Artelys | OPTIMIZATION SOLUTIONS

gie Gas Infrastructure Europe

Value of the gas storage infrastructure for the electricity system

Final report

October 2019

Objective and approach

This report presents the result of a study undertaken by Artelys on behalf of Gas Infrastructure Europe (GIE).

The key objective of this study is to identify and evaluate the cross-sectoral benefits brought by European gas storage assets.

The cross-sectoral benefits of the presence of gas storage assets are quantified by carrying out detailed multi-energy simulations of the European gas and electricity systems with the Artelys Crystal Super Grid modelling platform.

The methodology that has been designed for this study consists in comparing a counterfactual situation with sensitivity analyses where a share of the gas storage assets would be unavailable.

Thereby one can identify the benefits of the presence of gas storage assets, in particular in terms of value provided to the electricity sector.

The report begins by presenting the methodology and assumptions used for this study, and then proceeds with the presentation of the results, which show the cross-sectoral benefits of gas storage assets in terms of:

- Avoided operational costs in the electricity sector
- Avoided investment costs in the electricity sector
- Avoided variability of electricity prices

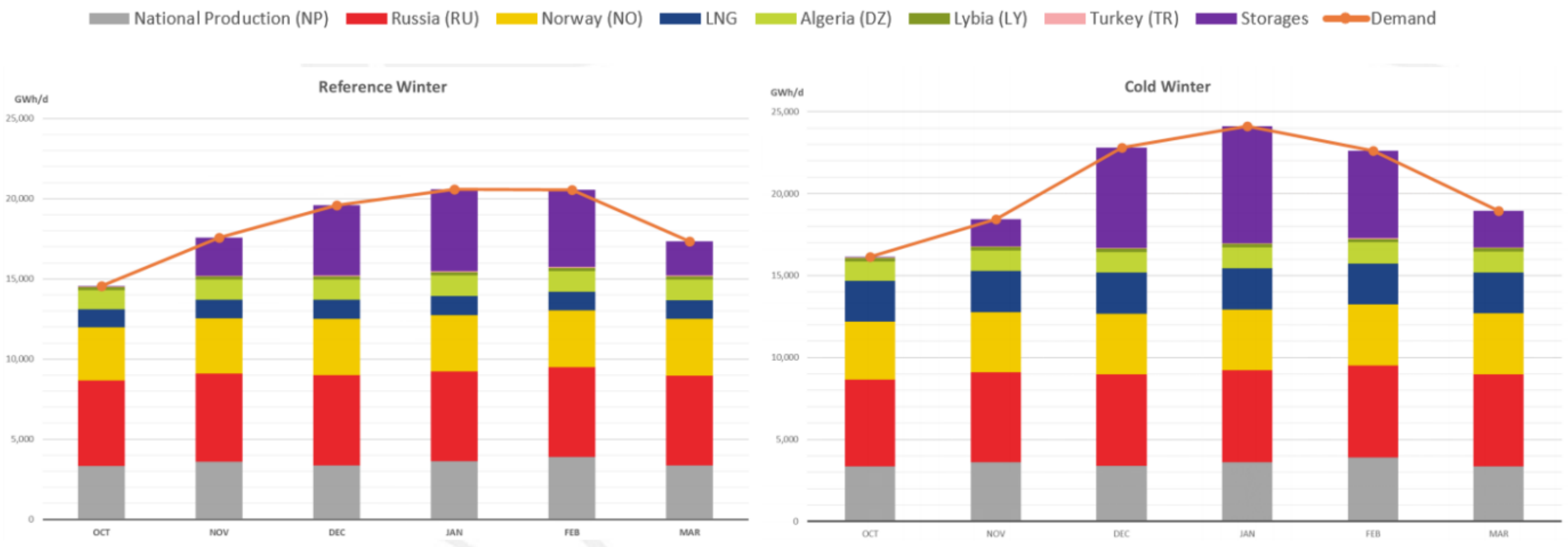
Should you have any questions, our contact details are available at the end of the slide deck.

Plan of the report

The key roles of gas storage assets

Importing, moving, storing and delivering gas to European consumers and businesses relies on the presence of gas infrastructure. Gas storage facilities have been shown to be key components of this complex system, as they allow to cover a large share of the seasonal flexibility needs, and enable the system to cope with cold winter conditions. In addition, gas storage is also providing flexibility on shorter timescales, e.g. to cope with disruptions of other infrastructures. It is therefore essential to ensure the value of these assets are properly identified and remunerated.

Storage is the key provider of seasonal flexibility during all winters



Storage is the key provider of additional flexibility during cold winters

Source: ENTSOG Winter Supply Outlook 2018/2019

Remark: The supply assumptions shown above by ENTSOG are based on the supply observed in the last five winters and should not be considered as a forecast, the actual supply mix will depend on market behaviour and other external factors

Motivation for the study

Gas Infrastructure Europe (GIE) has undertaken several analyses aiming at identifying the different services provided by gas storage assets, and at finding options to properly remunerate gas storage operators for these services.

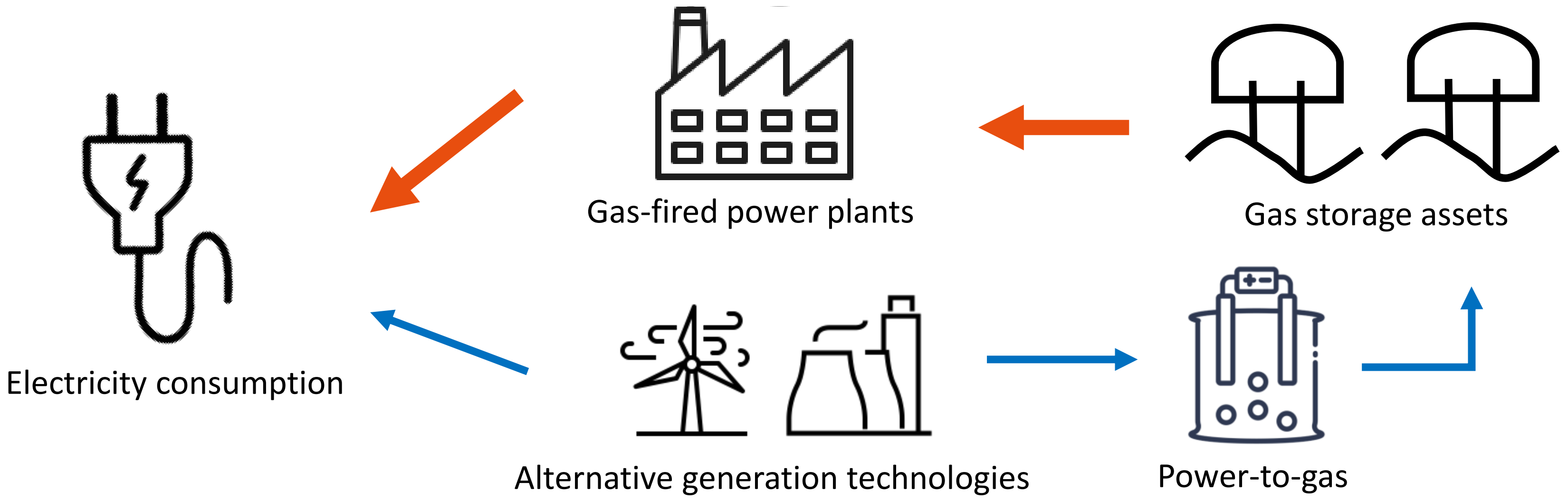
1. **Gas storage market failures** – The first study identifies how gas storage capacities provide value to the energy system (seasonal storage, medium- and short-term flexibility, insurance value related to security of supply, and system value), and which of these values are not currently remunerated by the markets.
2. **Pricing and regulatory measures** – This second study proposes market-based pricing and regulatory measures that could result in appropriate revenues for gas storage system operators, in a context where seasonal gas storage supports the decarbonisation effort.
3. **Gas demand curtailment** – Finally, the third study assesses the risk of gas demand curtailment following a reduction of gas storage capacity.

