Quantifying Gas Storage Needs for a Resilient and Integrated European Energy System

Final report

A study for: GSE Gas Storage Europe

COMPASS LEXECON Artelys

09 March 2026

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Table of Contents

Introduction	4
Executive Summary: Model-Based Assessment	7
Executive Summary: Regulatory Analysis	12
Model-Based Assessment: Role of UGS in Maintaining Resilience to Security of Supply Shocks	25
Table of contents of the modelling section (with links to subsections)	26
Regulatory Analysis	60
Starting Point – Economics of Gas Storage	61
Key Results	67
Summary of Conclusions	105
Annex A – Modelling approach and additional results	107
Annex B – Regulatory Analysis: Filling Measures – Description and Country Case Studies	121

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About this study

GSE has commissioned Compass Lexecon and Artelys to assess the suitability of the current regulatory framework for security of gas supply as well as to determine gas storage capacities required in the mid-term (up until 2040).

- The study aims to
  - **Assess the current framework for gas security of supply** against evolving risk drivers and provide insights on how to overcome potential shortcomings.
  - **Quantify gas storage capacity (volume and rate) needs** of the European energy system under various scenarios and impacted by various supply shocks.
- Both elements of the study **take into account the growing interconnection between the gas and electricity sectors** and the increasing importance of weather dependent power generation impacted e.g. by *Dunkelflaute* events.

- **Compass Lexecon** and **Artelys** have developed the study jointly:
  - **Compass Lexecon** analysed the suitability of the current **security of supply framework** and developed this analysis against the background of relevant past work – i.a.:
    - In its recent work for **Eurelectric** Compass Lexecon developed methodological principles for redefining security of supply in the power sector (link)
    - In earlier work for **GSE** Compass Lexecon analysed the failure of the market to remunerate all values provided by gas storages (link)
  - **Artelys** carried out the **modelling** for the study leveraging inter alia past work
    - In its recent work for **GSE** Artelys assessed the required hydrogen storage capacities (link)
    - In an earlier study for **GSE** Artelys assessed the values provided by hydrogen storage (link)

Source: Compass Lexecon and Artelys

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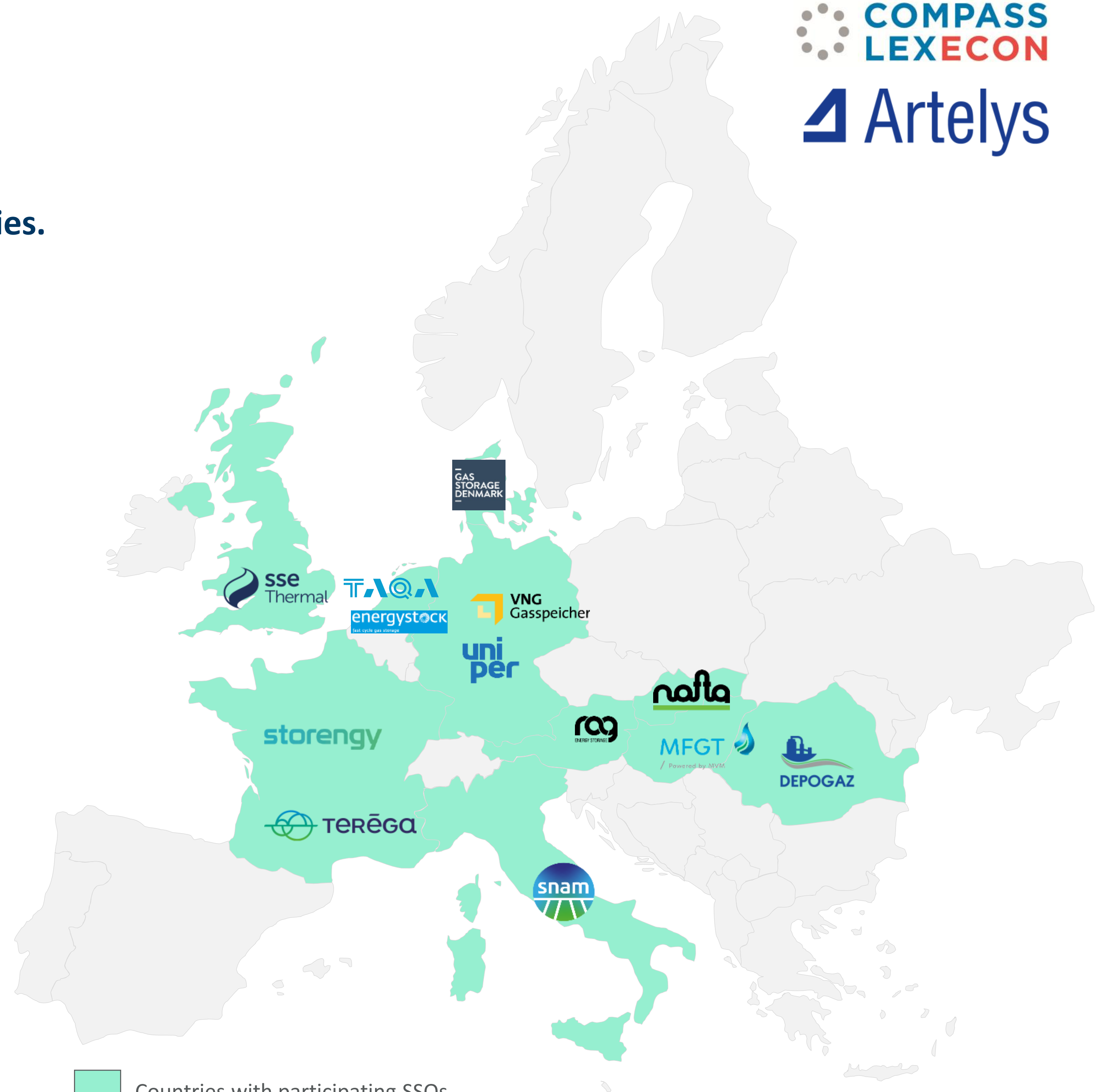
Participating SSOs (Funding Members)

The 13 funding members of the study are from ten different countries.

- 13 participating SSOs
  - Gasunie/Energystock
  - Gas Storage Denmark
  - Hungarian Gas Storage
  - Nafta
  - RAG
  - SSE Hornsea (UK)
  - Stogit/SNAM
  - Storengy
  - TAQA
  - Terega
  - Uniper
  - VNG
  - DEPOGAZ



Countries with participating SSOs.

Abbreviations: SSO … Storage System Operators
Source: GSE

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Study Approach

GSE has commissioned Compass Lexecon and Artelys to assess the suitability of the current regulatory framework for security of gas supply as well as to determine gas storage capacities required in the mid-term (up until 2040).

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Modelling-based assessment

Quantify methane storage capacity needs (volume and rate) of the European energy system under various scenarios and impacted by various supply shocks

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Regulatory analysis

Assess the current framework for gas security of supply against evolving risk drivers and provide insights on how to overcome potential shortcomings – with a view on the role of gas storages and their ability to provide insurance value to the EU energy system.

Source: Compass Lexecon and Artelys

Executive Summary:
Model-Based Assessment

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Model-based assessment of role of UGS in maintaining resilience to SoS shocks (1/4)

Introduction to the modelling study

- This GIE study assesses the role of underground gas storage (UGS) and illustrates how storage contributes to overall system resilience by modelling different evolution pathways for the future EU energy system under stress situations.
- The analysis uses the state-of-the-art *Artelys Crystal Super Grid* platform, which captures the complex interdependencies between methane, electricity, and hydrogen systems. The model includes all major cross-vector flexibility options, simulated at an hourly time resolution over full gas years, over the entire European system, with a national geographical resolution.
- The assessment focuses on the **2030** and **2040** horizons, using the **NT+ scenario** (reference scenario) developed by the ENTSOs in TYNDP 2024 (the NT+ scenario is itself based on a previous version of NECPs and used by the European Commission). A deviation scenario is also explored to perform a “stress-test” with a slower decline in methane consumption (slower uptake of hydrogen and heat pumps).
- System resilience is evaluated under three security-of-supply stress conditions:
  - Harsh winter (based on historical climate conditions),
  - 3-month LNG supply reduction, and
  - 3-month Norwegian supply reduction.

The drivers of UGS operations evolve, but seasonal flexibility services remain broadly unchanged in NT+ 2040

- The NT+ scenario assumes rapid decarbonisation trajectory, with methane demand falling by **36%** by 2040 compared to 2019, driven by hydrogen deployment, electrification of heating and renewable power generation. Storage capacities are assumed to decrease by 14.5% at EU-level in 2040, to reflect possible repurposing to UHS and national plans for closures and expansions.
- Despite these profound system changes – lower methane use, different gas-fired generation patterns, biomethane development and reduced annual imports – **UGS continues to play a vital role in 2040 and follows an operation profile similar to the one observed in 2023-2024,** with steady injections during summer and variable withdrawals in winter.
- **Seasonal flexibility needs remain broadly stable. Compared with the 2023-2024 gas year** (673 TWh injected, 614 TWh withdrawn), **gas cycled through UGS reaches 760 TWh in 2030 (+18%) and 575 TWh in 2040 (–10%).**

Sources: Artelys analyses and modelling based on NT+2030 and NT+2040 scenarios from TYNDP2024

Model-based assessment of role of UGS in maintaining resilience to SoS shocks (2/4)

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UGS is a key provider of sustained peak deliverability

- A key role of UGS for security of supply is the ability to provide sustained peak capacity.

Evolution of peak methane demand

- Two drivers impact the evolution of the methane peak demand, in opposite directions:
  - Methane annual demand for heating significantly decreases in NT+ scenarios (-57% of residential and tertiary demand in 2040 compared to 2019). As this demand presents a thermosensitive profile, methane peak daily final demand decreases to 11.1 TWh/day (vs above 20 TWh/day in 2021).
  - Electricity final demand volume grows and increasingly exhibits a thermosensitive component, particularly due to the development of heat pumps, which significantly increase electricity demand during cold periods. Variable renewable generation (wind, PV) also increases short-term volatility and raises the need for sustained back-up gas-fired power generation. Peak methane demand for power generation is **10.7 TWh/day** in 2040 (vs 5 TWh/day in 2021).
- Overall, sustained high deliverability rates from the methane system are required, notably during cold spells combined with low renewable output (*Kalte Dunkelflaute*). In NT+ 2040:
  - **Peak daily** methane consumption reaches **21.4 TWh/day** (-12% vs 24.5 TWh/day in 2023-2024),
  - **2-weeks peak** reaches **18.2 TWh/day** (-16% vs 21.6 TWh/day in 2023/24).
- In NT+ 2030, both metrics remain close to current levels (+0.7 TWh/day in 2030). **Peak demand therefore decreases less than annual methane consumption** (-23% in NT+ 2040 compared to 2023-2024).

Provision of methane peak demand requires UGS

- These high peak demand levels can only be met thanks to **short-term flexibility services from UGS**, which provides:
  - 58% of supply during peak day (vs 44% in 2024), 51% of supply during a 2-weeks peak (vs 34% in 2021), and 42% of the supply in January 2040.
- Peak withdrawals from UGS are found to **increase** despite decreasing consumption peaks, since import contribution at peak decreases due to lower annual methane demand:
  - 10.9 TWh/day in 2023-2024, 13.4 TWh/day in NT+ 2030 (+23%) and 12.5 TWh/day in NT+ 2040 (+15%).

Sources: Artelys analyses and modelling based on NT+2030 and NT+2040 scenarios from TYNDP2024

Model-based assessment of role of UGS in maintaining resilience to SoS shocks (3/4)

High UGS deliverability depends on adequate filling levels

- UGS withdrawal (and injection) rates depend heavily on UGS filling level (the more a storage site is filled, the more withdrawal capacity it has). **Therefore, the ability of UGS to support peak demand decreases during winter**, depend on initial filling levels and events occurring during the season (weather, supply shocks, etc.).
- As an illustration, in NT+ 2040, the 21.4 TWh/day peak demand could not be met if it occurred after mid-February, because storage levels would be too low to deliver the required withdrawal rates.
- **Maintaining filling levels at the beginning of winter is essential**. In all simulations, storages are assumed to be **90% full on 1 October**. Lower initial filling levels would cause withdrawal capacity to decline earlier and more sharply, threatening security of supply.

UGS is a cornerstone of system resilience under SoS shocks

- UGS has been found to be essential for meeting demand in normal conditions, and during all modelled SoS shocks (harsh winter, LNG disruption, Norwegian supply reduction).
  - **Harsh winter**: methane demand rises by 6-6.5%, reducing end of winter storage levels by 12-13% (reaching a minimum filling level of 17% of WGV UGS capacity in NT+ 2030 and 25% in NT+ 2040), resulting in minimum withdrawal capacity 22-23% lower (reduction by 13-14% of maximum withdrawal capacities, down to 51% of maximum in NT+2040 and 44% in NT+ 2030).
  - **Norwegian supply shock**: by mid-February, the capacity margin (between daily peak demand and system deliverability capacity) narrows to 11-13% of demand (1.9 to 2.8 TWh/day), on days where UGS supply 57% - 61% of the deliverability (2040 and 2030).
  - **LNG supply shock**: while peak daily demand on 8 January can be met, a similar peak in late January or early February could not be covered due to declining storage levels and therefore reduced withdrawal capacity.
- These narrow deliverability margins could become insufficient if shocks occur later in winter, if multiple shocks overlap, or if initial filling levels fall below 90% (storage filling levels were at 82.6% on 1 October 2025).

Sources: Artelys analyses and modelling based on NT+2030 and NT+2040 scenarios from TYNDP2024

Model-based assessment of role of UGS in maintaining resilience to SoS shocks (4/4)

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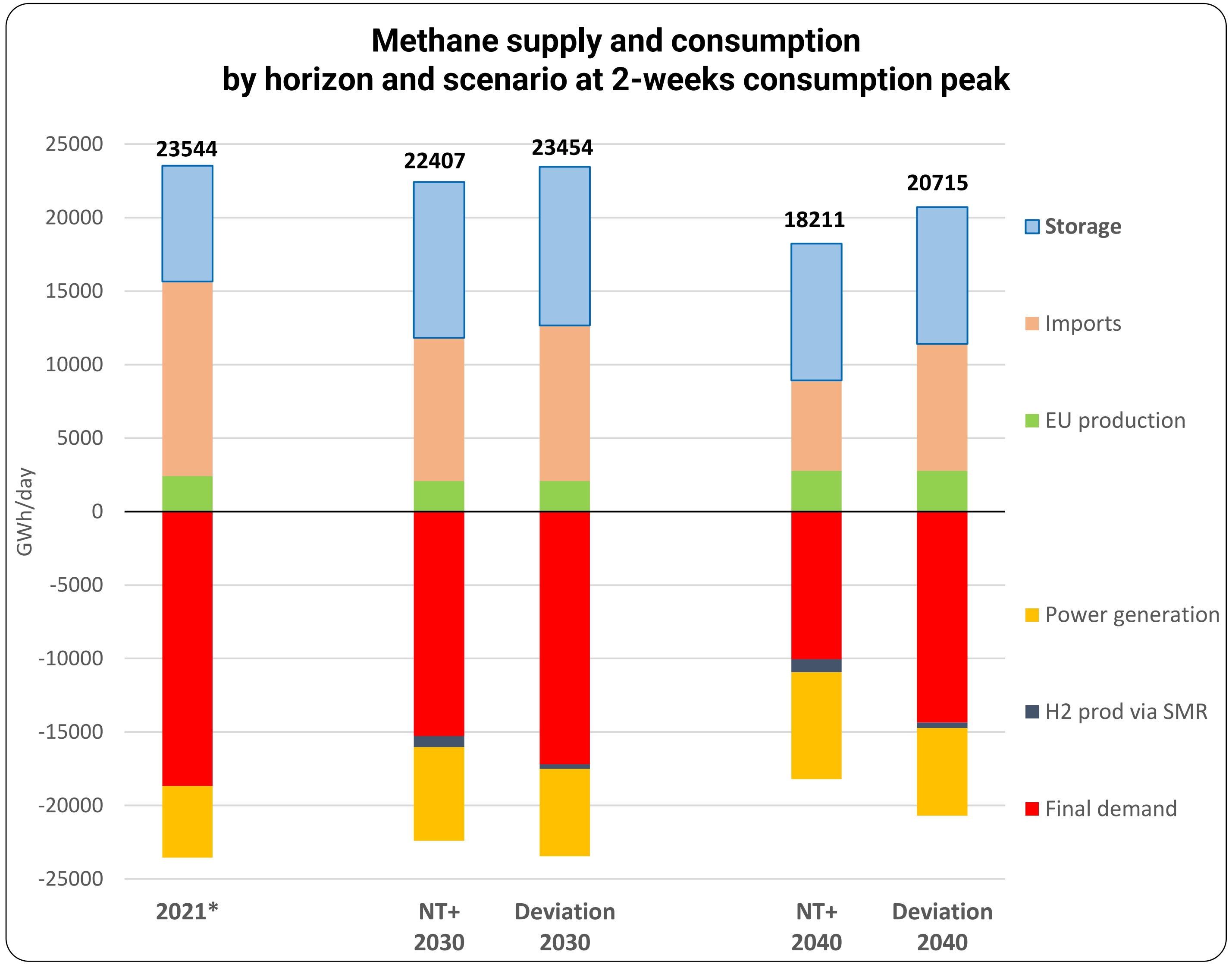
Deviation scenario: different flexibility dynamics, similar UGS needs

- The deviation scenario explores a slower decline in methane consumption due to slower deployment of hydrogen and heat pumps. Methane demand in 2040 is only **19% lower than in 2019** (vs -36% in NT+). This results in systematically higher peaks (+2.5 to 2.8 TWh/day across all flexibility timescales).
- In the 2040 peak consumption day:
  - Final methane demand is **45% higher** than in NT+,
  - Methane for power generation is **21% lower** (lower electrolysis and heat pump deployment).
- However, higher annual demand leads to higher baseload imports, which are found to offset the increased peaks. As a result, **overall UGS needs remain similar** to the ones observed in NT+.

Conclusion

- Across all scenarios, stress tests, and time horizons, the modelling demonstrates that while the underlying drivers of system flexibility evolve significantly, **UGS consistently remains a fundamental asset for EU gas and electricity security of supply.**
- UGS is particularly crucial for delivering high withdrawal rates during peak demand periods and under stress conditions. These deliverability levels can only be achieved when **storages are sufficiently filled**.



Sources: Artelys analyses and modelling based on NT+2030 and NT+2040 scenarios from TYNDP2024

Executive Summary: Regulatory Analysis

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Starting Point: Drivers for Rethinking Security of Supply in the Gas Sector

Various changes in the gas and wider energy system as well as in the wider geopolitical environment may require rethinking the EU security of supply framework.

Pre-Energy Crisis 2022

Driver group 1:
Supply changes

- **Reduced pipeline** import capacities (Russia)
- **Higher LNG** import capacities
- Expanding **global LNG supply**
- Expanding global **competition for LNG**
- Exits of **producers with own storage** (GPE)
- Low and volatile summer winter spreads ("missing money") **threatening economic viability of gas storages**

Driver group 2:
Demand changes

- (Temporary) **reduced total gas demand**
- Changed **power sector gas demand** – volume & flexibility (RES expansion, BESS, climate change)
- Changed **power sector elasticity of demand** (electrification and coal phase-out)
- Increased importance of affordability considerations

Driver group 3:
Supply shocks

- Increasing **weather dependency of power** generation (RES expansion + coal phase-out)
- Increased **dependency on single infrastructures**
- Increased **geopolitical risk**

"Today" and going forward over the mid- to long-term

.

Abbreviations: BESS … Battery Energy Storage System, GPE … Gazprom Export, RES … Renewable Energy Source
Source: Compass Lexecon analysis

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Key Contributions of the Regulatory Analysis Part of this GIE/GSE Gas Storage Study

This study makes contributions to (i) assessing gas and wider energy sector security of supply risks, (ii) enhancing the SoS standards, (iii) harmonising filling mechanisms and (iv) improving cost-sharing in the EU Security of Supply Framework.

Key Building Blocks of the EU SoS Framework	Contributions of this GIE/GSE Gas Storage Study towards a revised EU Gas SoS Framework
I. Security of Supply Risk Assessments	▪ Highlight the **disconnect between EU gas and electricity risk assessments** ▪ Demonstrate the **critical role of stored gas** in maintaining system-wide resilience, including within the electricity sector ▪ Propose **updated risk-assessment methodologies** better reflecting the integrated, multi-energy system
II. Infrastructure and Supply Standards	▪ Develop **clear, actionable recommendations** for updating security of supply standards that align with current system needs ▪ Conduct a systematic assessment of customer types to **underpin discussions on the appropriate scope for the supply standard**
III. Gas Storage Filling	▪ Analyse the **value of storage filling,** highlighting benefits that are only partially captured by market signals ▪ Introduce a **comprehensive toolbox of measures** to strengthen security of supply through gas storage ▪ Link these measures to **concrete implementation** within national preventive action and emergency plans.
IV. Cost Sharing for SoS measures	▪ Identify **limitations in the current cost- & burden sharing** for gas SoS measures ▪ Lay the foundation for a **debate** on **potential EU-wide funding mechanisms**

Abbreviations: SoS … Security of Supply
Source: Compass Lexecon analysis

Key Recommendations of the Regulatory Analysis

Ongoing and expected changes require an evolution of the market and regulatory framework for the EU gas sector.

I. Enhance the EU-wide SoS assessments

- **Improve & refine the SoS assessment and align it with the power sector** (gas <> electricity interlinkage, aligned & expanded shock scenarios, extended horizons, consider gas infrastructure changes)
- **Determine required storage infrastructure and filling**

II. Redefine national SoS standards

a) Infrastructure Standard

- **Improve & refine the standard; integrate it with the power sector** (volume assessments, forward-looking, consider storage properties, reinforce regional perspective, consider availability of gas sources, incorporate new peak demand scenarios)

b) Supply Standard

- **Expand coverage** (industry and electricity generation)
- **Provide guidance and monitoring of national implementation** also ensuring physically gas availability

III. Allow for / mandate storage filling measures post 2027 (in the light of missing money)

- **Establish a framework for gas storage beyond 2027 ensuring insurance value is provided** (i.e. storage capacity and their filling) contributing to the coverage of missing money
- **Consider increasing transport tariff discounts** (e.g. 90%) for storage access points.

IV. Re-assess EU-wide sharing of cost for SoS-measures

- **Reassess the principles and mechanisms for SoS cost sharing** (consider distribution of national storage capacities, gas sector’s contribution to power sector SoS and coverage of SoS cost incurred outside crisis situations).

Abbreviations: SoS … Security of Supply
Source: Compass Lexecon analysis

Enhance the EU-Wide SoS Assessments

December 2025 EC "Fitness check" on Energy Security
Also, the EC Study highlights the limited consideration of gas and power market interdependencies in EU energy risk assessment

The current EU gas security of supply framework has limitations in its assessment of risks faced by the European energy system.

Current regulation – SoS assessments

	Electricity	Gas		Hydrogen
SoS Assessment	European Resource Adequacy Assessment	SoS Simulation	Winter Supply Outlook	None
Region	EU-level	EU-level[1]	EU-level	–
Frequency	Annually	Every 4 years	Annually	–
Modelling horizon	Up to 10 years	Status quo	Up to 1 year	–

Issues

The gas sector risk assessments shows limited consideration of
- volatile **power sector gas demand** and
- dynamic **evolvements of the power sector** (electrification and RES-deployment, increase of gas-fired generation capacities, reduced coal to gas switching ability)

- Security of Supply assessments **do not determine storage needs** and **storage filling needs**

- **Limited alignment of the power and gas sector risk assessment,**
- Particularly: non-aligned weather risk scenarios (power: weather dependent RES generation (incl. kalte Dunkelflaute); gas: cold spells)

- Limited **modelling horizon** of gas SoS risk assessment: 1-year horizon of the union wide assessments
- Generally, backward looking demand assumptions (**historical peak demand**) – not taking into account changing gas demand patterns or alternative scenarios for the energy system evolvement

- Incongruencies in **infrastructure needs for SoS vs. decarbonisation impact on gas infrastructure** (e.g. via repurposing)
- Gas infrastructure decommissioning plans are generally not considered in risk assessments (also due to the limited time horizon of the latter)

Potential remedies

1 Improve the **interlinkage between the gas and electricity** security of supply and flexibility assessment

2 Determine **gas storage capacity and filling required** to ensure SoS at the desired level taking into account filling level dependence of storage withdrawal

3 **Expand shock scenarios** beyond cold-spells to account e.g. for **reduced renewable power generation** and other extreme events linked e.g. to climate and/or geopolitical events

4 **Extend the analysis horizon to 10 yrs. in the future** (and beyond)

5 Consider **gas infrastructure changes** (storage and pipeline), e.g. due to repurposing to hydrogen

Abbreviations: SoS … Security of Supply, RES … Renewable Energy Source.
Note: [1] Basis for national and regional risk assessments.
Source: Compass Lexecon analysis

Redefine National Infrastructure Standard

December 2025 EC "Fitness check" on Energy Security
In its study also the EC underscores the need for a more cross-sectoral approach in risk assessments and scenario planning.

The current infrastructure standards has several shortcomings that mandate improvement.

Current regulation

Infra-structure Standard

N-1 requirement:
- in the event of a **disruption of the single largest gas infrastructure**, the remaining infrastructure must be able to satisfy total gas demand **during a day of exceptionally high gas demand** occurring with a statistical probability of once in 20 years
- Requirements can also be met at a **regional level**

Issues

- Largely **peak demand (capacity) focused (N-1)** not taking into account the need to refill storages in summer
- Limited – if at all – consideration of **storage withdrawal curves** (i.e. significant dependence of withdrawal capacity on filling levels). Filling storages is therefore also important to have available hourly capacity to meet peak loads
- Often **limited to the individual member state** – thereby not always considering the impact of transit flows from/to neighbours in an emergency
- Usually **backward looking** (historical peak demand) – not taking into account changing gas demand patterns (cold winter vs. cold Dunkelflaute as main crisis event)

Relevance for gas storage:
- Might overlook infrastructure bottlenecks for storage refilling
- Might structurally overlook the regional impact of storages

Potential remedies

1 **Add volume assessments** to the current peak demand assessments (e.g. filling of storages in summer when withdrawal capacity does not count towards standard fulfilment)

2 Take a **forward-looking perspective** and **demand evolvements** (i.e. gas usage in the power sector)

3 Consider **storage filling needs and withdrawal curves** in the assessment

4 Reinforce the **regional perspective** considering **transit requirements** in crisis settings

5 Consider disregarding infrastructure that does not anymore give **access to gas sources** (e.g. historic routes for Russian imports) from the N-1 criteria

6 Incorporate **new peak demand scenarios** (e.g. early winter **kalte Dunkelflaute** events)

Source: Compass Lexecon analysis

December 2025 EC "Fitness check" on Energy Security
Also, the EC Study highlights the potential for a clearer definition of the supply standard to encourage storage filling and identifies a misalignment between the "protected customer" definition between the gas and electricity frameworks.

Redefine National Supply Standard

The assessment provided has highlighted several shortcomings of the supply standards that mandate improvements.

Current regulation

Supply Standard

Ensure gas supply to **protected customers** (households, and depending on member state SMEs, essential social services and/or district heating) for:

(a) extreme temperatures during 7-day peak period occurring with a probability of once in 20 years

(b) 30 days of **exceptionally high gas demand**, occurring with a probability of once in 20 years;

(c) 30 days in the case of **disruption of the single largest gas infrastructure** under average winter condition

Issues

- Missing coverage of customers **not falling within the "protected customer"** category (incl. **power generation and industry**) for whom continuity (or not) of gas supply might have wider economic impact
- **Binary choice** between protected and non-protected customer may **not reflect customers' willingness to pay** for security of supply
- Incongruencies between the **supply standard analysis horizon (next season) and end-user supplier switching lead-times (three weeks)** leading to difficulties in assigning responsibilities for the supply standard
- Unclear requirements – i.e. ***how*** member states must ensure compliance with supply standard and how to check if the supply standard was met

Relevance for gas storage:

- Unclear SoS requirements for end-user suppliers combined with reduced storage bookings by gas producers may lead to prolonged difficulties to market gas storage capacities absent gas storage filling targets.

Potential remedies

1 Consider **cross-sector drivers of demand** and in particular increasing importance of **gas-fired power generation**

2 Account for the **economic value** of ensuring continuous gas supply also to **SMEs and industrials** (potentially differentiating based on ability for fuel switch and/or willingness to pay for SoS – beware of free-rider problem!)

3 Consider **responsibilities within the market model** (i.e. short-term retail supplier switching dynamics vs. longer-term nature of security of supply) when assigning responsibilities to realise the insurance value of gas storages

4 **Harmonise national means of compliance** both in terms of (i) permissible ways to ensuring the actual, physically backed availability of gas, and (ii) measures to ensure compliance with the requirements

Abbreviations: SME ... Small and medium enterprise
Source: Compass Lexecon analysis

"Families" of Approaches to Improve Security of Supply via Gas Storages

There are three broad families of interventions aiming at improving security of supply by targeting gas storages and their filling.

	A. Incentives aligned with externalities	**B. Obligations** forcing provision of externalities	**C. Administrative action** for provision of externalities
Approach	Incentive mechanisms for market participants leading them to (partly) internalise the insurance and system value of storage	Regulatory measures requiring market participants to act in line with full social benefit of storage availability and usage	Administrative induced booking of separate storage capacities as well as their filling & usage to ensure (i) availability and usage of the optimal storage capacities and stored volumes, and (ii) cost recovery for both SSO filling entity
Addressed party/ies	Storage users (which may or may not have another role in the respective gas market ➔ self selection)	Suppliers or retailers of gas in the national market	Administratively dedicated entities
Driver for storage filling	Financial incentive to fill (which may or may not be sufficient to achieve storage filling)	Obligation to fill (with a penalty in case of no- compliance)	Administrative duty to fill
Certainty of filling	The volume filled depends on the price paid / total budget available ("Price-based measures")	The volume filled is specified as part of the measure and sure to be provided ("Volume-based measures")	

Source: Compass Lexecon analysis

Approaches for Gas Storage Filling and their Relation to National Emergency Plans

Member states already today must establish emergency plans containing measures to be taken to remove or mitigate the impact of disruptions of gas supply for each crisis level. The different storage filling approaches benefit gas security of supply at different crisis levels.

	A. Incentives aligned with externalities	**B. Obligations** forcing provision of externalities	**C. Administrative action** for provision of externalities
Approach	Incentive mechanisms for market participants leading them to (partly) internalise the insurance and system value of storage	Regulatory measures requiring market participants to act in line with full social benefit of storage availability and usage	Administrative induced booking of separate storage capacities as well as their filling & usage to ensure (i) availability and usage of the optimal storage capacities and stored volumes, and (ii) cost recovery for both SSO filling entity
Crisis level: Early warning *"significant **deterioration of supply might occur** and lead to alert or emergency level"*	Gas volumes stored can be withdrawn **by market participants, based on market incentives** but subject to restrictions resulting from filling incentives or obligations (e.g. 90% per 1 November and 80% per 1 December implies a market-based withdrawal of up to 10%)		*No access to strategic storage*
Crisis level: Alert *"significant deterioration of supply, but **market is able to manage** the event"*			
Crisis level: Emergency *"**all relevant market-based measures have been implemented,** but gas supply is still insufficient"*	**Administratively enforced storage withdrawal** of stored gas (potentially also covering gas stored based on filling incentives or obligations and in deviation from filling trajectories)		**(Administrative) usage** of strategic storage possible

Source: Compass Lexecon analysis

"Toolbox" of Measures to Improve the Internalisation of the Insurance Value of Gas Storages

There are three broad families of interventions targeting gas storages aiming at improving SoS – measures can also be combined.

	A. Incentives aligned with externalities			**B. Obligations** forcing provision of externalities		**C. Administrative action** for provision of externalities	
Approach	Incentive mechanisms for market participants leading them to (partly) internalise the insurance and system value of storage			Regulatory measures requiring market participants to act in line with full social benefit of storage availability and usage		Administratively induced booking of separate storage capacities as well as their filling & usage to ensure (i) availability and usage of the optimal storage capacities and stored volumes, and (ii) cost recovery for both SSO filling entity	
Examples – Measure type (generic[1])	**1. Storage filling premium**	**2. Storage filling CfDs**	**3. Auctioned filling obligations**	**4. Retailers' stockholding obligations**	**5. Importers' stockholding obligations**	**6. Strategic storage**	**7. Storage filling of last resort**
Examples – Details	▪ Storage users receive a premium for meeting filling targets / trajectories[2] ▪ The premium is set administratively and ex-ante (this could also be a reduced transport tariff)	▪ Storage users receive the difference between a strike price and the / a summer-winter spread for stored gas volumes ▪ Usually combined with filling targets / trajectories[2]	Obligations to meet storage targets / trajectories[2] including the relevant storage capacities are auctioned-off against a reduced storage tariff and/or a fee paid to the storage user	An obligation is placed on suppliers of (selected) customers to secure storage capacity and meet storage targets / trajectories[2] corresponding to e.g. a share of their consumers' demand	An obligation is placed on importers to secure storage capacity and meet storage targets / trajectories[2] based on e.g. a share of their imported gas	▪ Storage capacity is contracted and filled by a dedicated entity and then held outside the market ▪ Stored gas can only be used for SoS purposes upon administrative order	▪ Dedicated entity purchases and stores gas after it becomes clear that market filling will fall short of targets ▪ Gas is released back to the market during the same winter

Abbreviations: SoS … Security of Supply, CfD … Contract for Difference.

Notes: [1] for each of these measure types there is a wide variety of design details that can have a significant impact on intended and unintended effects of the measure [2] The trajectories may stretch beyond the initial filling deep into the winter.

Source: Compass Lexecon analysis

"Tool-Box" of Measures to Improve SoS via Ensuring Gas Storages are Adequately Filled

On the EU level a predictable framework for the national implementation of the most appropriate filling measure should be established.

A. Incentives aligned with externalities

Incentive mechanisms for market participants leading them to (partly) internalise the insurance and system value of storage

- **1. Storage filling premium**
- **2. Storage filling CfDs**
- **3. Auctioned filling obligations**

B. Obligations forcing provision of externalities

Regulatory measures requiring market participants to act in line with full social benefit of storage availability and usage

- **4. Retailers' stockholding obligations**
- **5. Importers' stockholding obligations**

C. Administrative action for provision of externalities

Administratively induced booking of separate storage capacities as well as their filling & usage to ensure (i) availability and usage of the optimal storage capacities and stored volumes, and (ii) cost recovery for both SSO filling entity

- **6. Strategic storage**
- **7. Storage filling of last resort**

EU level requirements

1 Establish a **long-term and predictable market and regulatory framework for gas storage** going well beyond 2027 (thereby replacing current non-market measures / interventions)

2 Establish a **set of conditions and requirements** for (i) specifying non-market measures and (ii) setting target filling levels

3 Take into account the **EU-wide impact of achieving storage filling** when setting national targets

4 Provide guidance on how to **design measures using market compatible approaches** to limit distortions

5 Consider increasing the minimum **transport tariff discount (e.g. 90%) for storage access points**

Abbreviations: SoS … Security of Supply, CfD … Contract for Difference.
Source: Compass Lexecon analysis

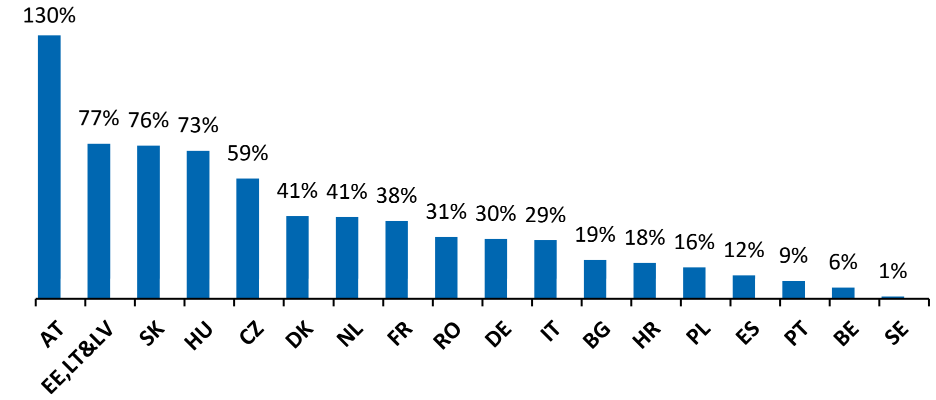
Re-Assess EU-Wide Sharing of Cost for SoS-Measures

The current EU gas security of supply framework lacks sufficient provisions for cost-sharing between member states.

Current regulation

- Member states with gas storages have to **fill 90% of their gas storage capacity** – subject to tolerances of up to 20 percentage points – or, if lower, store volume equal to at least 35% of national average annual gas consumption over the preceding five years
  - If market-driven filling is not sufficient**, member states carry the cost for additional storage filling measures themselves**
- Member states without underground gas storages have an obligation **to store only at least 15% of annual gas consumption** in another member state

Gas storage capacities as a share of inland gas consumption, 2024[1]



Issues

Limited cost sharing for storage filling between member states

- Cost sharing is currently limited to countries without any gas storage (obligation to fill storages in other countries).
- However, also among countries with storage, storage capacity to demand ratios varies widely
- "Uniform" filling targets combined with – generally – nationally borne costs lead to
  - different levels of prevention across member states
  - differing participation of individual member states to the broader Union's risk preparedness, as within the interconnected EU gas market, gas storage provide benefits beyond the individual member state
  - potential for free-rider problems

Potential remedies

1 Reassess the **principles and mechanisms for the cost sharing** of Security of Supply across member states to ensure fair burden sharing – either based on bilateral agreements or EU-wide cost sharing ("EU-fund")

2 Take into account the **inhomogeneous distribution** of gas storage capacities and **contribution to regional and EU Security of supply**

3 Take into account the **contribution of gas storage to power sector** security of supply

4 Factor in **cost associated with insurance value of storages for gas security of supply** also in the absence of acute crisis situations

Notes: [1] Based on GIE – Storage Inventory and Eurostat
Source: Compass Lexecon analysis.

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Key Recommendations of the Regulatory Analysis

Ongoing and expected changes require an evolution of the market and regulatory framework for the EU gas storage sector.

I. Enhance the EU-wide SoS assessments

1 Improve the **interlinkage between the gas and electricity** security of supply and flexibility assessment

2 Determine **gas storage capacity and filling required** to ensure SoS at the desired level taking into account filling level dependence of storage withdrawal

3 **Expand shock scenarios** beyond cold-spells to account e.g. for **reduced renewable power generation** and other extreme events linked e.g. to climate and/or geopolitical events

4 **Extend the analysis horizon to 10 yrs. in the future** (and beyond)

5 Consider **gas infrastructure changes** (storage and pipeline), e.g. due to repurposing to hydrogen

II. Redefine national SoS standards

a) Infrastructure Standard

1 **Add volume assessments** to the current peak demand assessments (e.g. filling of storages in summer when withdrawal capacity does not count towards standard fulfilment)

2 Take a **forward-looking perspective** and **demand evolvements** (i.e. gas usage in the power sector)

3 Consider **storage filling needs and withdrawal curves** in assessment

4 Reinforce the **regional perspective** considering **transit requirements** in crisis settings

5 Consider disregarding infrastructure that does not anymore give **access to gas sources** (e.g. historic routes for Russian imports) from the N-1 criteria

6 Incorporate **new peak demand scenarios** (e.g. early winter **kalte Dunkelflaute** events)

b) Supply Standard

1 Consider **cross-sector drivers of demand** and in particular increasing importance of **power generation**

2 Account for the **economic value** of ensuring continuous gas supply also to **SMEs and industrials** (potentially differentiating based on ability for fuel switch and/or willingness to pay for SoS – beware of free-rider problem!)

