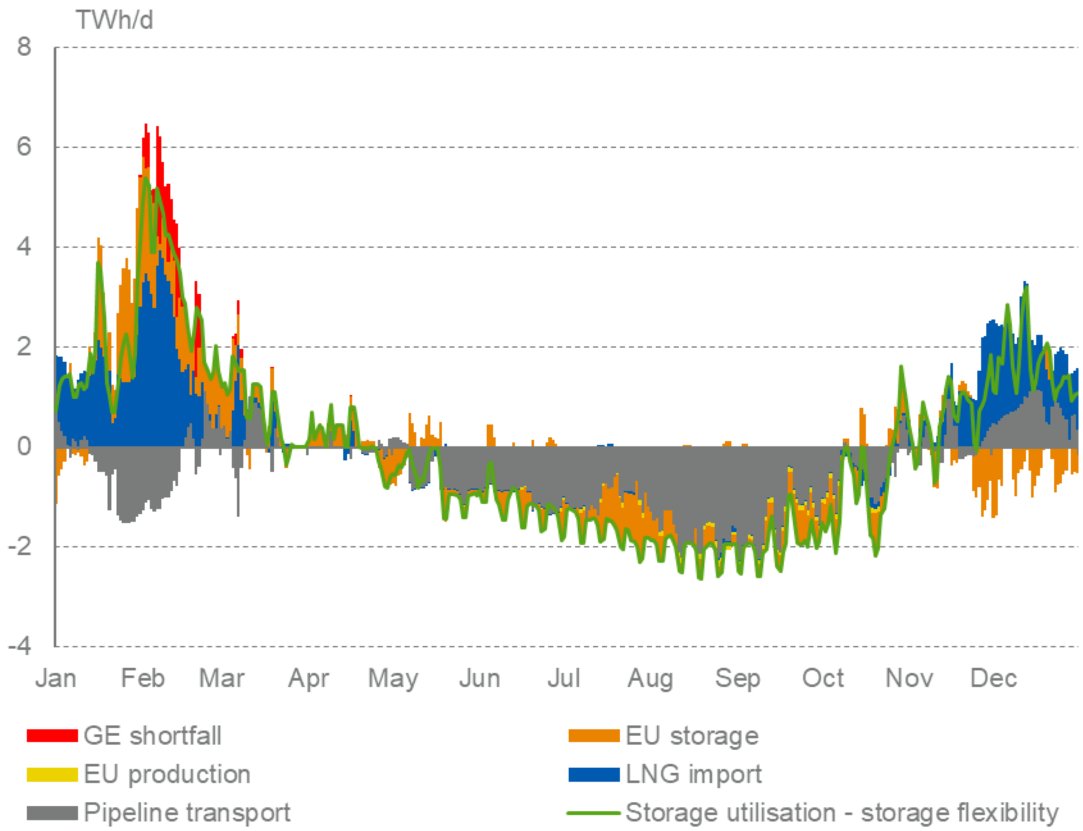

Figure 39: Flexibility according to transport route

The graphic illustrates how flexibility is provided. To some extent EU storage facilities can compensate for portions of German storage facilities. However, high levels of additional flexibility will be provided by the LNG infrastructure. Shifts in pipeline transport and EU import and export volumes also provide flexibility.

The shift in load flows and the increased utilisation of LNG ultimately lead to higher system costs. In addition, the economic performance of the storage facilities in Germany will be lost and will be shifted to other countries that provide the flexibility. Furthermore, loads in Germany must be shut down. The flexibility cannot be sufficiently imported from other sources if German gas storage is removed from the model.

6.3 Avoidance of load shedding by infrastructure

The shutdown of the German gas storage leads to supply bottlenecks in Germany. Shutdowns of end customers with significant economic costs would be the result. The calculations in the previous sections were based on the current gas transmission network (cf. section 3.2.5). This section sets out to what extent upgrading the transmission network can avoid load shedding. To this end, pipeline projects and associated network capacity have been modelled based on the Ten Year Network Development Plan (TYNDP).