The objective of this study is to perform a **quantitative analysis** of the **cross-sectoral benefits** of gas storage assets:

- Impact on the **electricity system,** its costs and the structure of electricity market prices
- Evaluation of the **capacity value** of European gas storage capacities, in terms of avoided costs for the electricity sector

Capacity value of gas storage assets – An introduction

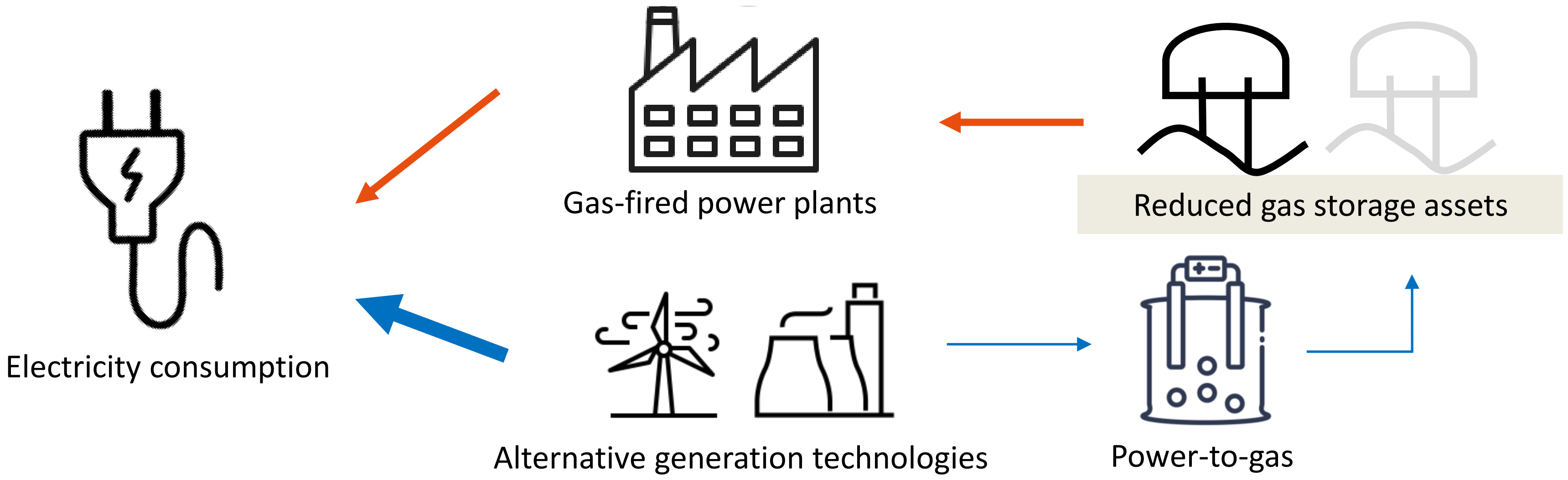
The gas that is delivered through the European gas infrastructure is used for a variety of purposes, amongst which firing open-cycle gas turbines (OCGTs), combined-cycle gas turbines (CCGTs), and a number of combined heat and power facilities (CHPs).



In the 2018 edition of the *Ten-Year Network Development Plan* (TYNDP), the ENTSOs evaluate that **gas-fired power plants will account for around 20% of the European gas consumption in 2020**.

Capacity value of gas storage assets – An introduction

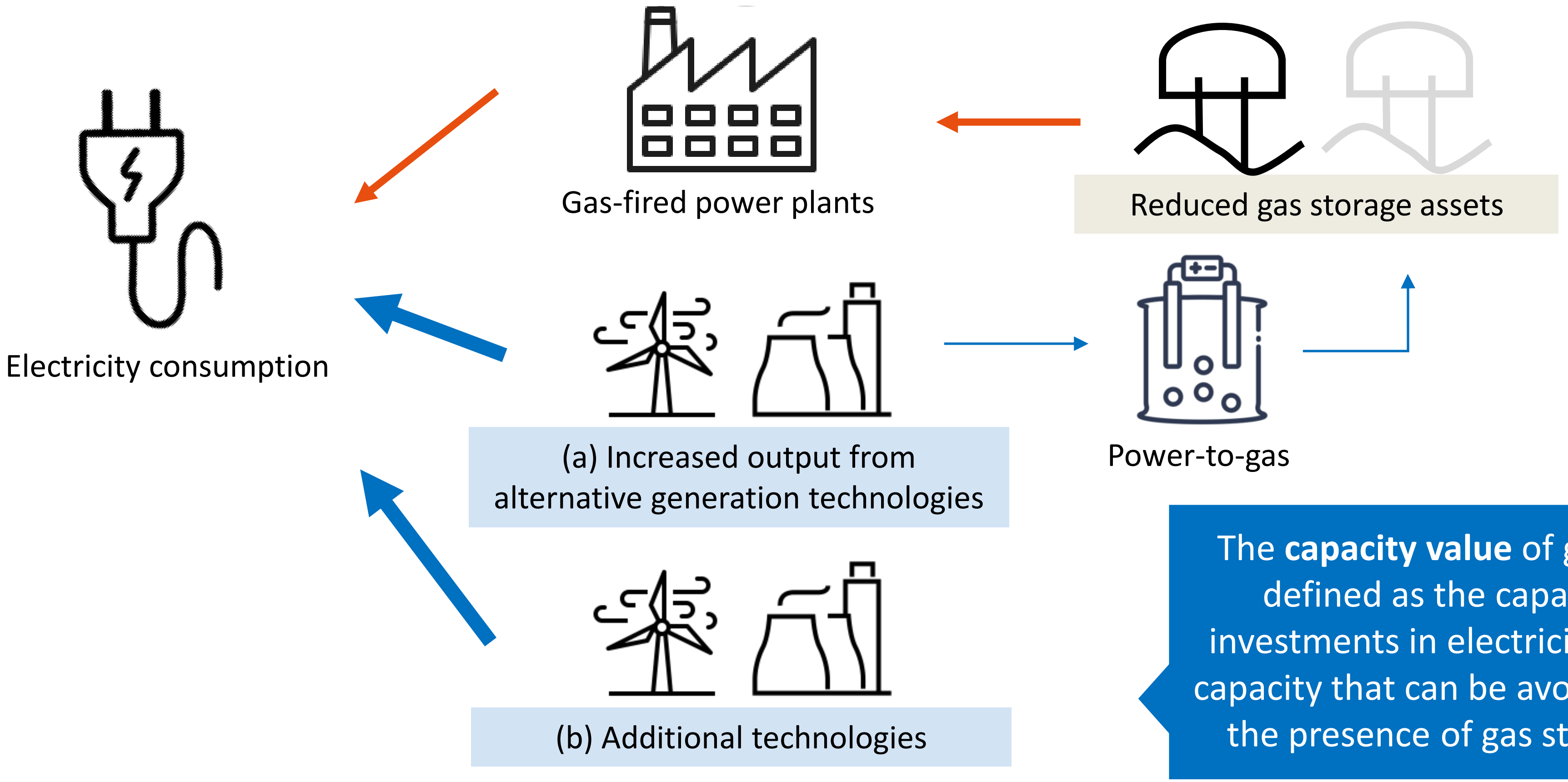
In a system where part of the gas storage assets were to be unavailable, gas-fired electricity generation power plants may not be able to gain access to sufficient quantities of gas during episodes of peak (residual) electricity demand and may have to **reduce their outputs compared to a situation where gas storage assets are available**.



In **adverse situations** this could lead to the electricity system having to consider **electricity demand curtailment**.

Capacity value of gas storage assets – An introduction

In order to compensate for such a reduction of gas-based electricity generation, the system may adapt by (a) **exploiting existing flexibilities** (e.g. running more expensive power plants), and, if this proves insufficient to ensure the electricity demand can be met, (b) **investing in alternative electricity generation technologies** until the electricity demand can be met.



The **capacity value** of gas storage is defined as the capacity of the investments in electricity generation capacity that can be avoided thanks to the presence of gas storage assets

Plan of the report

Key principles of the methodology

The key objective of the study is to quantify the **cross-sectoral benefits** of gas storage assets, and in particular to assess the capacity value of gas storage from the point of view of the electricity sector. To do so, we compare the following situations:

Counterfactual scenario

ENTSOs' TYNDP 2018[1]
Sustainable Transition scenario for 2030[2]

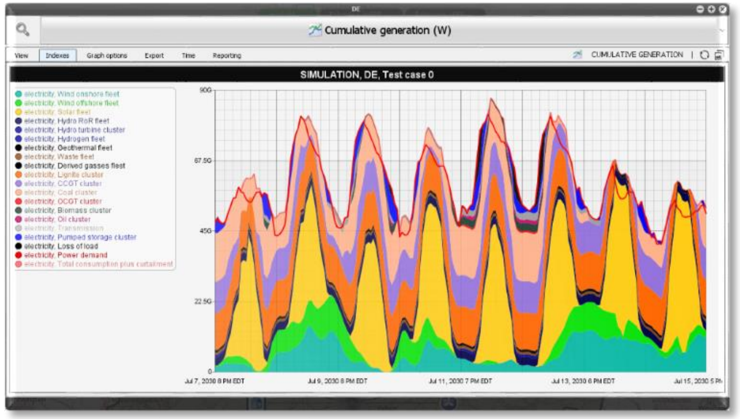
Sensitivity analysis

Decrease of the gas storage capacity by 10%, 20%, etc.