3 Consider **responsibilities within the market model** (i.e. short-term retail supplier switching dynamics vs. longer-term nature of security of supply) when assigning responsibilities to realise the insurance value of gas storages

4 **Harmonise national means of compliance** both in terms of (i) permissible ways to ensuring the actual, physically backed availability of gas, and (ii) measures to ensure compliance with the requirements

III. Allow for / mandate storage filling measures post 2027 (in the light of missing money)

1 Establish a **long-term and predictable market and regulatory framework for gas storage** going well beyond 2027 (thereby replacing current non-market measures / interventions)[1]

2 Establish a **set of conditions and requirements** for (i) specifying non-market measures and (ii) setting target filling levels

3 Take into account the **EU-wide impact of achieving storage filling** when setting national targets

4 Provide guidance on how to **design measures using market compatible approaches** to limit distortions

5 Consider increasing the minimum **transport tariff discount (e.g. 90%) for storage access points**

IV. Re-assess EU-wide sharing of cost for SoS-measures

1 Reassess the **principles and mechanisms for the cost sharing** of Security of Supply across member states to ensure fair burden sharing

2 Take into account the **inhomogeneous distribution** of gas storage capacities and **contribution to regional and EU Security of supply**

3 Take into account the **contribution of gas storage to power sector** security of supply

4 Factor in **cost associated with insurance value of storages for gas security of supply** also in the absence of acute crisis situations

Note: [1] In the light of the missing money problem as described in this deck. Source: Compass Lexecon analysis

Model-Based Assessment:
Role of UGS in Maintaining Resilience to Security of Supply Shocks

COMPASS LEXECON Artelys

Table of contents – Modelling section

Model-based assessment of role of UGS in maintaining resilience to shocks

Context, objectives and key messages	27
Approach for the model-based assessment of the role of UGS in maintaining resilience to security of supply shocks	30
Analysis of UGS role for security of supply with a multi-energy perspective, based on National Trends+ scenarios	33
Analysis of UGS role under security of supply shocks	47
Analysis of UGS role under a deviation scenario	54
Key conclusions	58
Annex – Modelling approach	108
Annex – Additional modelling results	116

Table of contents – Modelling section

Model-based assessment of role of UGS in maintaining resilience to shocks

Context, objectives and key messages

Approach for the model-based assessment of the role of UGS in maintaining resilience to security of supply shocks

Analysis of UGS role for security of supply with a multi-energy perspective, based on National Trends+ scenarios

Analysis of UGS role under security of supply shocks

Analysis of UGS role under a deviation scenario

Key conclusions

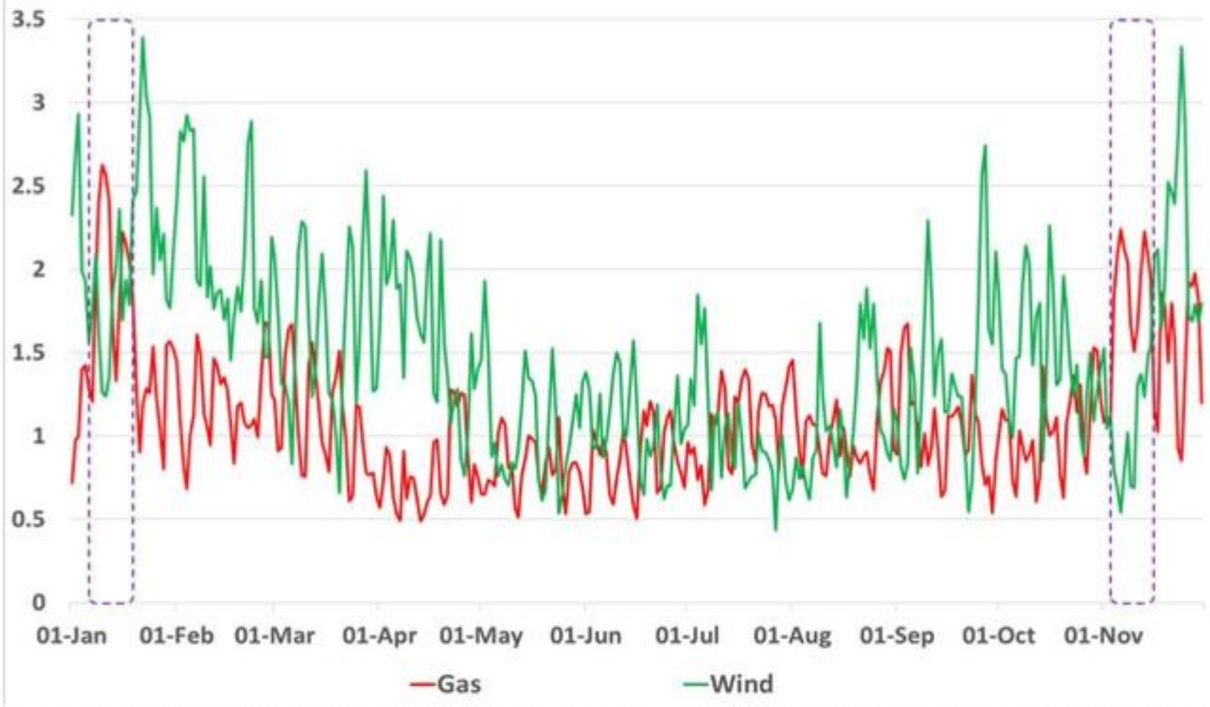
Annex – Modelling approach

Annex – Additional modelling results

Context and objectives of the modelling study

The energy sector is undergoing a structural transformation, with accelerating electrification levels, increasing RES deployment and heightened exposure to system shocks. This study develops novel approaches to assess the role of UGS in maintaining security of supply, based on a cross-sectoral perspective and an assessment of the resilience of the system to a series of shocks.

Figure 9: Daily electricity generation from gas and wind in EU27 + UK (TWh/d) **(2024)**



Source: A. Honoré (OIES). Data calculated by this author using raw data from ENTSOE Transparency Platform, Gridwatch and NESO. Graph by the author.

Recent system stress events have reaffirmed the value of UGS in safeguarding the EU against cold snaps and low renewable output. UGS acts as a stabilising asset contributing to system adequacy and resilience.

This study develops a framework to assess the future need for UGS by
(a) characterising how the structural changes impact the way UGS will be operated, using a multi-energy modelling approach
(b) identifying the type of shocks against which the system needs to be resilient and
(c) proposing a scenario-based approach to evaluate the impact of different transition pathways on the role of UGS to maintain SoS

This study provides the results of applying this framework to two transition scenarios: one that is aligned with TYNDP 2024 NT+ scenario and a second one where the uptake of electrification and H2 is delayed.

Source: Artelys analysis

Key messages based on the results of the quantitative analysis

The modelling framework that has been developed for this study has allowed to reveal the evolution of the role of UGS throughout the transition. UGS is found to have a crucial role to play in all considered scenarios and time horizons.

From annual to peak demand
UGS remains essential throughout the transition

Annual methane consumption evolution **do not reflect** the evolving role of UGS throughout the transition.

The flexibility needs provided by UGS are highly dependent on methane demand dynamics. **UGS is dimensioned to support both seasonal and short-term flexibility needs**, which evolve with both supply and the role of gas in end-uses and for power generation as back-up to variable RES.

Between 2023-2024 and NT+2040:
- Annual consumption decreases by 24%
- Daily consumption peak decreases by 12%
- UGS peak withdrawal increases by 15%

Resilient by design
UGS role heightens under security of supply shocks

A **robust** energy system needs to be resilient against **shocks of different natures** (weather events, infrastructure disruptions and geopolitical events).

The SoS shocks studied result in **narrow deliverability margins**, which could become insufficient if shocks occur late in the winter, if multiple shocks overlap, or if initial filling levels fall below 90%.

Under 2012-2013 (vs 08-09) climate:
- Methane demand rises by 6%
- End-of-winter filling decrease by 13pp
- Withdrawal capacities decrease by 14pp

Sustained deliverability
UGS must be adequately filled to provide high withdrawal rates

The key services delivered by UGS include the ability to provide **sustained output over extended periods of time.**

To play this role, it is crucial to ensure UGS assets are **adequately filled**.

UGS provides more than 60% of gas supply under 2-weeks peak during an LNG disruption shock in 2040.

Consistent role across scenarios
UGS is key for security of supply for contrasted drivers

In a **deviation scenario, characterised by increased final gas demand in 2040** *(+51% annually)* due to delayed electrification of heating and H2 ramp-up, **baseload imports are higher, and the role of gas-fired power generation is reduced at peak** *(-18 to 21% at peaks vs -4% at annual level).*

Both effects tend to cancel out, leading to tight margins in both cases.

Under a Norwegian supply shock, the minimum capacity margin is between 1.9 and 2.8 TWh/day, representing 9 to 13% of consumption, across scenarios and horizons.

Source: Artelys modelling based on NT+ scenarios (2030 & 2040)

Table of contents – Modelling section

Model-based assessment of role of UGS in maintaining resilience to shocks

Context, objectives and key messages

Approach for the model-based assessment of the role of UGS in maintaining resilience to security of supply shocks

- **The study analyses the role of UGS vis a vis a series of shocks, in two scenarios: the NT+ scenario developed by ENTSO-E and ENTSOG in TYNDP 2024, and a deviation scenario that translates a delayed uptake of H2 and of electrification.**
- **Multi-energy modelling is a "must have" for the analysis of resilience to shocks, in particular to capture the impacts of SoS methane shocks on electricity SoS.**

Analysis of UGS role for security of supply with a multi-energy perspective, based on National Trends+ scenarios

Analysis of UGS role under security of supply shocks

Analysis of UGS role under a deviation scenario

Key conclusion

Annex – Modelling approach

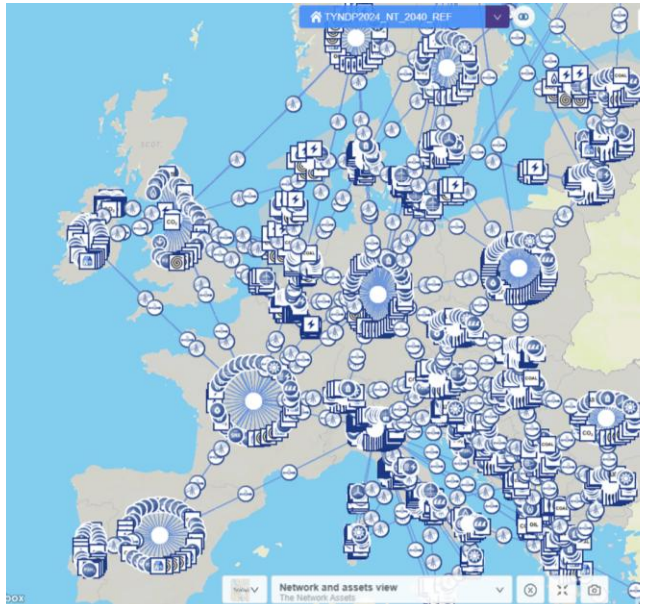
Annex – Additional modelling results

A state-of-the-art modelling framework has been developed for this study

To provide a comprehensive analysis of the role of UGS in energy SoS, the *synergies* and *interdependencies* between the methane, electricity and hydrogen systems must be accounted for. Crucially, the multi-energy modelling approach adopted allows to capture the impacts of SoS methane shocks on electricity SoS (via the explicit link between the gas infrastructure and CCGTs and OCGTs).

- Multi-energy modelling, **beyond** the state-of-the-art (methane, electricity, hydrogen)
- All **interlinkages** between methane, electricity and hydrogen are accounted for:
  - Gas to power, via gas-fired CCGTs/OCGTs
  - Gas to H2, via SMR
  - Power to H2, via electrolysis
  - H2 to power, via hydrogen-fired CCGTs/OCGTs
- Cross-sector flexibility synergies and interdependencies are explicitly modelled (e.g. during low renewable output period, batteries and demand-side flexibility *vs* gas-fired turbines and gas storage *vs* H2 storages and SMR)
- Hourly modelling over entire gas years (multiple climate years)
- European-wide model, with bidding zone (electricity) and country-level granularity (gas, hydrogen)
- Centralised vs decentralised hydrogen models

Artelys Crystal Super Grid



Artelys Crystal Super Grid –
A fit-for-purpose solution for the analysis of security of hydrogen, gas and electricity supply

Overview of the modelling approach

Artelys

The study analyses the role of UGS vis a vis a series of shocks, in two scenarios: the NT+ scenario developed by ENTSO-E and ENTSOG in TYNDP 2024, and a deviation scenario that translates a delayed uptake of H2 and of electrification.

TYNDP NT+

Co-design with Funding Members

Scenario		Final Demand (households, services, industry, etc)	Transformation demand (power, H2, district heat)	Gas production and import	Security of Supply (SoS) Shock
1	ENTSOs Scenario ("baseline scenario") 2030 & 2040	Aligned with **TYNDP 2024 NT+** (model amended for consistency, with SoS loop; 2008-2009 climate)	Modelling *(Interlinked CH4 – electricity - H2 model)*	Based on NT+ *(total import volumes resulting from modelling)*	• **Harsh weather shock** (based on 2012-2013 climate) • **LNG supply shock** (reduced supply from November to January) • **Norwegian supply shock** (reduced supply from January to March)
2	Deviation Scenario 2030 & 2040	**Key deviations vis-à-vis TYNDP 2024 NT+** • Delayed / reduced hydrogen ramp-up • More/longer use of methane in industry & power generation • Delayed / reduced electrification of residential heat	Modelling *(Interlinked CH4 – electricity - H2 model)*		

Model-based assessment of the ability of the gas-electricity-hydrogen system to ensure SoS under shocks

Table of contents – Modelling section

Model-based assessment of role of UGS in maintaining resilience to shocks

Context, objectives and key messages

Approach for the model-based assessment of the role of UGS in maintaining resilience to security of supply shocks

Analysis of UGS role for security of supply with a multi-energy perspective, based on National Trends+ scenarios

- **There are important structural changes of both demand and supply patterns towards 2040.**
- **Despite these profound changes, the seasonal services delivered by UGS in 2040 are similar to the ones we observe today.**
- **Beyond seasonal flexibility needs, peak methane consumption (for final demand and power generation) decreases less rapidly than annual volumes, as the methane system deliverability need for electricity SoS is found to increase in 2040 to support electrification and RES expansion.**
- **UGS is the only large-scale option of sustained supply to meet peak consumption. Despite decreasing consumptions peaks, UGS withdrawal needs increase as import contribution decreases due to lower annual demand volumes.**
- **The high deliverability rates needs from UGS can only be met if storages are sufficiently filled. It is therefore crucial to assess UGS withdrawal capacity throughout the winter, depending on gas withdrawals occurring earlier in the winter and initial filling levels.**

Analysis of UGS role under security of supply shocks

Analysis of UGS role under a deviation scenario

Key conclusion

Annex – Modelling approach

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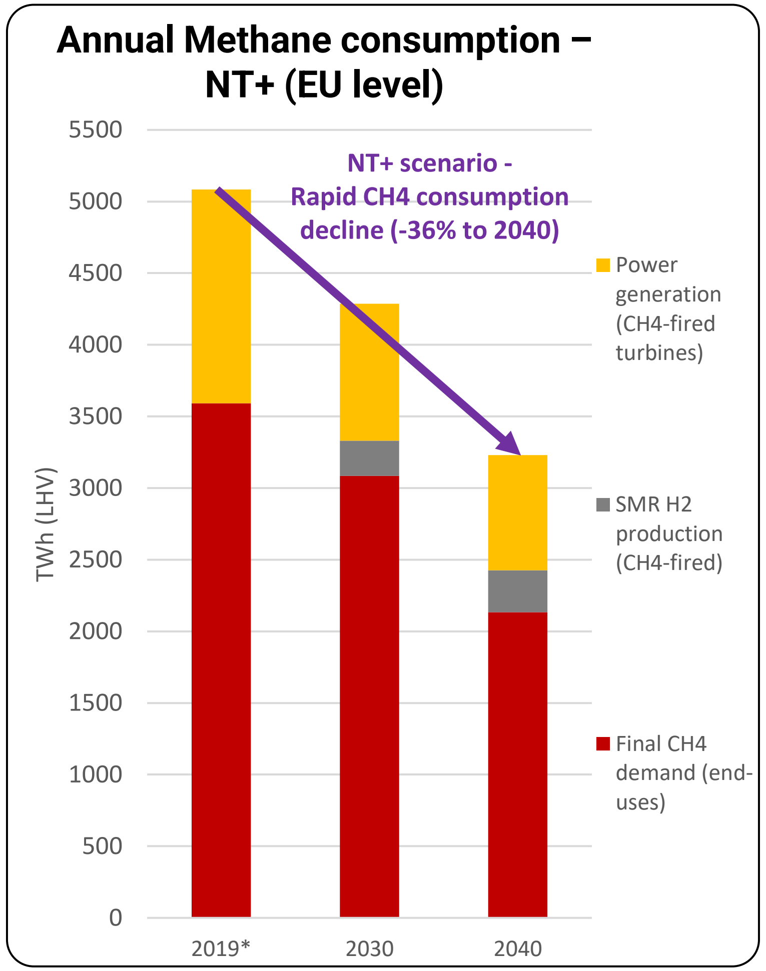
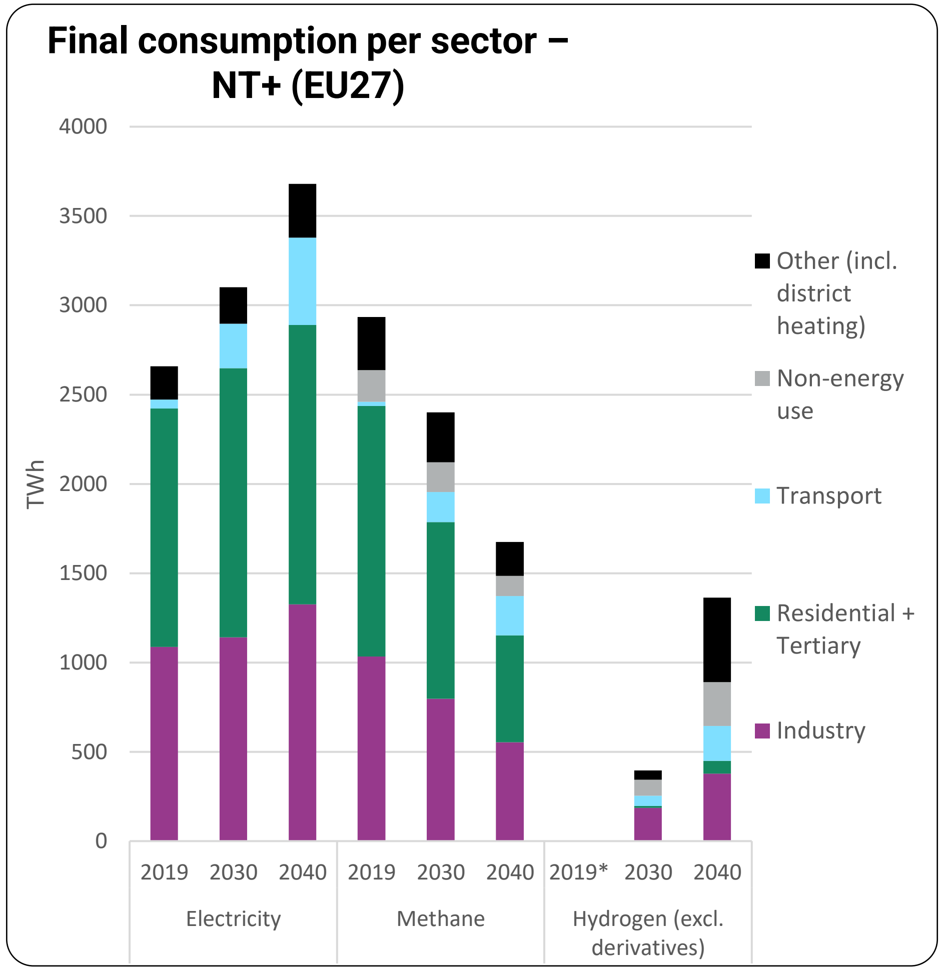
Methane **consumption** in Europe decreases in NT+ scenarios

The NT+ scenario assumes rapid decarbonisation trajectory, with methane demand expected to decrease by 36% by 2040 compared to 2019, driven by hydrogen deployment, electrification, and renewable power generation.

- **Methane annual consumption volume gradually decreases in the reference NT+ scenario.** Compared to 2019 *(reference year prior to Covid and Russian crises used by the ENTSOs to build the TYNDP scenarios)*, annual consumption is circa:
  - 16% lower in 2030 and
  - **36% lower in 2040**.
- This decline is driven by a reduction of both:
  - final methane demand (-14% in 2030 and -41% in 2040),
  - methane consumption for power generation (-36% in 2030 and -46% in 2040).
- This is driven by:
  - **Rapid electrification** (in particular for building heating and industry),
  - **Hydrogen ramp-up** (in particular for industry), and
  - **Development of renewable electricity** (leading to lower gas-fired power generation annual volumes).
- A deviation scenario exploring a slower decline in methane consumption is analysed in the study *(see dedicated section)*.



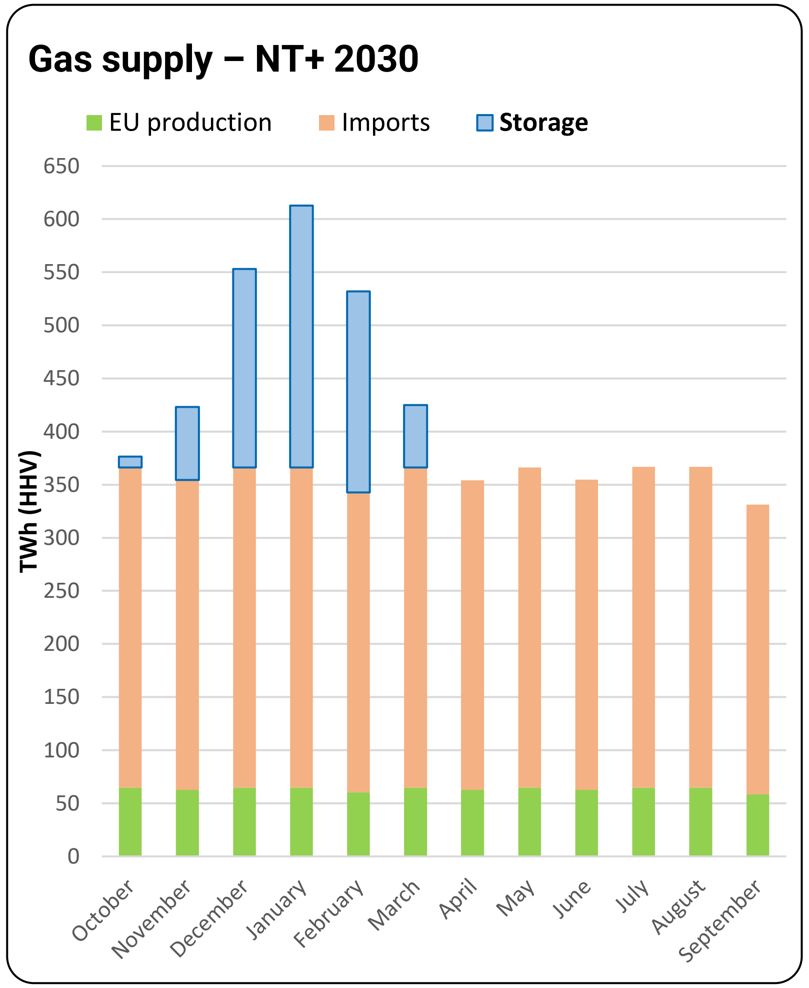


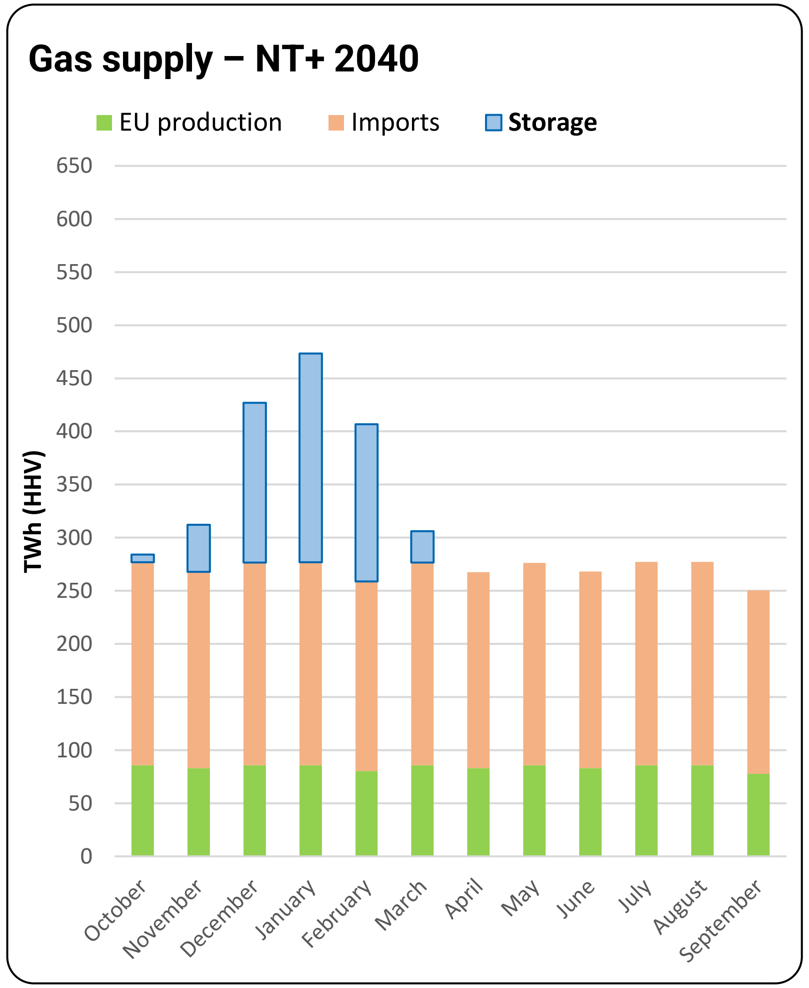
All figures are provided in low heating value (LHV, or NCV). Unless indicated otherwise, all figures are given for an "EU perimeter" which consists in EU27 + UK + CH + Balkans (+ NO for electricity).
Sources: Artelys modelling based on NT+ scenarios (2030 & 2040); 2019 is chosen as reference for consistency as data is taken from TYNDP 2024 datasets (for EU27); other 2019 estimates are based on DUKES (UK), IEA (CH), and Eurostat (Balkans).
**European Hydrogen Observatory indicates an SMR H2 production around 7.3 Mt H2 in 2022 (covering most consumption beyond byproducts), which is equivalent to around 315 TWh of methane consumption.*

The structure of methane **supply** in Europe significantly evolves in NT+ scenarios

The NT+ scenarios assumes a very different methane supply, with reduced import volumes driven by decreasing consumption and increasing share of domestic supply (31% in 2040 in NT+ scenario driven by a significant uptake of biomethane production).

- Average imports from pipelines and LNG decrease from 295 TWh/month in NT+2030 to 190 TWh/month in NT+2040 (-37%).
  - A first driver is the reduction of methane consumption (-25% between 2030 and 2040, excluding storages).
  - The second driver is the development of domestic production, from 63 TWh/month in 2030 to 84 TWh/month in 2040.
- **Domestic supply in EU** (excluding Norway, including UK) **represents about 18% of total demand in 2030** (760 TWh) **and 31% in 2040** (1000 TWh). In 2023-2024 EU domestic production was around 700 TWh (17% of consumption). The key drivers of the evolution of EU domestic production are:
  - Important development of biomethane in EU27 (379 TWh in 2030 and 767 TWh in 2040);
  - Declining natural gas production (184 TWh in 2030 and 105 TWh in 2040 in EU27);
  - Development of e-methane (54 TWh in 2040 in EU27);
  - The UK scenario includes 83 TWh of domestic production in 2040 and 194 TWh in 2030.
- LNG represents slightly above half of methane import potential in TYNDP 2024 NT+ 2030 and 2040 (42% of imports in 2023-2024).





Sources: Artelys modelling based on NT+ scenarios (2030 & 2040). 2023-2024 data from ENTSOG-GIE System capacity map 2025. In the figures above, supply is relatively stable during the injection season as storages are filled (imports are flat).

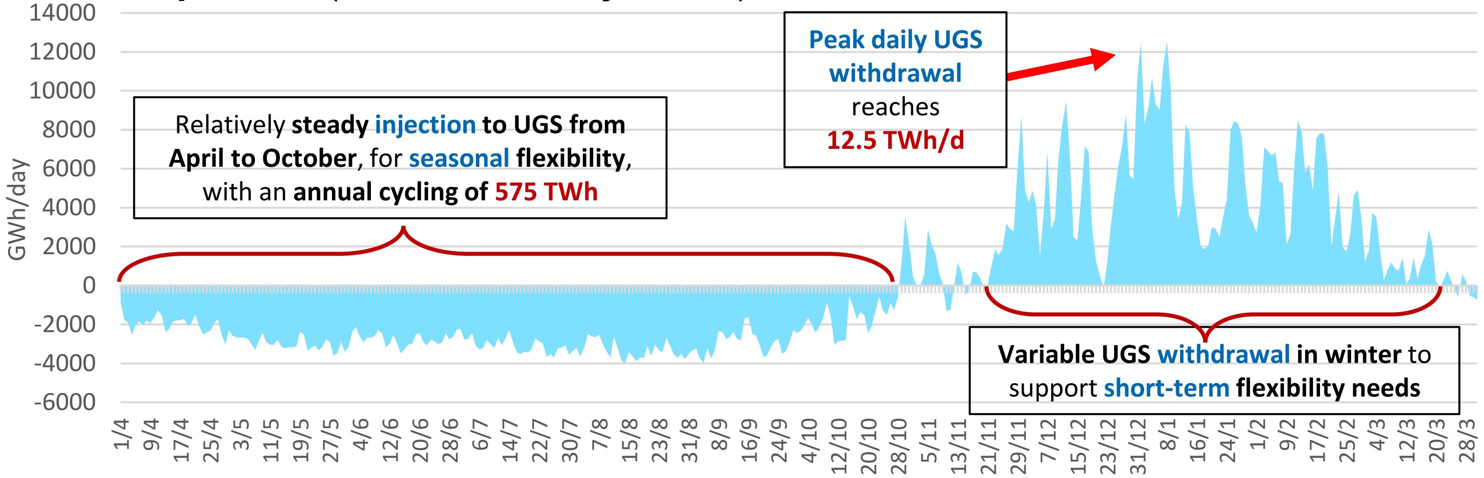
UGS remains essential to meet seasonal flexibility needs

Artelys

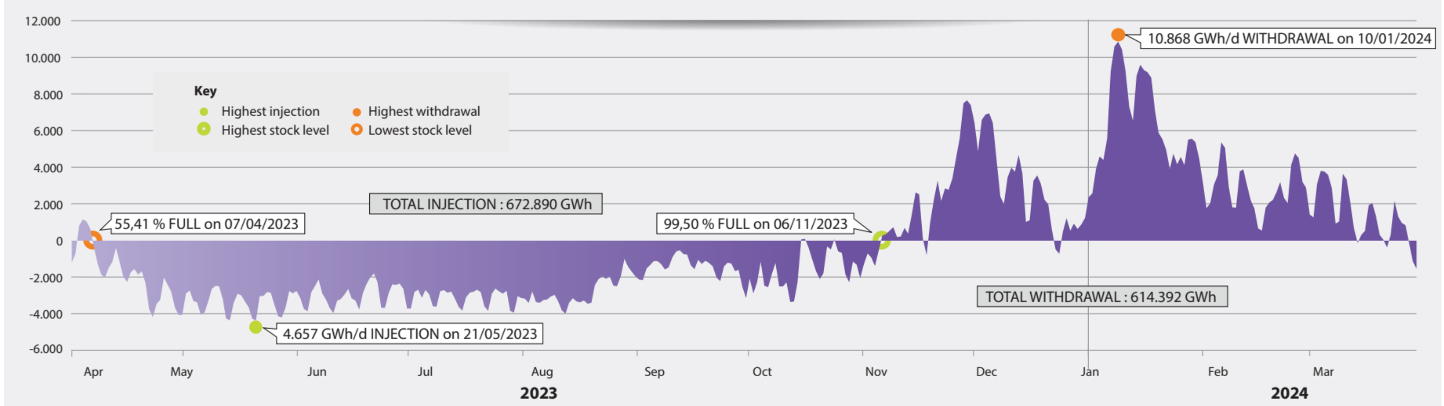
The drivers of UGS operation change (see previous slides) but the seasonal flexibility services delivered by UGS remain similar to today. The operation profile of UGS and volumes of gas cycled through storages are similar to the ones observed in 2023-2024.

- **The operation profile of UGS is similar despite different drivers**.
  - The upper graph shows UGS injection and withdrawal profiles at EU-level in the NT+ 2040 scenario, for climate year 2008-2009 (modelling result).
  - The bottom graph represents the 2023-2024 operation profile of UGS (observed injections and withdrawals).
  - Despite profound system changes (lower CH4 final demand and different profile, different gas-fired power generation patterns, biomethane development, reduced annual imports, etc.), **UGS continues to play a vital role in 2040 and follows an operation profile similar to the one observed in 2023-2024,** with steady injections during summer and variable withdrawals in winter.
- **Seasonal flexibility need remains broadly stable, with similar volumes of gas cycled through storages.** Compared with the 2023-2024 gas year (673 TWh injected, 614 TWh withdrawn), gas cycled through UGS reaches 760 TWh in 2030 (+18%) and 575 TWh in 2040 (–10%).
- Storage capacities in the model are reduced by 14.5% at EU-level in 2040 compared to 2025*, to reflect potential repurposing to UHS as well as projects of UGS closures and expansion (depending on countries). This modelling assumption does not reflect a structural decline in storage relevance.

UGS operation (withdrawals - injections) in EU27+UK, NT+ 2040, climate 2008-2009



Observed UGS operations (withdrawals - injections) in EU27+UK, 2023-2024



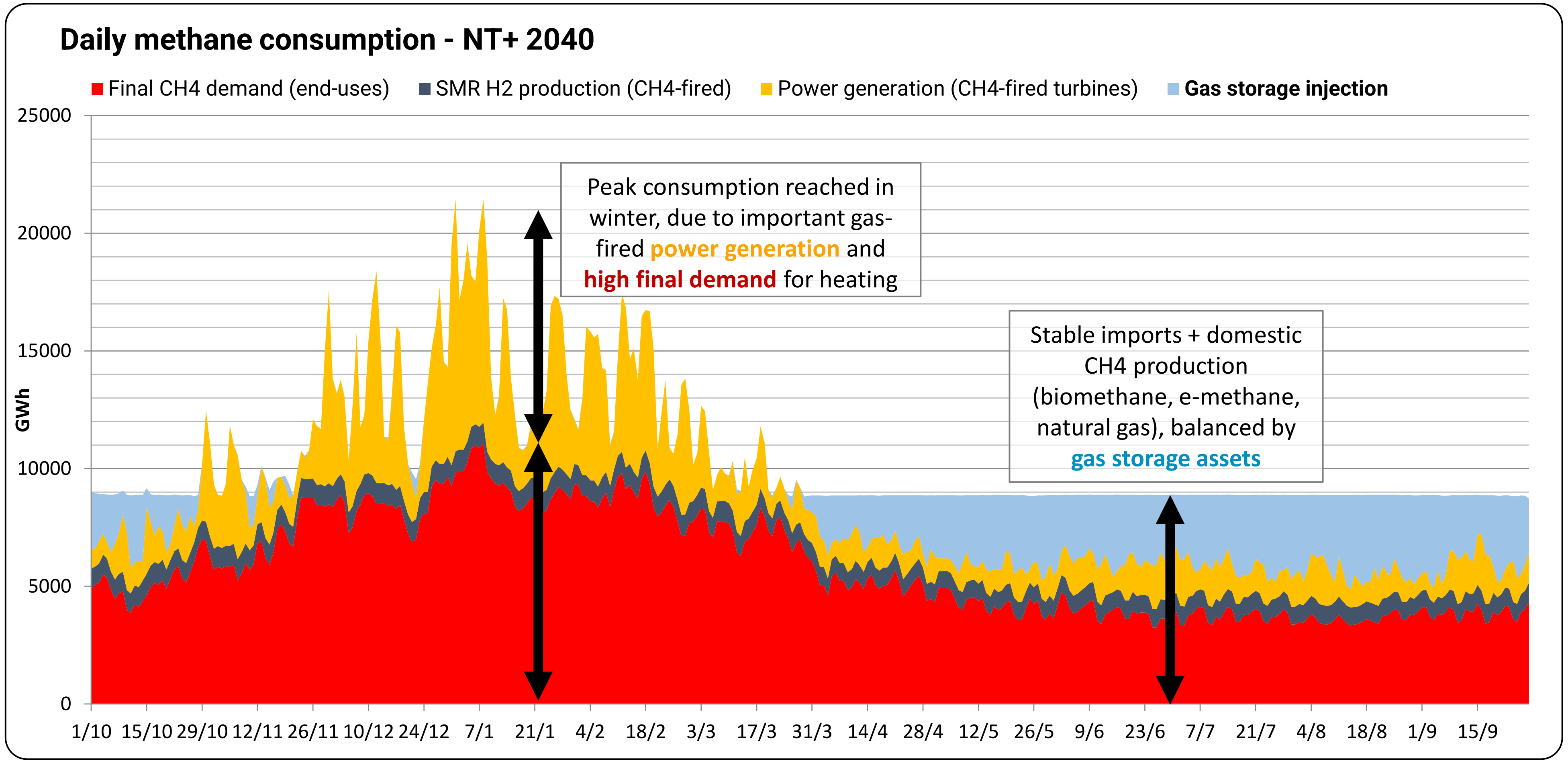
Sources: Artelys modelling based on NT+ scenarios (2030 & 2040) and ENTSOG-GIE system capacity map 2025.

**See modelling annex for more details on how the 14% value was obtained. UGS withdrawal capacities published by ENTSOG in TYNDP 2024 datasets for 2030 and 2040 are 11% lower than 2025 EU withdrawal capacities (based on AGSI datasets).*

Methane consumption profiles show significant seasonal and short-term variability

Methane consumption variability is driven by heating needs and renewable electricity generation patterns. The role of UGS to meet the high withdrawal capacity needs for gas-fired turbines to ensure electricity SoS increases. Indeed, the peak methane demand for power generation doubles by 2040 compared to 2021.

- Methane annual demand for heating significantly decreases in NT+ scenarios (-57% of residential and tertiary demand in 2040 compared to 2019). As this demand presents a thermosensitive profile, methane peak daily final demand decreases to 11.1 TWh/day (vs above 20 TWh/day in 2021*).
- Electricity final demand volume grows and increasingly exhibits a thermosensitive component, particularly due to the development of heat pumps, which significantly increase electricity demand during cold periods. Variable renewable generation (wind, PV) also increases short-term volatility and raises the need for sustained back-up gas-fired power generation. **Peak methane demand for power generation is 10.7 TWh/day** in 2040 (vs 5 TWh/day in 2021*).