For the pipeline projects, investment costs of approx. 120 thsd. €/(GWh/h) per kilometre have been assumed.[18] To largely compensate for the identified load shedding, projects with an investment volume of approx. €16.5 billion would be required.

However, these pipeline projects alone are not enough to avoid load shedding of L-gas. In the L-gas market, insufficient sources of flexibility can be tapped. Therefore, with the installation of a technical conversion plant in the model, load shedding in the German L-gas regions can be avoided. Capacity expansion of 18.8 GW with an investment volume of approx. €178 million is necessary for this.[19] However, load shedding in the H-gas regions can also not be completely avoided by network expansion, since sources of flexibility in the H-gas sector cannot be adequately tapped.

All in all, the expansion measures of the pipeline network and the conversion plant represents annuity costs of €1.4 billion p.a.[20]

In the *flexibility import* scenario, excluding expansion measures, peak load shedding would be 2,210 GWh/d and affect all regions of Germany. The modelled capacity-building measures reduce this peak to 462 MWh/d and only the DE.NCG.H zone is affected by this load shedding. Figure 40 below shows the course of the load shedding in the *flexibility import* scenario with and without expansion measures.

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18 enervis analyses; see i.a. FNB Gas, Netzentwicklungsplan Gas 2016-2026 plus Annex „Ausbaumaßnahmen (2016 – NEP Bestätigt).

19 Based on investment costs of €9.43/kW derived from: TU Clausthal, TU Clausthal, Alternativen für die Sicherstellung der Gasversorgung in heutigen L-Gas-Versorgungsgebieten, 2013, p. 6.

20 Pipeline projects have been amortised over 40 years, conversion plants over 25 years. Furthermore, a mixed interest of 6.91% p.a. is used as the basis calculation as well as operating costs of 1% of the investment sum per year.

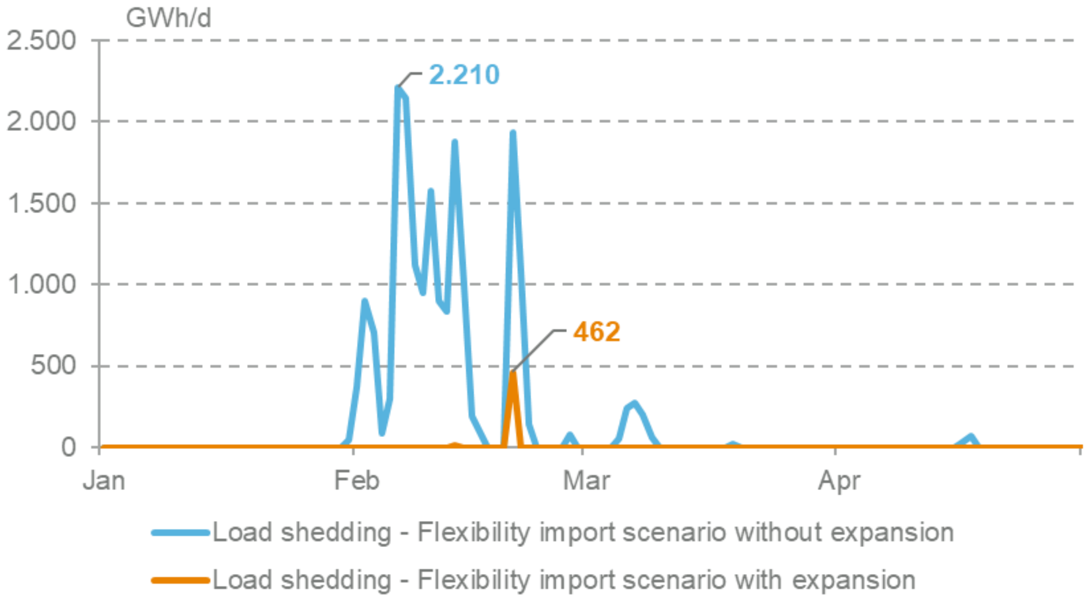

Figure 40: Avoidance of load shedding through expansion of the transmission network

The reduced load shedding is associated with a reduction in the cost of load shedding. Without expansion measures, the "value of lost load" is about €4.3 billion p.a. Capacity expansion between regions reduces the cost of load shedding to around € 82 million p.a.