When reducing the gas storage capacity, we assume an homogenous decrease of storage volume, withdrawal and injection rates, in all countries.

The **key impacts** are measured in terms of:

- Electricity **dispatch**, its costs and market prices
- Avoided **operational** costs for electricity generation (OPEX)
- Avoided **investment** costs in the electricity system (CAPEX)

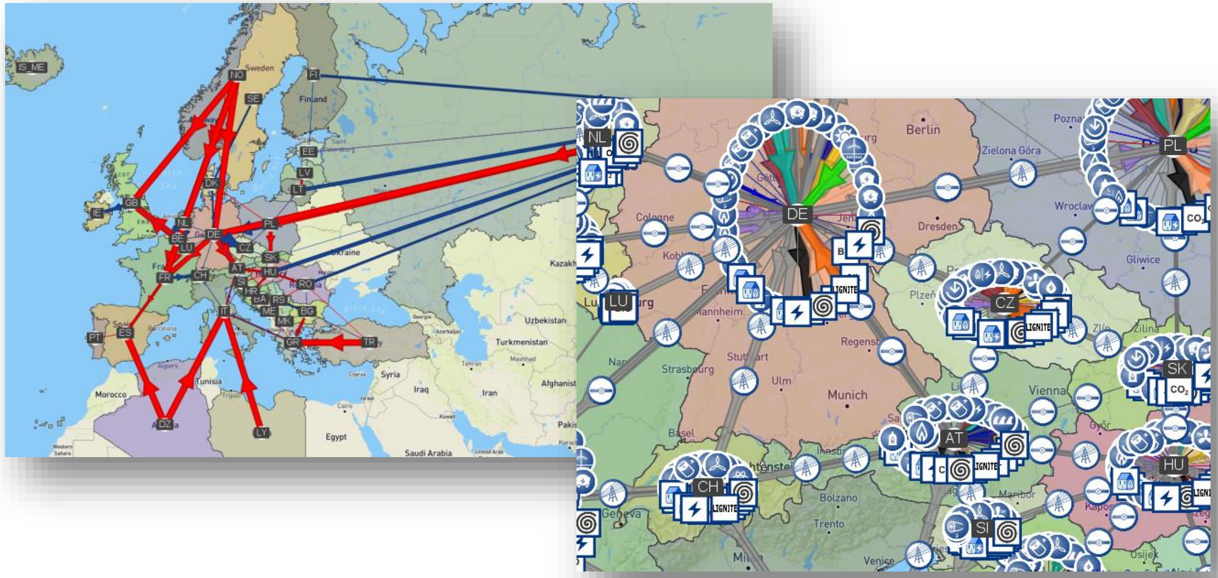


Source: Artelys (Artelys Crystal Super Grid)

(1) Latest edition of the Ten-Year Network Development Plan, prepared jointly by the European Network of Transmission System Operators for Electricity and Gas (2) The scenario is presented on Slide 12.

Key principles of the methodology

Artelys Crystal Super Grid, a modelling platform developed by Artelys for the analysis of large-scale interconnected multi-energy systems, has been used to undertake the analysis. It allows to capture the benefits of gas storage capacity for the electricity system.



Source: Artelys (views from Artelys Crystal Super Grid)

Technologies are explicitly represented at the country level, **both for the electricity and gas systems**:

- ✓ Electricity generation technologies (coal, nuclear, hydro, RES, etc.), storage assets and interconnections
- ✓ Gas production, import sources, storage assets and interconnections

The simulations are run on an **entire year**, using an **hourly time resolution** (8760 consecutive time-steps per year), and capture the impacts of RES-induced and end-user-driven **flexibility needs** on all timescales. This modelling platform is the basis on which **METIS** – a set of models and datasets delivered by Artelys to the European Commission – was developed.

Key assumptions – Scenario selection

Our simulations are carried out with Artelys Crystal Super Grid, a multi-energy modelling platform. For this study, the tool has been configured to jointly simulate the European gas and electricity sectors. The TYNDP 2018 **Sustainable Transition** scenario for the year 2030 has been chosen as the basis of this analysis.

"**Sustainable Transition** seeks a quick and economically sustainable CO_2 reduction by replacing coal and lignite by gas in the power sector. Gas also displaces some oil usage in heavy transport and shipping. The electrification of heat and transport develops at a slower pace than other scenarios. In this scenario, reaching the EU goal (80-95% CO2 reduction in 2050) requires rapid development during the 2040s to be achieved through increased technological adoption or evolution"

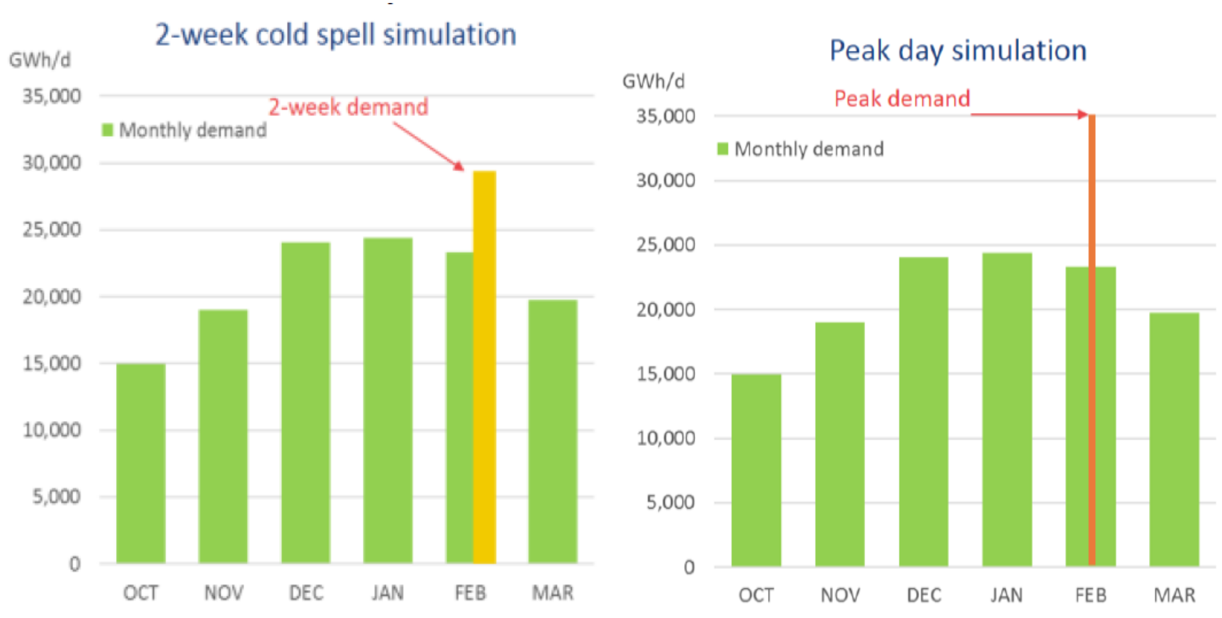
Sustainable Transition 2030

Key characteristics

- Commodity prices such that using gas is cheaper than using coal for power generation ("gas before coal" merit-order)
- The electricity generation mix includes:
  - 250 GW of gas-fired power plants
  - 120 GW of coal/lignite
  - 250 GW of solar photovoltaics
  - 325 GW of wind power

Key assumptions – Calibration

The model has been calibrated to reproduce the key results of a joint analysis carried out by ENTSOG and GIE, which aimed at assessing the impacts of a reduced availability of gas storage on gas demand curtailment. This calibration procedure was performed by using the gas module of Artelys Crystal Super Grid (i.e. without cross-sectorial flexibility).