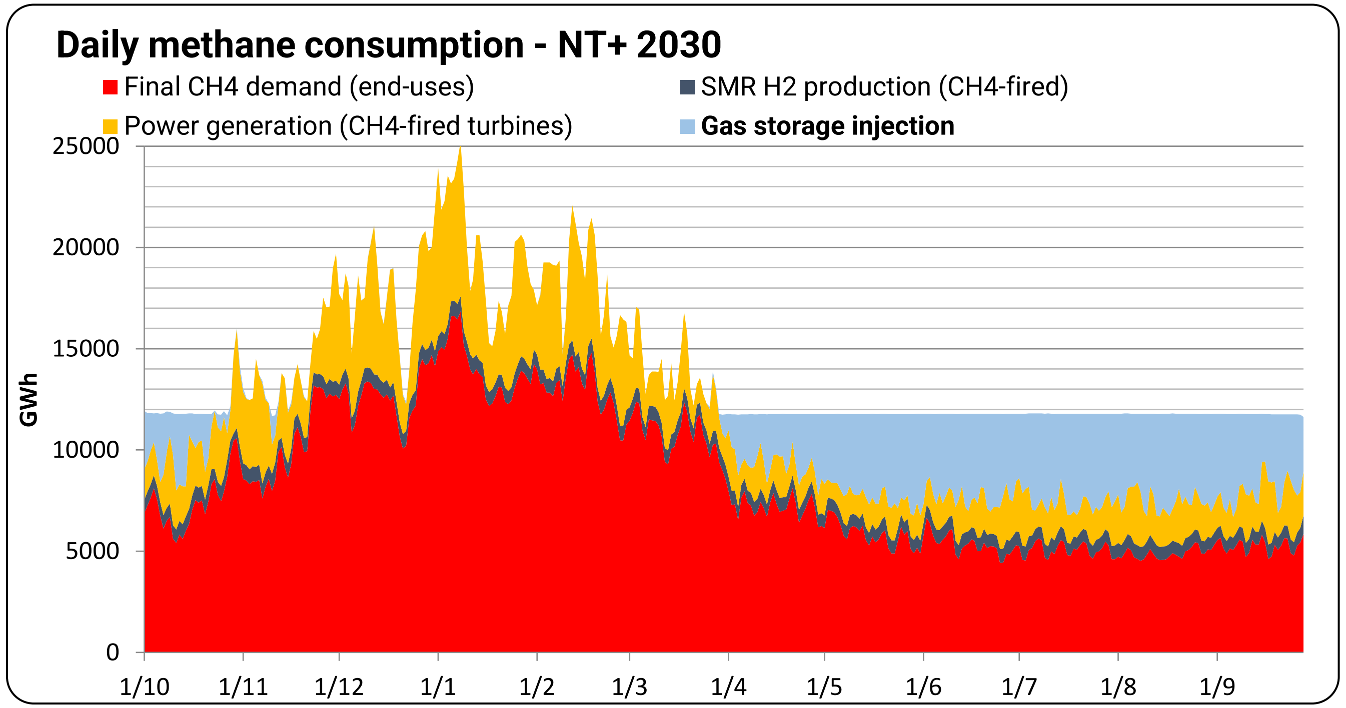


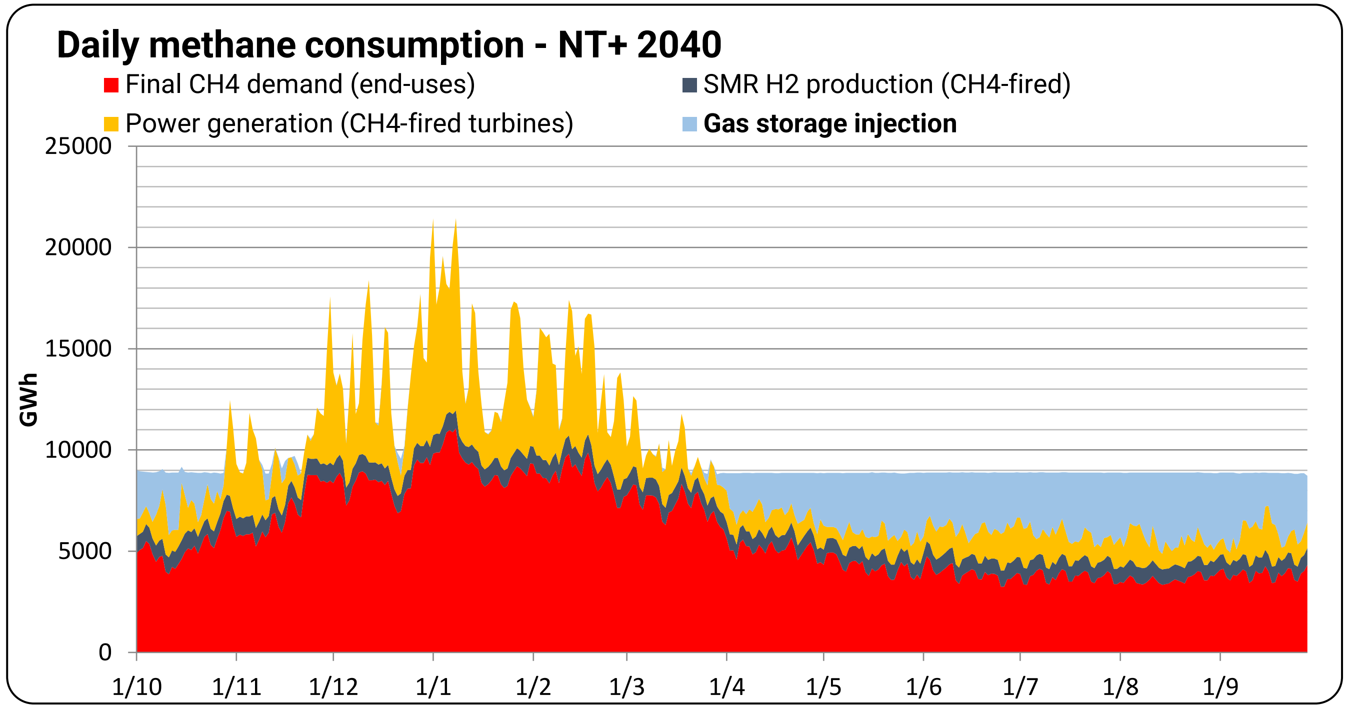
Source: Artelys modelling based on NT+ scenarios (2030 & 2040). 2021 data is based on ENTSOG winter supply review 2020/2021.
**Where possible, the most recent data from ENSTOG has been used (2023-2024 at the date of this study), but the most recent report including an analysis of the contribution of gas-fired power generation to peak CH4 consumption is from 2021.*

Methane consumption profiles differ significantly between 2030 and 2040

Methane annual consumption volumes decrease between 2030 and 2040 (-25%), with final methane demand decrease representing 90% of the difference in total consumption. Final demand profile is less thermosensitive in 2040 than 2030, and methane demand for power generation is more variable in 2040.

- Methane final demand profile is less thermosensitive in 2040 than in 2030, as residential and tertiary demand decrease more rapidly than other sectors, resulting in a lower final demand peak (-34%) and lower contribution of final methane demand to overall peak day (67% in 2030 vs 52% in 2040) and peak 2-weeks (68% in 2030 vs 55% in 2040).
- Importantly, peak methane demand for power generation is found to increase by 29% between 2030 and 2040, driven by electrification*. However, due to the evolution of flexibility needs associated with renewable electricity development, methane demand for power generation is more variable and annual volumes decrease (-16%).
- Total peak consumption decreases between 2030 and 2040, by 15% for daily peak and 19% for 2-weeks peak (compared to -25% for annual volumes).



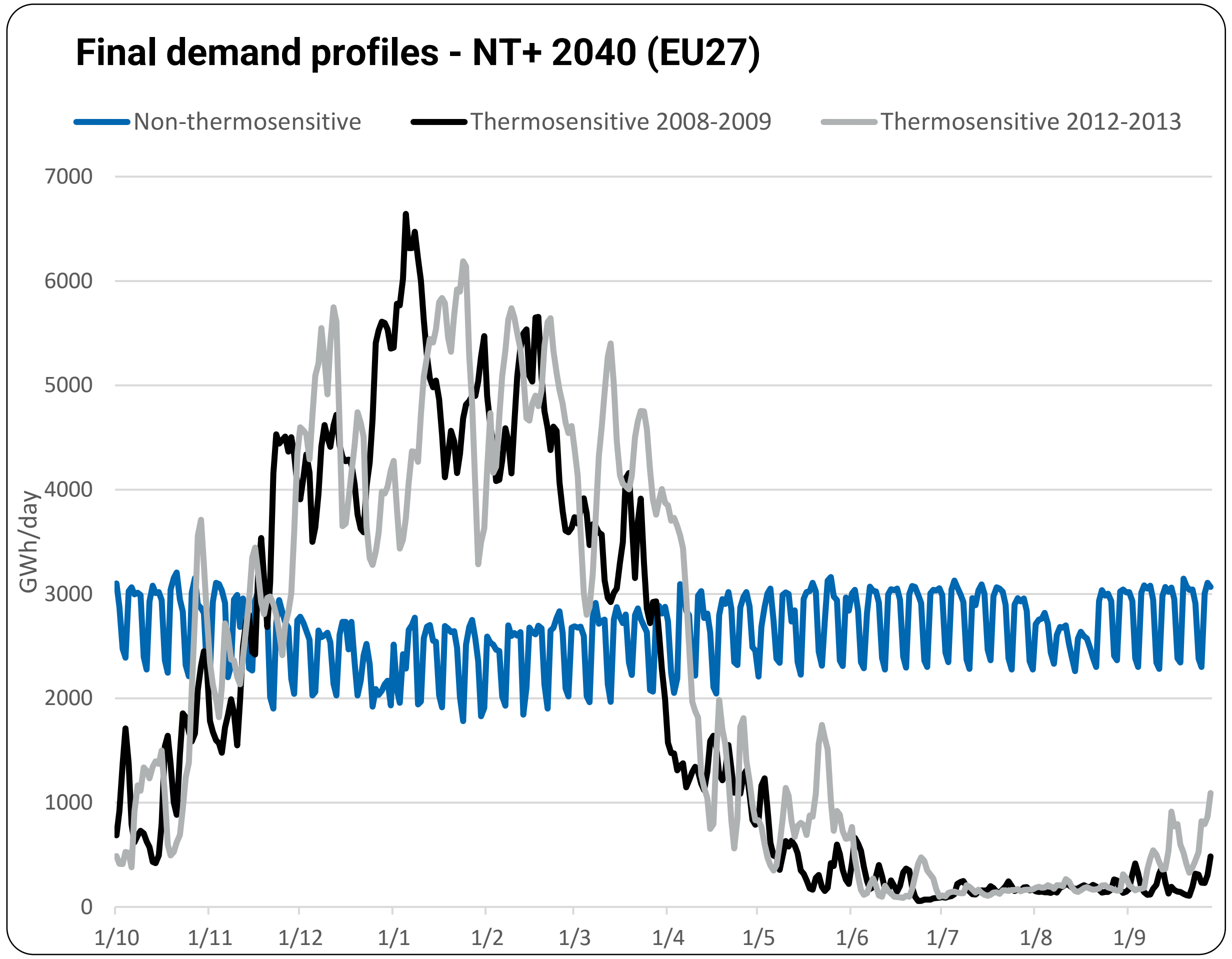


*Source: Artelys modelling based on NT+ scenarios (2030 & 2040). *Peak methane-fired power generation increases by 18%, the higher increase in methane demand is due to different average efficiency of power plants at peak.*

The thermosensitivity of gas final demand impacts when peaks occur

The final methane demand has a thermosensitive component (heating) and a non-thermosensitive part (other end-uses). Demand profiles are different between climate years and time horizons to reflect structural changes in the gas consumption.

- **Demand thermosensitivity** refers to the **variability of demand due to temperature**.
  - Both methane and electricity demands are thermosensitive and therefore depend on climate years. The reference climate used for the study is 2008-2009, and a harsher climate (2012-2013*) with 6 to 6.5% higher annual demand is studied as a security of supply shock.
  - Methane final demand is particularly thermosensitive since a major end-use of methane is for heating (residential and tertiary sectors, district heating).
  - In NT+ 2040, during the core of heating season (December to March), the thermosensitive profile used is typically between 3.5 and 6.5 TWh/day (EU27), with significant variability between days, while it decreases to close to zero during summer.
- Part of final demand is non-thermosensitive, typically representing between 2 and 3 TWh/day throughout the year in NT+ 2040 (EU27). The non-thermosensitive profile is mainly driven by:
  - Week and weekend day difference (e.g. some processes are interrupted during weekends),
  - Holidays (e.g. during summer holidays in August and holidays at the end of the year).
- Due to thermosensitivity, **peak final methane demand is reached at different moments of the year and at different intensity from one climate year to the other.**
  - Daily peak is slightly higher with 2008-2009 climate than with 2012-2013 climate.
  - However, there is only one major peak occurring at the beginning of January in 2008-2009, while in 2012-2013 there are significant demand peaks from December to March, which can result in more stressful conditions for the system as it reduces storage filling levels.

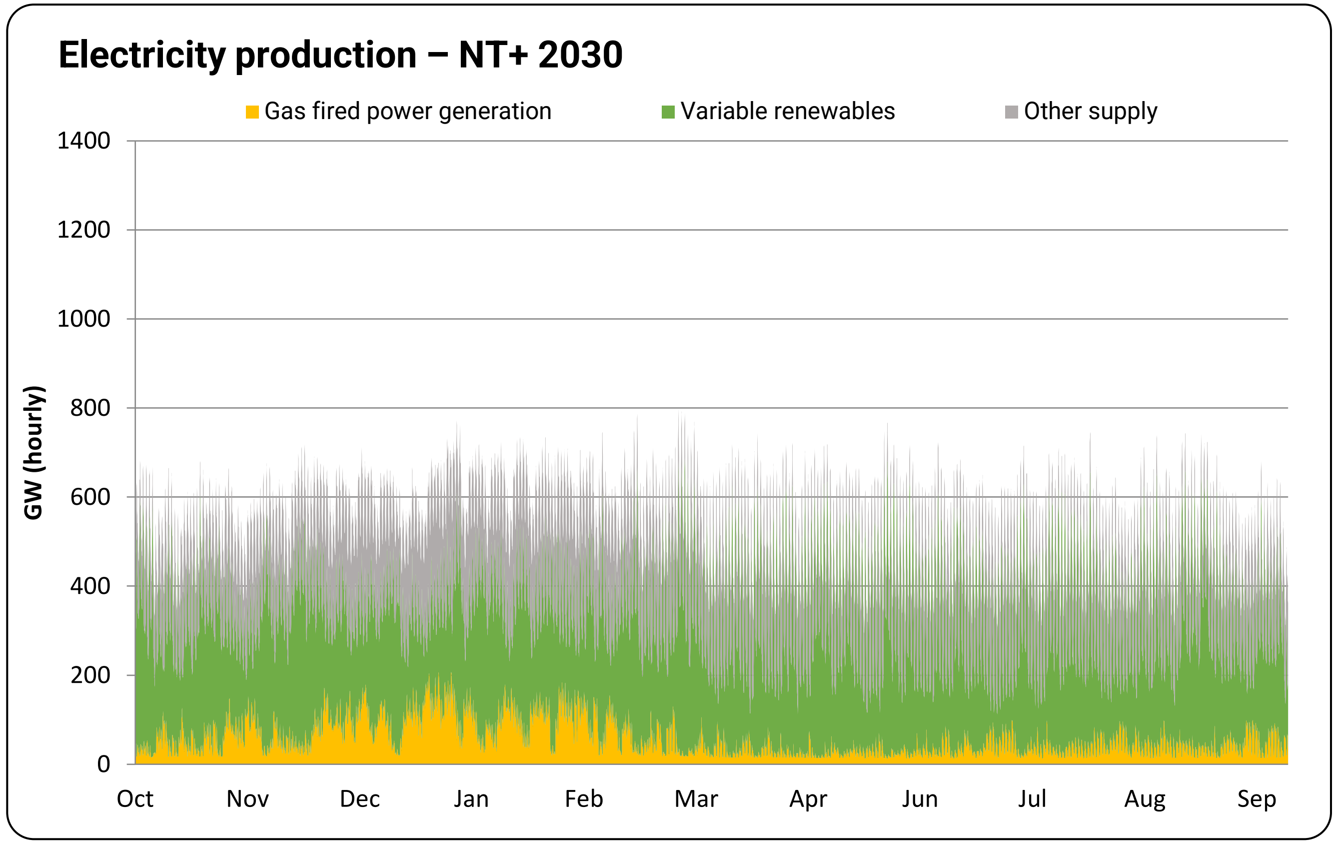


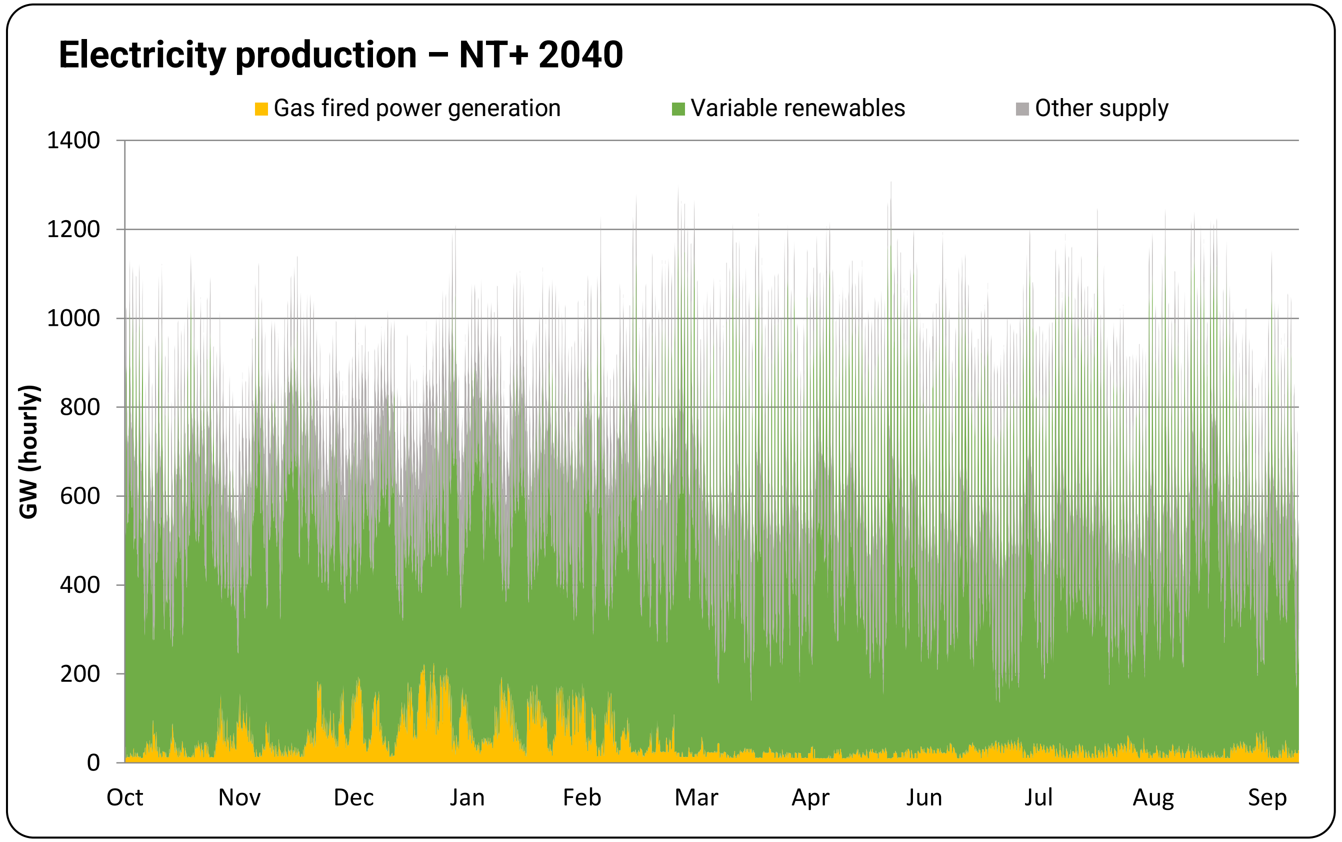
Source: Artelys modelling based on NT+ scenarios (2030 & 2040). Thermosensitive and non-thermosensitive profiles have been calibrated by Artelys based on historical data within the framework of the METIS project. Annual demand volumes have been rescaled to match NT+ volumes, and differences between climate years are based on historical data. The respective share of thermosensitive and non-thermosensitive demand is based on sectoral demand decomposition from TYNDP 2024.
**The ENSTOs analysed for TYNDP 2024 the representativeness of climate over the last 30 years. Since 2008 and 2009 were found to be two of the three most representative climate, the 2008-2009 gas year has been taken as reference for this study. 2012-2013 has been chosen as a stress-test situation, since the ENTSOs found 2012 to be the most stressful year and the modelling showed more stressful conditions under NT+ scenarios (higher annual volumes and peaks throughout the winter)*

Electricity production volumes and variability increases between 2030 and 2040

Electricity production variability exists at different timescales, from short-term (e.g. wind, PV, daily consumption patterns) to long-term (e.g. seasonal consumption due to heating). Gas-fired generation (for renewable back-up and peak demand) profile therefore evolves.

- In NT+, renewable capacities significantly increase between 2030 and 2040, from 710 to 1225 GW for solar PV (+73%), 410 to 580 GW for onshore wind (+42%), and 155 to 375 GW for offshore wind (+41%).
- Methane-fired power generation shows lower annual volumes (-16%) but higher peaks (+19%) in 2040 compared to 2030.



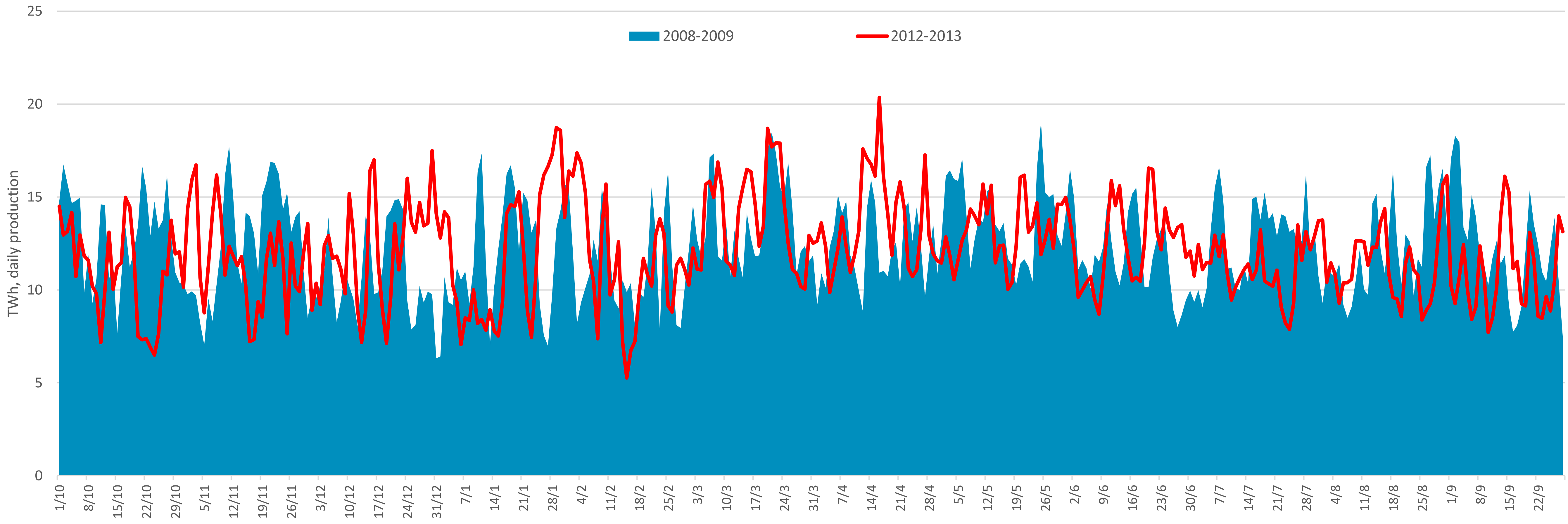


Source: Artelys modelling based on NT+ scenarios (2030 & 2040).

Renewable power generation variability requires long-term flexibility

Renewable generation patterns aggregated at daily level present very significant variability from one day to the next. Many flexibility options (e.g. batteries, industrial or domestic demand-side flexibility) present limited potential beyond a few hours. Dispatchable generation (for renewable back-up) or long-term energy storage / flexibility is therefore necessary.

Daily wind and solar electricity generation, under NT+ 2040 scenario, for 2008-2009 and 2012-2013 climate

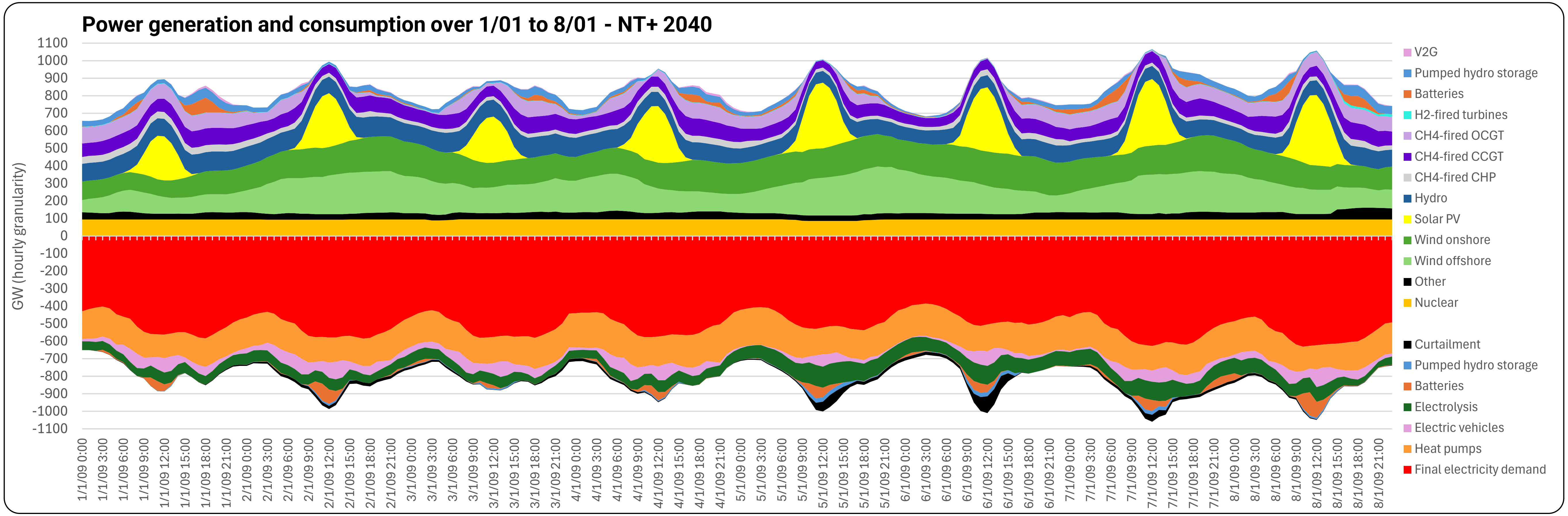


Sources: Artelys modelling based on NT+ scenarios (2030 & 2040).

Despite important levels of demand-side flexibility, gas-fired generation is required

Demand-side flexibility (batteries, pumped-hydro, flexible part of electric vehicles, heat pumps and electrolysers) is optimised in the model to accommodate renewable production patterns. Despite this, gas-fired generation is found to be essential to meet demand.

Peak hourly power demand increases from roughly 700 GW in 2030 to 1000 GW in 2040. The highest hourly consumption peak occur during renewable production peaks (in particular PV production peak), as demand-side flexibility is fully exploited. On the highest peaks, flexible assets consume at their maximum potential and curtailment might occur.

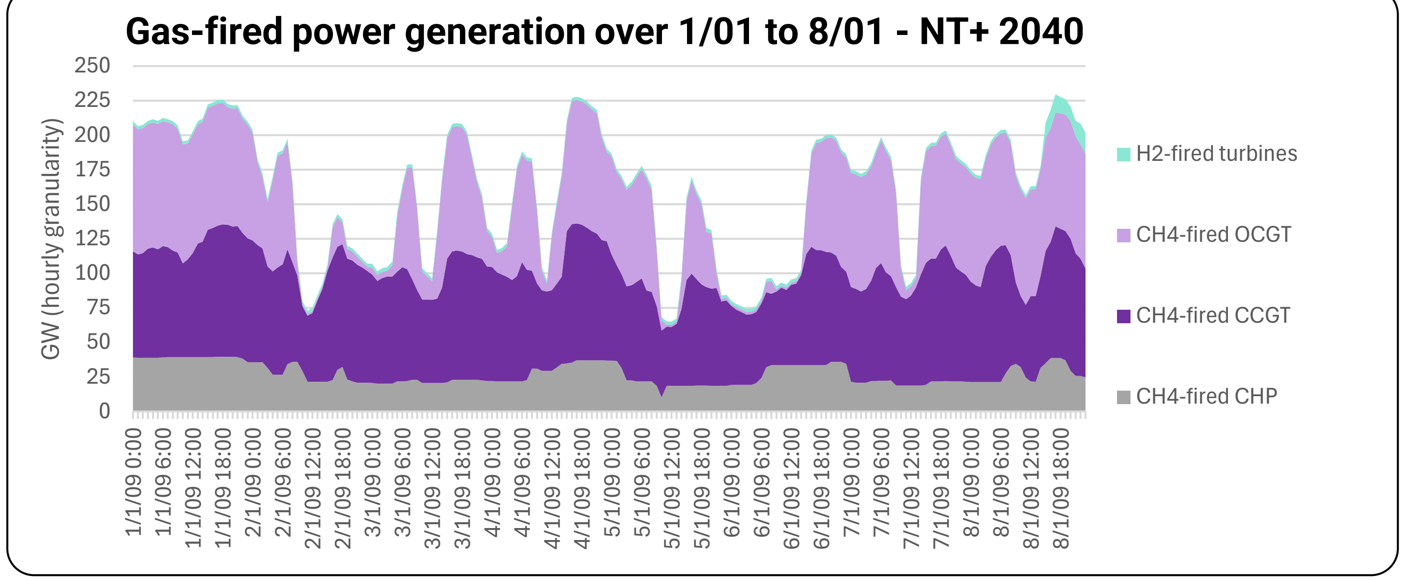


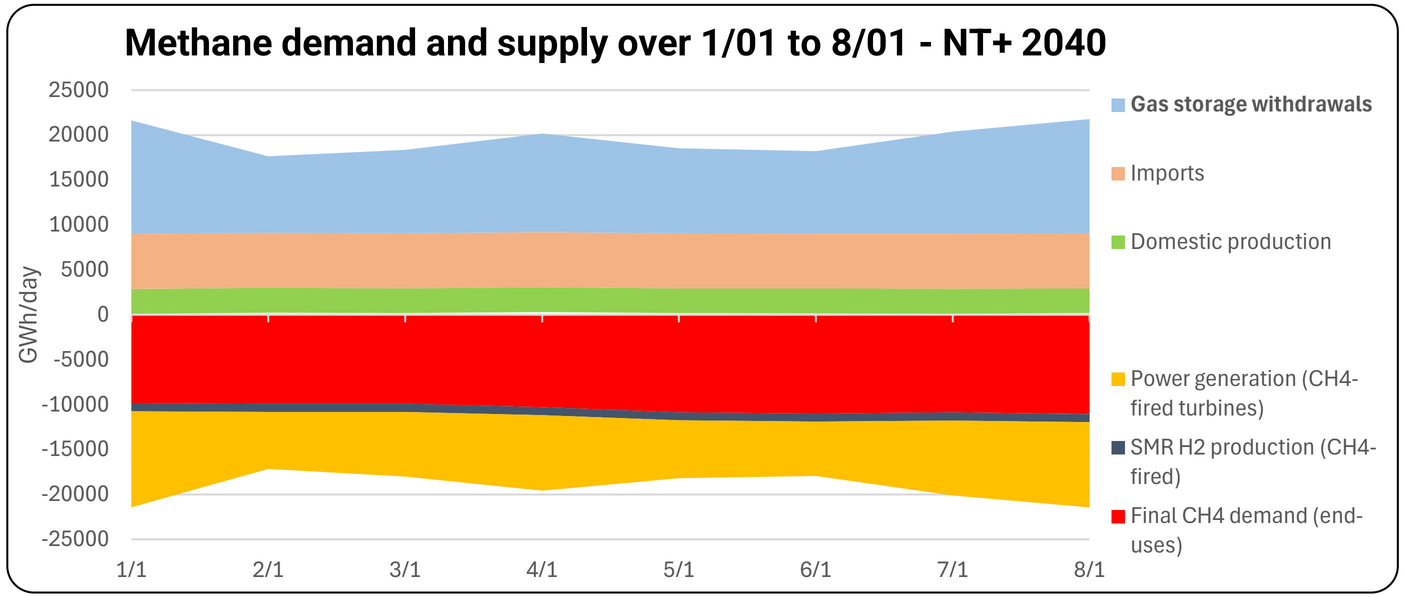
Source: Artelys modelling based on NT+ scenarios (2030 & 2040).

UGS is the key enabler of short-term flexibility of gas-fired power generation

Gas-fired power generation presents significant daily variability, in particular for peakers (OCGTs) during periods of tight margins for the power system. UGS provides the necessary flexibility in methane supply from one day to another.

- In NT+ 2040, between January 1 and 8 (climate 2009) daily methane demand for power generation varies from 6 to 10.7 TWh/day.
  - UGS is the only option for methane supply-side flexibility above a day.
  - Linepack is assumed to meet flexibility needs within the same day. Tank storages in LNG terminals are assumed to accommodate LNG tankers only (LNG imports are flat at EU level but flexible between terminals).
- Compared to TYNDP 2024 NT+ published results and methodology, flexibility options of the system are explicitly represented to correctly evaluate the role of UGS for the interlinked energy system (methane, electricity, hydrogen)*.
  - Demand-side flexibility of electric vehicles and heat pumps is explicitly modelled and its operation is optimised. ENTSO-E DSR model is adapted.
  - The hydrogen system model includes a separation between assets with access to the transport network and decentralised assets, to reflect constraints on flexibility (e.g. access to H2 storages)**. H2-fired power generation is explicitly linked to the hydrogen system and its power supply potential therefore depends on H2 storage capacities and associated filling levels.
  - A security-of-supply loop with investment options in H2 (UHS, SMRs, electrolysers) and electricity (batteries, CH4-fired OCGTs) is carried out to ensure that there is no adequacy issue in the model.





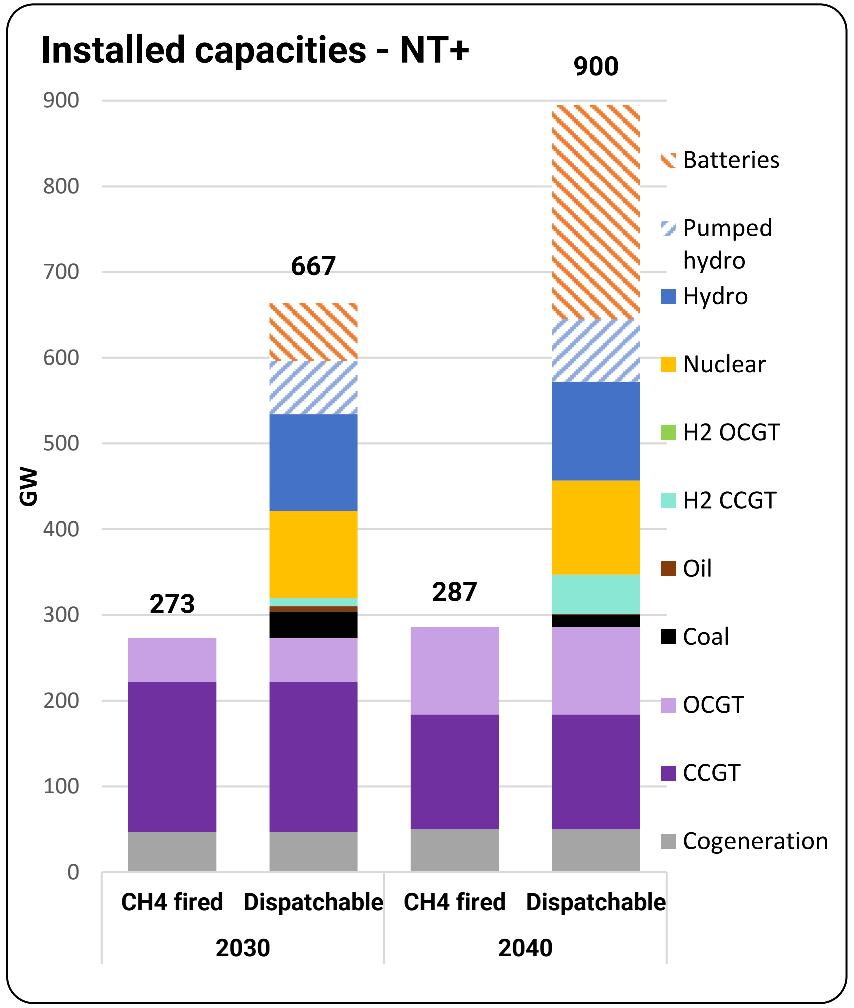
Source: Artelys modelling based on NT+ scenarios (2030 & 2040).

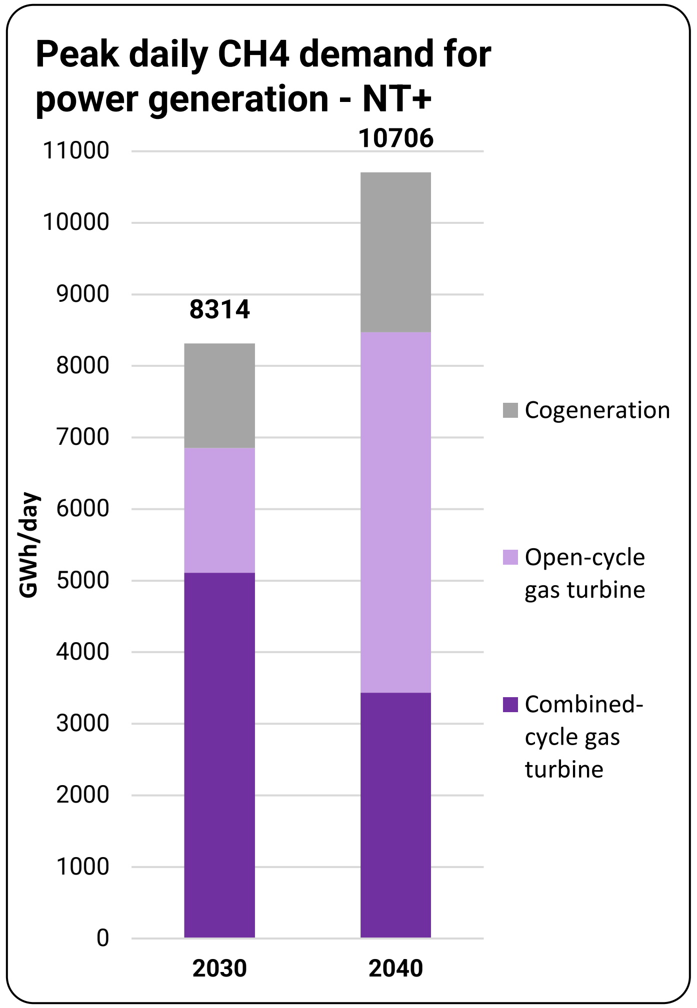
** The modelling appendix provides more details on modelling methodology and assumptions. ** The separation of H2 assets is based on TYNDP 2024 zone 1 / zone 2 topology.*

Peak gas demand for power generation increases between 2030 and 2040

Methane-fired capacities are similar in 2030 and 2040, while H2-fired capacities increase. Daily peak methane demand for power generation however significantly increase (+29%) due to a different demand profile and asset portfolio.

- Methane-fired capacities are relatively similar in 2030 and 2040 (+15 GW, 5% increase).
  - OCGT *(Open-cycle gas turbine)* capacities are higher in the model than in TYNDP2024 published datasets following the security-of-supply loop, which resulted in +22 GW in 2030 and +88 GW in 2040*.
- H2-fired capacities increase in 2040 by 36 GW, reaching 14% of total gas-fired capacities.
- Due to an important development of batteries between 2030 and 2040 (x3.7, up to 250 GW), gas-fired capacities (including H2-fired) represent a smaller share of dispatchable capacities (37% in 2040 vs 42% in 2030).
- Peak daily methane consumption for power generation significantly increases between 2030 and 2040 (+29%**).
  - Despite similar capacities, cogeneration at peak increases by 52%, driven by higher peak demand and country distribution.
  - OCGT (which have a lower fuel yield than CCGT) capacity doubles but peak daily methane consumption almost triples due to higher peak demand and country distribution.
  - CCGT *(Combined Cycle Gas Turbine)* capacity decreases in NT+ scenarios by 23% and consumption at peak reduces by 33% due to different country distribution and slightly increasing average fuel yield.