In the further course, the costs of the reduced load shedding and the costs for the expansion measures outlined in the previous section are taken into account.

6.4 Cost differences of the scenarios

The cost effect of removing German gas storage can be approximately quantified by comparing the system cost of the two scenarios. There are sometimes counteractive cost effects when considering the costs for different types of infrastructure:

- Gas storage costs decrease:
  The deployment of German gas storage in the *storage flexibility* scenario cannot be completely compensated in the *flexibility import* scenario through the remaining gas storage available worldwide plus expansion measures. This results in lower gas storage utilisation in the *flexibility import* scenario, which lowers the global system cost of gas storage deployment.
- Production costs increase:
  In the *flexibility import* scenario with expansion measures, supply bottlenecks leading to load shedding occur in Germany. Consequently, the associated volumes in this scenario no longer have to be produced, but the previous load flows are shifting significantly. Other sources of production are utilised, and some of them have to provide flexibility themselves. In addition, the quantities are transported over longer distances, which increases the need for LPG. Therefore, the worldwide system costs for production are slightly higher than in the *storage flexibility* scenario.
- LNG transport costs increase:
  In peak demand periods, the use of the LNG infrastructure increases and transport takes place over longer sea routes. As a result, global system costs for using the LNG infrastructure also increase.

- Load shedding incurs costs ("value of lost load"):
  The loss of secured supply leads to costs which must be taken into account in the calculation.
- Additional investments in gas network infrastructure:
  As no gas storage facilities are available in Germany, new pipeline investments are necessary. These increase the system costs.

The system cost differences between the scenarios for production, transport, storage and load shedding are explained in more detail below. The difference costs of the *flexibility import* scenario taking into account the extension measures are depicted in comparison to the *storage flexibility* scenario.

In contrast to the *storage flexibility* scenario, network expansion measures to reduce load shedding must be taken into account in the *flexibility import* scenario. These result in annual costs of €1.4 billion (cf. section 6.3).

Since German gas storage is eliminated in the *flexibility import* scenario, these are partly compensated by other storage facilities. Since the substitute gas storage is not complete, the absolute variable system costs of global gas storage sink by €66 million p.a. in the *flexibility import* scenario in comparison with the *storage flexibility* scenario.

Simultaneously, the expansion measures lead to longer transport routes and thus to a higher LPG requirement and a changed utilisation of production sources. The production itself provides flexibility, which increases production costs by €196 million p.a. in the *flexibility import* scenario taking the expansion measures into account.

Since the gas volumes have to be transported over longer distances both via pipelines and LNG, the transport costs increase significantly. The use of flexible LNG supplies from all over the world leads to additional liquefaction and regasification requirements. The average number of days at sea increases. In other words, the *flexibility import* scenario also draws on sources of flexibility outside Europe that are significantly more costly to transport via LNG than gas storage in Germany would be. Therefore, taking into account the expansion measures, the transport costs increase by € 557 million p.a. in the *flexibility import* scenario compared to the *storage flexibility* scenario.

The measures taken are nevertheless not able to restore security of supply without German gas storage. The continuing supply restrictions lead to costs of approx. €0.1 billion p.a.

The cost situation of this scenario in comparison to the *storage flexibility* scenario is as shown in Figure 41 on page 58.

In sum, with the expansion measures, the *flexibility import* scenario leads to an increase in the system costs of about €2.2 billion annually compared to the *storage flexibility* scenario.

Although load-shedding can be significantly reduced by network expansion measures, network-conducive deployment of storage can provide flexibility more efficiently and cost-effectively. In the *storage flexibility* scenario, many projects are not absolutely necessary to maintain European supply.