Source: Joint ENTSOG-GIE analysis (for illustration purposes only)

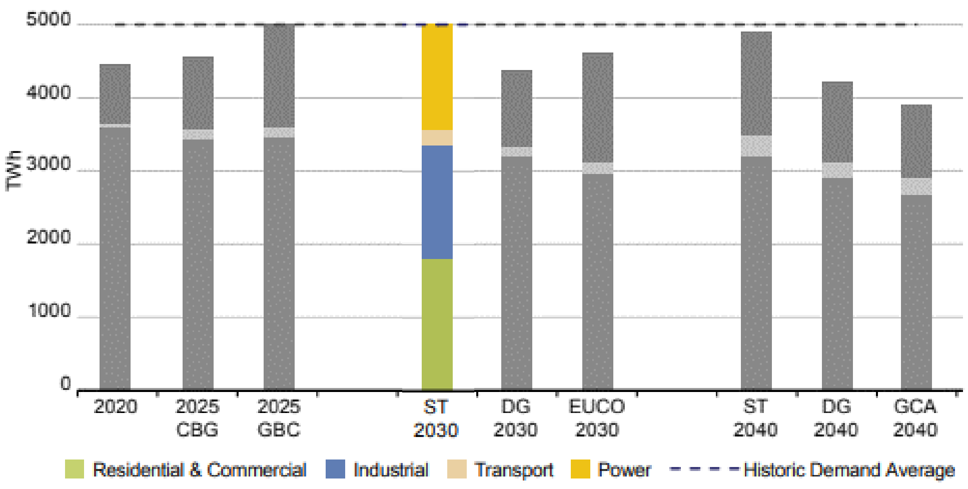
Model **calibration** to reproduce **key results** of the ENTSOG-GIE analysis in terms of gas demand curtailment

	ENTSOG-GIE analysis	This study
Peak day (TWh/day)	35	30.3
2-week demand (TWh/day)	29.5	27.7

Key assumptions – Gas module

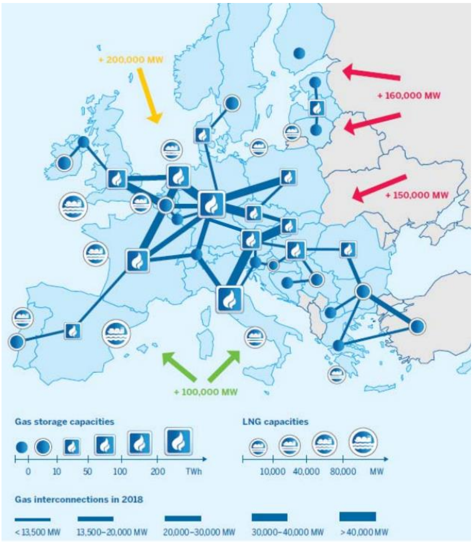
The assumptions used in the gas module are consistent with the ENTSOG assumptions presented in TYNDP 2018, in particular in terms of infrastructure, storage injection and withdrawal capacities, storage volumes, injection/withdrawal rates, and share of gas from each of the gas supply sources. The “Low” infrastructure assumption, corresponding to current infrastructure and projects having reached final investment decision, has been adopted.

Total annual gas demand in the ST 2030 scenario



Source: ENTSOs, TYNDP 2018 Scenario Report

Overview of the key EU gas infrastructure



Source: ENTSOG TYNDP 2018

Key assumptions – Electricity module

The assumptions used in the electricity module are consistent with the ENTSO-E assumptions presented in TYNDP 2018, in particular in terms of infrastructure (the “Reference Grid” assumption is used), installed capacities, commodity and CO_2 prices.

		Fuel & CO_2 prices								
	Year	2020	2025	2025	2030	2030	2030	2040	2040	2040
	Scenario	Expected Progress	Coal Before Gas	Gas Before Coal	Sustainable Transition	EUCO	Distributed Generation	Sustainable Transition	Global Climate Action	Distributed Generation
€/ net GJ	Nuclear	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
	Lignite	1.1	1.1	1.1	1.1	2.3	1.1	1.1	1.1	1.1
	Hard coal	2.3	2.5	2.1	2.7	4.3	2.7	2.5	1.8	2.8
	Gas	6.1	7.4	7.0	8.8	6.9	8.8	5.5	8.4	9.8
	Light oil	15.5	18.7	15.5	21.8	20.5	21.8	17.1	15.3	24.4
	Heavy oil	12.7	15.3	12.7	17.9	14.6	17.9	14.0	12.6	20.0
	Oil shale	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
€/ ton	CO_2 price	18.0	25.7	54.0	84.3	27.0	50.0	45.0	126.0	80.0
	Fuel Price Source	WEO 2016 New Policies	WEO2016 New Policies	WEO 2016 450	WEO 2016 New Policies with higher CO_2	Fuel Prices Provided by DG Energy	WEO 2016 New Policies with higher CO_2	WEO 2016 New Policies Fuel Prices adjusted to create a “Low Oil Price Scenario”	WEO 2016 450	WEO 2016 New Policies with higher CO_2

Source: ENTSOs TYNDP 2018

Assuming standard efficiencies and CO_2 contents

Technology	Variable cost (€/MWh_e)
Solar photovoltaics, Wind, Hydropower	0
Nuclear	5
CCGTs	95
Coal	105
Lignite	109
OCGTs	144
Oil	273

Source: Artelys. Based on TYDNP 2018 ST 2030 data; efficiency and carbon content assumptions from “Energy Technology Reference Indicator projections for 2010-2050”, EU Joint Research Centre

Definition of the sensitivity analysis

The benefits of the presence of gas storage assets is assessed by comparing a counterfactual to sensitivity analyses where the gas storage capacity is gradually reduced. In terms of gas storage volumes and injection/withdrawal rates, this corresponds to:

Storage capacity reduction (%)	Storage capacity (TWh)	Maximum injection rate (GW)	Maximum withdrawal rate (GW)
Counterfactual	**1180**	**507**	**859**
- 10 %	1062	456	773
- 20 %	944	405	688
- 30 %	826	355	602

Source: Artelys assumptions for 2030, based on current capacities and projects in several countries. Figures in Lower Heating Value.

The capacity of all the other elements of the gas infrastructure remain unchanged in the simulations (LNG terminals and onsite storage assets, pipelines).

Assumptions relative to the capacity value

Evaluating the capacity value of gas storage involves comparing different strategies to ensure electricity demand can be met at all times (counterfactual *vs* reduced gas storage sensitivity analyses). As first step, the model is calibrated in the counterfactual scenario, so as to ensure the electricity demand can be met at all times in all countries.

When simulating the sensitivity analyses, the model might find that alternative investments are required to ensure the demand can still be met at all times. The following table presents the investment options that are available to the model:

Storage reduction (%)	Investment options available to the model
Counterfactual	• **Gas-fired CCGTs & OCGTs power plants** • **Pumped-Hydro Storage** • **Batteries** • **Generic dispatchable power plants**
- 10 % - 20 % - 30 %	• **Pumped-Hydro Storage** • **Batteries** • **Generic dispatchable and flexible power plants**

Required to ensure the electricity demand can be met at all times

Investment options available in case a reduction of gas storage would result in a demand curtailment in the electricity sector

Plan of the report

Cross-sectoral impacts of a lower gas storage capacity

When comparing the counterfactual to situations where the gas storage is gradually removed we can expect to observe the following phenomena. The **tipping point** between the two regimes depends on the details of the scenario.

Small reduction
of gas storage capacity

Gas may not be available to gas-fired power plants during periods of high electricity demand due to the lower gas storage capacity.

This forces **more expensive** generation units to generate more electricity in order to meet the demand for electricity at all times.

Key benefit of gas storage measured in this case: **avoided operational costs**.