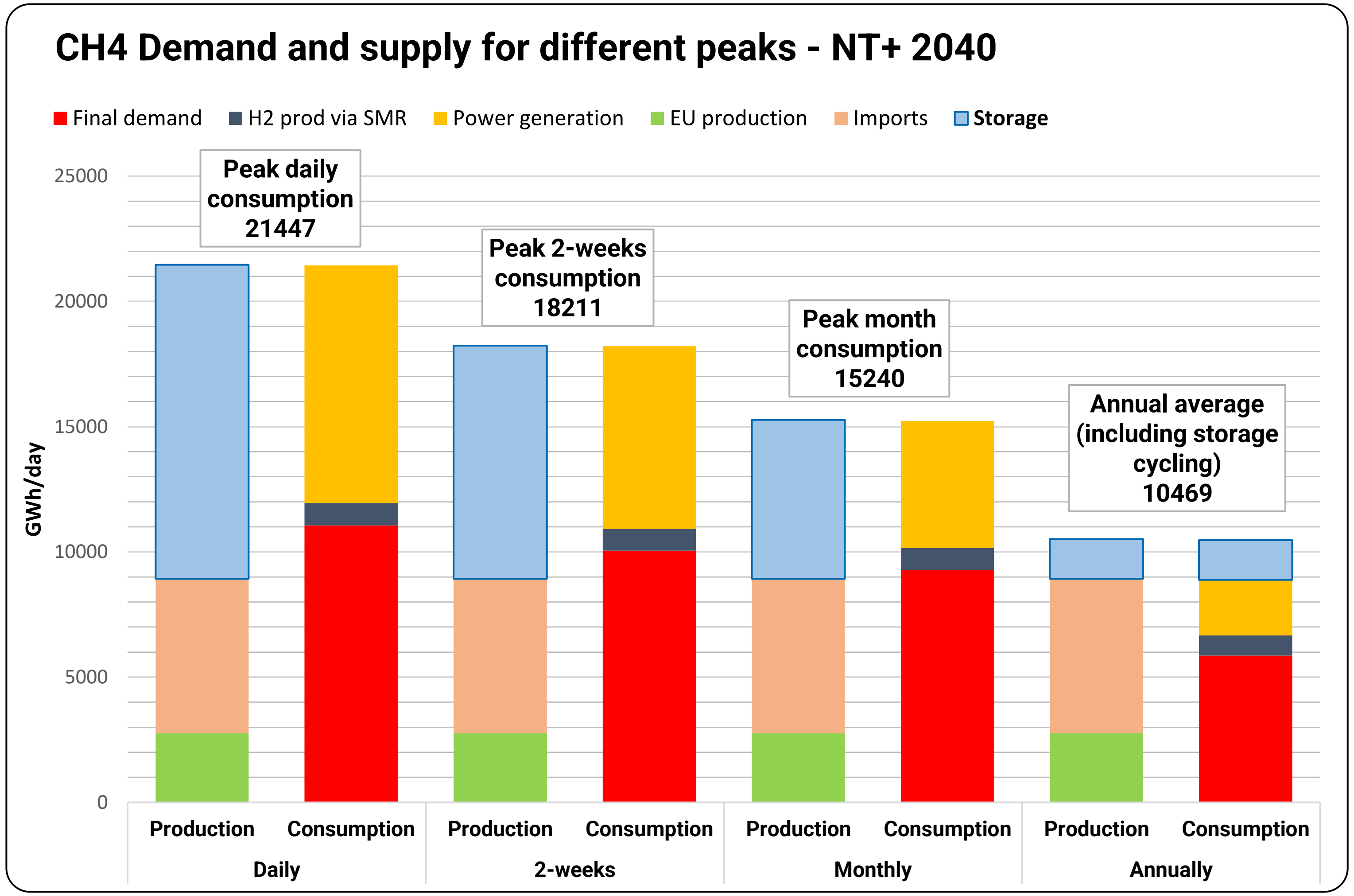


*Source: Artelys modelling based on NT+ scenarios (2030 & 2040). *The capacities are endogenously determined by the model as optimal capacities (including cross-vector investment and flexibility options) at EU-level, to avoid loss of load above 3 hours for each energy vector at country/bidding-zone level. **The difference between +18% of peak gas-fired electricity generation and +29% peak gas consumption for power generation is due to lower average efficiency of the gas turbines mix in 2040.*

UGS is the only large-scale option of sustained supply to meet peak consumption

A key role of UGS for security of supply is the ability to provide sustained peak capacity, in particular for daily and 2-week consumption peaks where UGS provide more than half of supply in NT+ 2040, which is a higher supply share than in recent years.

- Sustained very high deliverability rates from the methane system are required, for periods of several consecutive days, notably during cold spells combined with low renewable output (*Kalte Dunkelflaute*).
  - In NT+2040, **peak daily** methane consumption reaches 21.4 TWh/d (-12% compared to 24.5 TWh/d in 2023-2024), and **maximum average consumption over a period of 14 days** reaches 18.2 TWh/d (-16% compared to about 21.6 TWh/d in 2023-2024).
  - In **NT+2030, daily and 2-weeks peak are slightly higher than in 2023-2024** (respectively 25.2 TWh/d and 22.4 TWh/d).
  - **Peak demand (both daily and 2-weeks peaks) therefore decreases less than annual consumption** (-23% in NT+ 2040 compared to 2023-2024).
- **Such high deliverability rates can only be met thanks to short-term flexibility services from UGS**, which provide **58% of supply during peak day** (44% in 2024), **51% for the 2-weeks peak** (34% in 2021*), **and 42% in January** in NT+2040.
  - Import contribution at peak decreases due to lower annual consumption volumes.
- Peak withdrawals from UGS are found to **increase** despite lower annual methane demand. While peak withdrawals from UGS reached 10.9 TWh/d during the 2023-2024 gas year, it increases to 13.4 TWh/d in NT+ 2030 (+23%) and 12.5 TWh/d in NT+ 2040 (+15%).

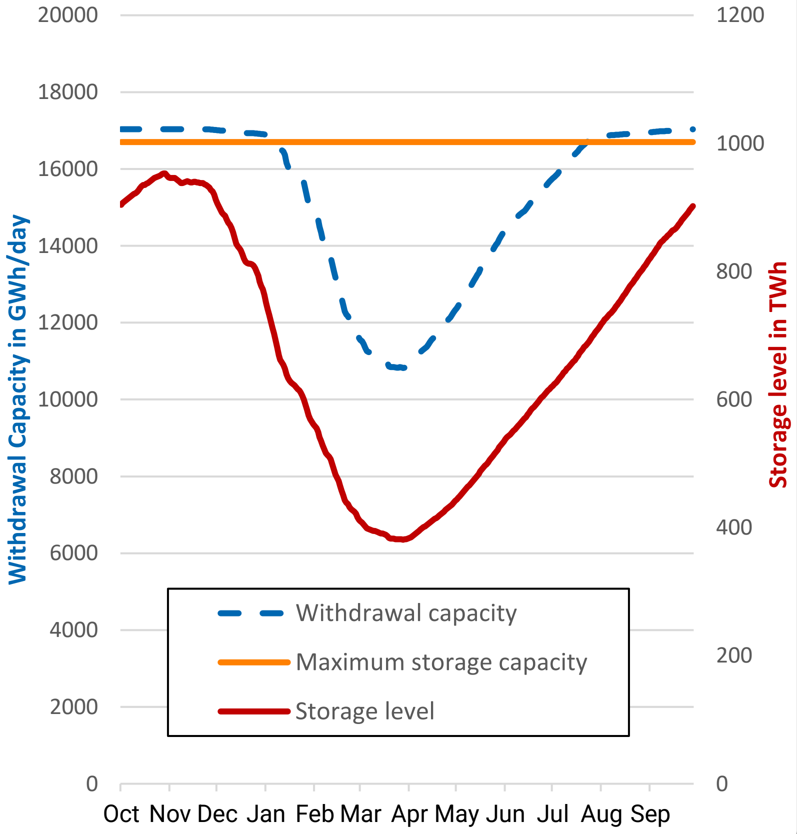


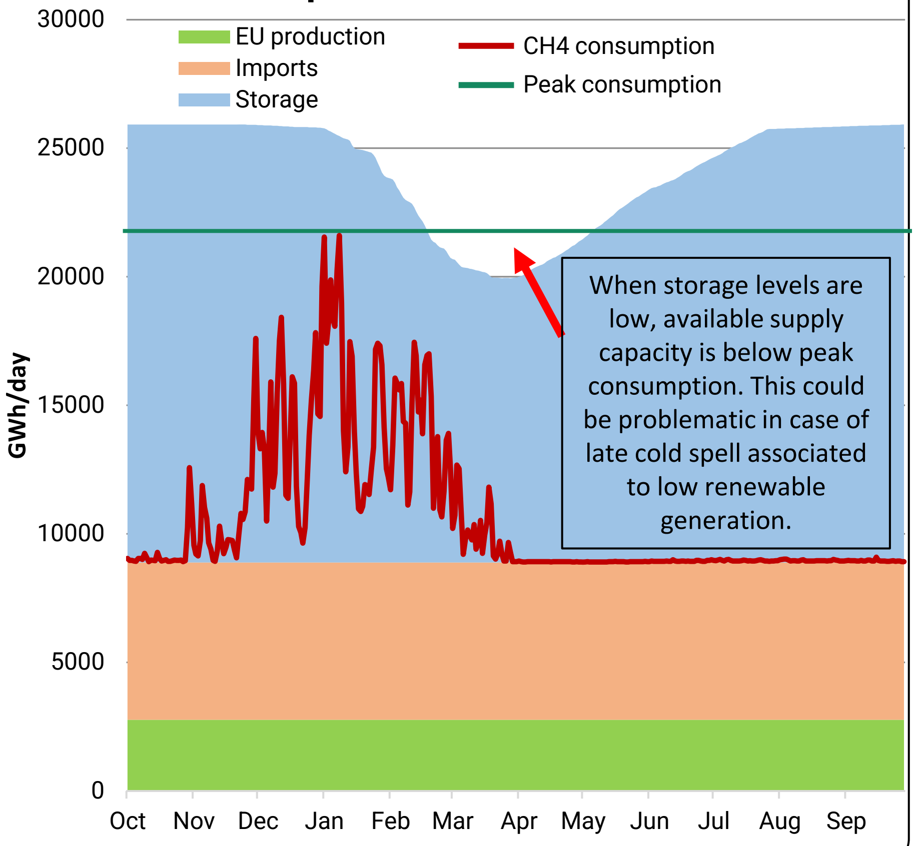
*Source: Artelys modelling based on NT+ scenarios (2030 & 2040); 2023-2024 data based on ENTSOG winter supply outlook 2025/2026 and ENTSOG-GIE system capacity map 2025. *2021 data is based on ENTSOG winter supply review 2020/2021 (which is the most recent report where we could find the supply data on such 2-week peak).*

The withdrawal capacity of UGS depends on its filling level

Maximum UGS withdrawal rates strongly depend on UGS filling level. High deliverability rates needs from UGS can only be met if storages are sufficiently filled. It is therefore crucial to assess UGS withdrawal capacity throughout the winter, depending on gas withdrawals occurring earlier in the winter and initial filling levels.

- UGS withdrawal (and injection) rates depend heavily on UGS filling level (the more a storage site is filled, the more withdrawal capacity it has). **Therefore, the ability of UGS to support peak demand decreases during winter** depends on initial filling levels and events occurring during the season (weather, supply shocks, etc.).
- As an illustration, in NT+ 2040, the 21.4 TWh/d peak demand could not be met if it occurred after mid-February, because storage levels would be too low to deliver the required withdrawal rates.
- **Adequate filling levels at the beginning of winter are essential**. In all simulations, storages are assumed to be **90% full on 1 October**.
  - Lower initial filling levels would cause withdrawal capacity to decline earlier and more sharply.
  - Given the low withdrawal capacity margins identified, lower initial filling levels are likely to pose significant SoS risks, especially in case of shocks. Dedicated modelling would be required to provide figures.
  - Storage filling levels were at 82.6% on 1 October 2025





Source: Artelys modelling based on NT+ scenarios (2030 & 2040).

Table of contents – Modelling section

Model-based assessment of role of UGS in maintaining resilience to shocks

Context, objectives and key messages

Approach for the model-based assessment of the role of UGS in maintaining resilience to security of supply shocks

Analysis of UGS role for security of supply with a multi-energy perspective, based on National Trends+ scenarios

Analysis of UGS role under security of supply shocks

- **The impact of several SoS shocks on the role of UGS for energy system security of supply is analysed: harsh winter, Norwegian supply disruption, LNG supply disruption.**
- **UGS has an even more important supply role under these shocks, which results in lower storage filling levels and therefore available withdrawal capacity. Supply shocks also result in lower capacity contribution of import for the shock duration. This results in very narrow capacity margins to meet peak demand. Other shocks or lower initial storage levels could be unsustainable.**

Analysis of UGS role under a deviation scenario

Key conclusion

Annex – Modelling approach

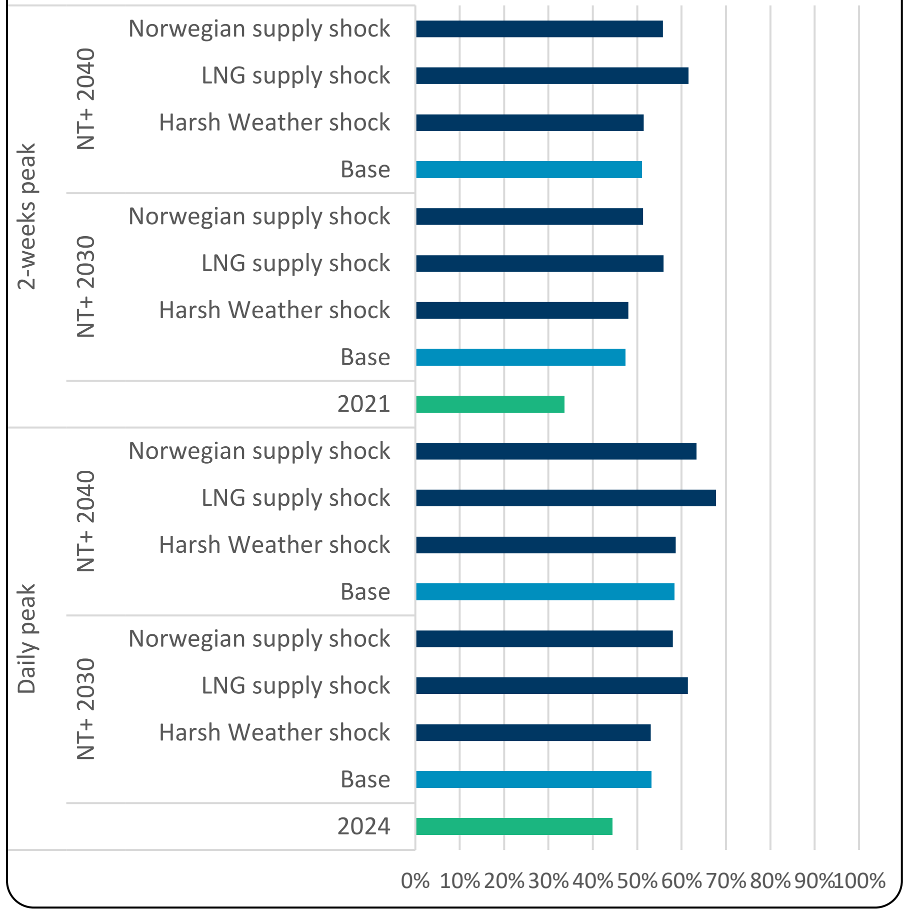
Annex – Additional modelling results

UGS is a cornerstone of system resilience under SoS shocks – Overview

UGS has been found to be essential for meeting demand in normal conditions and during all modelled SoS shocks (harsh winter, LNG supply disruption, Norwegian supply reduction).

- Three security of supply shocks of different nature and timing have been studied.
  - **Harsh winter**: analysis of the energy system under 2012-2013 climate, which shows higher annual methane consumption volumes (+6 to 6.5% applied to NT+ scenarios) and significant consumption peaks from December to March (although the highest peak is lower than in the reference climate used, 2008-2009).
  - **Norwegian supply disruption**: reduction of Norwegian supply from January to March equivalent to Troll field 2024 production (-37.5 TWh/month).
  - **LNG supply disruption**: reduction of LNG supply from November to January, equivalent to flows diverted from Europe during an historical Asian cold spell (-30 TWh in November, -48.9 TWh in December, -63 TWh in January).
- To avoid modelling biases and to represent a plausible behaviour of market actors*, it is assumed that imports are the same between the base situation and SoS shocks from 1/10 to March (1/03 for LNG shock, 31/03 for the others). Imports then increase until 31/09 to ensure that storage filling levels reach 90% at the end of the year.
- The analysis of impact of these SoS shocks on the energy system shows that UGS, which is already essential for meeting demand in normal conditions, plays an event more important role under SoS shocks conditions.
  - The share of total supply provided by UGS at peak (daily and 2-weeks) is higher by 5 to 10% under imports shocks compared to the base situation (NT+ 2030 or 2040). **UGS supply share at peak is up to 23% (daily peak) and 28% (2-weeks peak) higher in 2040 under LNG supply shock compared to recent years**.
  - The SoS shocks result in capacity margin (between daily peak demand and system deliverability capacity) narrower than in base conditions. **These margins could become insufficient if shocks occur later in winter, if multiple shocks overlap, or if initial filling levels fall below 90%**.

Share of CH4 supply provided by UGS at daily and 2-weeks peaks

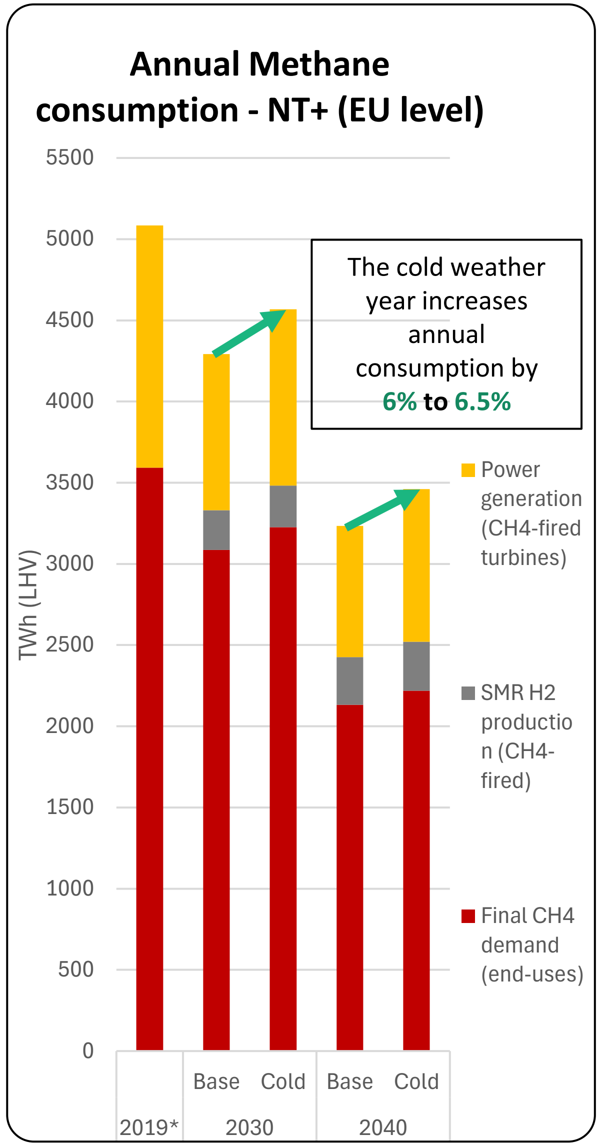


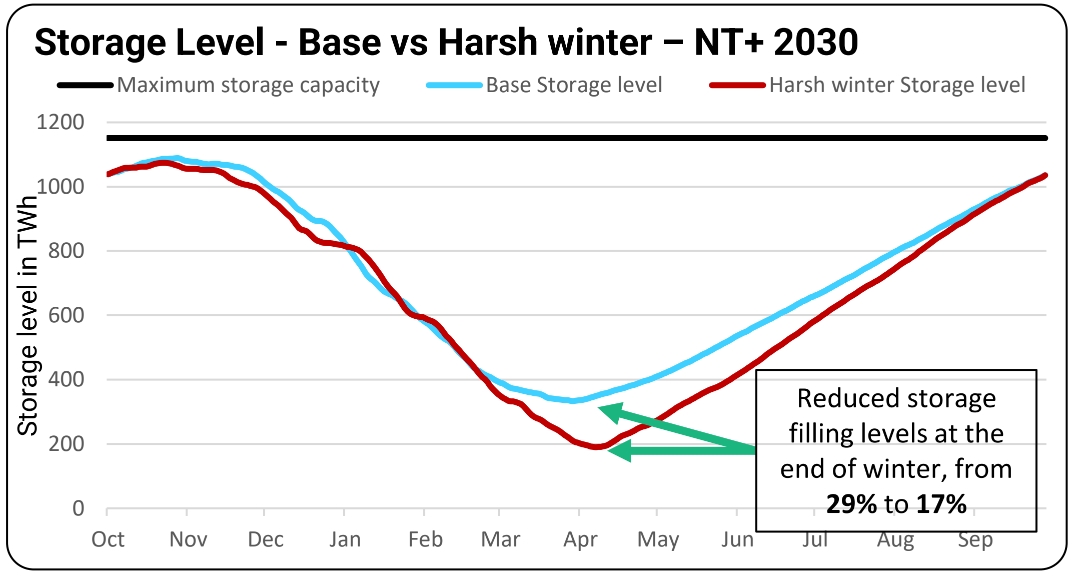
*Sources: Artelys modelling based on NT+ scenarios (2030 & 2040). EU27 UGS storage filling level on 1 October 2025 is based on AGSI datasets [Link]. Equinor published that Troll field delivered 42.5 bcm of natural gas in 2024 [Link]. The Oxford institute for energy studies published in 2021 an analysis of the impact of an Asian cold spell on the LNG market [Link]. *Imports are supposed not to increase before March (LNG shock) or April (Harsh winter and Norwegian shocks) to avoid modelling bias (foresight of shock before it happens) and represent a possible behavior of actors (e.g. trader waiting for the end of heating season to increase imports volumes to prepare for next year, as prices might be lower due to lower demand).*

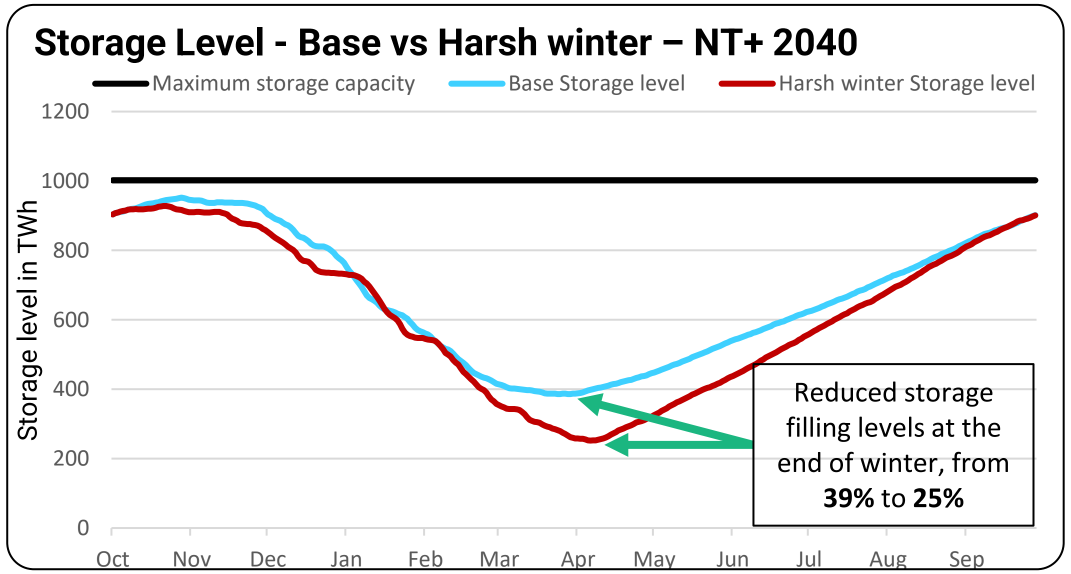
Harsh winter shock – Higher consumption results in lower storage levels in March

In the harsh winter shock, annual consumption increases by 6 to 6.5% compared to reference, which results in storage levels around 13% lower at their minimum.

- Part of energy consumption is thermosensitive (heating). Based on historical energy consumption and temperature datasets it is possible to separate thermosensitive (depending on climate year) and non-thermosensitive profiles, and evaluate climate impact on annual consumption volumes.
- Also considering NT+ sector-level annual consumptions levels, it is possible to adequately determine final consumption profiles and volumes in prospective scenarios for historical climate years.
- Renewable electricity annual production volumes and profiles are also climate-dependent, resulting in different gas-fired power generation needs.
- The analysis shows that using the 2012-2013 climate year results in annual consumption volumes higher by 6 to 6.5% compared to climate year 2008-2009 for NT+ 2030 and 2040 scenarios.
  - Final gas demand increases by 4% and demand for gas-fired power generation by 11% in 2030 and 14% in 2040.
- Since UGS are assumed to be the only supply source which can increase its supply volumes*, the higher demand is met by withdrawals, resulting in storage levels roughly 13% lower.







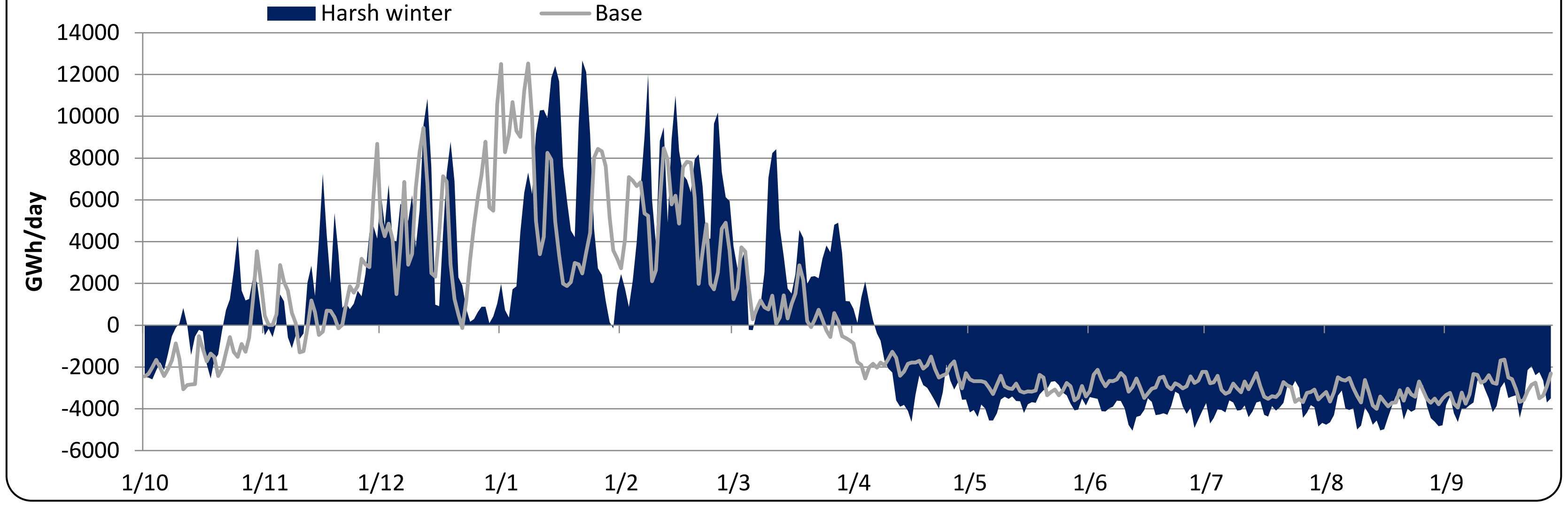
*Source: Artelys modelling based on NT+ scenarios (2030 & 2040). Datasets used to evaluate methane final demand thermosensitive profiles and demand volumes differences between climate years are based on Artelys analyses carried out within the METIS project. *See note on previous slide.*

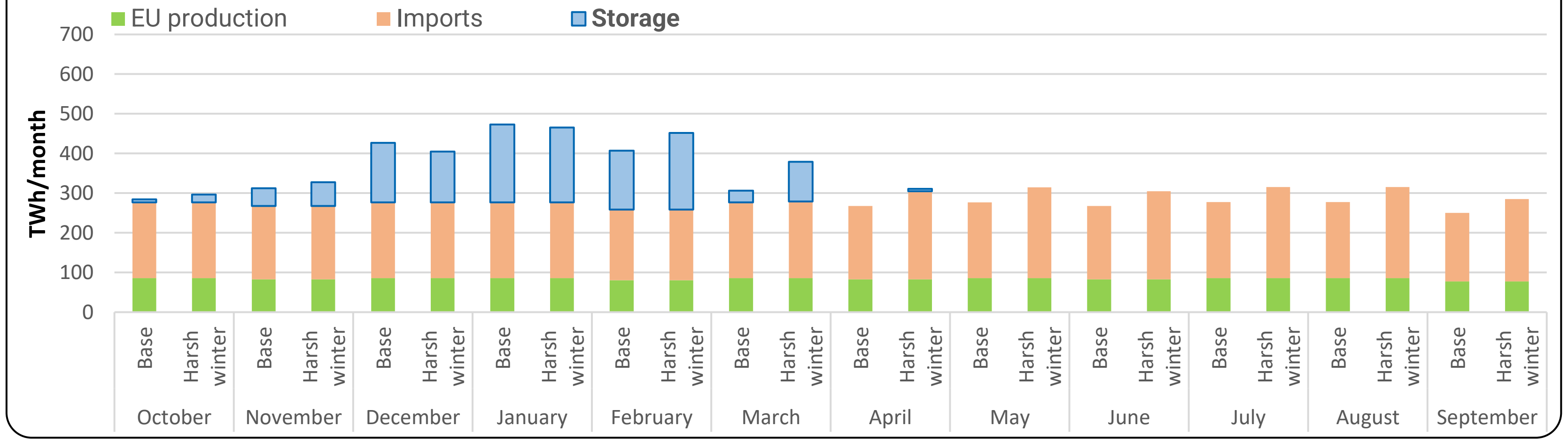
Harsh winter shock – UGS withdrawals show significant daily to monthly variability

Artelys

UGS operation profile during the winter period presents significant variability at daily granularity between climate years due to different temperature and RES patterns, resulting in significant differences in monthly volumes.

- **While the seasonal pattern remains broadly similar, withdrawals occurring from November to March present major variability at daily to monthly level**.
  - Daily peak ranges from 0 to 12.7 TWh/d in 2012-2013 climate (maximum is 12.5 TWh/d under 2008-2009 climate).
  - On a given week there can also major variability, for example during the last 7 days of the year withdrawals amount to 4.2 TWh in 2012-2013 climate against 48.7 TWh in 2008-2009 climate.
  - On March, UGS net withdrawals amount to 100 TWh in 2012-2013 climate against 30 TWh in 2008-2009.
- In 2012-2013 climate, several important withdrawal peaks occur throughout the winter, with 11 days above 10 TWh/d against 5 in 2008-2009 climate. A significant withdrawal peak also occur in March (above 8 TWh/d), when UGS filling levels are low and therefore can only provide limited withdrawal capacity.



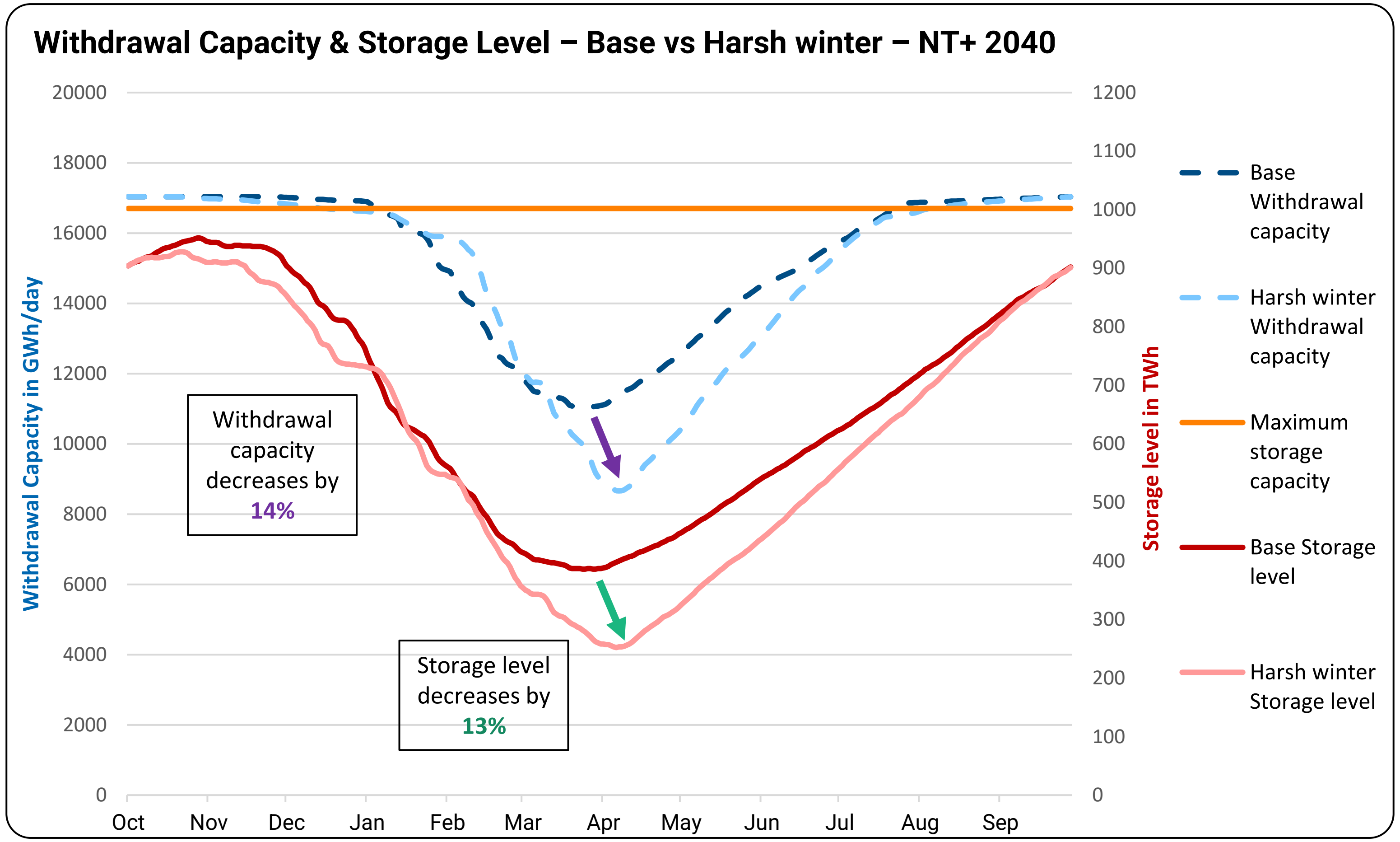


Source: Artelys modelling based on NT+ scenarios (2030 & 2040).

Harsh winter shock – Higher withdrawn volumes results in lower UGS deliverability

Lower storage filling levels towards the end of the winter in the harsh winter shock result in lower withdrawal capacity.

- UGS filling level shows an overall decrease under 2012-2013 climate compared to 2008-2009 climate in NT+2040, although not uniformly:
  - Early in the winter season (mid-November to end of December), UGS levels are 4 to 9% lower.
  - In early January, consumption is significantly lower under 2012-2013 climate, which compensates the earlier difference, resulting in similar storage filling levels until early February.
  - At the end of winter, consumption is significantly higher under 2012-2013 climate (+11% in February and +24% in March), resulting in much lower UGS filling levels at minimum (**-13%**, reaching a minimum filling level of 25% of WGV UGS capacity in NT+ 2040 and 17% in NT+ 2030).
- The lower storage filling levels results to much lower withdrawal capacity at the end of winter in NT+ 2040*.
  - The minimum withdrawal capacity reached is 8.7 TWh/d under 2012-2013 climate against 11.1 TWh/d for 2008-2009 climate (**22% lower**).
  - Compared to maximum withdrawal capacity, minimum withdrawal capacity reached is only 51% under 2012-2013 climate, against 65% in 2008-2009 climate (-14%). Minimum capacity reached in NT+2030 is 44% (vs 58% in 2008-2009 climate).



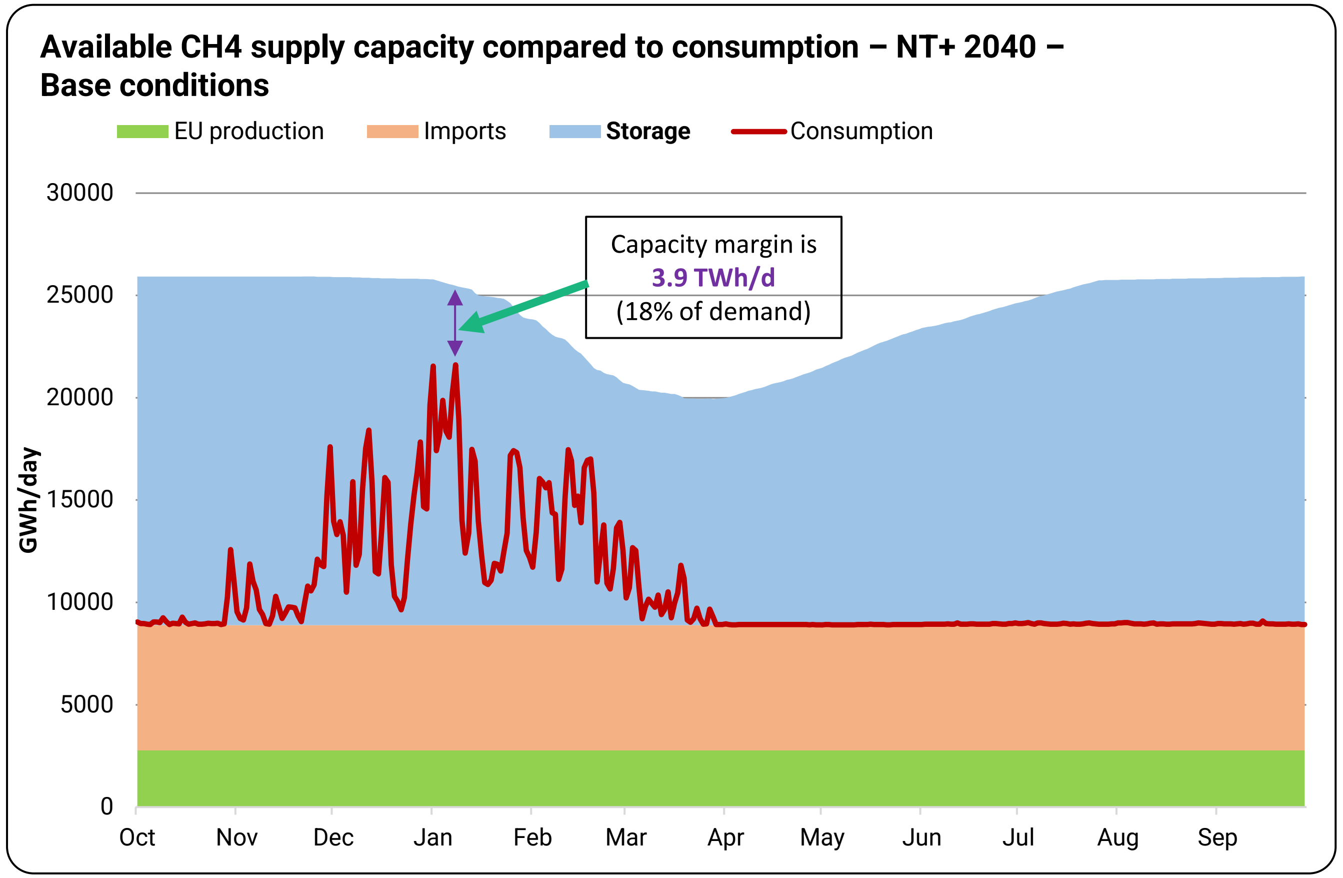
*Source: Artelys modelling based on NT+ scenarios (2030 & 2040). *Storage filling levels and withdrawal capacity are not linearly related (although in most countries the curves can be approximated by two-part linear functions). At EU-level under NT+ 2040 scenario, withdrawal capacity typically remain above 90% as long as storage are filled above 60-70%% of their capacity, with strong decrease when filling levels are lower (typically -1% of withdrawal capacity per reduced percentage of filling level withing the range 30-60% of storage filling levels, although there is significant variability depending on storage types and countries, and therefore the scenario and climate considered has an impact on EU-level figures). Injection and withdrawal curves published by ENTSOG for summer 2025 outlook were used as a basis for the modelling.*

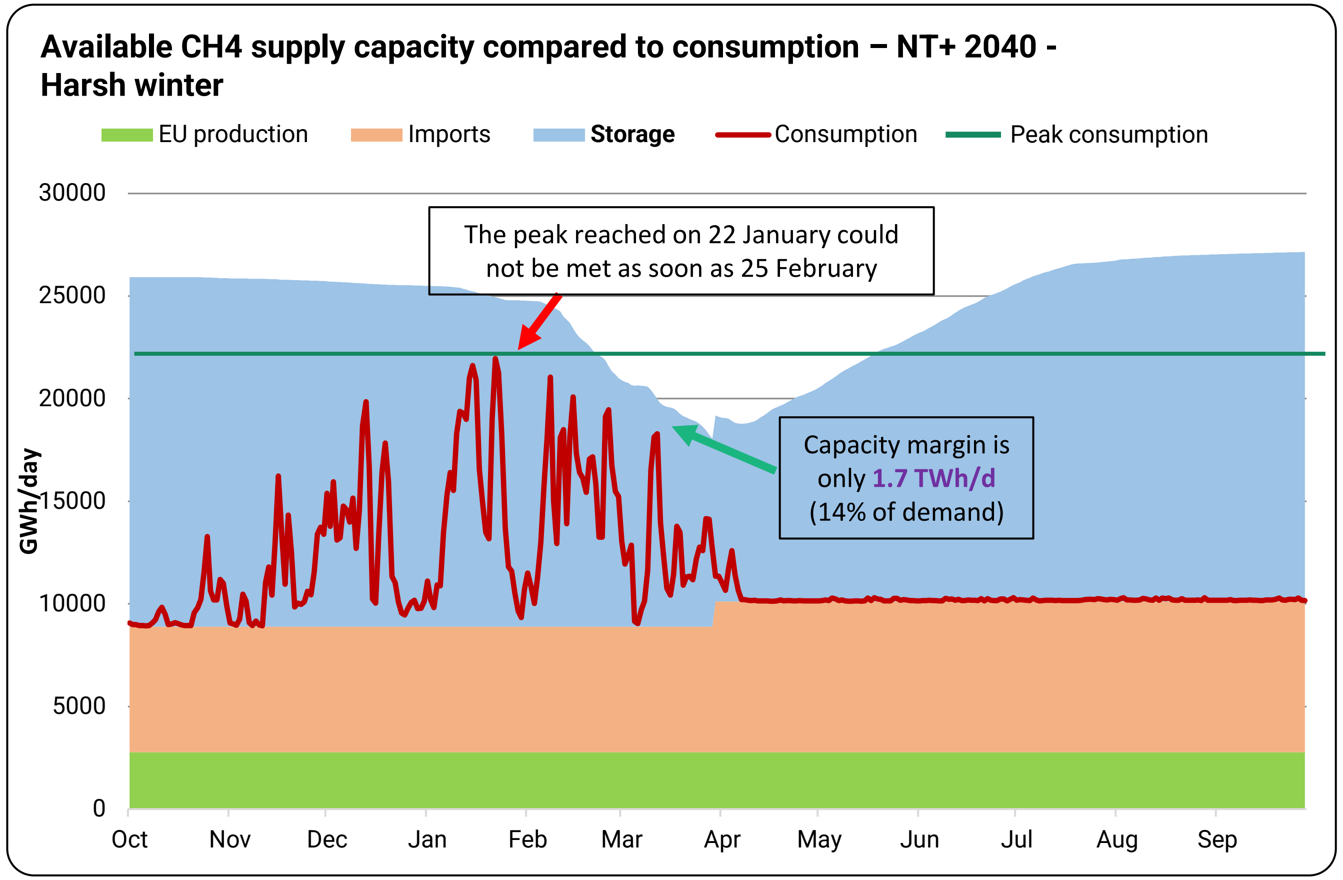
Harsh winter shock – Supply capacity margins are very narrow

Artelys

Capacity margin (between daily peak demand and system deliverability capacity) are significantly lower in the harsh winter shock compared to base conditions. Several daily peaks could not be met a few weeks afterwards despite 90% initial filling levels.