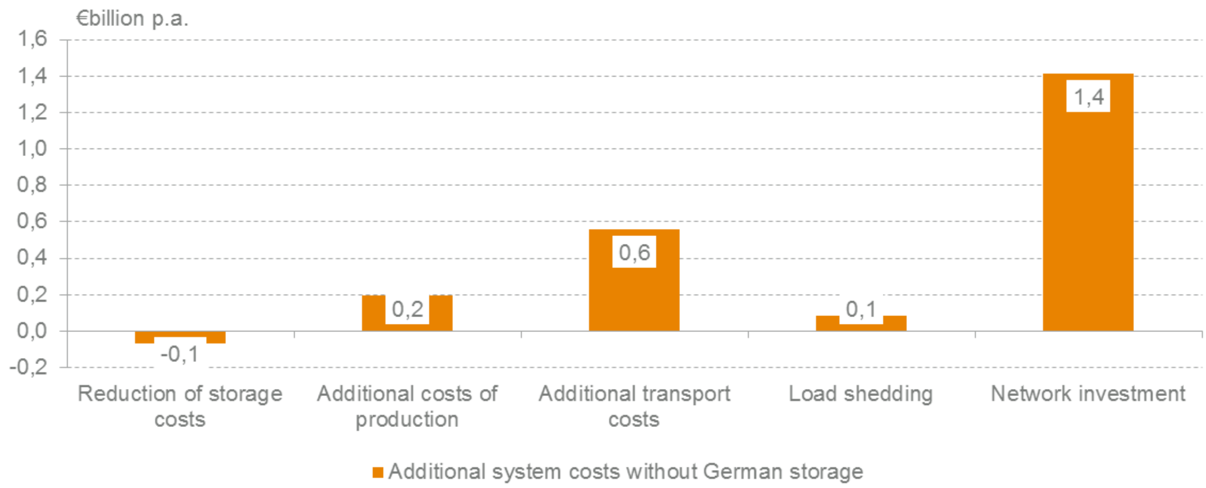

Figure 41: Additional system costs of the *flexibility import* scenario taking TYNDP FID projects into account compared to the *storage flexibility* scenario

6.5 Scenario comparison conclusion

Compensating for German gas storage facilities has an impact on the European and worldwide gas infrastructure. In particular, "nearby" storage facilities in Europe, Russia, Ukraine and Belarus are used to compensate. Furthermore, flexibility is imported through LNG, which comes from more remote storage or production facilities. In addition, in order to reduce load shedding, expansion measures on the transmission network must be taken to increase capacities between regions. These measures can avoid 97% of load shedding. Nevertheless, the entire supply situation is strained to the utmost.

The seasonal flexibility previously provided by the German gas storage facilities is essentially compensated by the following effects:

- The gas storage facilities in the EU and RU aggregated regions provide flexibility to compensate for German gas storage facilities.
- Norwegian production provides more flexibility.
- LNG is also included as a source of flexibility.
- Germany increases flexibility access at the expense of neighbouring regions.

Nonetheless, sources of flexibility are insufficient, resulting in consumer shutdowns. These shortfalls can be reduced from 2,210 GWh/d to 462 GWh/d through network expansion measures. However, it must be remembered that the enervis model used assumes an absolute forecast of all market participants and, moreover, seamless global cooperation.

Under these premises, the elimination of gas storage facilities in Germany can be partially compensated by other regions. The resulting increased flexibility of production, the changes in LNG flows and the changes in storage methods have a significant impact on the import and export balance in Germany.

The massive change in load flows and sources of flexibility and the network expansion necessary to avoid load shedding lead to an increase in system costs of about €2.2 billion p.a.

Given the numerous planned investments in pipeline projects which, however, could be avoided by using the system value of the gas storage facilities, the current gas storage situation must be reconsidered. Changes in the gas market design and the regulatory framework should bring these economic cost advantages more into focus. Currently, investments in pipelines in Germany are preferred to the use of storage facilities, because a return on capital is only granted on the network operator's property, plant and equipment. The use of storage facilities, however, represents costs that can only be earned back at 100% efficiency. For this reason, the system value of storage is successively replaced by network investment, resulting in an increase in infrastructure costs. These costs must ultimately be borne by the consumer.