Tipping point

Larger reductions
of gas storage capacity

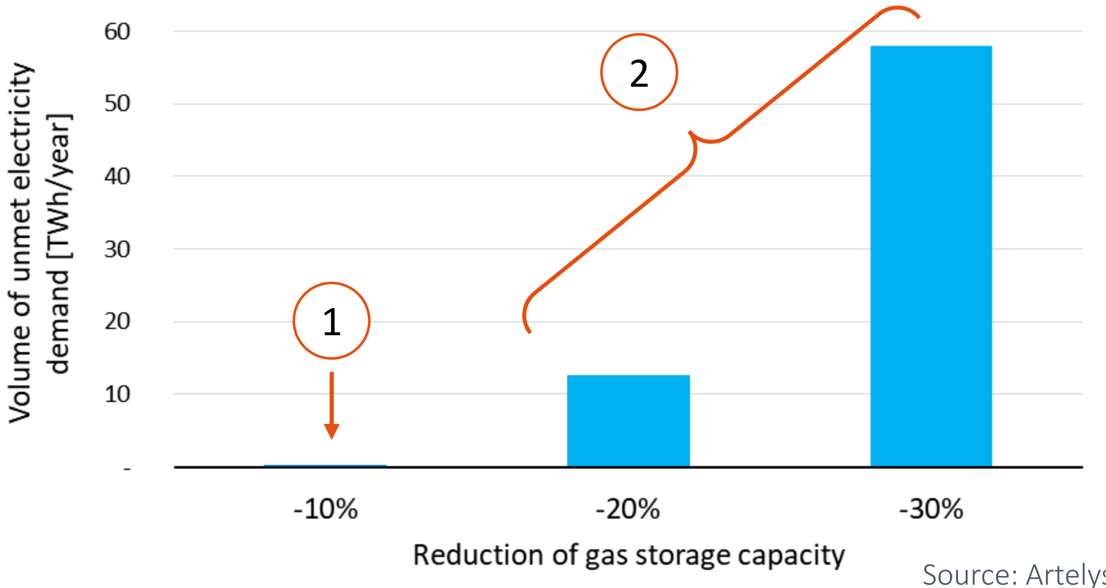
For more important reductions of gas storage capacity, the flexibility of the electricity system will be found to be totally used, and the system is not able to meet the electricity demand at all times.

This forces **additional investments** in alternative flexibility solutions in the electricity sector to be built and operated.

Key benefit of gas storage measured in this case: **avoided investment costs**.

Where is the tipping point?

In the scenario we have considered, **the tipping point between the two regimes appears between 10% and 20% reduction of gas storage capacity**. The following figure presents the annual volumes of electricity demand that cannot be met in the sensitivity analyses:



Source: Artelys

1 The reduction of gas storage capacity prevents CCGTs and OCGTs to run during high electricity demand episodes in winter due to the lack of readily available gas. The production costs of alternative generation units are found to increase.

2 A further reduction of gas storage capacity would result in **electricity demand curtailment**. This signals a need for investments in electricity flexibility or generation technologies to allow the system to meet the demand.

Key result #1 – Avoided operational costs

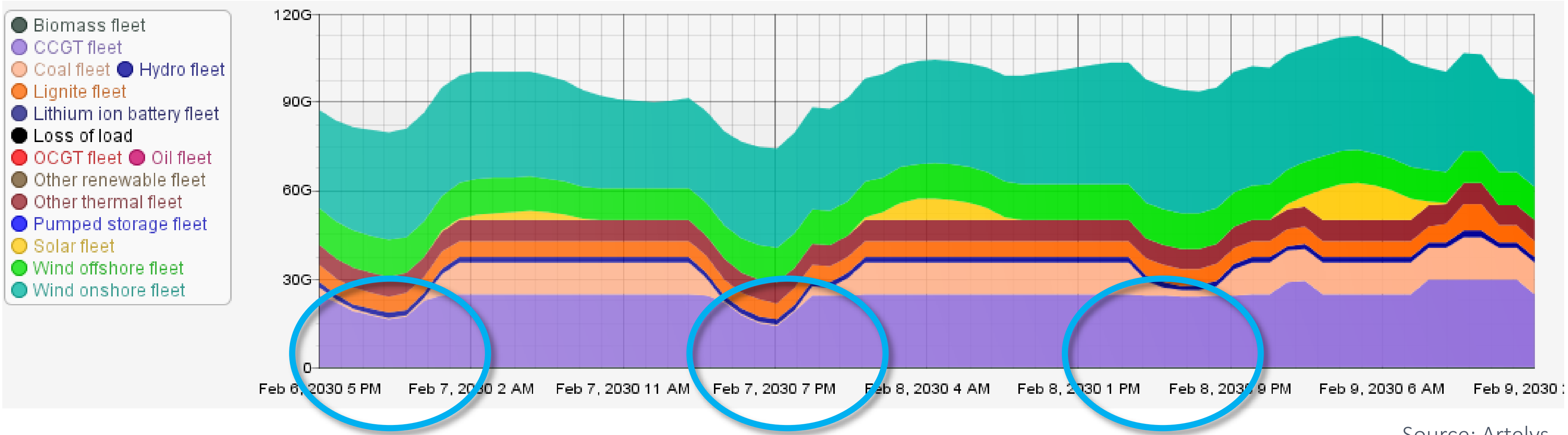
The absence of **10% of gas storage capacity** induces additional operational costs of the order of **1 B€ per year**

Remark: While the evaluation of the EU-level benefits is robust, the country-level allocation of these benefits is highly dependent on assumptions related to e.g. the portfolio of electricity generation technologies, available flexibility solutions and interconnectors. This study focuses on stakes at the EU level.

Avoided operational costs

The presence of gas storage prevents additional operational costs from materialising. This can be observed on the following two figures. They represent the way technologies are combined to ensure the electricity demand can be met at all times. The different colours represent different electricity generation technologies (see legend on the left).

Situation #1 – Counterfactual



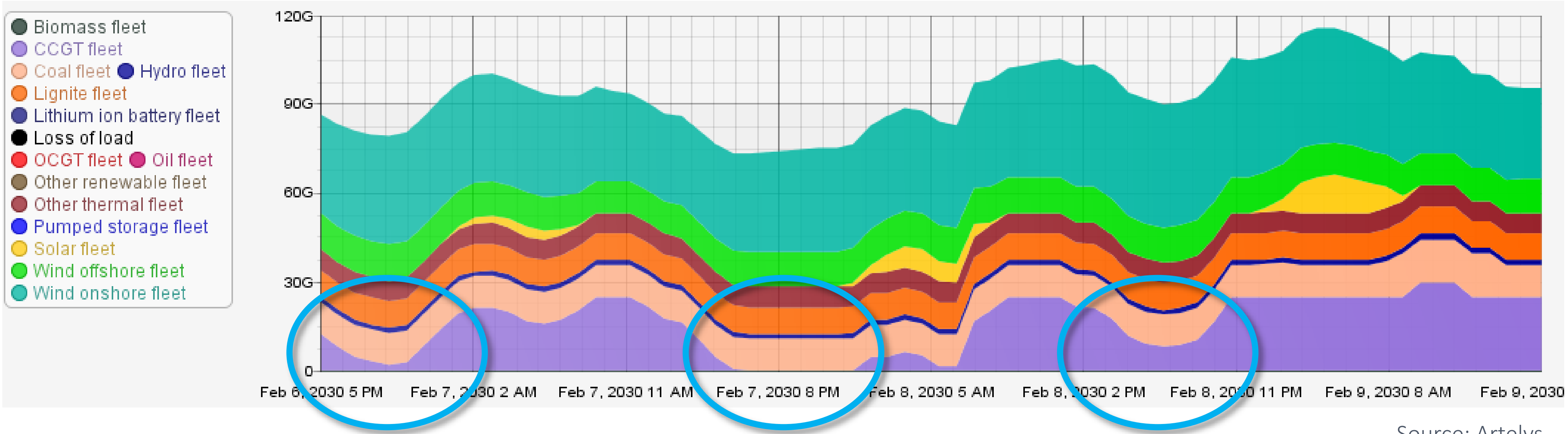
Source: Artelys

Thanks to CCGTs running almost continuously, **more expensive power plants** (in this illustration coal power plants are more expensive to operate than CCGTs due to the commodity prices assumptions) **can be stopped during some periods of the day**.

Avoided operational costs

In the situation where gas storage assets are reduced by 10%, there are some periods of the year where gas-fired power plants cannot gain access to gas. Therefore more expensive generation technologies have to remain online or to be started in order for the electricity demand to be met at all times.

Situation #2 – Additional operational costs due to the use of more expensive power plants



Source: Artelys

With our assumptions, a **10% reduction** of gas storage capacity results in more coal being used (and more greenhouse gas emissions of around 6 $MtCO_2e$/year), for an overall **extra cost of 1 B€ per year**. The impact on costs could be higher if coal use were to be limited.