- The minimum capacity margin under the harsh winter shock is 1.7 TWh/d (in mid March) against 3.9 TWh/day (in early January) in NT+2040 base conditions.
- In the harsh winter, the peak reached on 22 January (22 TWh/d) could not be met after 25 February, and the peak of 26 February (19.5 TWh/d) could not be met 3 weeks later.



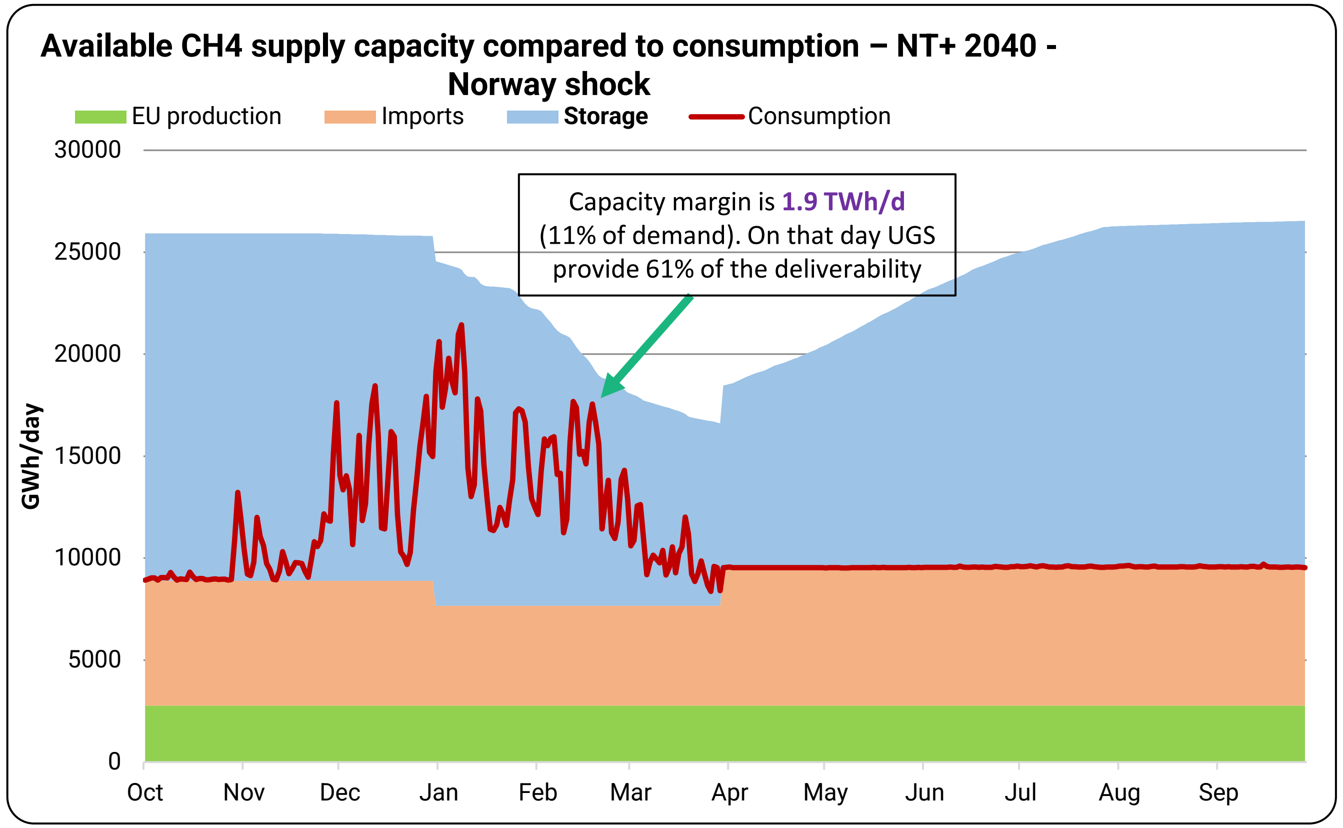


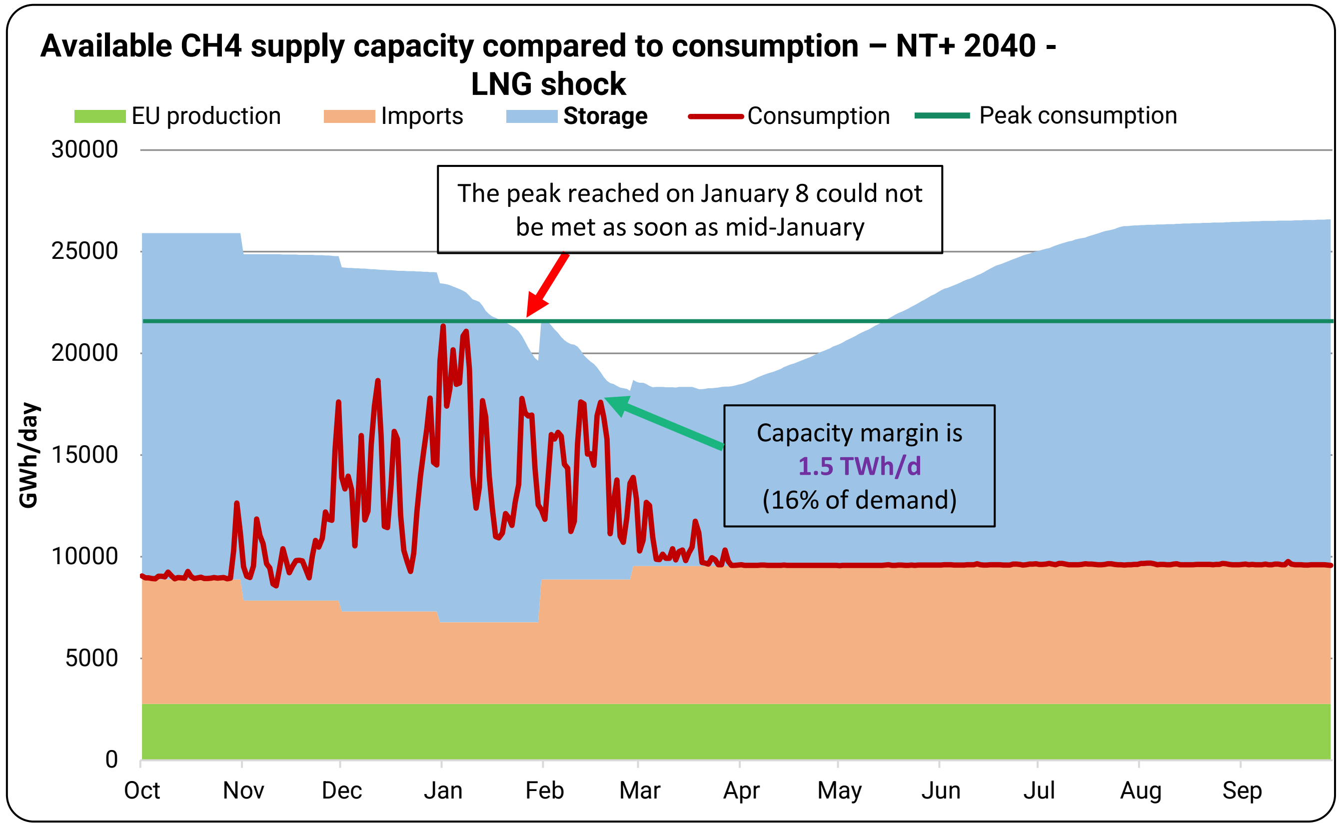
Source: Artelys modelling based on NT+ scenarios (2030 & 2040).

In Norwegian and LNG supply shocks, capacity margins are also very narrow

The capacity contribution of imports is reduced during supply shocks, resulting in both a decline in capacity margins and an increase in capacity contribution of UGS. UGS also provides additional supply during the shock, leading to lower filling levels and therefore withdrawal capacity. The timing of the shock therefore has different implications for SoS.

- A shock occurring early in the winter leads to low UGS filling levels early in the winter. The capacity contribution of storages is therefore already significantly decreasing in January when peaks typically occur. A shock occurring at the end of winter results in very low system capacity (as import contribution is reduced and UGS filling levels are low).
- On NT+2040 peak consumption day, UGS provide 68% of supply under the LNG shock and 63% in Norwegian shock, against 58% in base conditions.





Sources: Artelys modelling based on NT+ scenarios (2030 & 2040).

Table of contents – Modelling section

Model-based assessment of role of UGS in maintaining resilience to shocks

Context, objectives and key messages

Approach for the model-based assessment of the role of UGS in maintaining resilience to security of supply shocks

Analysis of UGS role for security of supply with a multi-energy perspective, based on National Trends+ scenarios

Analysis of UGS role under security of supply shocks

Analysis of UGS role under a deviation scenario

- **The deviation scenario explores a slower decline in methane consumption due to slower deployment of hydrogen and heat pumps. Methane demand in 2040 is only 19% lower than in 2019 (vs -36% in NT+).**
- **The drivers of methane system are significantly different in the scenario, with higher peak final demand but lower peak demand for power generation, resulting in overall similar UGS needs.**

Key conclusion

Annex – Modelling approach

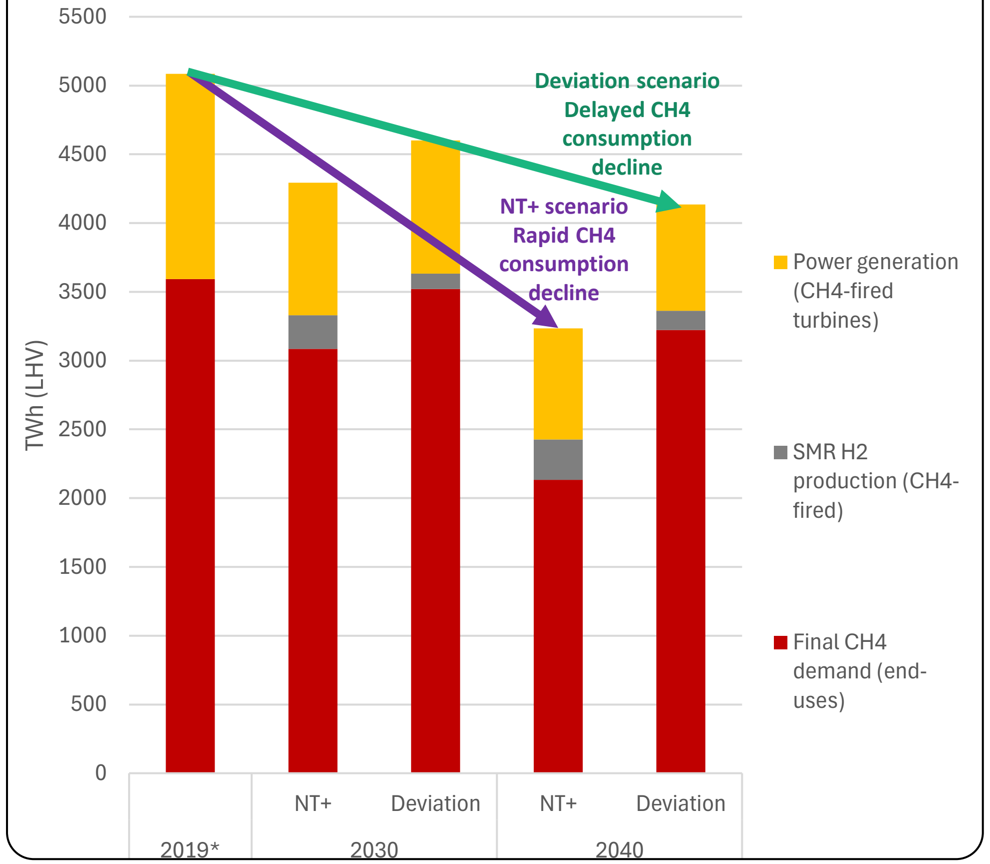
Annex – Additional modelling results

The deviation scenario explores a slower decline in methane consumption

The deviation scenario explores a slower decline in methane consumption, due to slower deployment of hydrogen and heat pumps. Methane demand in 2040 is only 19% lower than in 2019 (vs -36% in NT+).

- The deviation scenario explores **the impact of a slower decline in methane consumption.** Annual methane demand in 2040 is **19% lower than in 2019** (compared to -36% for NT+).
- Compared to NT+, the key differences in the deviation scenario are:
  - Lower H2 development, with associated annual volumes transferred towards methane (mostly non-thermosensitive additional final methane demand in NT+2040)
    - **-54%*** of H2 demand, production capacities, import capacities and H2-fired power generation capacities, resulting in roughly -270 TWh in 2030 and -820 TWh in 2040 of final H2 demand (EU level).
  - Lower heat pump development, with associated annual volumes of heating demand transferred towards methane (additional thermosensitive consumption, taking into account efficiencies of heat systems).
    - The growth rate of heat pumps between 2019 and 2040** were reduced by **0.5%** per annum, resulting in -51 TWh in 2030 and -85 TWh of electricity consumption in 2040.
  - To compensate the lower electricity demand from electrolysis and heat pumps, solar and wind capacities have been reduced accordingly, proportionally to their annual production at country level.
- Other scenarios more stressful for the methane system could be imagined, for example with lower electricity demand-side flexibility (leading to higher peak need of dispatchable generation), high electrification but limited RES development (leading to higher need from gas-fired assets, both for annual methane volumes and peaks), or increased share of thermosensitive demand (e.g. due to lower renovation of buildings, leading to higher demand peaks).

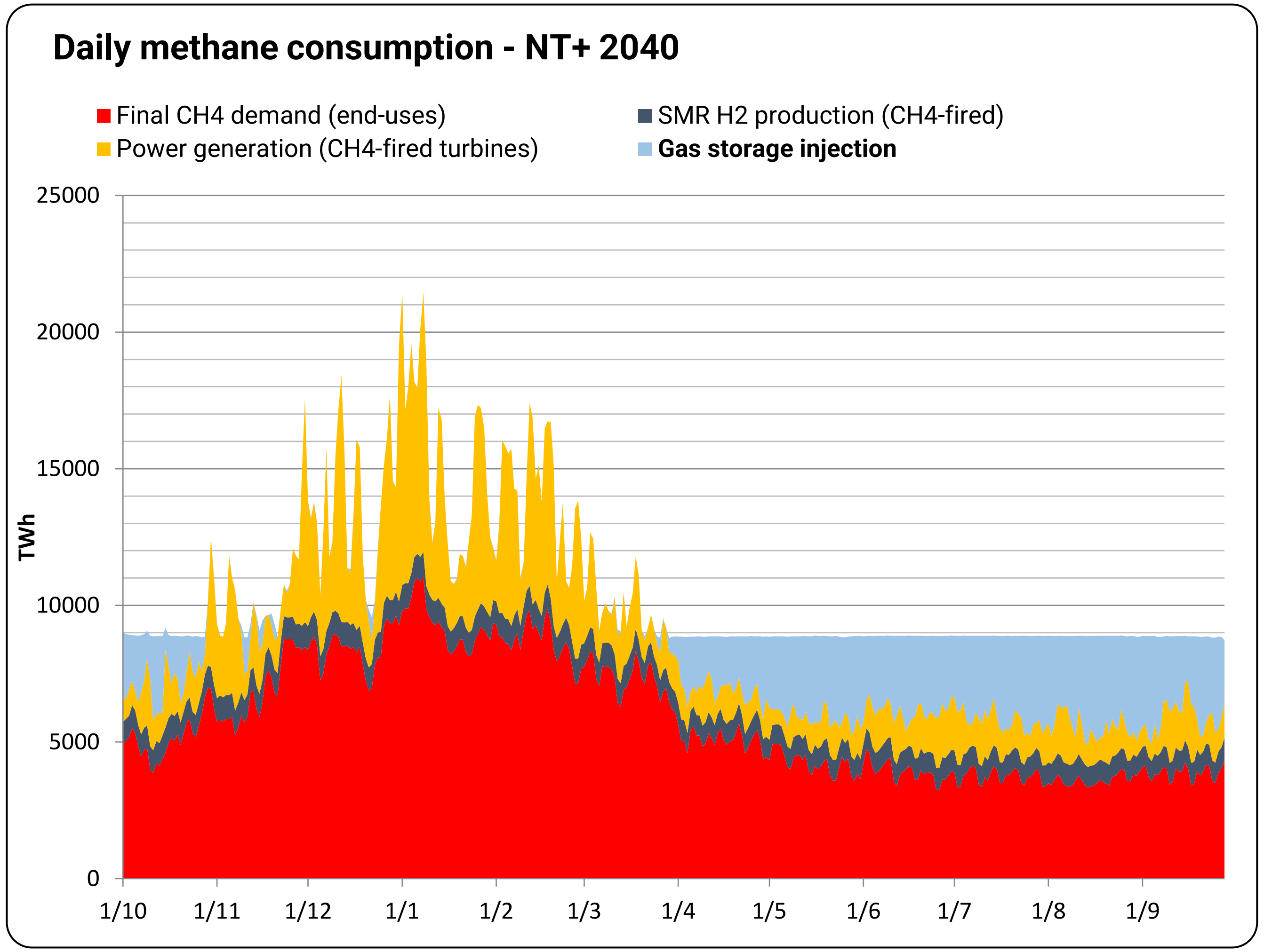
Annual Methane consumption – NT+ compared to deviation scenario (EU level)

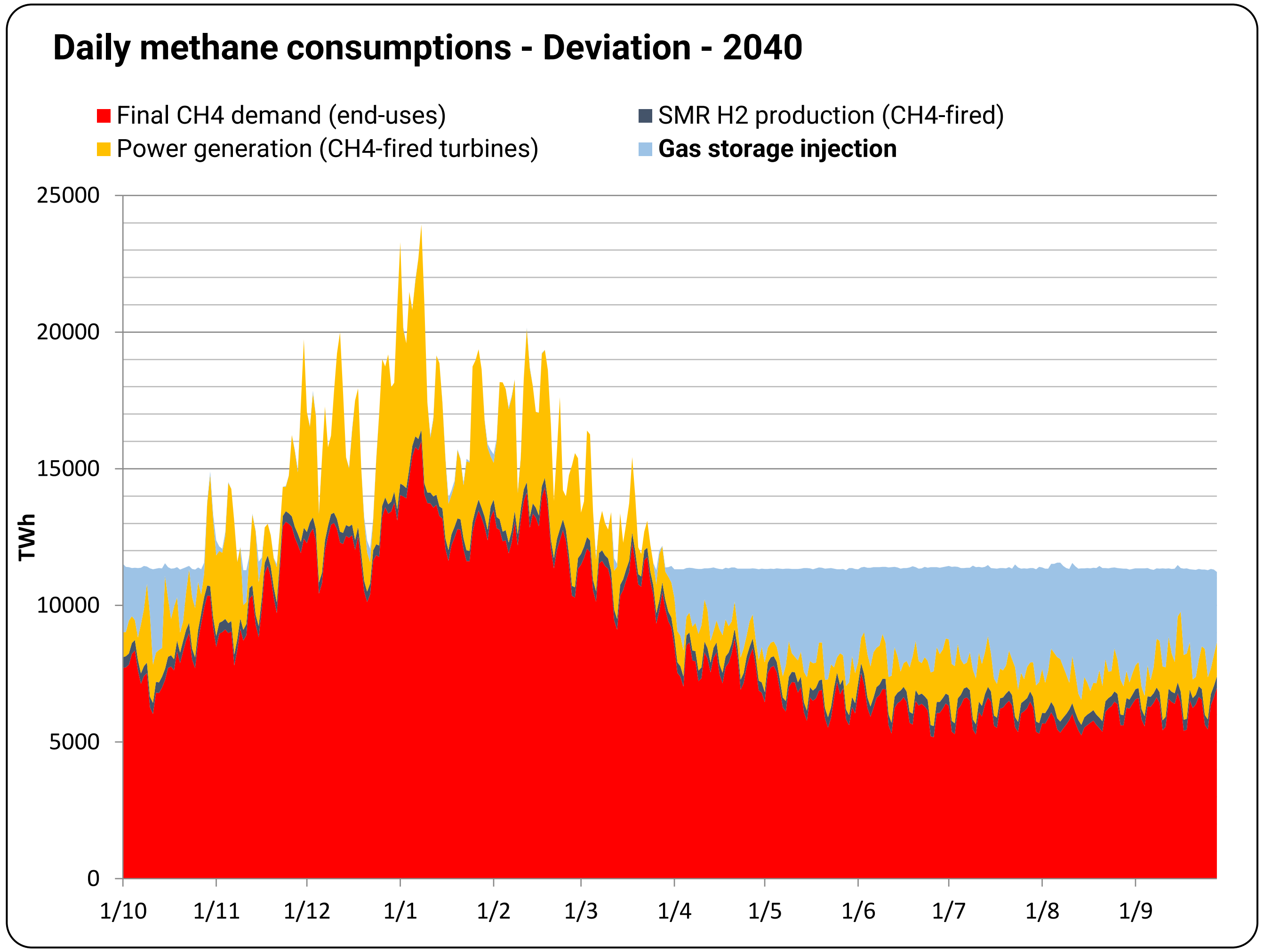


Source: Artelys modelling based on NT+ scenarios (2030 & 2040). The deviation scenario has been co-designed with GIE Funding Members and Compass Lexecon.
**The figure of -54% has been estimated by Compass Lexecon based on an analysis of the Hydrogen Council's 2024 report [Link]. The lower boundary of supply potential ranges for 2030 (based on probability-weighted EU production volumes and import potentials) were compared to NT+, leading to an estimation of -54% which was then also applied to 2040. **Since no national-level data on heat pumps is provided for NT+, distributed energy scenario was used as a proxy.*

Methane consumption profile is significantly different in the deviation scenario

Final methane demand significantly increases in the deviation scenario compared to NT+ (by around 3000 GWh/day on average and up to 5000 GWh/day at peak). Due to lower electrification, peak methane consumption for power generation decreases.



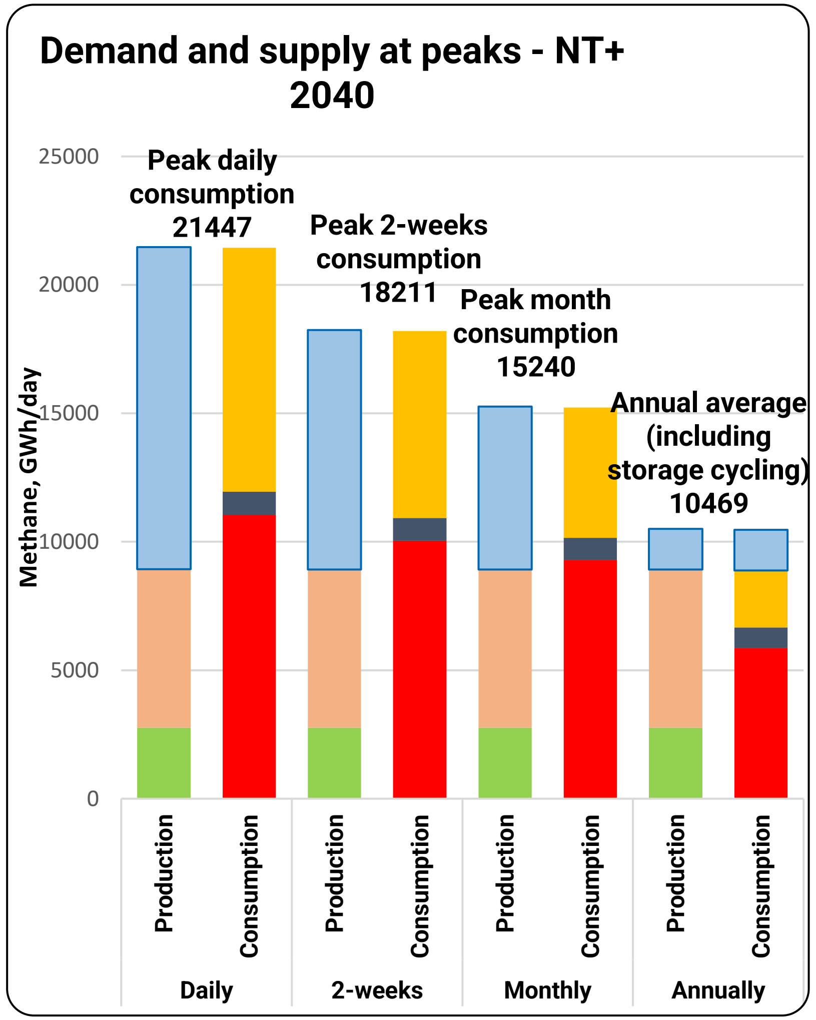


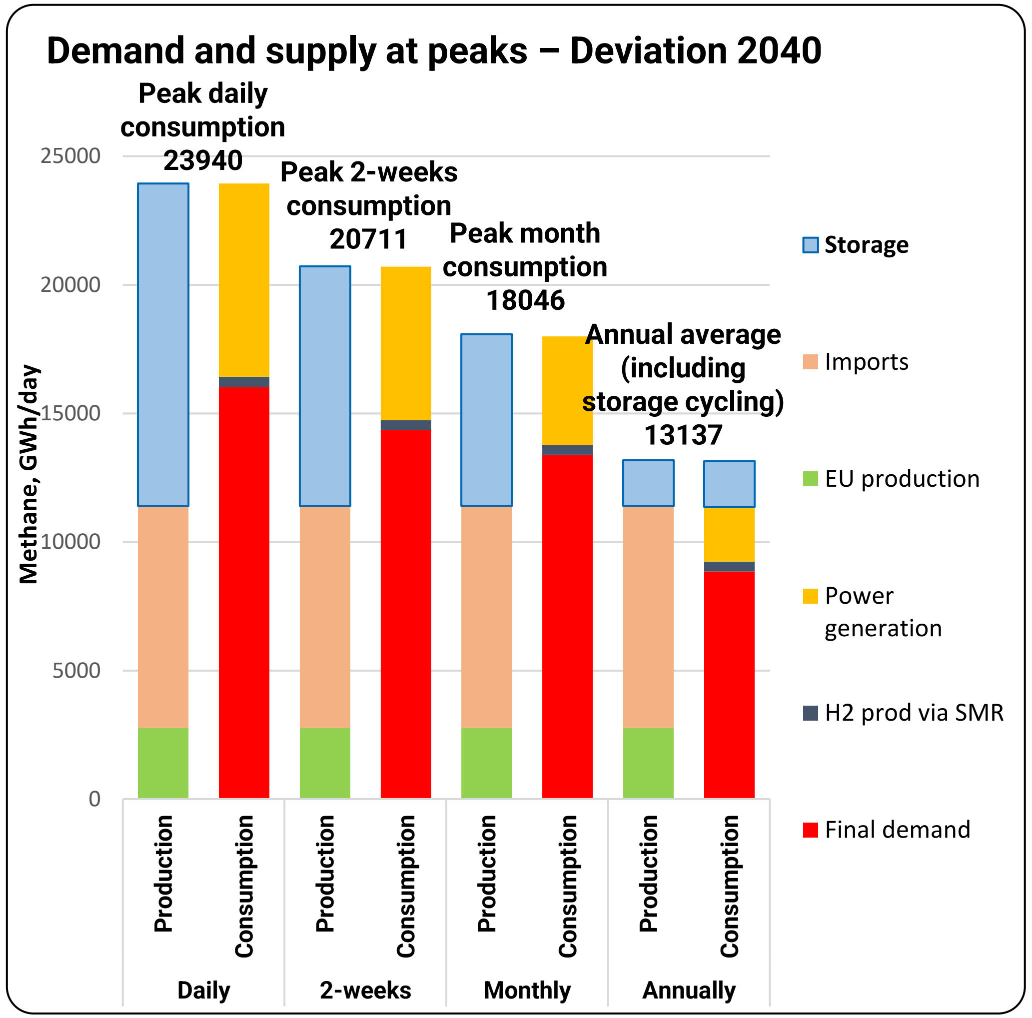
Sources: Artelys modelling based on NT+ scenarios (2030 & 2040).

The deviation scenario show similar UGS needs for different flexibility needs drivers

The deviation scenario shows very different drivers of methane flexibility need, with increased peak final demand but decreased peak demand for power generation. Increased import levels offsets the increased overall peak, resulting in similar UGS needs in both scenarios.

- **The deviation scenario results in higher peaks across all flexibility timescales** (+2500 to +2800 GWh/day).
- During peak consumption day in 2040:
  - **Final methane demand is 45% higher in deviation.**
  - **Methane demand for power generation is 21% lower in deviation** (due to lower electrolysis and heat pump deployment).
  - These differences between NT+ and the deviation scenario are similar for the 2-weeks peak (respectively 43% and 18%).
- However, **the higher annual demand also leads to higher baseload imports**, which are found to offset the increased peaks.
- As a result, **UGS needs remain similar to the ones observed in NT+**.
  - For example, under the Norwegian supply shock, the minimum capacity margin is between 1.9 and 2.8 TWh/day, representing 9 to 13% of consumption (across all scenarios and horizons).





Source: Artelys modelling based on NT+ scenarios (2030 & 2040).

Table of contents – Modelling section

Model-based assessment of role of UGS in maintaining resilience to shocks

Context, objectives and key messages

Approach for the model-based assessment of the role of UGS in maintaining resilience to security of supply shocks

Analysis of UGS role for security of supply with a multi-energy perspective, based on National Trends+ scenarios

Analysis of UGS role under security of supply shocks

Analysis of UGS role under a deviation scenario

Key conclusion

- **The underlying drivers of system flexibility evolve significantly across scenarios, stress tests, and time horizons.**
- **UGS consistently remains a fundamental asset for EU gas and electricity security of supply.**
- **The high withdrawal rates required from UGS to meet peak demand periods can only be achieved when storages are sufficiently filled.**

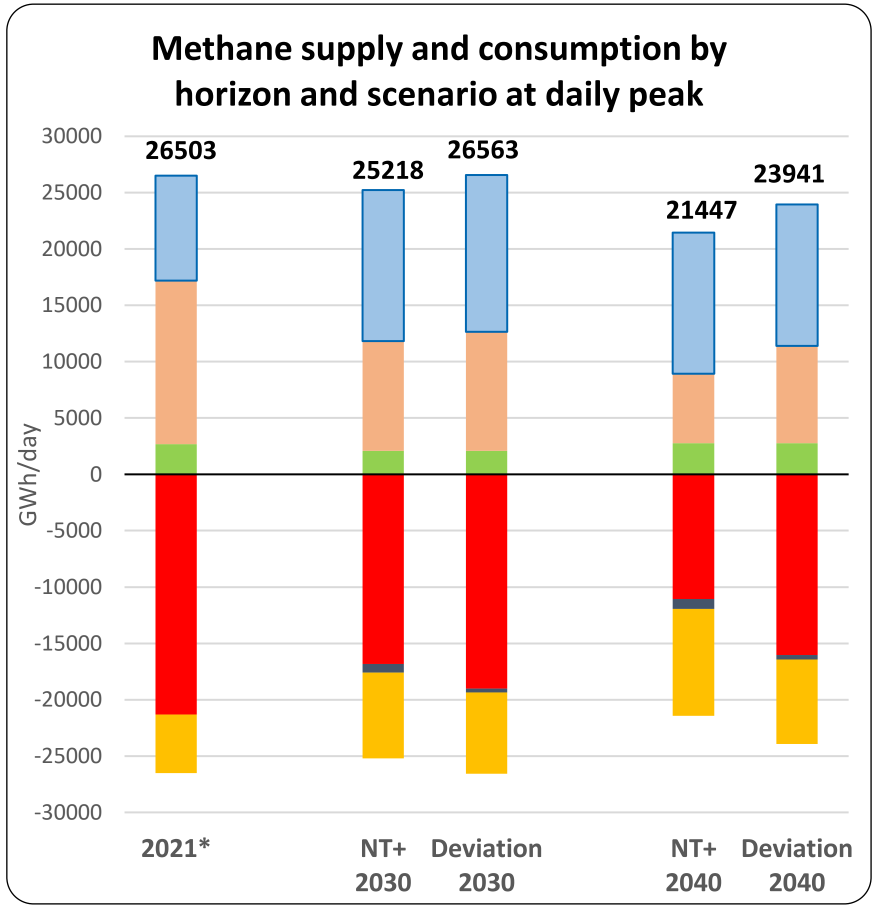
Annex – Modelling approach

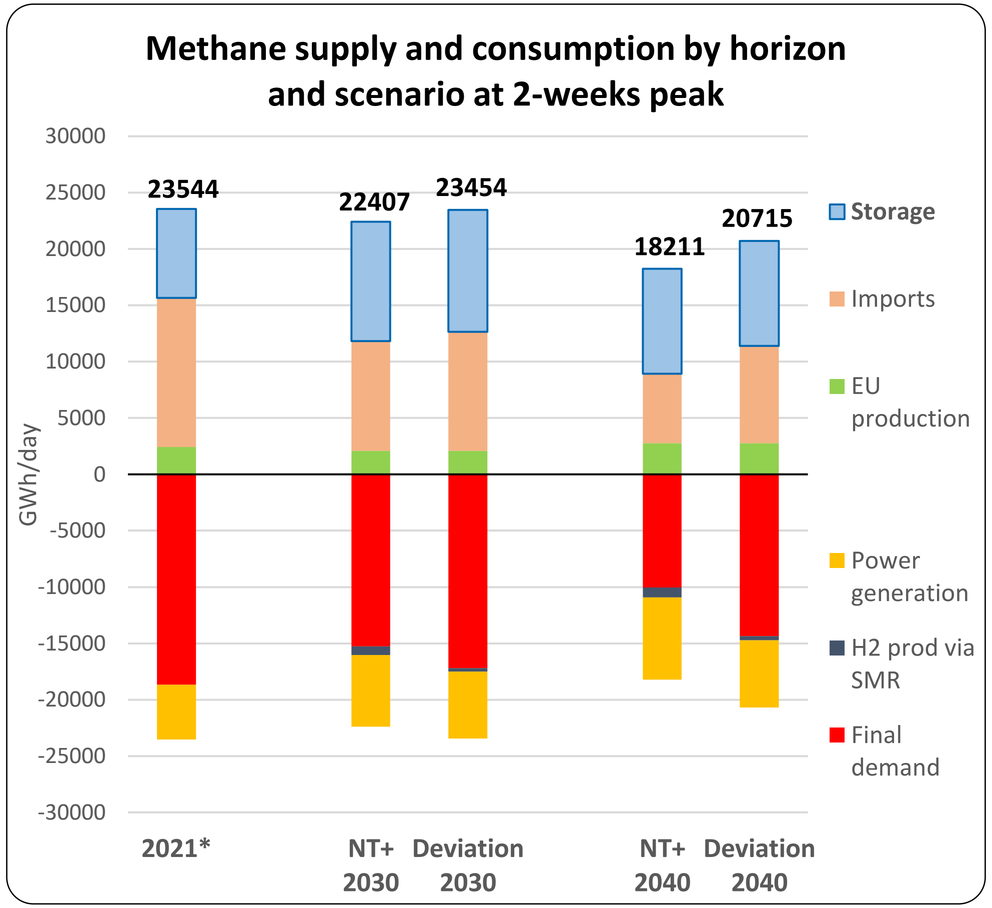
Annex – Additional modelling results

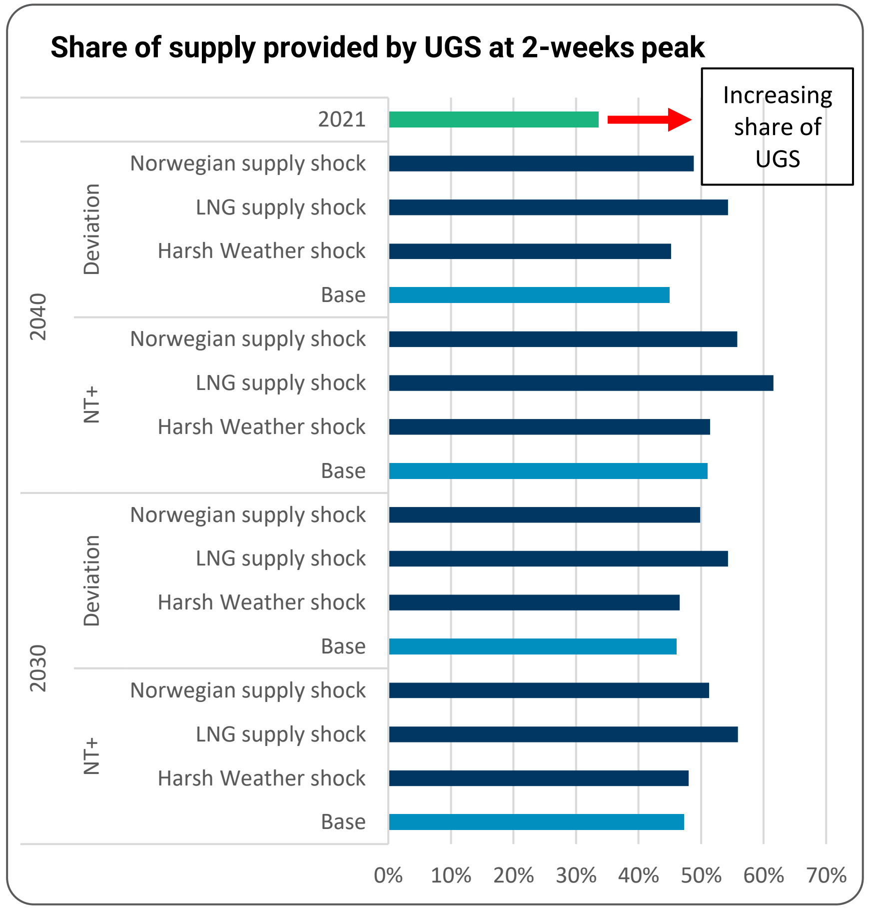
UGS plays a key role for methane and electricity security of supply

Across all scenarios, SoS stress tests, and time horizons, the modelling demonstrates that while the underlying drivers of system flexibility evolve significantly, UGS consistently remains a fundamental asset for EU gas and electricity security of supply.

UGS is particularly crucial for delivering high withdrawal rates during peak demand periods and under stress conditions. These deliverability levels can only be achieved when storages are sufficiently filled.







Source: Artelys modelling based on NT+ scenarios (2030 & 2040).
**2021 data is based on ENTSOG winter supply review 2020/2021, which is the most recent year where granular-enough data could be found; ENTSOG 2021 supply data has been rescaled to match peak consumption data volume.*

Regulatory Analysis

Regulatory Analysis:
Starting Point – Economics of Gas Storage

COMPASS LEXECON Artelys

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A Well-Known Problem: The Incomplete Remuneration of the Values of Gas Storage

In addition to (1) the market-remunerated arbitrage value, gas storages offer (2) system and (3) insurance value – the latter two are not fully reflected in market prices.