I. Attachment

I.1 Detailed results on the utilisation of pipelines from Germany to neighbouring countries

Load flows in GWh/d *Storage flexibility scenario*								
			Source			Delivery		
Region	Season	Neighbour	medium	max.	capacity	medium	max.	capacity
DE.GPL.H	Winter (Dec-Feb)	BE	0	0	130	166	171	171
DE.GPL.H	Winter (Dec-Feb)	NL	0	0	98	256	334	334
DE.GPL.H	Winter (Dec-Feb)	NO	0	0	520	0	0	0
DE.GPL.H	Winter (Dec-Feb)	DK	0	0	0	0	13	97
DE.GPL.H	Winter (Dec-Feb)	RU	342	809	809	0	0	0
DE.GPL.H	Winter (Dec-Feb)	PL	810	925	925	0	0	197
DE.GPL.H	Winter (Dec-Feb)	CZ	0	0	198	1	101	639
DE.GPL.H	Winter (Dec-Feb)	DE	0	0	58	308	308	308
DE.GPL.H	Summer (Mar-Nov)	BE	0	0	130	46	171	171
DE.GPL.H	Summer (Mar-Nov)	NL	0	0	98	80	334	334
DE.GPL.H	Summer (Mar-Nov)	NO	296	520	520	0	0	0
DE.GPL.H	Summer (Mar-Nov)	DK	0	0	0	0	0	97
DE.GPL.H	Summer (Mar-Nov)	RU	773	809	809	0	0	0
DE.GPL.H	Summer (Mar-Nov)	PL	856	925	925	0	0	197
DE.GPL.H	Summer (Mar-Nov)	CZ	0	0	198	179	602	639
DE.GPL.H	Summer (Mar-Nov)	DE	0	0	58	308	308	308
DE.NCG.H	Winter (Dec-Feb)	AT	0	0	0	0	0	347
DE.NCG.H	Winter (Dec-Feb)	CH	0	0	0	173	544	544
DE.NCG.H	Winter (Dec-Feb)	FR	0	0	0	90	577	577
DE.NCG.H	Winter (Dec-Feb)	BE	0	0	138	18	147	147
DE.NCG.H	Winter (Dec-Feb)	NL	0	0	537	21	162	162
DE.NCG.H	Winter (Dec-Feb)	NO	477	655	655	0	0	0
DE.NCG.H	Winter (Dec-Feb)	CZ	329	732	906	0	0	0
DE.NCG.H	Winter (Dec-Feb)	DE	308	308	308	0	0	58
DE.NCG.H	Summer (Mar-Nov)	AT	0	0	0	0	0	347
DE.NCG.H	Summer (Mar-Nov)	CH	0	0	0	66	183	544
DE.NCG.H	Summer (Mar-Nov)	FR	0	0	0	6	416	577
DE.NCG.H	Summer (Mar-Nov)	BE	89	138	138	0	85	147
DE.NCG.H	Summer (Mar-Nov)	NL	156	537	537	0	6	162
DE.NCG.H	Summer (Mar-Nov)	NO	644	655	655	0	0	0
DE.NCG.H	Summer (Mar-Nov)	CZ	55	441	906	0	0	0
DE.NCG.H	Summer (Mar-Nov)	DE	308	308	308	0	0	58
DE.GPL.L	Winter (Dec-Feb)	NL	38	157	268	0	0	0
DE.GPL.L	Winter (Dec-Feb)	DE	47	47	47	42	147	147
DE.GPL.L	Summer (Mar-Nov)	NL	24	160	268	0	0	0
DE.GPL.L	Summer (Mar-Nov)	DE	47	47	47	2	147	147
DE.NCG.L	Winter (Dec-Feb)	NL	545	898	898	0	0	0
DE.NCG.L	Winter (Dec-Feb)	DE	42	147	147	0	0	0
DE.NCG.L	Summer (Mar-Nov)	NL	381	697	898	0	0	0
DE.NCG.L	Summer (Mar-Nov)	DE	2	147	147	0	0	0

Table 6: Load flows in Germany and neighbouring countries in GWh/d – *storage flexibility scenario*