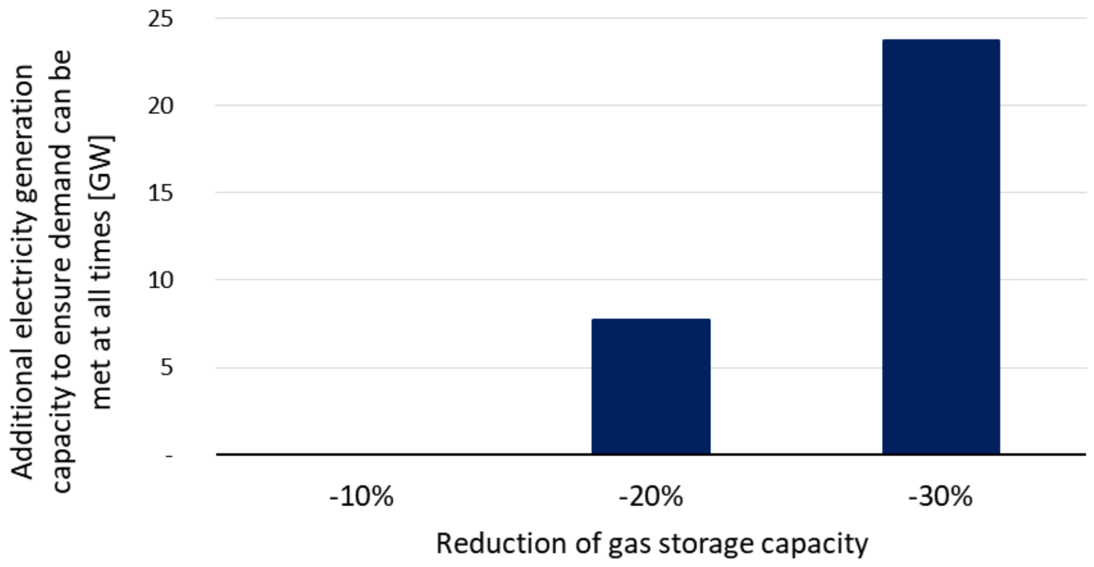
Key result #2 – Avoided investment costs

The absence of **30% of gas storage capacity** induces additional investment costs of the order of **55 B€**

Remark: While the evaluation of the EU-level benefits is robust, the country-level allocation of these benefits is highly dependent on assumptions related to e.g. the portfolio of electricity generation technologies, available flexibility solutions and interconnectors. This study focuses on stakes at the EU level.

Capacity value

Beyond a 10% reduction of gas storage assets, **a tipping point appears**. The energy system is not able to meet the demand for electricity, meaning that gas storage assets begin to develop a **capacity value**. In order to quantify this value, we have calculated the investments that are required in case the gas storage capacity is reduced by 10, 20 and 30%.



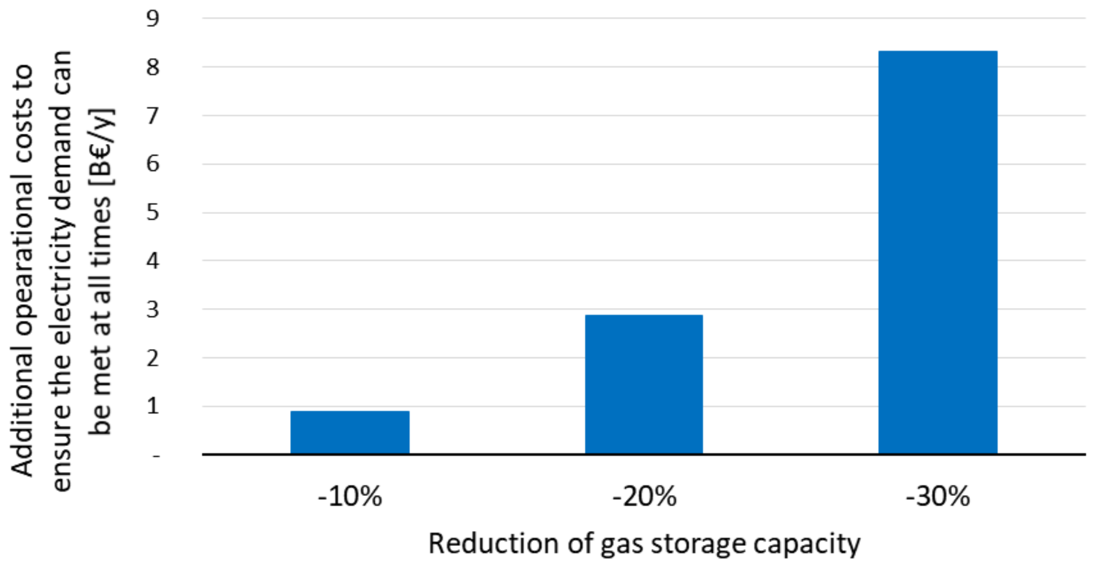
Source: Artelys

This graph shows that the absence of 30% of gas storage capacity induces additional investments in a generic electricity generation technology (assumed to be dispatchable and flexible) reaching around **23 GW** at the European level. This investment is required in order to avoid electricity demand curtailment.

The absence of 30% of gas storage assets would induce investment costs that have been estimated to reach **55 B€**.

Beyond the capacity value: operational savings

Beyond a 10% reduction of gas storage assets, gas storage assets have been shown to have a capacity value. An additional benefit of the presence of gas storage assets is that they **prevent the appearance of operational costs in the electricity sector**.



Source: Artelys

This graph shows that the absence of 30% of gas storage capacity would lead to additional operational costs of around **8 B€/year**.

This amount corresponds to the sum of the costs that would be induced by using more expensive existing assets and of the operational costs of operating the 23 GW of additional generation capacity.

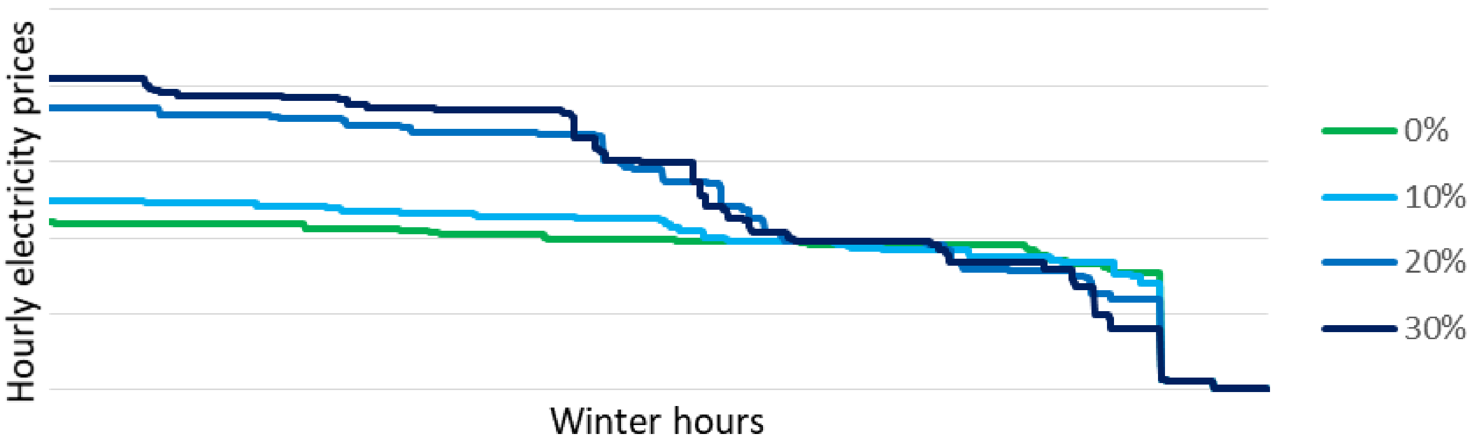
Key result #3 – Reduction of electricity price variability

In all cases, gas storage assets allow to
reduce the variability of electricity prices

Gas storage reduces the variability of electricity prices

The presence of gas storage assets in the energy system allows to **reduce the variability of electricity prices**. This is due to the better use of gas-fired power plants during the winter period and to the lower exposure to potentially higher gas prices. The winter price duration curves provided below show that, when gas storage assets are part of the system: (a) electricity prices are lower, and (b) that the variability of electricity prices (especially during the winter) is lower.

Note: periods with lower electricity prices can also appear as the system can make immediate use of gas instead of storing gas for later use (since part of the gas storage assets are unavailable).