Value		Remuneration		Issues
(1) Arbitrage value	Gas storage enables arbitrage via **temporal flexibility** (Seasonal / Daily / Hourly)	**Remunerated through market activities**	**Remuneration influenced by market conditions**, e.g.: ▪ Price spreads ▪ Available forward products ▪ Hedging strategies ▪ Anticipatory behaviour	Remuneration through market activities is potentially **not sufficient** to cover storage and filling cost
				Non-market-based remuneration should be **additional** and not distort the market-based remuneration of the arbitrage value
(2) System value	Gas storage can lead to cost reductions by enhancing **geographical flexibility** (allowing for optimising infrastructure investment)	**Not (fully) remunerated through market activities**	**Markets are inefficient at pricing these storage values**: ▪ Low-probability, high-impact events are typically underpriced ▪ End-users lack mechanisms to express willingness to pay for reliability ▪ Retailers, facing limited liability, are not fully incentivized to hedge against extreme supply events	Regulatory framework should ensure **sufficient remuneration** to make system and insurance value of storage attainable.
(3) Insurance value	Gas storages provide a fundamental contribution to **security of gas and electricity supply**			

Sources: Compass Lexecon analysis based on FTI-CL Study on measures for a sustainable gas market (2018)

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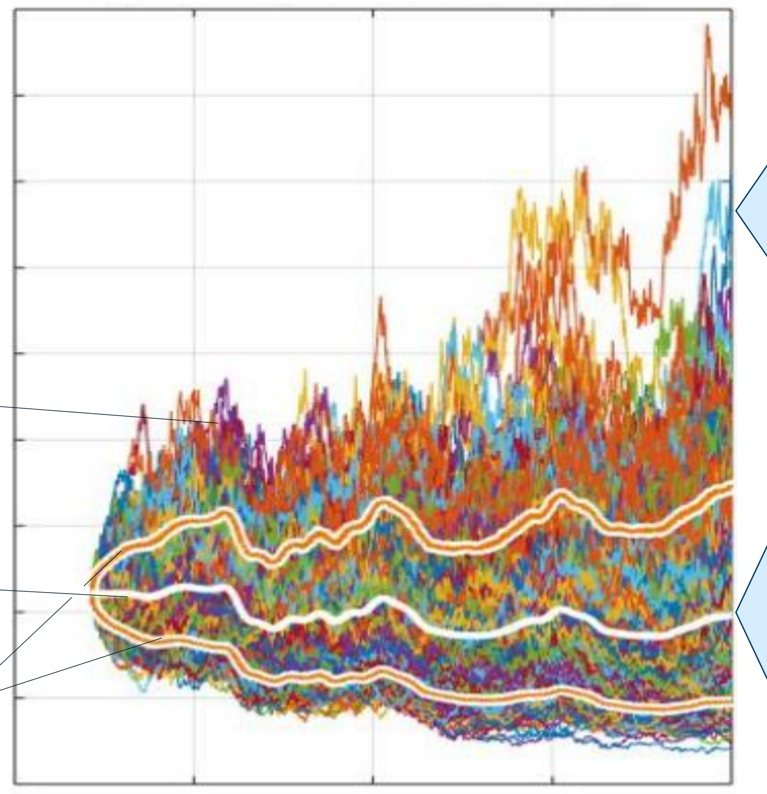
Gas Market Prices Show Limitations to Incentivise Preparedness for Security of Supply

Gas is traded both on forward/futures markets (for delivery several months or years in the futures) and spot markets (for next day delivery). Both show limitations in providing price signals to prepare for security of supply events.



From today's perspective there are **many spot price trajectories possible** as the spot prices react quickly to current events (e.g. shocks or expected shocks) that are not be foreseen well in advance.

Limitations of spot price signals regarding security of supply
Gas spot prices may be perceived as not fully reflecting the supply and demand equilibrium in scarcity / shock situations due to **price caps** expected (and historically (2022/23) planned) in such situations

Today's **futures prices** reflect[1] the market participants current expectations of future spot prices and their potential evolvement. They incorporate all known facts about future developments. Many events (incl. shocks) that will drive spot prices to come are, however, not yet known.

Limitations of future price signals regarding security of supply
- Gas forward prices do reflect average situations but **not reflect directly all possible scarcity / shock situations**.
- Driven inter alia by the storage paradox[2], future prices may also **not provide for positive summer <> winter spreads**.

What do market prices reflect?

Market signals mainly reflect anticipated parameters such as:
- expected demand (i.e. an average winter and average RES-generation),
- seasonal weather conditions,
- known industrial consumption cycles.

Extreme events are only partially taken into account in market signals:
- Cold winters (unexpected increase in demand),
- Dunkelflaute (periods of low wind and solar generation),
- LNG or pipeline supply disruption.

Notes: [1] but do not necessarily equal; [2] The storage paradox describes the effect that after a cold winter with heavily depleted storages that indicate the necessity of storage, the additional demand to fill storages again leads to additional summer gas demand increasing summer gas prices, thereby reducing the summer/winter spread and therefore ultimately the commercial incentive to fill-up storage capacities again.
Source: Compass Lexecon analysis; graph adapted from price[it]

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Market Players Only Capture Part of the Storages' *System* and *Insurance* Value

Due to limitations of gas prices to reflect scarcity / shock situations (see before) and limitations to the retail value of security of supply, the full value of gas storage is generally not internalised by market players and not provided absent interventions.

Simplified illustration

Limitations to the internalisation of the retail value of security of supply
- End-users generally lack (mechanisms to express) willingness to pay for security of supply
- Most retailers have no general service obligation and might exit in stress situation (see 2022/23)
- Legal/regulatory obligations for retailers to provide for security of supply are often limited

To the extent that:
- End-users are willing to pay for additional security of supply, and/or
- Retail suppliers are mandated by government to provide for (additional) security of supply

Limitations of trading activity to provide security of supply
As gas spot and futures prices do not fully reflect scarcity / shock situations, arbitrage trading strategies generally cannot profitably provide for security of supply in exceptional situations[1]

Driven by:
- Forward prices (**intrinsic value** of storage)
- Expected changes to (i) forward price structure and (ii) spot prices (**extrinsic value** of storage)
- Reduced by (transaction) cost (storage capacity cost, TSO grid tariffs from/to the storage, capital cost for filling the storage, trading cost, …)

Retail value of security of supply provided by gas storage

Trading value of gas storage[2]

Values of storage internalised and captured by market players

System value of gas storage

Insurance value of gas storage (i.e. value of security of supply provided by gas storage)

Arbitrage value of gas storage

Values of storage potentially available

Insurance value and system value are generally not fully internalised by gas market prices. Market prices therefore may not provide sufficient incentives to book and fill storages so that these two storage values become available.

Note: [1] Trading strategies going beyond pure arbitrage may *also provide additional security of supply. [2] trading strategies for gas storage may go beyond pure arbitrage strategies thereby capturing additional extrinsic value – the trading value is therefore shown to be higher than the arbitrage value.*
Source: Compass Lexecon Analysis

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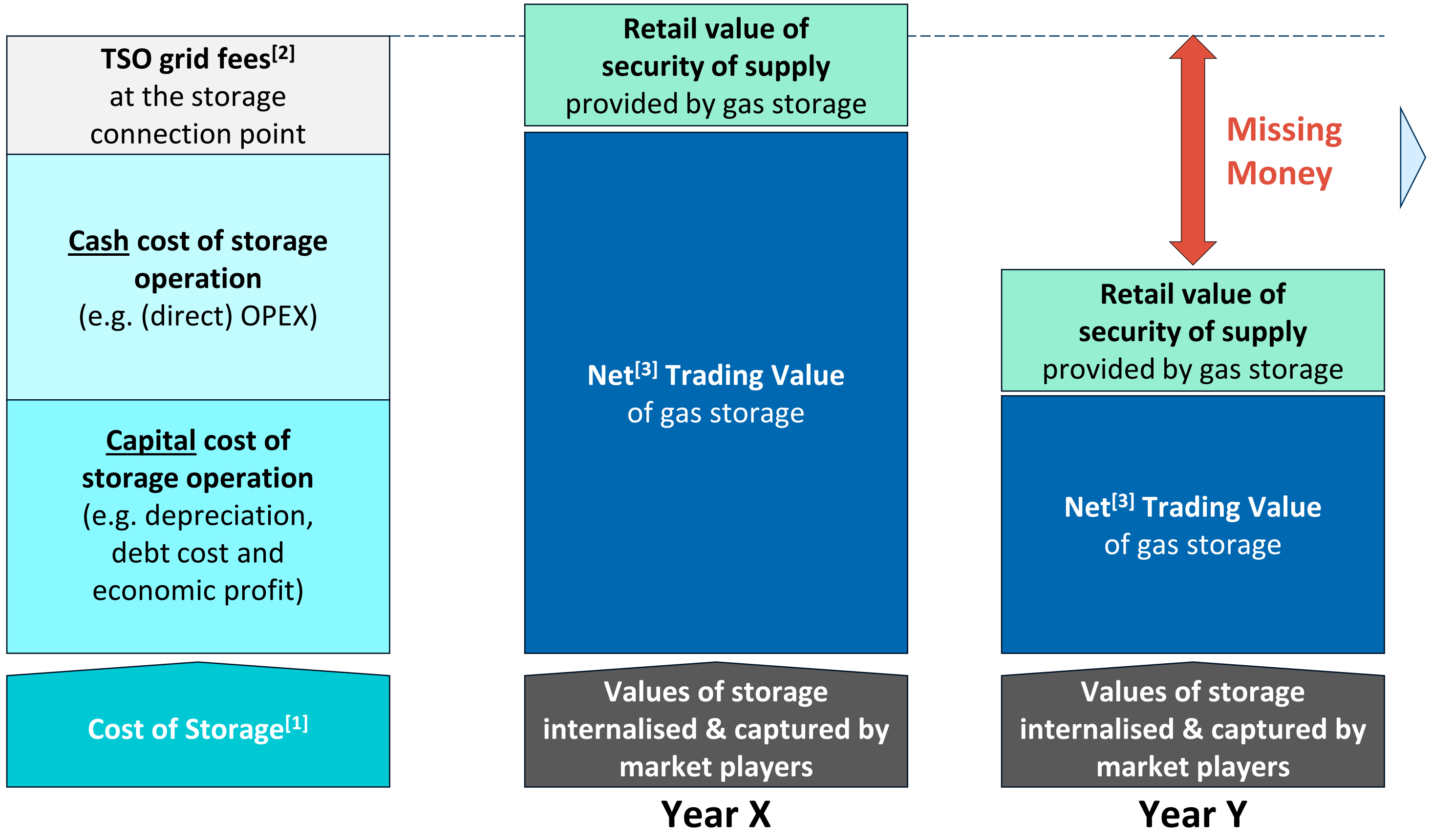
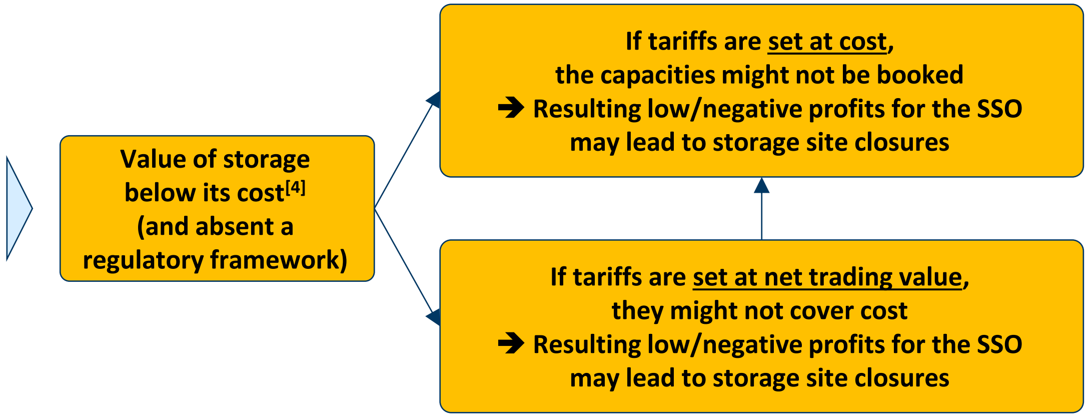
The Market Value of Storage and the Threat for Security of Supply

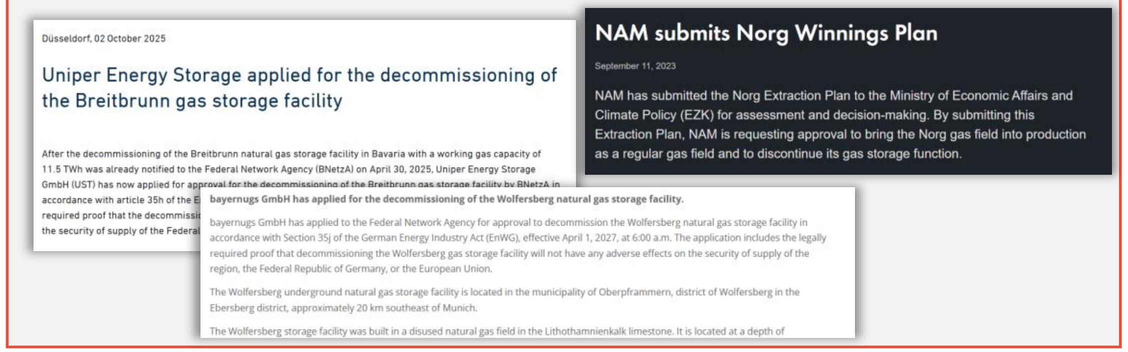
The availability of storages depends on their economic viability. The insurance value of storages needs therefore to be reflected in the regulatory / market framework.

Simplified illustration





Several European SSOs have already announced plans for storage site closures



Düsseldorf, 02 October 2025

Uniper Energy Storage applied for the decommissioning of the Breitbrunn gas storage facility

After the decommissioning of the Breitbrunn natural gas storage facility in Bavaria with a working gas capacity of 11.5 TWh was already notified to the Federal Network Agency (BNetzA) on April 30, 2025, Uniper Energy Storage GmbH (UST) has now applied for approval for the decommissioning of the Breitbrunn gas storage facility by BNetzA in accordance with article 35h of the E[...] required proof that the decommissi[...] the security of supply of the Federal[...]

NAM submits Norg Winnings Plan

September 11, 2023

NAM has submitted the Norg Extraction Plan to the Ministry of Economic Affairs and Climate Policy (EZK) for assessment and decision-making. By submitting this Extraction Plan, NAM is requesting approval to bring the Norg gas field into production as a regular gas field and to discontinue its gas storage function.

bayernugs GmbH has applied for the decommissioning of the Wolfersberg natural gas storage facility.

bayernugs GmbH has applied to the Federal Network Agency for approval to decommission the Wolfersberg natural gas storage facility in accordance with Section 35j of the German Energy Industry Act (EnWG), effective April 1, 2027, at 6:00 a.m. The application includes the legally required proof that decommissioning the Wolfersberg gas storage facility will not have any adverse effects on the security of supply of the region, the Federal Republic of Germany, or the European Union.

The Wolfersberg underground natural gas storage facility is located in the municipality of Oberpframmern, district of Wolfersberg in the Ebersberg district, approximately 20 km southeast of Munich.

The Wolfersberg storage facility was built in a disused natural gas field in the Lithothamnienkalk limestone. It is located at a depth of

Note: [1] From a storage operator's perspective, differentiation is mandated: situations where not even the short-run marginal cost (approx. equivalent to the cash cost) are covered from storage tariffs, are an immediate threat to the economic survival of storage assets. [2] … in some member states these cost are directly incurred by the SSO (as shown in this example) in other member states they are borne by storage customers – thereby reducing the net trading value of storage [3] net of e.g. capital cost for filling the storage, trading cost, …; [4] This assumes that storage tariffs are set at the full cost of storage capacities.

Source: Compass Lexecon analysis; storage site closure announcements from Uniper, bayernugs and NAM.

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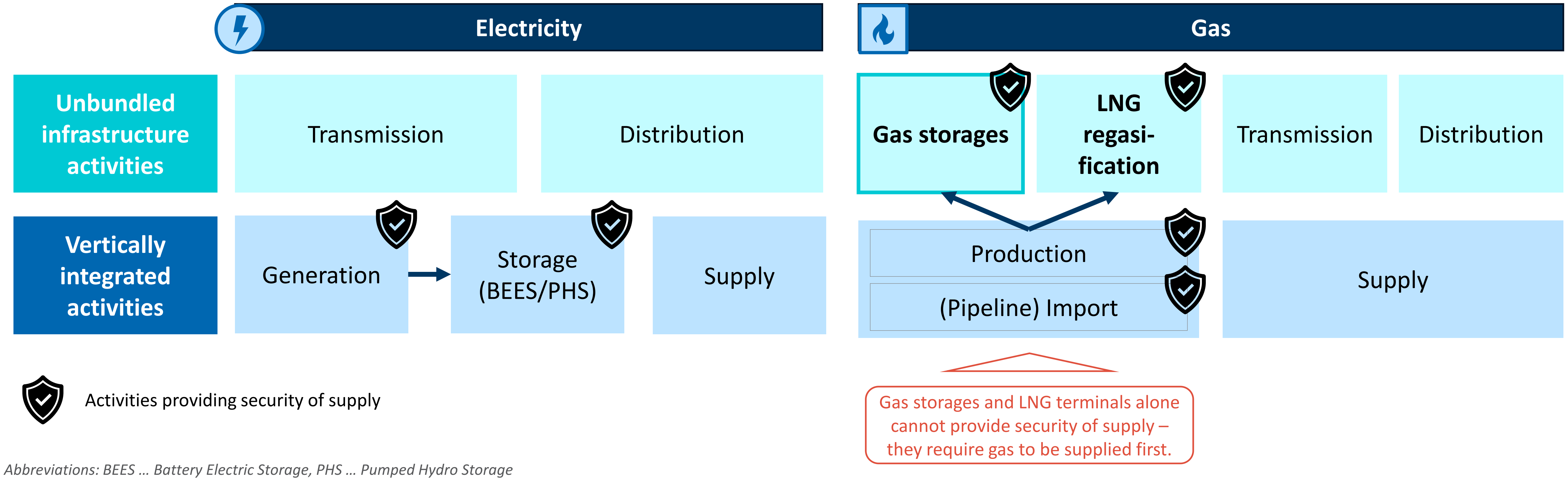
EU Unbundling Requirements Impacting Security of Supply in the Gas and Electricity Sector

The role of gas storage as an unbundled infrastructure asset providing security of supply has no equivalent in the power sector.

- Both electricity and gas sector have unbundled infrastructure activities (transmission and distribution) alongside vertically integrated supply and production
- However, while electricity storage is typically part of a vertically integrated undertaking, with operators owning the electricity they store, **gas storage and LNG terminals** are classified as **unbundled infrastructure**, and **operators do not own the gas themselves.**[1]

Structural overview of power and gas markets



Abbreviations: BEES … Battery Electric Storage, PHS … Pumped Hydro Storage
Notes: [1] there might be exceptions with cushion gas being the most important.
Sources: Compass Lexecon analysis

Regulatory Analysis: Key Results

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Drivers for Rethinking Security of Supply in the Gas Sector

Various changes in the gas and wider energy system as well as in the wider geopolitical environment may require rethinking the EU security of supply framework.

Pre-Energy Crisis 2022

Driver group 1:
Supply changes

- **Reduced pipeline** import capacities (Russia)
- **Higher LNG** import capacities
- Expanding **global LNG supply**
- Expanding global **competition for LNG**
- Exits of **producers with own storage** (GPE)
- Low and volatile summer winter spreads (“missing money”) **threatening economic viability of gas storages**

Driver group 2:
Demand changes

- (Temporary) **reduced total gas demand**
- Changed **power sector gas demand** – volume & flexibility (RES expansion, BESS, climate change)
- Changed **power sector elasticity of demand** (electrification and coal phase-out)
- Increased importance of affordability considerations

Driver group 3:
Supply shocks

- Increasing **weather dependency of power** generation (RES expansion + coal phase-out)
- Increased **dependency on single infrastructures**
- Increased **geopolitical risk**

“Today” and going forward over the mid- to long-term

Abbreviations: BESS … Battery Energy Storage System, GPE … Gazprom Export, RES … Renewable Energy Source
Source: Compass Lexecon analysis

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Background: Revision Process of the EU Security of Gas Supply Framework

The current EU energy security-of-supply framework has been in force since 2017[1], with storage-filling targets introduced in 2022. It is currently under review. A legislative proposal is expected in 2026 and national implementation will follow the EU-level adoption.

Current EU Security of Gas Supply Framework

2017
Security of Gas Supply (G-SoS) Regulation[a]
- Regional cooperation
- Preventive planning
- Risk assessment and
- Solidarity mechanisms

2022
Gas Storage Regulation[b]
- Introduction of binding 90% filling target (sunset clause expiring in 12/2025)
- Replaced by extension in July 2025

May 2024
Hydrogen & Gas Market Package[c]
- Amends G-SoS Regulation to include green gases, cyberthreats, extended solidarity mechanism
- During discussions, Parliament & Council asked EC to further revise the G-SoS Regulation

Sep 2025
Extension of Gas Storage Regulation[d]
- Extension of storage-filling provisions until 12/2027
- Increased flexibility of the filling target

Revision process

Oct 2023
EC review of EU Gas SoS regulation[e]
- Review report required by GSoS Regulation 2017/1983
- Identifies need revision of regulatory framework

EC "Fitness check" on energy security

Sep – Nov 2024
Public consultation[f]
Evaluate effectiveness, efficiency, coherence, and relevance of existing SoS framework and identify potential issues

Sep 2025
Call for evidence[g]
Tackle lack of operational readiness, cross-sector interaction, decarbonisation, multi-faceted threats and energy dependencies

Dec 2025
New

Results[h]
Identifies need for a more robust and cross-sectoral approach to security of gas and electricity supply

1HY 2026
Planned adoption of legislative proposal

Source: Compass Lexecon analysis based on [a] (EU) 2017/1938 [b] (EU) 2022/1032, [c] (EU) 2024/1789, (EU) 2024/1788, [d] (EU) 2025/1733, [e] Review of (EU) 2017/1938 & accompanying document [f] EC Consultation, [g] EC Call for evidence, [h] EC "Fitness Check"

European Commission “Fitness Check” on Energy Security

The European Commission’s analysis of the EU gas and electricity security of supply frameworks underscores the instrumental role of gas storage during the last energy crisis and identifies the need for a revised SoS regulation in a changed energy system.

EUROPEAN COMMISSION

Brussels, 22.12.2025
SWD(2025) 435 final

COMMISSION STAFF WORKING DOCUMENT

EU energy security - evaluating the EU's security of electricity and gas supply framework

EN EN

Dec 2025

- In December 2025, the European Commission published the results of its **“Fitness Check” evaluating the EU’s security of electricity and gas supply framework**, based on a public consultation, call for evidence and the evolution of EU security of gas and electricity supply 2017-2024

The EC Fitness Check highlights economic benefits of preparing for SoS crises

- Argues that the impact of Russian supply cuts on gas and electricity prices underscores the **socio-economic consequences of supply crises** and shows that the **existing SoS framework was insufficient** to protect EU citizens and industry from gas supply shocks
- Highlights the **economic insurance value of security of supply measures,** importance of preventing gas supply crises and the **significant societal benefits** (e.g., minimising forced energy supply cuts to citizens and industries) that outweigh the costs of crisis preparation

The EC Fitness Check underlines the importance of gas storage in responding to the 2022 energy crisis

- Gas storage played a **critical role** in the EU’s response to Russia’s weaponization of gas supplies, helping to prepare for winter amid declining Russian flows, **avoid curtailments, reassure markets, and contribute to price stabilization**

Gas storage and Security of Gas Supply: EC lessons

1. Need for **better alignment** between gas and electricity security frameworks **and a cross-sectoral approach**
2. **More robust risk assessments and scenario planning required**, especially for emerging risks (cybersecurity, hybrid threats, critical minerals, climate change)
3. Need for improved operationalisation of the **energy solidarity principle**
4. **Potential to align and simplify gas supply standard and storage targets that both** aim to ensure sufficient gas is available during crises

Abbreviations: SoGS … Security of Gas Supply
Source: Compass Lexecon analysis based on EC “Fitness Check”

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Summary: Key Recommendations of the Regulatory Analysis

Ongoing and expected changes require an evolution of the market and regulatory framework for the EU gas storage sector.

I. Enhance the EU-wide SoS assessments

1 Improve the **interlinkage between the gas and electricity** security of supply and flexibility assessment

2 Determine **gas storage capacity and filling required** to ensure SoS at the desired level taking into account filling level dependence of storage withdrawal

3 **Expand shock scenarios** beyond cold-spells to account e.g. for **reduced renewable power generation** and other extreme events linked e.g. to climate and/or geopolitical events

4 **Extend the analysis horizon to 10 yrs. in the future** (and beyond)

5 Consider **gas infrastructure changes** (storage and pipeline), e.g. due to repurposing to hydrogen

II. Redefine national SoS standards

a) Infrastructure Standard

1 **Add volume assessments** to the current peak demand assessments (e.g. filling of storages in summer when withdrawal capacity does not count towards standard fulfilment)

2 Take a **forward-looking perspective** and **demand evolvements** (i.e. gas usage in the power sector)

3 Consider **storage filling needs and withdrawal curves** in assessment

4 Reinforce the **regional perspective** considering **transit requirements** in crisis settings

5 Consider disregarding infrastructure that does not anymore give **access to gas sources** (e.g. historic routes for Russian imports) from the N-1 criteria

6 Incorporate **new peak demand scenarios** (e.g. early winter **kalte Dunkelflaute** events)

b) Supply Standard

1 Consider **cross-sector drivers of demand** and in particular increasing importance of **power generation**

2 Account for the **economic value** of ensuring continuous gas supply also to **SMEs and industrials** (potentially differentiating based on ability for fuel switch and/or willingness to pay for SoS – beware of free-rider problem!)

3 Consider **responsibilities within the market model** (i.e. short-term retail supplier switching dynamics vs. longer-term nature of security of supply) when assigning responsibilities to realise the insurance value of gas storages

4 **Harmonise national means of compliance** both in terms of (i) permissible ways to ensuring the actual, physically backed availability of gas, and (ii) measures to ensure compliance with the requirements

III. Allow for / mandate storage filling measures post 2027 (in the light of missing money)

1 Establish a **long-term and predictable market and regulatory framework for gas storage** going well beyond 2027 (thereby replacing current non-market measures / interventions)[1]

2 Establish a **set of conditions and requirements** for (i) specifying non-market measures and (ii) setting target filling levels

3 Take into account the **EU-wide impact of achieving storage filling** when setting national targets

4 Provide guidance on how to **design measures using market compatible approaches** to limit distortions

5 Consider increasing the minimum **transport tariff discount (e.g. 90%) for storage access points**

IV. Re-assess EU-wide sharing of cost for SoS-measures

1 Reassess the **principles and mechanisms for the cost sharing** of Security of Supply across member states to ensure fair burden sharing

2 Take into account the **inhomogeneous distribution** of gas storage capacities and **contribution to regional and EU Security of supply**

3 Take into account the **contribution of gas storage to power sector** security of supply

4 Factor in **cost associated with insurance value of storages for gas security of supply** also in the absence of acute crisis situations

Note: [1] In the light of the missing money problem as described in this deck. Source: Compass Lexecon analysis

Regulatory Analysis – Recommendation 1:
Enhance the EU-wide SoS assessments

Key Requirements Resulting from the Regulatory Analyses

Ongoing and expected changes require an evolution of the market and regulatory framework for the EU gas storage sector.

I. Enhance the EU-wide SoS assessments	II. Redefine national SoS standards: a) Infrastructure Standard	II. Redefine national SoS standards: b) Supply Standard	III. Allow for / mandate storage filling measures post 2027 (in the light of missing money)	IV. Re-assess EU-wide sharing of cost for SoS-measures

1 Improve the **interlinkage between the gas and electricity** security of supply and flexibility assessment

2 Determine **gas storage capacity and filling required** to ensure SoS at the desired level taking into account filling level dependence of storage withdrawal

3 **Expand shock scenarios** beyond cold-spells to account e.g. for **reduced renewable power generation** and other extreme events linked e.g. to climate and/or geopolitical events

4 **Extend the analysis horizon to 10 yrs. in the future** (and beyond)

5 Consider **gas infrastructure changes** (storage and pipeline), e.g. due to repurposing to hydrogen

Source: Compass Lexecon analysis

The Three Pillars of the Current EU SoS Framework

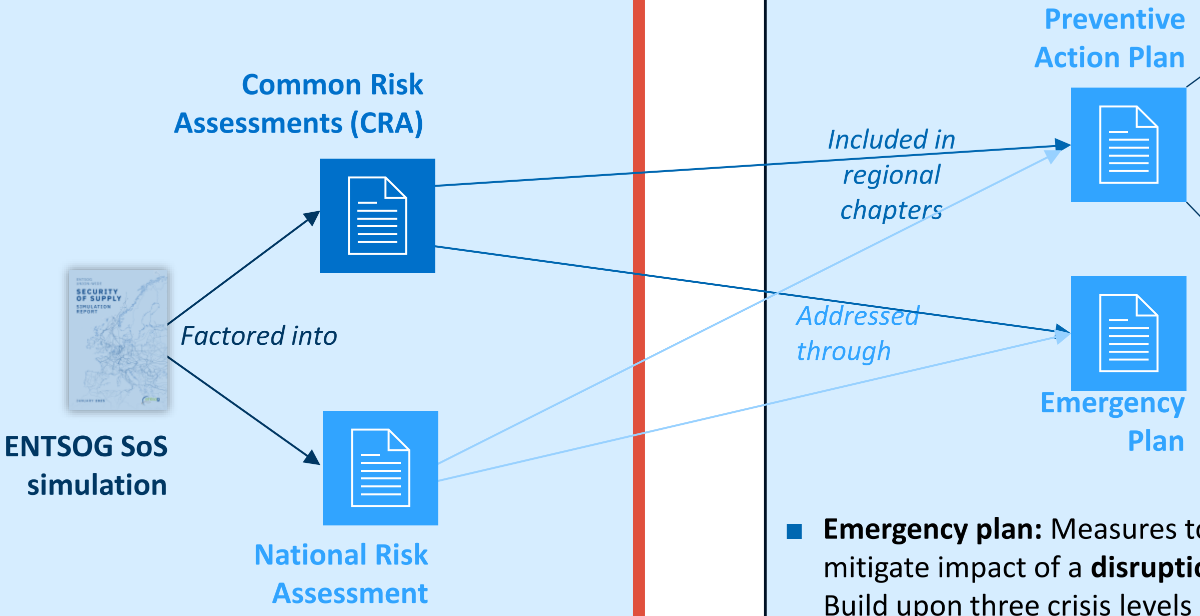
The EU regulations sets a framework for gas SoS risk assessments, preventive planning and action as well as emergency measures and specifies Security of Supply standards to be met be Member States.

1 Risk Assessment

- Based on a **four-yearly ENTSOG EU-wide simulation** of gas supply and infrastructure disruption scenarios, Member states develop **national and regional risk assessments**

2 Risk Planning

- **Preventive action plan:** Measures and obligations needed to remove or mitigate the risks identified and fulfil the (i) **infrastructure** and (ii) **gas supply standards**



Focus of this section

- **Emergency plan:** Measures to remove or mitigate impact of a **disruption of gas supply;** Build upon three crisis levels (early warning, alert, emergency)

3 SoS Standards

Infra-structure Standard

Requirement to **satisfy total** gas demand **during a day of exceptionally high gas demand** occurring with a statistical probability of once in 20 years **in an N-1 case**

Supply Standard

Ensure gas supply to **protected customers** (households, and depending on member state SMEs, essential social services and/or district heating) for:

(a) **extreme temperatures** during 7-day peak period

(b) 30 days of **exceptionally high gas demand**,;

(c) 30 days average winter if the **single largest gas infrastructure is disrupted**

Source: Compass Lexecon Analysis based on EU 2022/1032 , EU 2017/1983.

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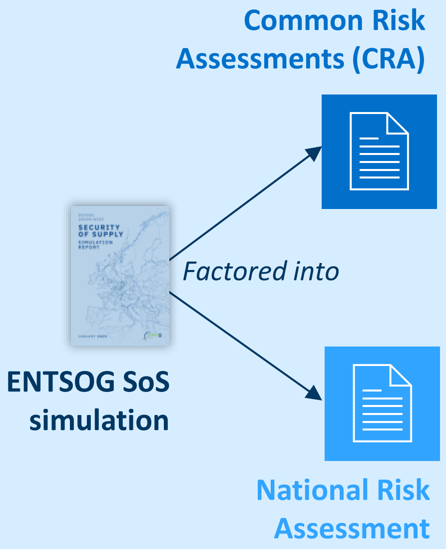
The Three Pillars of the Current EU SoS Framework – 1. Risk Assessment

The EU regulations set a framework for gas SoS risk assessments on three geographical scopes

1 Risk Assessment

- Based on a **four-yearly ENTSOG EU-wide simulation** of gas supply and infrastructure disruption scenarios, Member states develop **national and regional risk assessments**



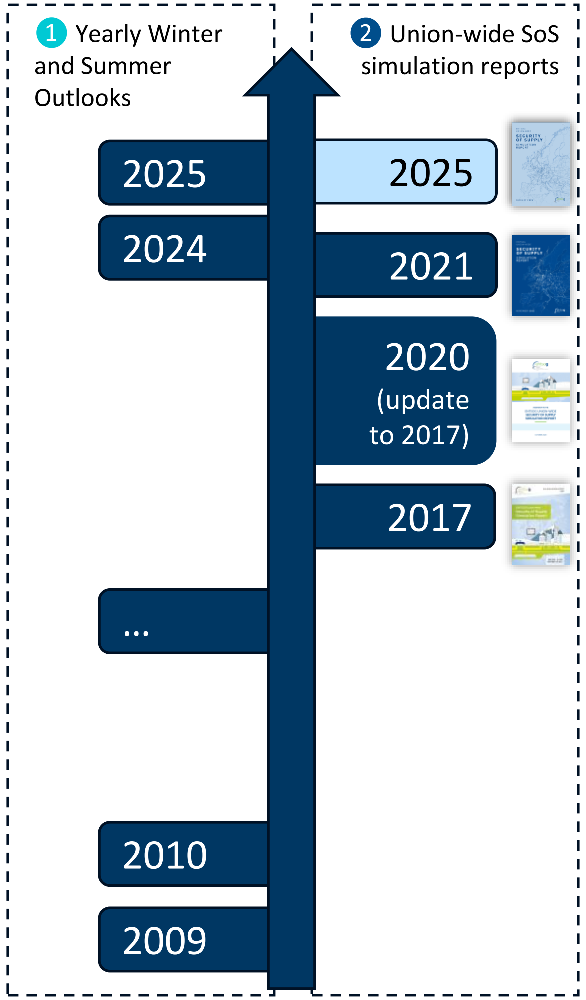
EU-wide, regional and national gas supply risk assessments

	Responsible entity	Content	Frequency
ENTSOG simulation	ENTSOG & Gas Coordination Group	▪ EU-wide simulation of gas supply and infrastructure disruption scenarios	At least every four years, or upon need
Common risk assessment (CRA)	MS via 13 regional risk groups each member state belongs to 2 - 8 risk groups	▪ Evaluation of regional risk scenarios	
National risk assessment (NRA)	Member states	▪ National SoS risks and gas supply disruption scenarios	

Source: Compass Lexecon Analysis based on EU 2022/1032 , EU 2017/1983.

Gas Security of Supply Shocks Regularly Assessed

Since 2009, ENTSOG conducts annually Winter and Summer Supply outlooks. Following the 2017 Gas SoS regulation, ENTSOG additionally publishes comprehensive union-wide SoS risk assessments at least once every four years.



1 Winter outlooks consider two/three supply disruption scenarios that reflect imminent risks (e.g. 2025: Russian and Algerian supply disruptions)

2 2025 SoS simulation report evaluates the following 12 *supply and infrastructure disruption* scenarios[1] for different disruption durations:

Risk Group		No	*Disruption scenario*	Assessed disruption duration
North Sea	Norway	1	*Disruption of the largest offshore infrastructure to the UK (**Langeled**)*	6 months (1 October – 31 March)
		2	*Disruption of the largest offshore infrastructure to continental EU (**Europipe 2**)*	
		3	*Disruption of the largest onshore infrastructure from Norway (**Emden station**)*	2 weeks (15 – 28 February)
	Denmark	4	*Disruption of the largest infrastructure to Denmark (**Nybro area**)*	
	United Kingdom	5	*Disruption of **Forties** pipeline system*	6 months (1 October – 31 March)
North African	Algeria	6	*Disruption of the largest offshore infrastructure to Italy (**Transmed**)*	
		7	*Disruption of the largest offshore infrastructure to Spain (**Medgaz**)*	
		8	*Disruption of imports from Algeria, including **LNG***	
	Libya	9	*Disruption of **all imports from Libya***	
South-East	Southern Corridor	10	*Disruption of all imports from Turkey to Greece (**TANAP + Kipi** import point)*	
		11	*Disruption of the largest onshore infrastructure to Greece (**TANAP**)*	2 weeks (15 – 28 February)
LNG	All member states	12	*S-1 LNG[2]. Limited availability of **LNG supply***	6 months (1 October – 31 March)

1 & 2 For every supply scenario, 3 different *high-demand cases* are simulated:

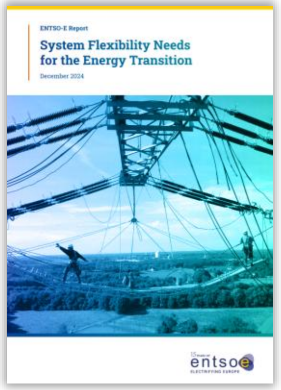
1) **High demand winter** (1 October – 31 March) – highest gas demand since winter 2009-2010,
2) **2 weeks** in February of exceptionally high demand, occurring with a statistical probability of once in 20 years,
3) **Peak demand day** in February, occurring once in 20 years.

Note: [1] All scenarios assume the complete disruption of Russian pipeline supply during the winter season period. [2] Reference LNG supply potential is based on the last two winter seasons (2022/23, 2023/24) plus projects to be commissioned by January 2026. "S-1" refers to the unavailability of Russian LNG and anticipates a situation where Europe would not be able to attract enough other LNG.

Source: Compass Lexecon analysis based on ENTSOG – Outlooks & Reviews, ENTSOG – Security of Supply Simulation.

Digression: Importance of Gas-fired Flexibility Sources for the Power Sector

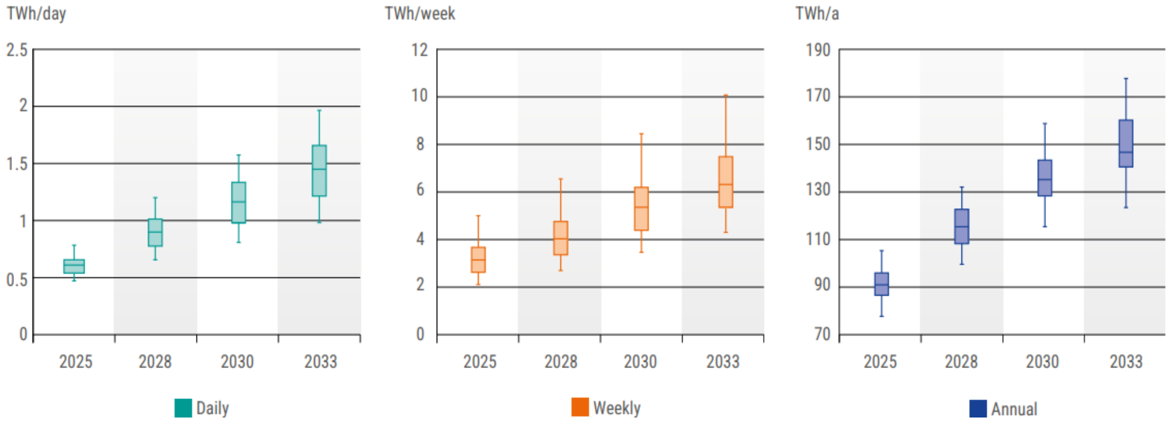
European energy system flexibility needs are projected to double between 2025 and 2033, while EU-27 coal generation capacity is expected to decline to around one third by 2035, increasing importance of gas-fired flexibility sources.