Load flows in GWh/d
Flexibility import scenario

Region	Season	Neighbour	Source medium	Source max.	Source capacity	Delivery medium	Delivery max.	Delivery capacity
DE.GPL.H	Winter (Dec-Feb)	BE	21	130	130	61	171	171
DE.GPL.H	Winter (Dec-Feb)	NL	7	98	98	214	334	334
DE.GPL.H	Winter (Dec-Feb)	NO	465	520	520	0	0	0
DE.GPL.H	Winter (Dec-Feb)	DK	0	0	0	0	11	97
DE.GPL.H	Winter (Dec-Feb)	RU	808	809	809	0	0	0
DE.GPL.H	Winter (Dec-Feb)	PL	923	925	925	0	0	197
DE.GPL.H	Winter (Dec-Feb)	CZ	2	136	198	28	313	639
DE.GPL.H	Winter (Dec-Feb)	DE	0	0	58	287	308	308
DE.GPL.H	Summer (Mar-Nov)	BE	0	0	130	137	171	171
DE.GPL.H	Summer (Mar-Nov)	NL	0	0	98	187	334	334
DE.GPL.H	Summer (Mar-Nov)	NO	261	520	520	0	0	0
DE.GPL.H	Summer (Mar-Nov)	DK	0	0	0	21	97	97
DE.GPL.H	Summer (Mar-Nov)	RU	785	809	809	0	0	0
DE.GPL.H	Summer (Mar-Nov)	PL	878	925	925	0	0	197
DE.GPL.H	Summer (Mar-Nov)	CZ	0	0	198	332	639	639
DE.GPL.H	Summer (Mar-Nov)	DE	0	0	58	308	308	308
DE.NCG.H	Winter (Dec-Feb)	AT	0	0	0	0	0	347
DE.NCG.H	Winter (Dec-Feb)	CH	0	0	0	77	544	544
DE.NCG.H	Winter (Dec-Feb)	FR	0	0	0	21	508	577
DE.NCG.H	Winter (Dec-Feb)	BE	61	138	138	0	0	147
DE.NCG.H	Winter (Dec-Feb)	NL	201	537	537	1	38	162
DE.NCG.H	Winter (Dec-Feb)	NO	655	655	655	0	0	0
DE.NCG.H	Winter (Dec-Feb)	CZ	489	808	906	0	0	0
DE.NCG.H	Winter (Dec-Feb)	DE	287	308	308	0	0	58
DE.NCG.H	Summer (Mar-Nov)	AT	0	0	0	156	347	347
DE.NCG.H	Summer (Mar-Nov)	CH	0	0	0	373	544	544
DE.NCG.H	Summer (Mar-Nov)	FR	0	0	0	17	577	577
DE.NCG.H	Summer (Mar-Nov)	BE	5	138	138	0	0	147
DE.NCG.H	Summer (Mar-Nov)	NL	356	537	537	0	0	162
DE.NCG.H	Summer (Mar-Nov)	NO	647	655	655	0	0	0
DE.NCG.H	Summer (Mar-Nov)	CZ	130	743	906	0	0	0
DE.NCG.H	Summer (Mar-Nov)	DE	308	308	308	0	0	58
DE.GPL.L	Winter (Dec-Feb)	NL	125	268	268	0	0	0
DE.GPL.L	Winter (Dec-Feb)	DE	46	47	47	0	20	147
DE.GPL.L	Summer (Mar-Nov)	NL	19	164	268	0	0	0
DE.GPL.L	Summer (Mar-Nov)	DE	47	47	47	49	116	147
DE.NCG.L	Winter (Dec-Feb)	NL	593	898	898	0	0	0
DE.NCG.L	Winter (Dec-Feb)	DE	0	20	147	0	0	0
DE.NCG.L	Summer (Mar-Nov)	NL	298	704	898	0	0	0
DE.NCG.L	Summer (Mar-Nov)	DE	49	116	147	0	0	0

Table 7: Load flows in Germany and neighbouring countries in million m³/d *flexibility import* scenario