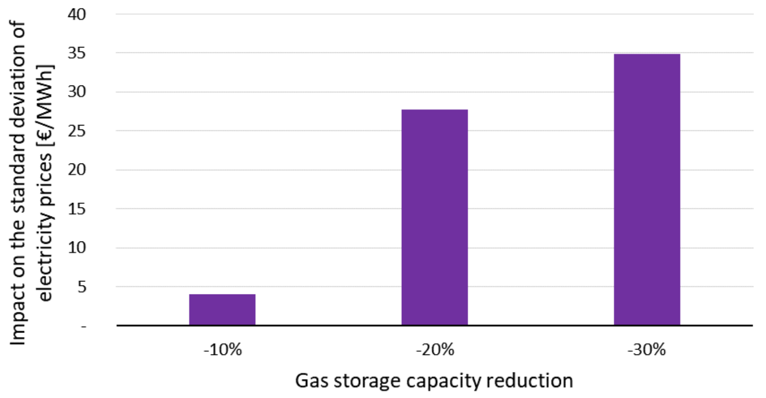


Source: Artelys

Gas storage reduces the variability of electricity prices

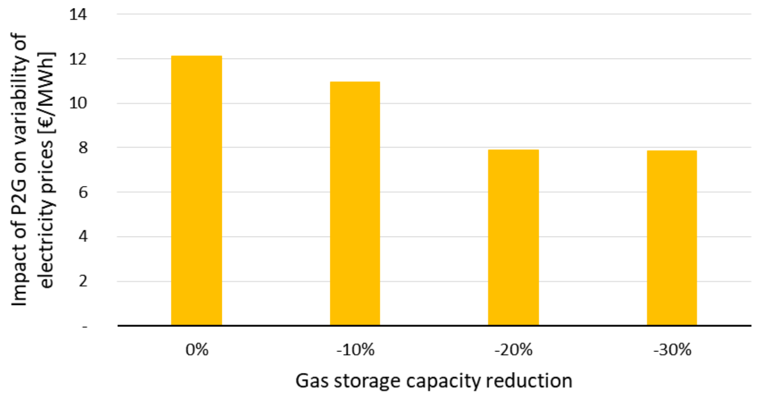
The variability of electricity prices, as measured by the standard deviation of the distribution of hourly electricity prices, is shown to increase rapidly as gas storage assets are taken out of the system. Furthermore, removing gas storage assets reduced the damping effect that P2G may have on the variability of electricity prices.

The **variability of electricity prices increases as the gas storage capacity is reduced**. This figure presents the impacts in terms of the standard deviation of the electricity prices for a given country.



Source: Artelys

Finally, we have found that the ability of P2G to reduce the variability of electricity prices is **most effective** with high levels of gas storage capacity.



Source: Artelys

Note: see annex for details on the calculations.

Plan of the report

Key conclusions and outlook

Key conclusions

- Through arbitrage, gas storage assets allow for the **best use of available resources** in well-functioning markets
- **Electricity demand curtailment** situations could appear when the gas storage capacity is reduced by 20%*
- The presence of gas storage assets **prevents unnecessary investments in electricity generation from materialising**. For illustration, we have estimated that the around 23 GW of electricity generation capacity would be required in the absence of 30% of gas storage capacity
- The presence of gas storage assets allow to **decrease the variability of electricity prices**

Outlook

The assessment of the value brought by gas storage assets undertaken in this study is based on a scenario with **limited** interlinkages between the gas and electricity sectors: P2X is absent from the scenario, and the deployment of hybrid consumption technologies is rather low compared to other scenarios. Including further cross-sectoral interlinkages, in particular in a net zero 2050 scenario, would shed light on the key role of the gas infrastructure as an enabler of the energy transition.

*In some countries, problems may arise for lower reductions of gas storage capacity due to local circumstances that have not been modelled in this study

Plan of the report

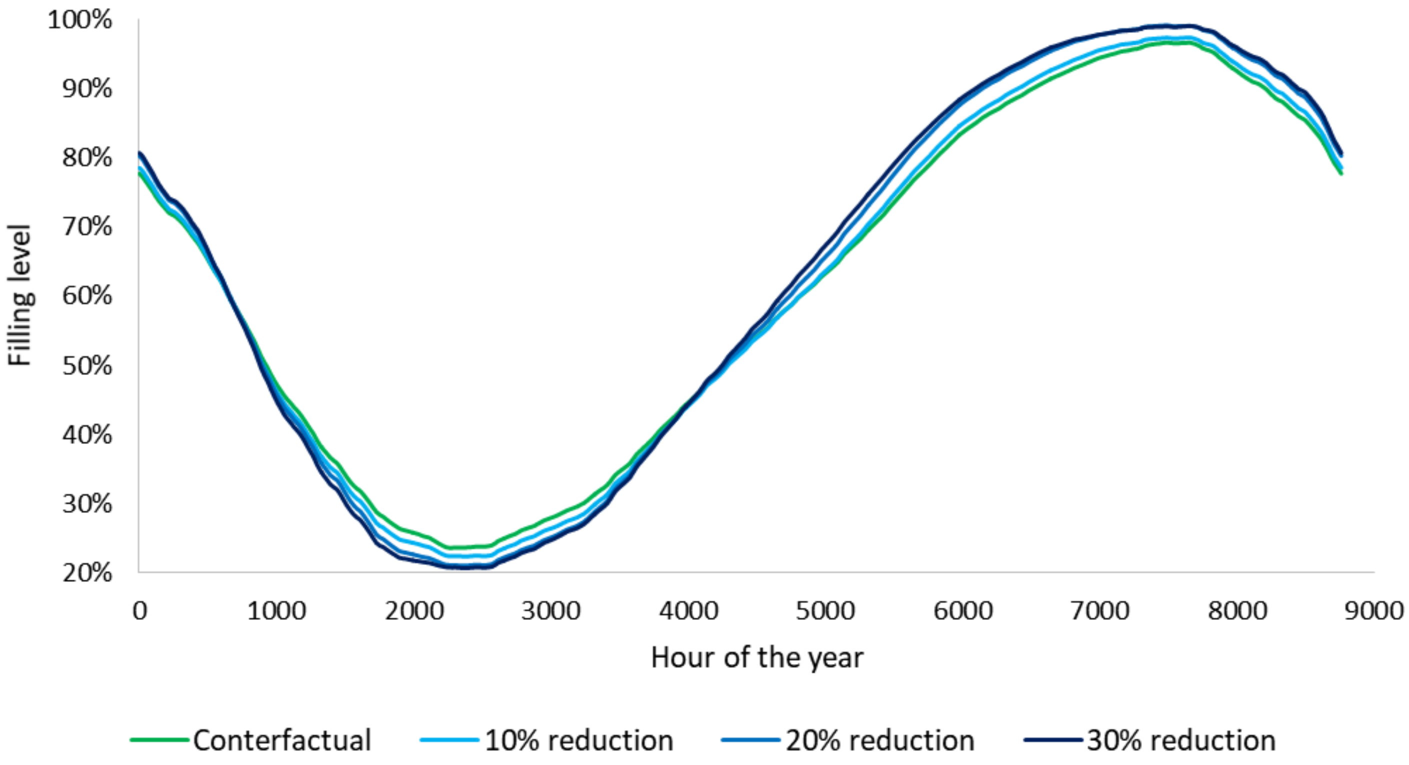
Annexes

The annexes contain the following analyses:

- Evolution of the filling level of EU gas storage assets in the counterfactual and sensitivity analyses
- Sensitivity analysis with milder climatic conditions and reduced gas storage availability
- Impacts of P2G on electricity prices

Gas storage filling levels

The injection/withdrawal strategy is not profoundly modified by the reduction of the gas storage capacity, as can be seen from the following figure, where we present the evolution of the volume of gas stored in the EU gas storage assets over the year for the counterfactual scenario and the three sensitivity analyses.



Source: Artelys

Annexes

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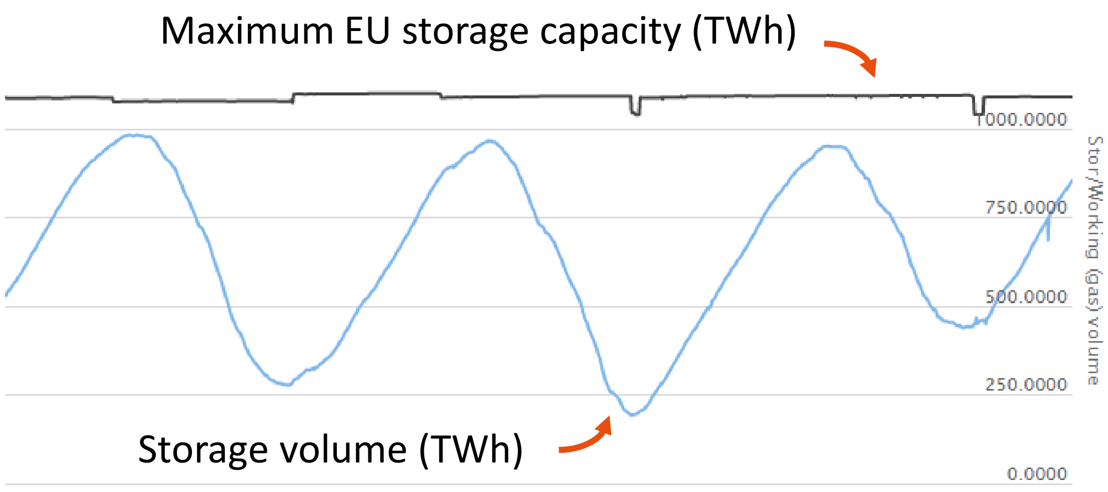
Sensitivity analysis

A sensitivity analysis has been performed in a situation with lower stress on the system (**higher temperatures**), but with a **maximum filling level of 80%**.