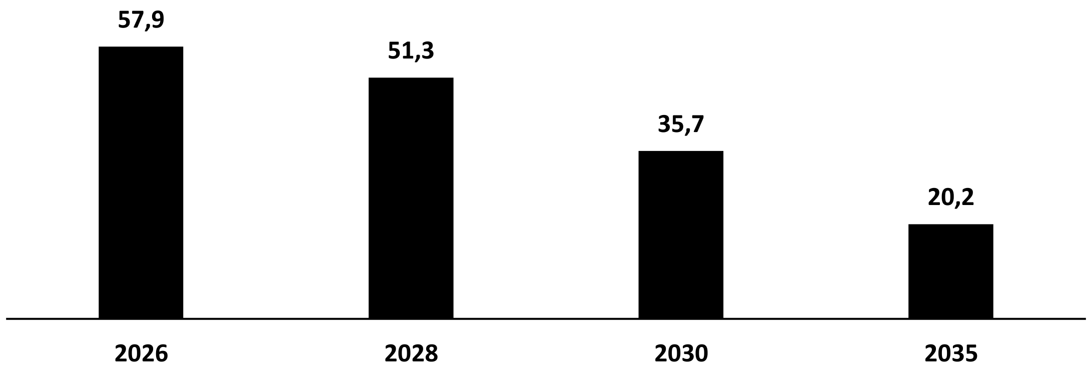
- RES-based power sector decarbonisation and ongoing electrification will lead to a **highly weather-dependent energy system** with **increased volatility of both generation and demand**
- Pan-European flexibility needs linked to generation and demand variability are **projected to double between 2025 and 2033 across all examined timeframes**
- **Main factors driving flexibility needs are**
  - Increasing electricity demand (electrification of energy demand)
  - Significant growth of variable renewable energy sources (vRES) with limited forecast accuracy
  - Gradual coal phase-out reducing traditional sources of (longer-term) flexibility
  - Potential energy system disruptions caused by extreme weather events (storms, draughts, Dunkelflaute)
- **Extended system stress events** (e.g. kalte Dunkelflaute)
  - Countries with significant reliance on vRES generation are likely to face increased system stress due to prolonged vRES shortage periods around 2–4 times annually, lasting on average up to 6–10 days and resulting in a vRES generation gap ranging between just a few MWh up to several TWh in the worst cases.
  - Prolonged shortages in vRES generation are anticipated to affect multiple countries within the same region, heightening the risk of system stress and reducing the mitigation effect of interconnections.

- Phase out of dispatchable coal-fired generation (currently significantly contributes to flexibility) increases dependence on gas-fired power generation as a flexibility source to respond to increased volatility of both power generation and demand

Evolution of daily, weekly and annual European[1] flexibility needs[2,a], 2025–2033



Development of coal power generation capacity[b], EU-27, 2026– 2035 [GW]



Notes: [1] EU-27, West-Balkan 6, Norway, Switzerland and the UK; [2]Daily variations: fluctuations in residual load (changes in demand and renewable generation throughout the day); Weekly variations: fluctuations between days of the same week (habitual consumption behaviours/periodic events); Annual variations: long-duration seasonal changes (weather conditions and daylight hours).

Source: Compass Lexecon analysis based on [a] ENTSOE- System Flexibility Needs, [b] ENTSOE-ERAA 2024.

Enhance the EU-Wide SoS Assessments

December 2025 EC "Fitness check" on Energy Security
Also, the EC Study highlights the limited consideration of gas and power market interdependencies in EU energy risk assessment

The current EU gas security of supply framework has limitations in its assessment of risks faced by the European energy system.

Current regulation – SoS assessments



	Electricity	Gas		Hydrogen
SoS Assessment	European Resource Adequacy Assessment	SoS Simulation	Winter Supply Outlook	None
Region	EU-level	EU-level[1]	EU-level	–
Frequency	Annually	Every 4 years	Annually	–
Modelling horizon	Up to 10 years	Status quo	Up to 1 year	–

Issues

The gas sector risk assessments shows limited consideration of
- volatile **power sector gas demand** and
- dynamic **evolvements of the power sector** (electrification and RES-deployment, increase of gas-fired generation capacities, reduced coal to gas switching ability)

- Security of Supply assessments **do not determine storage needs** and **storage filling needs**

- **Limited alignment of the power and gas sector risk assessment,**
- Particularly: non-aligned weather risk scenarios (power: weather dependent RES generation (incl. kalte Dunkelflaute); gas: cold spells)

- Limited **modelling horizon** of gas SoS risk assessment: 1-year horizon of the union wide assessments
- Generally, backward looking demand assumptions (**historical peak demand**) – not taking into account changing gas demand patterns or alternative scenarios for the energy system evolvement

- Incongruencies in **infrastructure needs for SoS vs. decarbonisation impact on gas infrastructure** (e.g. via repurposing)
- Gas infrastructure decommissioning plans are generally not considered in risk assessments (also due to the limited time horizon of the latter)

Potential remedies

1 Improve the **interlinkage between the gas and electricity** security of supply and flexibility assessment

2 Determine **gas storage capacity and filling required** to ensure SoS at the desired level taking into account filling level dependence of storage withdrawal

3 **Expand shock scenarios** beyond cold-spells to account e.g. for **reduced renewable power generation** and other extreme events linked e.g. to climate and/or geopolitical events

4 **Extend the analysis horizon to 10 yrs. in the future** (and beyond)

5 Consider **gas infrastructure changes** (storage and pipeline), e.g. due to repurposing to hydrogen

Abbreviations: SoS … Security of Supply, RES … Renewable Energy Source.
Note: [1] Basis for national and regional risk assessments.
Source: Compass Lexecon analysis

Regulatory Analysis – Recommendation 2: Redefine national SoS standards

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Key Requirements Resulting from the Regulatory Analyses

Ongoing and expected changes require an evolution of the market and regulatory framework for the EU gas storage sector.

I. Enhance the EU-wide SoS assessments

II. Redefine national SoS standards

a) Infrastructure Standard

b) Supply Standard

III. Allow for / mandate storage filling measures post 2027 (in the light of missing money)

IV. Re-assess EU-wide sharing of cost for SoS-measures

a) Infrastructure Standard

1 **Add volume assessments** to the current peak demand assessments (e.g. filling of storages in summer when withdrawal capacity does not count towards standard fulfilment)

2 Take a **forward-looking perspective** and **demand evolvements** (i.e. gas usage in the power sector)

3 Consider **storage filling needs and withdrawal curves** in assessment

4 Reinforce the **regional perspective** considering **transit requirements** in crisis settings

5 Consider disregarding infrastructure that does not anymore give **access to gas sources** (e.g. historic routes for Russian imports) from the N-1 criteria

6 Incorporate **new peak demand scenarios** (e.g. early winter **kalte Dunkelflaute** events)

b) Supply Standard

1 Consider **cross-sector drivers of demand** and in particular increasing importance of **power generation**

2 Account for the **economic value** of ensuring continuous gas supply also to **SMEs and industrials** (potentially differentiating based on ability for fuel switch and/or willingness to pay for SoS – beware of free-rider problem!)

3 Consider **responsibilities within the market model** (i.e. short-term retail supplier switching dynamics vs. longer-term nature of security of supply) when assigning responsibilities to realise the insurance value of gas storages

4 **Harmonise national means of compliance** both in terms of (i) permissible ways to ensuring the actual, physically backed availability of gas, and (ii) measures to ensure compliance with the requirements

Source: Compass Lexecon analysis

The Three Pillars of the Current EU SoS Framework

The EU regulations requires specifies Security of Supply standards and requires member states to monitor if they are met.

1 Risk Assessment

- Based on a **four-yearly ENTSOG EU-wide simulation** of gas supply and infrastructure disruption scenarios, Member states develop **national and regional risk assessments**

ENTSOG SoS simulation — *Factored into* → **Common Risk Assessments (CRA)** and **National Risk Assessment**

2 Risk Planning

- **Preventive action plan:** Measures and obligations needed to remove or mitigate the risks identified and fulfil the (i) **infrastructure** and (ii) **gas supply standards**

Included in regional chapters → **Preventive Action Plan**

Addressed through → **Emergency Plan**

- **Emergency plan:** Measures to remove or mitigate impact of a **disruption of gas supply;** Build upon three crisis levels (early warning, alert, emergency)

Focus of this section

3 SoS Standards

Infra-structure Standard

Requirement to **satisfy total** gas demand **during a day of exceptionally high gas demand** occurring with a statistical probability of once in 20 years **in an N-1 case**

Supply Standard

Ensure gas supply to **protected customers** (households, and depending on member state SMEs, essential social services and/or district heating) for:

(a) **extreme temperatures** during 7-day peak period

(b) 30 days of **exceptionally high gas demand**,;

(c) 30 days average winter if the **single largest gas infrastructure is disrupted**

Source: Compass Lexecon Analysis based on EU 2022/1032 , EU 2017/1983.

Infrastructure Standard

According to the EU Gas Security of Supply Regulation framework, Member States must fulfil an N-1 infrastructure standard.

Current state of Regulation[1]

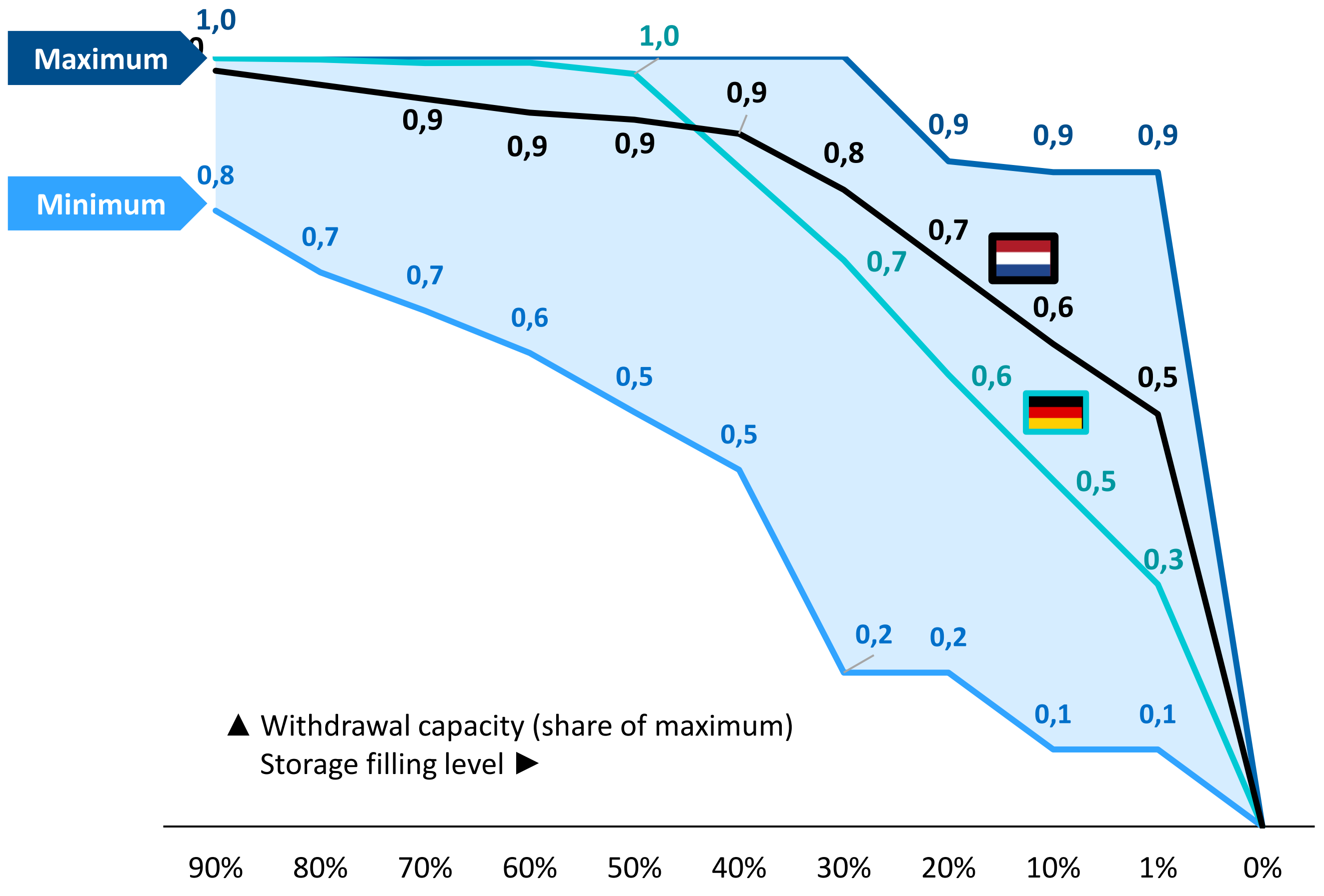
1) N-1 requirement:

- Member states have to ensure that in the event of a **disruption of the single largest gas infrastructure** (N-1 formula), the remaining infrastructure can satisfy total gas demand of the calculated area **during a day of exceptionally high gas demand** occurring with a statistical probability of once in 20 years.
- Standard must be met taking into account **gas consumption trends**, the long-term impact of energy efficiency measures and the utilisation rates of existing infrastructure
- Gas infrastructure includes gas transmission network (incl. interconnectors), production, LNG and storage facilities
- Requirements can also be met at a **regional level**

2) Reverse flow requirement:

- Obligation on TSOs to establish **bidirectional capacity** on interconnections between Member States

Storage withdrawal capacity depending on storage inventory level – Examples for selected countries as well as EU max and min [% of max][2,3]



Note: [1] According to the Gas Security of Supply Regulation (EU 2017/1983, Art. 5), [2] ENTSOG Winter Supply Outlook 2025/2026 [3] Country-specific trajectories show national averages.
Source: Compass Lexecon analysis based on EU 2017/1983

Supply Standard (1/2): Principle and Contribution to Storage Filling

Member states can meet the gas supply standard through different measures. Currently, the standard does not necessarily contribute to national storage filling.

Current state of Regulation

Member states have to require gas undertakings to ensure gas supply to **protected customers** for each of the following cases:

(a) extreme temperatures during a 7-day peak period occurring with a probability of once in 20 years

(b) period of 30 days of **exceptionally high gas demand**, occurring with a probability of once in 20 years;

(c) for a period of 30 days in the case of **disruption of the single largest gas infrastructure** under average winter condition

- **Protected customers** include households and Member States may under certain conditions include small and medium enterprises (SMEs), essential social services and district heating (DH).

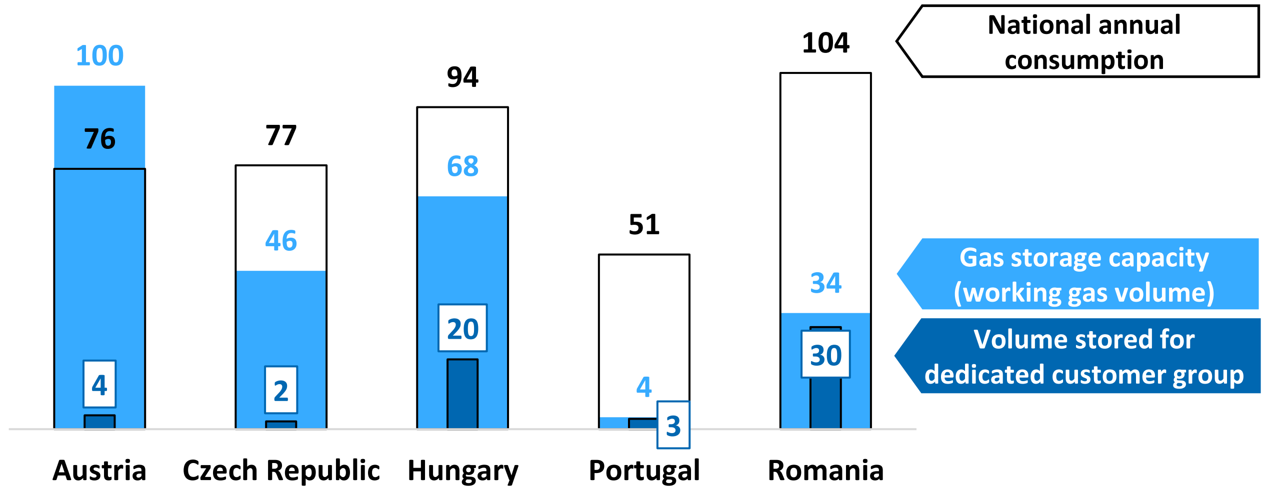
National implementation – Examples

Country	Protected customers	Compliance with supply standard
	Households, essential social services, DH facilities (if dependent on gas)[1]	Suppliers of protected customers have to provide procurement and storage contracts that meet the supply standard
	Households, SMEs, essential social services, DH facilities (if dependent on gas)	Sufficient national import capacity
	Households, SMEs, essential social services, DH facilities (if dependent on gas)	All suppliers are obligated to ensure supply continuity and diversification of entry points

Interactions of the supply standard with storage filling

- Compliance with the gas supply standard does currently **not require** that the corresponding volumes are backed by **physical gas in storage**
- Depending on how each member state has implemented the standard, it can be fulfilled through **physical, contractual and/or market-based measures**, for example: supply contracts, import capacities (pipeline / LNG) or gas in storage
- In member states with large storage capacity (e.g. Austria), even a physically backed supply standard would not significantly contribute to storage filling.

Stockholding by suppliers of specific customer groups (in 2022/23)[2] [TWh]



Note: [1] In addition, a supply standard for operators of gas-fired power plants (> 50 MW) was introduced in 2024. Operators must maintain sufficient gas reserves in storage to ensure supply for up to 45 days. [2] based on ACER & VIS (2023).
Source: Compass Lexecon analysis based on EU 2017/1983, AT - Preventive Action Plan, DE – Preventive Action Plan, FR – Preventive Action Plan

Supply Standard (2/2): Considerations for Gas Customers Covered by the Supply Standard

The supply standard does not include all customer groups – thereby excluding cases where gas supply interruptions can have significant impact. If customers should be included in the supply standard and how respective cost should be covered depends on a cost benefit assessment.

Customer type	Current inclusion in supply standard based on the EU framework ("protected customer")	Negative impact of gas supply interruption	Economic consideration (cost benefit assessment) for the inclusion of the customer group in the supply standard
Households	Yes (if connected to distribution network)	▪ Hardship / severe physical consequences for households not able to switch to other fuels for heating or cooking.	▪ Expected cost for SoS measures vs. the expected direct (only partly internalized) and indirect (macro economic and societal) negative effects of gas not supplied ▪ Where options for fuel or technology switch exist, the additional cost of these fuels / technologies may provide an upper limit for justifiable security of gas supply cost. ▪ The personal, physical and societal cost of interrupted gas supply in the absence of switching opportunities are, however, particularly hard to assess.
Small or medium-sized enterprise (SME)	Depending on the member state's decision[2] (if connected to distribution network)	▪ Direct commercial impact for SMEs (temporary or lasting) ▪ Indirect impact on the wider economy (loss in tax revenues, increased budgetary spending needs, inflation) ▪ Indirect impact on the population from supply interruption for necessary goods (bakeries, general food, …)	
Essential social services[1]	Depending on the member state's decision[2] (if connected to distribution network)	▪ Direct impact on population health and public order ▪ Indirect impact on the wider economy	
District heating installation	Depending on the member state's decision[2] (if heat is delivered to households, SMEs or essential social services, and switching from gas is impossible)	▪ Hardship / severe direct (lack of heating) and/or indirect (lack of social services) physical consequences if end-users cannot switch to other fuels/technologies for heating	
Gas-fired power plants	No (but national initiatives exist, e.g. in Austria)	▪ Direct social / commercial impact of increased electricity prices on end-users ▪ Direct end-user impact of electricity demand not served ▪ Indirect impact on the wider economy (inflation, increased budgetary spending needs)	▪ Expected cost for SoS measures vs. the expected direct and indirect negative effects of electricity not served and increased power prices ▪ SoS costs should not be levied onto the unit of gas to avoid these cost driving overall electricity prices leading to negative macro impact (inflation / reduced competitivity)
Industrial installations	No	▪ Direct commercial impact for industrials actor (temporary or lasting) ▪ Indirect impact on the wider economy (loss in tax revenues, increased budgetary spending needs, inflation)	▪ Expected cost for SoS measures (and their impact on industrial competitiveness) vs. the expected direct (only partly internalised) and indirect (macro economic) negative effects of gas not supplied (incl. resulting loss of competitiveness / markets)

Note: [1] Healthcare, essential social care, emergency, security, education and public administration. [2] Provided SMEs and services together do not account for more than 20 % of national annual final gas consumption.
Source: Compass Lexecon analysis based on EU 2017/1983

Redefine National Infrastructure and Supply Standards

The current infrastructure and supply standard have several shortcomings that mandate improvement.

	Issues	Potential remedies
Infra-structure Standard	▪ Largely **peak demand (capacity) focused (N-1)** not taking into account the need to refill storages in summer ▪ Limited – if at all – consideration of **storage withdrawal curves** (i.e. significant dependence of withdrawal capacity on filling levels). Filling storages is therefore also important to have available hourly capacity to meet peak loads ▪ Often **limited to the individual member state** – thereby not always considering the impact of transit flows from/to neighbours in an emergency ▪ Usually **backward looking** (historical peak demand) – not taking into account changing gas demand patterns (cold winter vs. kalte Dunkelflaute as crisis event) **Relevance for gas storage**: ▪ Might overlook infrastructure bottlenecks for storage refilling ▪ Might structurally overlook the regional impact of storages	**1** **Add volume assessments** to the current peak demand assessments (e.g. filling of storages in summer when withdrawal capacity does not count towards standard fulfilment) **2** Take a **forward-looking perspective** and **demand evolvements** (i.e. gas usage in the power sector) **3** Consider **storage filling needs and withdrawal curves** in the assessment **4** Reinforce the **regional perspective** considering **transit requirements** in crisis settings **5** Consider disregarding infrastructure that does not anymore give **access to gas sources** (e.g. historic routes for Russian imports) from the N-1 criteria **6** Incorporate **new peak demand scenarios** (e.g. early winter **kalte Dunkelflaute** events)
Supply Standard	▪ Missing coverage of customers **not falling within the "protected customer"** category (incl. power generation) for whom continuity (or not) of gas supply might have wider economic impact ▪ **Binary choice** between protected and non-protected customer may **not reflect customers' willingness to pay** for security of supply ▪ Incongruencies between the **supply standard analysis horizon (next season) and end-user supplier switching lead-times (three weeks)** leading to difficulties in assigning the responsibilities for supply standard ▪ Unclear requirements – i.e. ***how*** member states must ensure compliance with supply standard and how to check if the supply standard was met **Relevance for gas storage**: ▪ Unclear SoS requirements for end-user suppliers combined with reduced storage bookings by gas producers may lead to prolonged difficulties to market gas storage capacities absent gas storage filling targets.	**1** Consider **cross-sector drivers of demand** and in particular increasing importance of **gas-fired power generation** **2** Account for the **economic value** of ensuring continuous gas supply also to **SMEs and industrials** (potentially differentiating based on ability for fuel switch and/or willingness to pay for SoS – beware of free-rider problem!) **3** Consider **responsibilities within the market model** (i.e. short-term retail supplier switching dynamics vs. longer-term nature of security of supply) when assigning responsibilities to realise the insurance value of gas storages **4** **Harmonise national means of compliance** both in terms of (i) permissible ways to ensuring the actual, physically backed availability of gas and (ii) measures to ensure compliance with the requirements

Source: Compass Lexecon

Regulatory Analysis – Recommendation 3: Allow for / mandate storage filling measures post 2027

Key Requirements Resulting from the Regulatory Analyses

Ongoing and expected changes require an evolution of the market and regulatory framework for the EU gas storage sector.

I. Enhance the EU-wide SoS assessments

II. Redefine national SoS standards

a) Infrastructure Standard

b) Supply Standard

III. Allow for / mandate storage filling measures post 2027 (in the light of missing money)

IV. Re-assess EU-wide sharing of cost for SoS-measures

1 Establish a **long-term and predictable market and regulatory framework for gas storage** going well beyond 2027 (thereby replacing current non-market measures / interventions)[1]

2 Establish a **set of conditions and requirements** for (i) specifying non-market measures and (ii) setting target filling levels

3 Take into account the **EU-wide impact of achieving storage filling** when setting national targets

4 Provide guidance on how to **design measures using market compatible approaches** to limit distortions

5 Consider increasing the minimum **transport tariff discount (e.g. 90%) for storage access points**

Note: [1] In the light of the missing money problem as described in this deck. Source: Compass Lexecon analysis

The Two Dimensions of Improving Energy Security of Supply Using Gas Storage

Ensuring Security of Supply (SoS) by employing gas storages requires actions in two dimensions:
❶ Ensuring availability of adequate physical storage capacity and ❷ Ensuring that available storage capacity is adequately filled.

Technical aspects

- Which **volume** of storage capacity is required?
- Which withdrawal & injection **rates** are required?
- At which **location** is stored gas required?

↓ ↑

- Which **volumes of stored gas** are required?
- **When** is gas required to be available for withdrawal?
- How are the requirements **changing over time**?

1 Ensuring the availability of adequate physical storage capacity

↓ ↑

2 Ensuring that storage capacity is adequately filled

Commercial aspects

- How is the **economic viability of storage** ensured? (➔ remunerating insurance & system value)
- How should **cost for storage capacities** increasing SoS be allocated / borne?
- How are **distortions of the market for gas storage capacities** avoided?

↓ ↑

- How are **distortions of the gas market** (+ the market for gas storage capacities) avoided?
- How to ensure that stored gas is **available when it is needed**?
- How to ensure that stored gas is used at the economically or strategically **optimal time**?
- For what **purpose** can the withdrawn gas be used?

Sources: Compass Lexecon analysis

Commercial vs. Insurance Type Filling of Storage Capacities

Achieving the desired security of supply level may need storage filling going beyond the filling levels incentivised by market prices. This amount of additional storage filling required (insurance type filling) varies from year to year based on prevailing market prices.

Market-driven filling levels vary (significantly) between years

The need for non-market-based (insurance type) filling varies from year to year.

Storage capacity

(Note: To provide the desired level of security of supply the respective storage capacity needs first to be available – either in the member state itself or the wider region)

Storage filling level requirement based on desired SoS-level

(driven by gas demand trajectory, SoS shocks, political considerations, etc.)

Filling level resulting from market incentives vs storage capacity cost
(Year **X**)

Filling level resulting from market incentives vs storage capacity cost
(Year **Y**)

Top-up filling from filling instruments
(+ strategic storage if any)
(Year **X**)

Top-up filling from filling instruments
(+ strategic storage if any)
(Year **Y**)

Filling instruments should cover the difference between the SoS filling level requirement and the level achieved via market incentives. Filling instruments should, however, not be implemented too late (e.g. in early winter or once the emergency is already foreseeable)

Potential distortions of market incentive to fill storages should be minimized.

	Storage Capacity	Storage Filling	Market-based filling (“commercial” filling)
Short-run uncertainty	Storage availability interruptions	Short-term changes in relevant SoS shock	What are the market incentives (e.g. summer-winter spread) and what are the resulting filling levels?
Long-run uncertainty	Tech. storage capacity (due to repurposing / closure)	Future gas demand and/or changing political priorities	How will forward market price (spreads) evolve against the background of the evolving role of gas sector flexibility for power generation.

Storage Capacity | **Storage Filling** | **Market-based filling (“commercial” filling)** | **Non-market-based filling (“insurance type” filling)**

Source: Compass Lexecon analysis.

Digression: Key Factors Determining the Storage Level Required for Security of Supply

The national storage level required for security of supply is determined by demand, supply and political considerations.

Storage capacity

(Note: To provide the desired level of security of supply the respective storage capacity needs first to be available – either in the member state itself or the wider region)

Storage filling level requirement based on desired SoS-level

Storage Capacity | Storage Filling

1 Demand considerations

- **Value of unserved load:** How important / valuable is the gas consumed in peak load situations? Who could / would reduce consumption?
- **Availability of switching opportunities**, e.g. dual-fuel installations
- **Temperature-dependency** of consumption
- **Dependency on power sector gas demand drivers** (and their evolvement): vRES generation (i.e. Dunkelflaute etc.), hydro generation (droughts), NUC availability etc.
- **Demand flexibility need**
  - in terms of additional volumes over a month or season
  - in terms of demand gradient – day-to-day increase of demand

2 Supply considerations

- **Access to gas sources** (both in terms of connecting infrastructure and accessible gas volumes)
  - ... their **peak supply margin** (how much could be supplied additionally in a "normal" peak scenario)
  - ... **flexibility**: how quickly can they ramp up supply
- **Dependency on single infrastructure** elements

3 Political considerations

- Political **security of supply targets**
- Relevant and to be considered (see political SoS targets)
  - supply interruption scenarios
  - demand increase scenarios

Source: Compass Lexecon analysis.

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Overview:
Issues Limiting Storage Booking & Usage, Resulting Risks and Measures to Address them

Market prices not internalizing insurance value may lead to storage booking and filling below levels required for security of supply. Both issues can be addressed with separate (direct) measures or measures where increased capacity demand indirectly also supports SSOs.

Underlying Issues causing SoS risks

Capacity booking and usage are lower than required for security of supply

Cost of storage infrastructure exceeds willingness to pay based on market prices ("missing money") and the retail value of security of supply

SoS Risks

Short-term SoS risks
Storages are not adequately filled

Mid- to long-term SoS risks
Storages close because of missing money (see e.g. Breitbrunn in German)

Measures to address SoS risks

Direct measures

Filling incentives
- Premium, reduced transport tariff, CfD, auction filling obligations
- Address short-term filling; but not necessary storage capacity maintenance as market interest might be limited or necessary incentive payments to high

Economic storage regulation might provide secure storage revenues (if national market is not overburdened by missing money allocation); but not necessarily filling

Indirect measures

Obligations and **administrative measures**
- Stockholding obligations, strategic storage etc.
- Adress both storage filling and availability of capacities since market participants/ dedicated entities are required to
a) hold storage capacities thereby increasing demand and
b) fill these capacities

EU-wide approach
Securing long-term availability and filling of all storage capacities also in countries with – compared to national demand – high storage capacities may need measures across several member states / the entire EU

Source: Compass Lexecon analysis.

"Families" of Approaches to Improve Security of Supply via Gas Storages

There are three broad families of interventions aiming at improving security of supply by targeting gas storages and their filling.

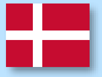
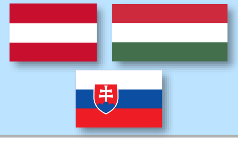
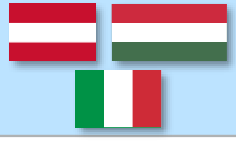
	A. Incentives aligned with externalities	**B. Obligations** forcing provision of externalities	**C. Administrative action** for provision of externalities
Approach	Incentive mechanisms for market participants leading them to (partly) internalise the insurance and system value of storage	Regulatory measures requiring market participants to act in line with full social benefit of storage availability and usage	Administrative induced booking of separate storage capacities as well as their filling & usage to ensure (i) availability and usage of the optimal storage capacities and stored volumes, and (ii) cost recovery for both SSO filling entity
Addressed party/ies	Storage users (which may or may not have another role in the respective gas market ➔ self selection)	Suppliers or retailers of gas in the national market	Administratively dedicated entities
Driver for storage filling	Financial incentive to fill (which may or may not be sufficient to achieve storage filling)	Obligation to fill (with a penalty in case of no- compliance)	Administrative duty to fill
Certainty of filling	The volume filled depends on the price paid / total budget available ("Price-based measures")	The volume filled is specified as part of the measure and sure to be provided ("Volume-based measures")	

For each of these three approaches, there exist various measures that both could be, and in many cases have already been, implemented at a national level. *(see next slide)*

Source: Compass Lexecon analysis

Regulatory approaches and example measures to improve SoS via gas storages

There are three broad families of interventions targeting gas storages aiming at improving SoS – measures can also be combined.

	A. Incentives aligned with externalities			**B. Obligations** forcing provision of externalities		**C. Administrative action** for provision of externalities	
Approach	Incentive mechanisms for market participants leading them to (partly) internalise the insurance and system value of storage			Regulatory measures requiring market participants to act in line with full social benefit of storage availability and usage		Administrative induced booking of separate storage capacities as well as their filling & usage to ensure (i) availability and usage of the optimal storage capacities and stored volumes, and (ii) cost recovery for both SSO filling entity	
Measure type (generic[1])	**1. Storage filling premium**	**2. Storage filling CfDs**	**3. Auctioned filling obligations**	**4. Retailers' stockholding obligations**	**5. Importers' stockholding obligations**	**6. Strategic storage**	**7. Storage filling of last resort**
Details (see appendix for detailed description, assessment and country-case studies)	▪ Storage users receive a premium for meeting filling targets / trajectories[2] ▪ The premium is set administratively and ex-ante (this could also be a reduced transport tariff)	▪ Storage users receive the difference between a strike price and the / a summer-winter spread for stored gas volumes ▪ usually combined with filling targets / trajectories[2]	Obligations to meet storage targets / trajectories[2] including the relevant storage capacities are auctioned-off against a reduced storage tariff and/or a fee paid to the storage user	An obligation is placed on suppliers of selected customers to secure storage capacity and meet storage targets / trajectories[2] corresponding to e.g. a share of their consumers' demand	An obligation is placed on importers to secure storage capacity and meet storage targets / trajectories[2] based on e.g. a share of their imported gas	▪ Storage capacity is contracted and filled by a dedicated entity and then held outside the market ▪ Stored gas can only be used for SoS purposes upon government order	▪ Dedicated entity purchases and stores gas after it becomes clear that market filling will fall short of targets ▪ Gas is released back to the market during the same winter
Selected country cases[3]		 *Only in 2022/23*			–		

Abbreviations: SoS … Security of Supply, CfD … Contract for Difference. Notes: [1] for each of these measure types there is a wide variety of design details that can have a significant impact on intended and unintended effects of the measure [2] The trajectories may stretch beyond the initial filling deep into the winter. [3] non-exhaustive analysis. Source: Compass Lexecon analysis

Distinction Between Filling Instruments, Strategic Storage and Storage Filling of Last Resort

Filling instruments target competitive market players, whereas strategic storage is maintained by dedicated entities to be used solely in emergencies. According to EU SoGS regulation, TSOs may maintain balancing stock, exclusively to fulfil their operational requirements.

Measure type (generic)	Filling instruments					6. Strategic storage	7. Storage filling of last resort
	1. Storage filling premium	2. Storage filling CfDs	3. Auctioned filling obligations	4. Retailers' stockholding obligations	5. Importers' stockholding obligations		
Details							
Storage capacity holder	Competitive market player (retailer, supplier, etc.)					Dedicated entity (can be TSO)	Dedicated entity
Gas owner	Competitive market player (retailer, supplier, etc.)					Dedicated entity (can be TSO)	Dedicated entity
Storage filling mechanism	Incentives or obligations (see previous slide)					Regulation/ administrative duty of dedicated entity	Regulation/ administrative duty of dedicated entity
Use of stored gas	Commercial usage permissible <u>but subject to filling targets and trajectories</u>					Exclusively for SoGS emergencies	Sold under administrative rules
Legal basis	EU Security of Gas Supply Regulation (2017/1983) – Article 6b.1 Measure a), b), f)					Article 6b.1 Measure h)	Article 6b.1 Measure i)

Abbreviations: SoGS … Security of Gas Supply
Source: Source: Compass Lexecon analysis based on EU 2017/1983

Approaches for Gas Storage Filling and their Relation to National Emergency Plans

Member states already today must establish emergency plans containing measures to be taken to remove or mitigate the impact of disruptions of gas supply for each crisis level. The different storage filling approaches benefit gas security of supply at different crisis levels.

	A. Incentives aligned with externalities	**B. Obligations** forcing provision of externalities	**C. Administrative action** for provision of externalities
Approach	Incentive mechanisms for market participants leading them to (partly) internalise the insurance and system value of storage	Regulatory measures requiring market participants to act in line with full social benefit of storage availability and usage	Economic regulation of storage as well as its filling & usage to ensure (i) availability and usage of the optimal storage capacities and stored volumes, and (ii) cost recovery for both SSO & suppliers
Crisis level: Early warning *"significant **deterioration of supply might occur** and lead to alert or emergency level"*	Gas volumes stored can be withdrawn **by market participants, based on market incentives** but subject to restrictions resulting from filling incentives or obligations (e.g. 90% per 1 November and 80% per 1 December implies a market-based withdrawal of up to 10%)		*No access to strategic storage*
Crisis level: Alert *"significant deterioration of supply, but **market is able to manage** the event"*			
Crisis level: Emergency *"**all relevant market-based measures have been implemented,** but gas supply is still insufficient"*	**Administratively enforced storage withdrawal** of stored gas (potentially also covering gas stored based on filling incentives or obligations and in deviation from filling trajectories)		**(Administrative) usage** of strategic storage possible

Source: *Compass Lexecon analysis*

Digression: Transport Tariff Discounts for Gas Storage Facilities

Setting transport tariff discounts for storage connection points at 90% is an easy-to-implement measure to incentivize storage filling. However, if summer-winter spreads remain narrow, it might need to be combined with other measures create sufficient filling incentive.

Current EU level regulation

Lower bound of 50% discount for transmission tariffs

- Member states have to apply a **discount of at least 50%** to capacity-based transmission tariffs at entry points from and exit points to storage facilities (excl. storages that compete with interconnection points)[1]
- 50% discount only **prevents double charging** for transmission to and from storage facilities

Member states can give additional discounts of up to 100% for security of supply reasons[2]

- Until 31 December 2025: discount of up to 100 % to capacity-based **transmission and distribution** tariffs
- From 1 January 2026: discount of up to 100 % **only for the purpose of increasing security of supply** (re-examined by regulatory authority during every regulatory period)

National implementation[3]

- **Some countries** have already **implemented a discount of >50%** on transmission entry and exit capacities to storage facilities
- However, the level of discounts **differs substantially** across Europe and **may be subject to changes** in future regulatory periods

Country case study ▼	Transport tariff discount	
	Entry	Exit
Austria	100%	50%
Denmark	100%	100%
France	60%	60%
Germany	75%	75%
Hungary	90%	100%
Italy	50%	50%
Netherlands	75%	75%
Romania	50%	50%
Slovakia[a]	0%	0%

Recommendation

- Increase the mandatory EU-wide transport tariff discount (and other potential levies) for gas storage (e.g. to 90%) to reduce filling cost and incentivise their booking/usage

Main Benefits

- Well known measure with well understood impact
- Simple and quick implementation compared to alternative support mechanisms
- Improves level playing field for gas storage across EU
- Implicit "cost" of the higher discount is socialised across other users of the gas transmission system through regulated tariffs

Limitations

- Transport tariff discounts alone might not create sufficient incentive for storage filling
- They therefore may **need topping-up by another measure from the toolbox**

Notes: [a] Slovakian gas storage facilities are exempt from the minimum 50% discount as they are connected to the distribution grid and/or compete with interconnection points.
Source: Compass Lexecon analysis based on [1] NC TAR (EU 2017/460), Art. 9, [2] EU 2024/1789, Art. 17(3), [3] E-Control, Energinet, CRE, Regent 2026, Arera, ANRE, Eustream , ACER analysis on the national tariff consultation documents

"Toolbox" of Measures to Improve the Internalisation of the Insurance Value of Gas Storages

On the EU level a predictable framework for the national implementation of the most appropriate filling measure should be established.

A. Incentives aligned with externalities

Incentive mechanisms for market participants leading them to (partly) internalise the insurance and system value of storage

- **1. Storage filling premium**
- **2. Storage filling CfDs**
- **3. Auctioned filling obligations**

B. Obligations forcing provision of externalities

Regulatory measures requiring market participants to act in line with full social benefit of storage availability and usage

- **4. Retailers' stockholding obligations**
- **5. Importers' stockholding obligations**

C. Administrative action for provision of externalities

Administrative induced booking of separate storage capacities as well as their filling & usage to ensure (i) availability and usage of the optimal storage capacities and stored volumes, and (ii) cost recovery for both SSO filling entity

- **6. Strategic storage**
- **7. Storage filling of last resort**

EU level requirements

1 Establish a **long-term and predictable market and regulatory framework for gas storage** going well beyond 2027 (thereby replacing current non-market measures / interventions)

2 Establish a **set of conditions and requirements** for (i) specifying non-market measures and (ii) setting target filling levels

3 Take into account the **EU-wide impact of achieving storage filling** when setting national targets

4 Provide guidance on how to **design measures using market compatible approaches** to limit distortions

5 Consider increasing the minimum **transport tariff discount (e.g. 90%) for storage access points**

Abbreviations: SoS … Security of Supply, CfD … Contract for Difference.
Source: Compass Lexecon analysis

Digression: Key Factors Determining the Selection of Appropriate Measures

The selection of an appropriate measures from the "toolbox" for national implementation depends on the structure of the domestic gas retail and storage sectors, the importance of gas-fired power generation, and financial considerations.