First change: milder conditions

Second change: filling level ≤ 80%

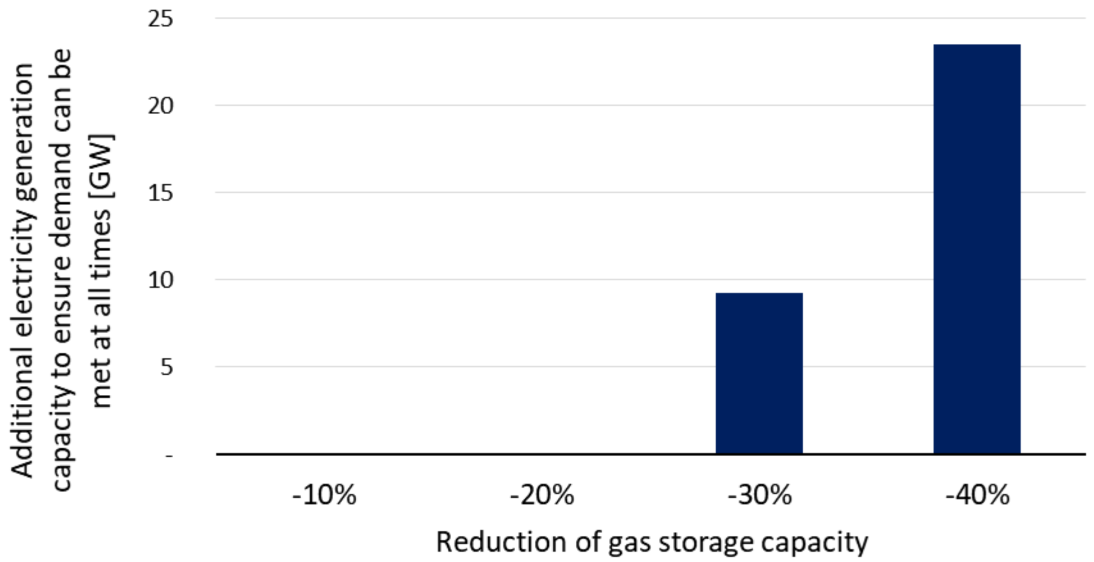
	ENTSOG-GIE analysis	Central set of results	Sensitivity analysis
Peak day (TWh/day)	35	30.3	26.7
2-week demand (TWh/day)	29.5	27.7	24.3



Source: GIE AGSI Transparency Platform

Sensitivity analysis - Capacity value

Beyond a 20% reduction of gas storage assets, a **tipping point appears**. The energy system is not able to meet the demand for electricity, meaning that gas storage assets begin to develop a capacity value. In order to quantify this value, we have calculated the investments that are required in case the gas storage capacity is reduced by 10, 20, 30 and 40%.



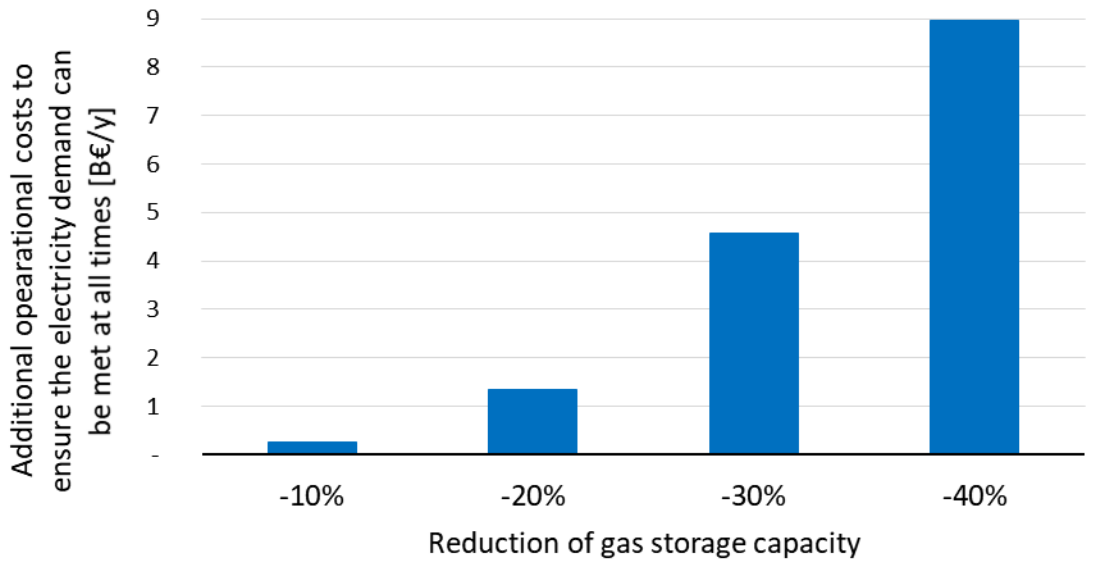
Source: Artelys

This graph shows that the absence of 40% of gas storage capacity induces additional investments in a generic electricity generation technology (assumed to be dispatchable and flexible) reaching around **23 GW** at the European level. This investment is required in order to avoid electricity demand curtailment.

The absence of 40% of gas storage assets would induce investment costs that have been estimated to reach **55 B€**.

Sensitivity analysis - Operational savings

Beyond a 20% reduction of gas storage assets, gas storage assets have been shown to have a capacity value. An additional benefit of the presence of gas storage assets is that they **prevent the appearance of operational costs in the electricity sector**.



Source: Artelys

This graph shows that the absence of 40% of gas storage capacity would lead to additional operational costs of around 9 B€/year.

This amount corresponds to the sum of the costs that would be induced by using more expensive existing assets and of the operational costs of operating the 23 GW of additional generation capacity.

Annexes

The annexes contain the following analyses:

- Evolution of the filling level of EU gas storage assets in the counterfactual and sensitivity analyses
- Sensitivity analysis with milder climatic conditions and reduced gas storage availability
- Impacts of P2G on electricity prices

Impacts of P2G on electricity prices

The scenario that has been selected for this study does not assumes a very low level of power-to-gas (P2G) capacity. In order to estimate the impacts P2G could have on electricity prices, we have performed an ex-post analysis described below.

1. **Computation of electricity prices without P2G** – This is a direct result of the simulation of the demand-supply equilibrium for electricity at each hour of the year.

2. **Modification of the structure of electricity prices –** This second step aims at representing the fact that, if P2G were to substantially develop, the number of hours with low marginal costs would almost disappear. Indeed, the structure of the electricity prices would take into account the willingness of hydrogen consumers to pay for electricity. Since hydrogen consumers would favour using electricity for hydrogen production as long as the produced hydrogen is cheaper than if produced using an alternative technology (steam methane reforming is considered here), the electricity price will be set by the cost of SMR (taking into account the efficiency of the electrolysers, the cost of CH_4 and of CO_2).

3. **We have then repeated these steps for each of the considered scenarios** (counterfactual and sensitivity analysis), and computed the variability of electricity prices in each case. In this case, the variability has been defined as the standard deviation of electricity prices.

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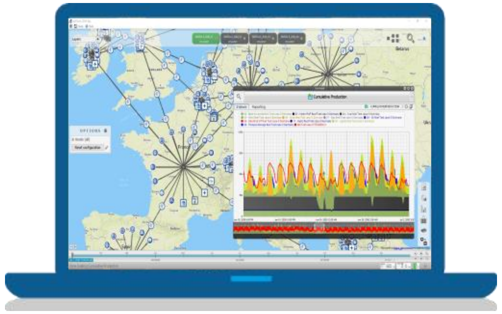

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