Options for relevant national contexts

Context	Factor	One end	Other end
Structure of gas suppliers	Number	Many	Few
	Size	Mainly small	Mainly large
	Concentration	Low	High
	Ownership	Mainly nationalised	Mainly private
Structure of gas storage sector	Number of SSOs	One	Many
	Regulatory regime	Revenue fully regulated	Revenue fully market-based
	Storage capacity	Less than 35% of national annual demand	Significantly more than national annual demand
Importance of gas-fired power generation		Low	High
Willingness to burden end-users with SoS cost		Low	High

Considerations for selecting the appropriate measure

Structure of gas suppliers:

- The greater the number – and the higher the level of sophistication – of gas import or retail supply entities active in a market, the more suitable tenders or auctions are for (i) assigning obligations and (ii) determining remuneration levels
- Presence of large and/or (partly) state-owned gas import or retail supply entities might favour entrusting them with security of gas supply obligations (e.g. by means of public service obligations)

Structure of gas storage sector:

- If storage capacities exceed the volume required for security of supply, filling mechanisms may need to establish a (self-)selection mechanism to determine which capacities or operators are covered by the measure
- Absent an economic regulatory framework, filling measures aimed at security of supply may not be sufficient to ensure the long-term viability of specific gas storage sites

Importance of gas-fired power generation:

As the share of gas-fired capacity rises, it becomes more important to clarify

i. Who is responsible to ensure storage filling for power generation?
ii. Who is to bear the respective cost and how not to increase power prices?

Willingness to burden end-users with SoS cost:

- Measures financed by levies or obligations on importers/suppliers lead to additional cost for end-users
- Measures that make storage booking less attractive or competitive may shy away arbitrage traders that fill storage out of economic self-interest

Source: Compass Lexecon analysis

Digression:
Intended Impact vs. Distortions from Inefficient Design or Implementation of a Filling Measure

When evaluating the impact of a filling measure, it is important to distinguish between (i) intended deviations from an initial situation not fulfilling SoS requirements and (ii) reducible or even avoidable distortions from inefficient design or implementation of the measure.

Initial Situation
without intervention – but not fulfilling SoS requirements[1]

- The **initial situation is not providing adequate[1] system resiliency against security of supply events** inter alia due to:
  - Not sufficient[1] gas storage capacity being booked
  - Not sufficient[1] gas storage capacity being filled
- The situation is therefore **not a baseline situation for the assessment of distortions**

Filling Measure →

Baseline Situation
fulfilling SoS requirements

- The baseline situation shows the minimum deviations to the initial situation required to meet the desired system resilience level inter alia regarding:
  - More gas storage capacity is booked
  - More gas is in storage at the start of the winter and over the winter as a whole
- These intended deviations, however, necessarily also lead to other deviations:
  - More gas is demanded to fill storages
  - Higher summer / lower winter gas prices
  - Additional cost accrue and need to be covered

These deviations are, however, the **intended impact of increasing system resilience and not distortions**

Potential distortions

I. Distortions from inefficient design

- Filling measure might be designed inefficiently in terms of:
  - Over-insurance
  - Limited incentives for efficiency or to avoid adverse market movements
  - Opening-up detrimental speculation opportunities
  - Overcompensation
- Inefficient design can lead to higher cost or market distortions.

Can be reduced by properly designing the measure

II. Distortions from inefficient implementation

- Distortions from rushed implementation e.g. short lead times
- Distortions from ad-hoc measures solving only the next problem
  - Multiple changes of measures
  - Lack of clarity
  - Unnecessary complexity
- These distortions could manifest themselves in higher than necessary volume or price impacts

Can be reduced by comprehensive measures for the long-term (i.e. a stable framework not only for "the next winter)

Notes: [1] specifying these is a policy choice based on comprehensive data and scenario analysis.
Source: Compass Lexecon analysis

Regulatory Analysis – Recommendation 4: Re-assess EU-wide sharing of cost for SoS-measures

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Key Requirements Resulting from the Regulatory Analyses

Ongoing and expected changes require an evolution of the market and regulatory framework for the EU gas storage sector.

I. Enhance the EU-wide SoS assessments

II. Redefine national SoS standards

a) Infrastructure Standard

b) Supply Standard

III. Allow for / mandate storage filling measures post 2027 (in the light of missing money)

IV. Re-assess EU-wide sharing of cost for SoS-measures

1 Reassess the **principles and mechanisms for the cost sharing** of Security of Supply across member states to ensure fair burden sharing

2 Take into account the **inhomogeneous distribution** of gas storage capacities and **contribution to regional and EU Security of supply**

3 Take into account the **contribution of gas storage to power sector** security of supply

4 Factor in **cost associated with insurance value of storages for gas security of supply** also in the absence of acute crisis situations

Source: Compass Lexecon analysis

Current EU SoS Framework – EU Storage Filling Requirements

The EU gas storage regulation, introduced in 2022 and updated in 2025, requires member states to fill 90% of storage capacity at the beginning of the withdrawal season, with flexibility of up to 20 percentage points under market or technical conditions.

- EU Storage Filling Requirements were **introduced in 2022** with a sunset clause for December 2025, **updated and extended** in July 2025 to last **until December 2027**

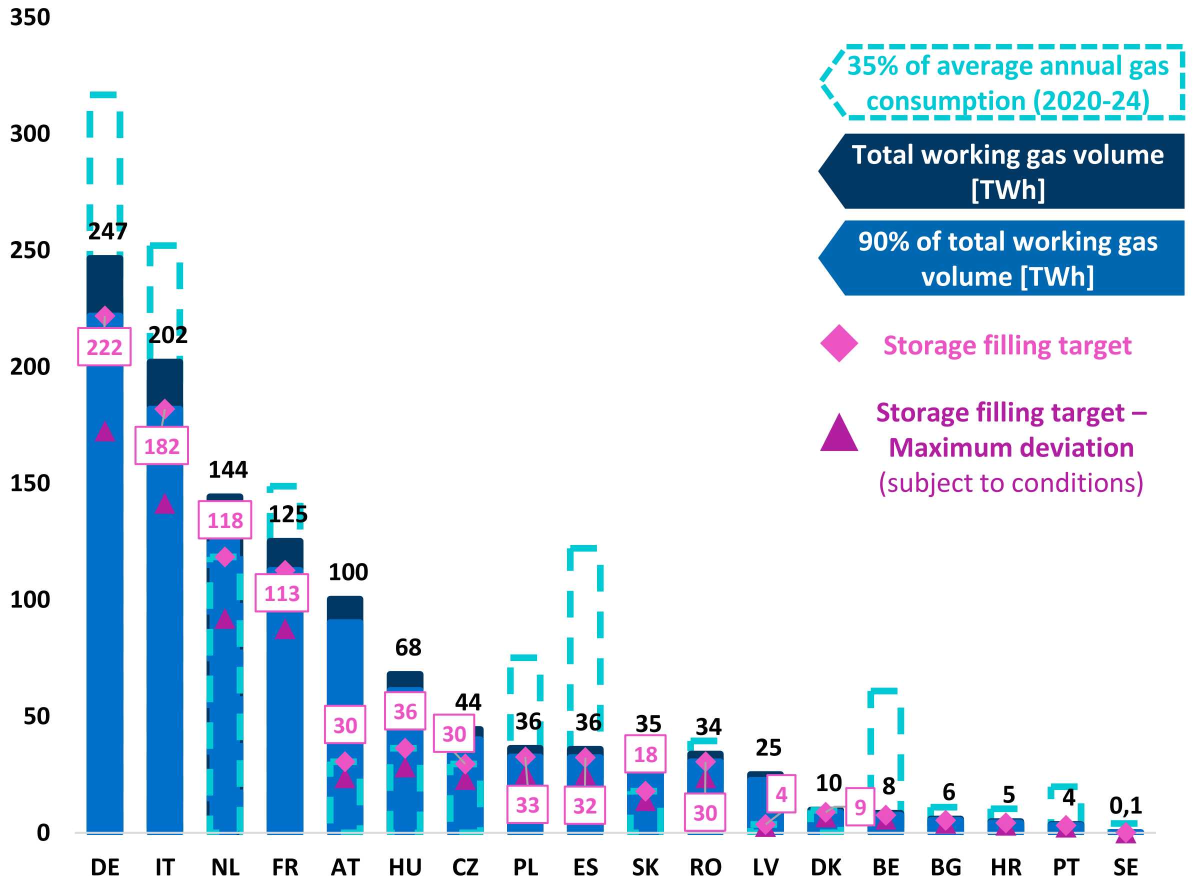
Original regulation (2022 – September 2025):

- Member states **with gas storages** have to **fill**
  - **90%** (80% in 2022) **of their gas storage capacity** or, if lower,
  - store volume equal to **at least 35% of average annual consumption** over the last five years
- Binding target to be reached on **1 November**, on a country-specific **binding filling trajectories**
- If market-driven filling is not sufficient, member states bear cost for additional storage filling

Updated regulation (September 2025 – December 2027)

- **Up to 20 percentage points deviation** from the 90% filling target:
  - **Member states:** 10 pp in case of difficult market conditions; additional 5 pp for member states that fulfil certain technical criteria
  - **EC:** additional 5 pp flexibility in case of persistent unfavourable market conditions
- Filling target can be reached anytime **between 1 October and 1 December**
- **Indicative** storage filling trajectory

Working gas volume (2025), 35 % of average annual gas consumption (2020-2024) and storage filling target by country [TWh][1]



Note: [1] Operational assets as of May 2025, gross calorific value (GCV) and average annual gas consumption from 2020-2024.
Source: Compass Lexecon analysis based on EU 2025/1733, EU 2022/1032 , EU 2017/1983, GIE – Storage Inventory, and Eurostat.

Current EU SoS Framework – Cost-Sharing Mechanisms

While several EU member states may benefit from guaranteed gas storage filling levels in a specific country, the mechanisms in the current EU regulation only partially address cost-sharing among the member states.

EU-wide SoS benefits

- In the **integrated EU gas market**, higher overall gas storage filling contributes to **EU-wide SoS**
- The **EU solidarity mechanisms** additionally enhances national SoS: in a national emergency, a member state can request gas from an inter-connected member state.

→ Member states with **smaller or no storage capacity benefit** from SoS provided by countries with higher capacity

SoS costs mainly at national level

Member states (MS) with (at least some) underground gas storage capacity

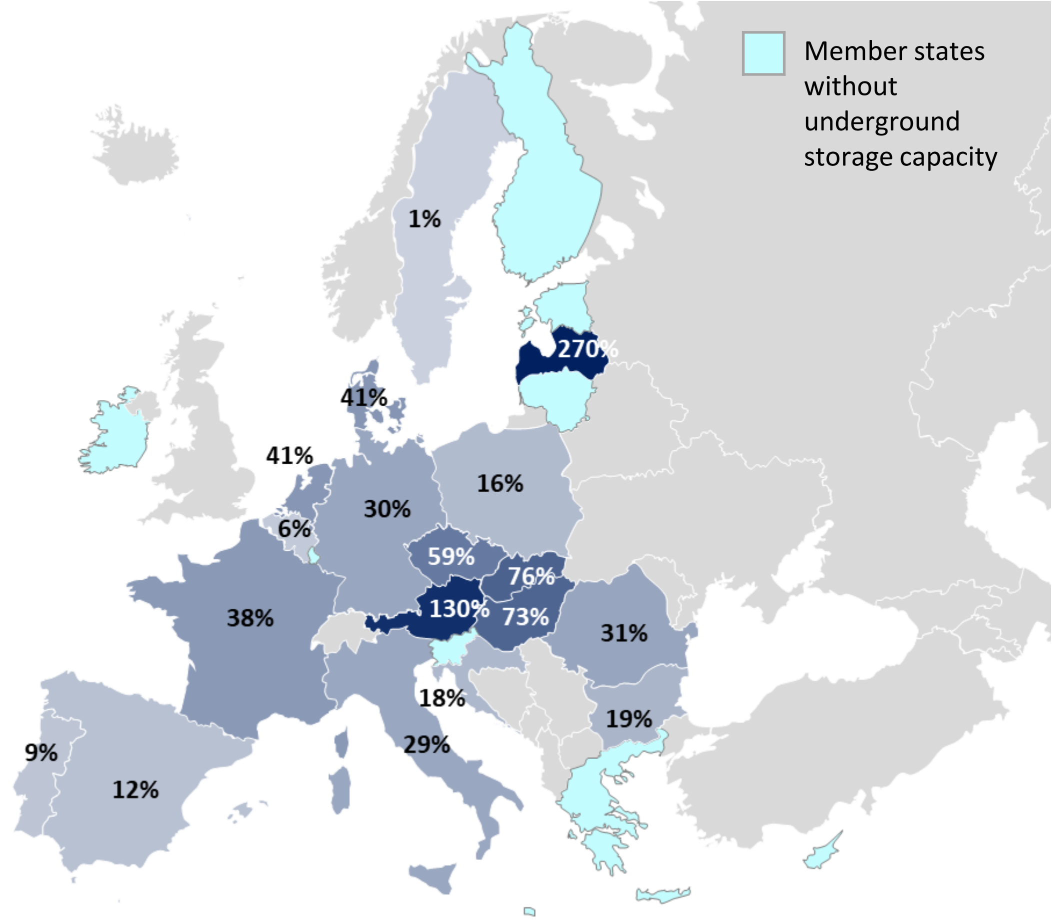
- **There is no EU-wide cost-sharing mechanism covering these MS in place**
- Under the **EU solidarity mechanism,** SoS support by connected MS is **only financially compensated if the gas is physically delivered** to the requesting MS; the **insurance provided in cases where risk does not materialise is thus not compensated**
- Given the **heterogeneity of storage capacities across MS** to which the same filling requirement is applied, MS **with storage contribute to EU gas SoS to very different extents**, while the **financial costs** of storage filling mainly occur at **national level:**

Member states without underground gas storage capacity[a]

Member states without storage are required to contribute to EU gas SoS through one of two alternative mechanisms:

A. **Storage arrangement:** market participants store gas volume of **at least 15% of average annual consumption** (over previous five years) in another Member State by 1 Dec[b], **or**
B. **Burden-sharing mechanism**: contribute financially towards storage filling by another Member State with underground storage; developed on a **case-by-case basis** based on cost of financial support for meeting the filling target, gas volumes needed for protected customers and technical limitations

Gas storage capacities as share of inland gas consumption, 2024[1]



Note: [a] Estonia, Ireland, Lithuania, Greece, Cyprus, Slovenia, Finland, Luxembourg, and Malta. [c] If technically possible. If a member state's storage capacity is larger than its annual gas consumption, member state without UGS with access to it, must ensure that storage volumes reach average usage level over the last five years (anytime between 1 Oct and 1 Dec) or demonstrate that corresponding capacity has been booked (up to 15% of annual consumption). Source: Compass Lexecon analysis based on EU 2025/1733, EU 2022/1032 , EU 2017/1983 and [1] GIE – Storage Inventory, and Eurostat.

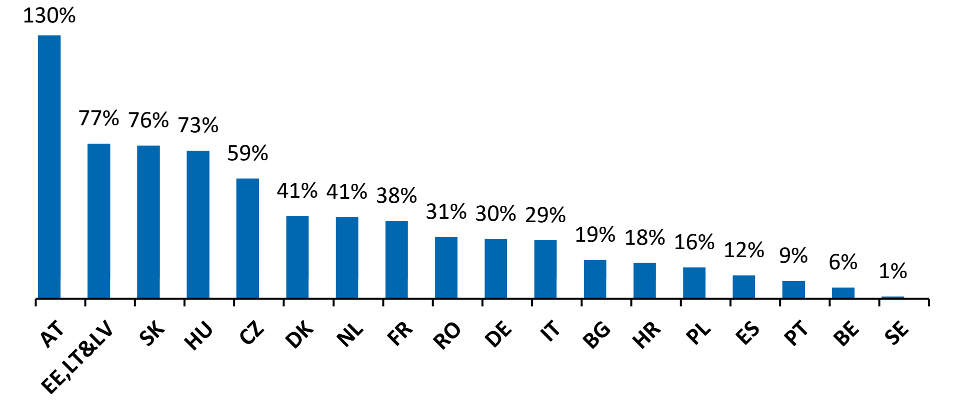
Re-Assess EU-Wide Sharing of Cost for SoS-Measures

The current EU gas security of supply framework lacks sufficient provisions for cost-sharing between member states.

Current regulation

- Member states with gas storages have to **fill 90% of their gas storage capacity** – subject to tolerances of up to 20 percentage points – or, if lower, store volume equal to at least 35% of national average annual gas consumption over the preceding five years
  - If market-driven filling is not sufficient**, member states carry the cost for additional storage filling measures themselves**
- Member states without underground gas storages have an obligation **to store only at least 15% of annual gas consumption** in another member state

Gas storage capacities as a share of inland gas consumption, 2024[1]



Issues

Limited cost sharing for storage filling between member states

- Cost sharing is currently limited to countries without any gas storage (obligation to fill storages in other countries).
- However, also among countries with storage, storage capacity to demand ratios varies widely
- "Uniform" filling targets combined with – generally – nationally borne costs lead to
  - different levels of prevention across member states
  - differing participation of individual member states to the broader Union's risk preparedness, as within the interconnected EU gas market, gas storage provide benefits beyond the individual member state
  - potential for free-rider problems

Potential remedies

1 Reassess the **principles and mechanisms for the cost sharing** of Security of Supply across member states to ensure fair burden sharing – either based on bilateral agreements or EU-wide cost sharing ("EU-fund")

2 Take into account the **inhomogeneous distribution** of gas storage capacities and **contribution to regional and EU Security of supply**

3 Take into account the **contribution of gas storage to power sector** security of supply

4 Factor in **cost associated with insurance value of storages for gas security of supply** also in the absence of acute crisis situations

Notes: [1] Based on GIE – Storage Inventory and Eurostat
Source: Compass Lexecon analysis.

Regulatory Analysis:
Summary of Conclusions

Key Requirements Resulting from the Regulatory Analyses

Ongoing and expected changes require an evolution of the market and regulatory framework for the EU gas storage sector.

I. Enhance the EU-wide SoS assessments

1 Improve the **interlinkage between the gas and electricity** security of supply and flexibility assessment

2 Determine **gas storage capacity and filling required** to ensure SoS at the desired level taking into account filling level dependence of storage withdrawal

3 **Expand shock scenarios** beyond cold-spells to account e.g. for **reduced renewable power generation** and other extreme events linked e.g. to climate and/or geopolitical events

4 **Extend the analysis horizon to 10 yrs. in the future** (and beyond)

5 Consider **gas infrastructure changes** (storage and pipeline), e.g. due to repurposing to hydrogen

II. Redefine national SoS standards

a) Infrastructure Standard

1 **Add volume assessments** to the current peak demand assessments (e.g. filling of storages in summer when withdrawal capacity does not count towards standard fulfilment)

2 Take a **forward-looking perspective** and **demand evolvements** (i.e. gas usage in the power sector)

3 Consider **storage filling needs and withdrawal curves** in assessment

4 Reinforce the **regional perspective** considering **transit requirements** in crisis settings

5 Consider disregarding infrastructure that does not anymore give **access to gas sources** (e.g. historic routes for Russian imports) from the N-1 criteria

6 Incorporate **new peak demand scenarios** (e.g. early winter **kalte Dunkelflaute** events)

b) Supply Standard

1 Consider **cross-sector drivers of demand** and in particular increasing importance of **power generation**

2 Account for the **economic value** of ensuring continuous gas supply also to **SMEs and industrials** (potentially differentiating based on ability for fuel switch and/or willingness to pay for SoS – beware of free-rider problem!)

3 Consider **responsibilities within the market model** (i.e. short-term retail supplier switching dynamics vs. longer-term nature of security of supply) when assigning responsibilities to realise the insurance value of gas storages

4 **Harmonise national means of compliance** both in terms of (i) permissible ways to ensuring the actual, physically backed availability of gas, and (ii) measures to ensure compliance with the requirements

III. Allow for / mandate storage filling measures post 2027 (bridging the missing money gap)

1 Establish a **long-term and predictable market and regulatory framework for gas storage** going well beyond 2027 (thereby replacing current non-market measures / interventions)[1]

2 Establish a **set of conditions and requirements** for (i) specifying non-market measures and (ii) setting target filling levels

3 Take into account the **EU-wide impact of achieving storage filling** when setting national targets

4 Provide guidance on how to **design measures using market compatible approaches** to limit distortions

5 Consider increasing the minimum **transport tariff discount (e.g. 90%) for storage access points**

IV. Re-assess EU-wide sharing of cost for SoS-measures

1 Reassess the **principles and mechanisms for the cost sharing** of Security of Supply across member states to ensure fair burden sharing

2 Take into account the **inhomogeneous distribution** of gas storage capacities and **contribution to regional and EU Security of supply**

3 Take into account the **contribution of gas storage to power sector** security of supply

4 Factor in **cost associated with insurance value of storages for gas security of supply** also in the absence of acute crisis situations

Note: [1] In the light of the missing money problem as described in this deck. Source: Compass Lexecon analysis

Annex A – Model-Based Assessment
Modelling approach and additional results

Table of contents – Modelling section

Model-based assessment of role of UGS in maintaining resilience to shocks

Context, objectives and key messages

Approach for the model-based assessment of the role of UGS in maintaining resilience to security of supply shocks

Analysis of UGS role for security of supply with a multi-energy perspective, based on National Trends+ scenarios

Analysis of UGS role under security of supply shocks

Analysis of UGS role under a deviation scenario

Key conclusion

Annex – Modelling approach

Annex – Additional modelling results

Modelling approach – Overview

The model of the energy system implemented in Artelys platform *Artelys Crystal Super Grid* mostly relies on TYNDP 2024 datasets, but some adaptations have been implemented to be able to carry out the analyses required for this study.

- **The energy system model is mostly based on the TYNDP 2024 NT+ scenario** for 2030 and 2040. Artelys has integrated this scenario in its modelling platform *Artelys Crystal Super Grid* leveraging the data provided on scenarios on the TYNDP 2024 website and other associated reports (e.g. Infrastructure Gap Identification Report, Implementation Guidelines, etc.).
- The TYNDP model has been adapted for this study, which induces **some differences from the results published by the ENTSOs**.
  - The energy system is modelled using gas year (1st October – 30th September) to better take into account the evolution of storage filling levels across the winter.
  - Other climate years are modelled (detailed NT+ results are published by the ENTSOs for 2009 climate year only): 2008-2009 and 2012-2013.
  - The systems of all major energy vectors are modelled together (explicitly modelling H2 and methane demand for power & methane SMR consumption for H2).
  - Several assumptions, notably regarding flexibility and cross-vector integration, are not published by the ENTSOs and were therefore taken based on expert judgment.
- As NT+ scenario is based on the aggregation of national data without implementing a pan-European process to ensure security of supply, the datasets published by the ENTSOs show significant amounts of loss of load in the electricity and hydrogen sectors. **A "SoS loop" is therefore necessary**.
- When datasets are missing for non-EU27 countries, a proxy-based approach have been implemented (e.g. AT for CH, SE for NO, etc.) and NESO data has been used for the UK, aiming to respect the overall NT+ philosophy. Some other minor corrections are not detailed in this document.
- **A deviation scenario**, which includes a delayed hydrogen and heat-pump ramp-up, is modelled as well.

Modelling approach – Methane system

The model of the methane system is based on datasets published by ENTSOG or GIE, where possible.

- **Methane production** (including biomethane and e-methane) volumes in EU27 are the one published in TYNDP 2024 Supply Tool for NT+ scenario.
- **Methane annual final demand** volumes in EU27 are taken from TYNDP 2024 NT+ scenario.
  - Demand linked to transformation in the energy sector (for power and hydrogen production) is determined endogenously by the model.
  - **Consumption profiles** calibrated by Artelys based on historical climate data are used to model weather-dependant demand at daily granularity. The profiles have been rescaled to match NT+ volumes **taking into account the relative evolution of methane demand in each sector** (the sectoral split being based on TYNDP 2024 NT+ survey). Volumes are adapted depending on the climate year (TYNDP volumes are considered average).
  - For **the UK**, methane volumes are taken from NESO *Pathways to net zero* study published on July 2025 [Link], scenario *Ten Year Forecast* for 2030 and *Hydrogen Evolution* for 2040, as no information is provided in TYNDP2024 for non-EU27 countries. For other countries, a proxy-based approach has been adopted.
- **Underground gas storages (UGS) capacities** are based on AGSI (with small updates based on the feedback received from GIE funding members on new or decommissioned storages as well as storages types). The capacities are aggregated by storage type (depleted field, aquifer, salt caverns, rock cavern) at country level in the model.
  - **Injection and withdrawal capacity curves** (depending on inventory level) based on ENTSOG Summer Supply Outlook 2025 are used.
  - An **initial storage level** at 1st of October is defined at **90%** as in the reference scenario of ENTSOG Summer Supply Outlook 2025. ENTSOG indicates that on October 1st storage inventory was 83% in 2025 and 94% in 2024.
  - UGS capacities are **reduced to take into account underground hydrogen storage (UHS) deployment,** with a **1 to 4 ratio** between CH4 and H2.
- **Pipeline capacities** are from TYNDP 2024 datasets for infrastructures capacity, using low natural gas infrastructure levels (which is based on existing infrastructures + FIDs), following ENTSOG approach for CBAs (p.103).
- **LNG terminals capacities** (import capacities) are from ALSI.
- **Methane import potentials** are based on TYNDP 2024 [Implementation Guidelines p. 104]
  - Imports are considered with a **flat profile over the year**. Imports per pipeline are proportional to consumption in NT+ scenarios compared to total potential (excluding imports from Russia) and LNG total import volume is endogenously defined by the model to match total demand. LNG imports are flexible between terminals.

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Modelling approach – Hydrogen system (1/2)

Key modelling adaptations have been introduced for the hydrogen system to ensure a more realistic representation of H2 flexibility, integrating a two-zone split between decentralised assets and those connected to the main transmission infrastructure.

- NT+ modelling approach is adapted for the **hydrogen system, integrating a two-zones split**.
  - In the TYNDP2024, the hydrogen system presents a split between a decentralised part (zone 1) and another part that is connected to the main transmission infrastructure system (zone 2), but only for *Distributed Energy* and *Global Ambition* scenarios. However, ENTSOG implementation guidelines for CBAs require to perform analyses based on NT+ *with* this two-zones split.
    - **Zone 1**: Decentralised hydrogen final demand and electrolysers, SMR (price-dependant switch)* and above-ground storage (covering 24h of consumption).
    - **Zone 2**: Hydrogen demand connected to the main system (including demand for power plants), electrolysers, underground storages, pipelines and imports.
- The datasets published in ENTSOG Hydrogen Infrastructure Gaps Identification Report (IGI) have been used to define parameters per zone:
  - Electrolysis capacities based on production capacities presented (pp. 106+).
  - Demand volumes per countries (provided in IGI report, minus demand associated to power generation as provided by the ENTSOs) have then been split between zones according to ENTSOG TYNDP Implementation Guidelines (which indicates the percentage of demand per sector is associated to which H2 zone) using country-level H2 demand per sector distribution (as described in NT+ Energy Mix Survey).
  - H2 in Spain is only partly explicitly modelled by the ENTSOs (no explicit model of national demand and associated production, as if it were off-grid).
    - For this study Spain H2 system is fully modelled as in other countries, with additional wind and solar capacities proportionally to the energy mix (to include the additional electricity production necessary for electrolysis). No off-grid H2 is considered.
- These modelling differences results in differing flexibility levels of the H2 system.
  - In particular, electrolysers in zone 1 have limited flexibility potential as they do not have access to underground hydrogen storages, which induces higher methane demand for SMR and collateral effects on the power system due to the lower flexibility of electrolysis.

In the ENTSOs model some SMR with CCS also have access to zone 2; here SMRs are restricted to Zone 1.

Modelling approach – Hydrogen system (2/2)

Key modelling adaptations have been introduced for the hydrogen system to ensure a more realistic representation of the role of storage infrastructures in security of supply.

- In the TYNDP scenarios, H2-fired power plants have access to an infinite H2 supply, without any consideration of hydrogen infrastructures limitations.
  - This overlooks the key role of underground hydrogen storages for seasonal flexibility. This modelling limitation is corrected in the model developed for this study.
- Underground hydrogen storage (UHS) modelling approach is adapted compared to ENTSOs for NT+ scenario.
  - Working gas volumes (WGV, in TWh) capacities are likely to be based on TSO data in NT+, with limited volumes at EU-level (5,6 TWh in 2030 ; 12,1 TWh in 2040).
    - These low WGV values are not a key issue for the ENTSOs model, as H2 supply for power generation is not linked to the H2 system. However, connecting H2-fired power plants to the H2 system with these limited capacities leads to adequacy issues.
  - Injection and withdrawal capacities (in GW) seem to be result of an optimisation in NT+*.
- Several elements of the H2 system are integrated to the security of supply (SoS) loop in order to ensure that the system shows no adequacy issue under normal conditions.
  - Production capacities are re-optimised (under the constraint that installed capacities cannot be lower than in NT+): electrolysis in zone 2 and SMR in zone 1.
  - UHS capacities are re-optimised under constraints.
    - Investment parameters are based on the 2024 GIE study on UHS needs (p.27; study realised by Artelys & Frontier Economics)
    - In each country, the maximum possible installed capacity is equivalent to a repurposing of 25% of current UGS capacities (in TWh) per type of storage (with a conversion ratio of 1 to 4). Various types of UHS are considered to better reflect geological options across Europe, in particular in CEE region (TYNDP only considers salt caverns). The value of 25% maximum repurposing was taken as a reference to calibrate the model setting UHS evolutions by reference to a real UGS figure, but do not mean a structural decline in UGS relevance. This is an approximation as some UHS projects could be greenfield, there could be other opening / closures projects of UGS and repurposing works take time. This investment limit is not reached at EU-level, as total UGS capacities are reduced by 14.5% in 2040 following the SoS loop and the integration of projects of opening and closure of UGS sites provided by GIE funding members.
- These modelling differences have significant impacts, in particular as high UHS WGV and withdrawal capacities are a key enabler of H2-fired power generation.

** In the file describing H2 assumptions maximum expansion capacities are provided. These capacities are reached in some countries but not all. The ratio between injection and withdrawal capacities as well as the ratio between WGV et injection capacities also greatly varies from one country to the other, with cycling duration ranging from a few days to more than a year.*

Modelling approach – Power system (1/2)

TYNDP 2024 datasets are used to model additional climate years, with some adaptations. DSR modelling by the ENTSOs is adapted as it was deemed unrealistic in Germany.

- TYNDP 2024 results for the power system are published for climate year 2009 only for NT+ scenario.
  - Hourly datasets on other historical climate years are provided in the PECD 3.1 (Pan-European Climatic Database). **Temperature** and **final power demand** profiles, as well as **wind** and **solar** generation profiles, have been taken from the PECD 3.1.
  - For consistency, these profiles were used for all climate years (there are some deviations from the hourly results published by the ENTSOs).
    - Some corrections were necessary, in particular for UK power demand which shows major issues (e.g. negative demand on many timesteps in NT+ 2040). UK hourly demand profiles have been replaced with profiles generated by Artelys.
- ENTSO modelling considers explicit DSR capacities. The model is particularly problematic in **Germany**.
  - DSR capacities are provided in the PEMMDB with price bands, ranging from 5 €/MWh to 820 €/MWh.
  - This results in over **60 TWh of DSR** in 2040 in Germany in the results published by the ENTSOs.
  - Artelys modelling with these input parameters show that many price bands are so low that DSR is activated **above 80% of the year**. This seems unrealistic to consider that industrial consumption can be curtailed for such high duration.
    - 6.6 GW is available all the year and curtailed 80% of the time. Furthermore, capacities with variable availabilities over the year (up to 19.3 GW, on average 3.11 GW) are added.
  - **DSR prices below 150 €/MWh were increased to 150 €/MWh, to reach lower load factor of DSR.**

Name	Volume (TWh)	Price (€/MWh)	Capacity (MW)	Availability	Load factor
band 1	4,1	5	571	100% all year	81%
band 2	16,5	5	2322	100% all year	81%
band 3	0,0	256	5	100% all year	5%
band 4	0,0	820	6	100% all year	3%
band 5	0,1	461	312	100% all year	4%
band 6	0,2	390	494	100% all year	5%
band 7	0,0	564	101	100% all year	3%
band 8	0,1	487	197	100% all year	4%
band 9	5,5	10	773	100% all year	80%
band 10	20,5	20	2932	100% all year	80%
band 11	0,4	115	406	100% all year	10%
band 12	0,0	150	30	100% all year	9%
band 13	0,5	200	848	100% all year	6%
band 14	5,6	98	10457	Avg: 1680 MW	38%
band 15	10,2	49	8800	Avg: 1414 MW	83%

German DSR in NT+ 2040, PEMMDB data and Artelys modelling results

Source: Artelys modelling based on initial implementation of NT+ scenarios (2030 & 2040).

Modelling approach – Power system (2/2)

Significant adaptations on the modelling of demand-side flexibility have been developed to correctly reflect their contribution to system flexibility and their impact on gas-fired power generation.

- The publicly available datasets and methodologies associated to NT+ scenarios published by the ENTSOs for TYNDP 2024 could not be used as such for demand-side flexibility.
  - In particular, the power consumption and associated flexibility of electric vehicles (EVs) and heat pumps (HPs) is not detailed in the methodology report for NT+ scenario.
    - Only an equivalent "black box" model is added to represent the flexibility of EVs and HPs (called DSRi, for implicit demand-side response). No publicly available information on DSRi parameters could be found.
    - DSRi capacities are large in some countries. In Germany, in NT+ 2040, despite 50 GW of DSRi, there is a peak loss of load hour of 83 GW.
  - This demand-side flexibility modelling approach has major implications on SoS, and in particular on peak methane / hydrogen demand from gas-fired power plants.
- Since the flexibility provided by EVs and HPs published by the ENTSOs in the hourly results cannot be taken as such for another climate year and the deviation scenario, EVs and HPs are explicitly modelled, which requires to define flexibility parameters. DSRi has therefore been deleted from our model to avoid double-counting this flexibility.
  - The profiles associated to EVs and HPs demand and flexibility potential are therefore different than in the ENTSOs model.
  - New profiles have been generated by Artelys, and the best-estimate of profiles used by the ENTSOs have been deduced from PECD total final power demand profiles.
- The EV model is based on Artelys expertise on EV modelling and TYNDP-inspired assumptions.
  - Arrival / departure curves (provided by Artelys) are used to represent charging needs and the number of EVs that are connected at each hour throughout the year.
  - Flexibility parameters have been inspired by TYNDP 2026 assumptions currently under consultation:
    - Medium flexibility level, "user-oriented" for 2030 (30% optimised) and "balanced" for 2040 (50% optimised).
  - Annual consumption volumes are based on the published datasets for Global Ambition scenario (no data is provided for NT+).
- The HP model is based on Artelys expertise on HP modelling and TYNDP-inspired assumptions.
  - HP annual consumption per country have been estimated based on TYNDP 2024 datasets on demand scenarios (and assumptions on e.g. average COP of heat pump).
  - Artelys model of HP hourly consumption depending on temperature (reflecting heat demand and variable COP efficiency), using historical hourly temperature datasets.
  - Assumption that 30% in 2030 and 60% in 2040 of HP can provide flexibility leveraging thermal inertia of buildings (15 min storage).

Sources: Artelys analysis of TYNDP 2024 published documents

Security of Supply (SoS) loop

Artelys

When modelling the CH4-H2-electricity system as presented above, significant amounts of loss of load appear. A "SoS loop" is therefore necessary to ensure that the system can correctly function under normal conditions, before analysing the impact of shocks.

- The SoS loop is based on the capacity expansion feature of *Artelys Crystal Super Grid*. The model optimises additional capacities to ensure adequacy for all energy vector.
  - The optimal mix is therefore determined in a way that takes into account interactions between technologies and energy vectors (e.g. impact of batteries on gas-fired power generation capacities, impact of H2 storages on electricity adequacy, etc.).
  - The SoS loop is calibrated to reach ~3h of loss of load maximum, which is a standard reference for adequacy studies.
  - The SoS loop is calibrated in such a way that if low gas supply capacities may lead to electricity loss of load, then gas final demand is curtailed to ensure supply electric final demand.
- The SoS loop is implemented on climate year 2012-2013, which is more stressful than 2008-2009 at EU-level under NT+ scenarios, for both NT+ and deviation scenarios.

Additional capacities resulting from the SoS loop (EU level)

GW	NT+ 2030	NT+ 2040	Deviation 2030	Deviation 2040
CH4-fired OCGTs	21.6	87.8	14.4	54.4
Batteries (4 hours storage)	5.8	0	7.6	4.1
Electrolysers (H2 zone 2)	6.3	17.4	9.1	19.4
SMRs (H2 zone 1)	0.5	10.1	0.2	4.9

Investment parameters for SoS loop

Asset	CAPEX 2040 (k€/MW)	Fixed OPEX 2040 (k€/MW/yr)	Lifetime (years)	WACC	Key source
CH4-fired OCGT	425	7,6	25	6%	TYNDP 2024
Batteries	627	15,7	25	6%	TYNDP 2024
Electrolyser (H2 zone 2)	375	12	25	6%	TYNDP 2024
SMR (H2 zone 1)	590	29	25	6%	EC / E3M, PRIMES assumptions
UHS	*Assumptions depend on storage type, see table below.*				2024 study on UHS

Investment parameters used for UHS

Technology	CAPEX (€/MWh)	OPEX (%CAPEX)	Lifetime (yr)	WACC	Maximum annual number of cycles
Salt caverns	900	4 %	50	5 %	10
Hard rock caverns	1 200	4 %	50	5 %	10
Depleted gas fields	450	4 %	50	5 %	4
Aquifers	450	4 %	50	5 %	4

Source: Artelys modelling based on NT+ scenarios (2030 & 2040).

Table of contents – Modelling section

Model-based assessment of role of UGS in maintaining resilience to shocks

Context, objectives and key messages

Approach for the model-based assessment of the role of UGS in maintaining resilience to security of supply shocks

Analysis of UGS role for security of supply with a multi-energy perspective, based on National Trends+ scenarios

Analysis of UGS role under security of supply shocks

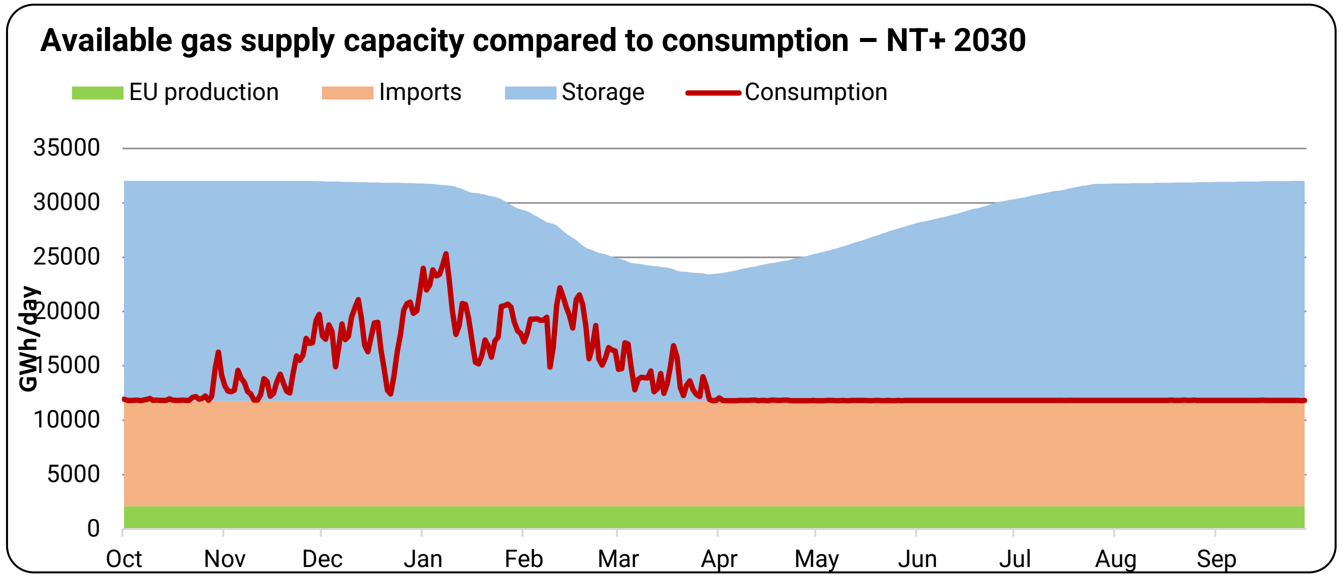
Analysis of UGS role under a deviation scenario

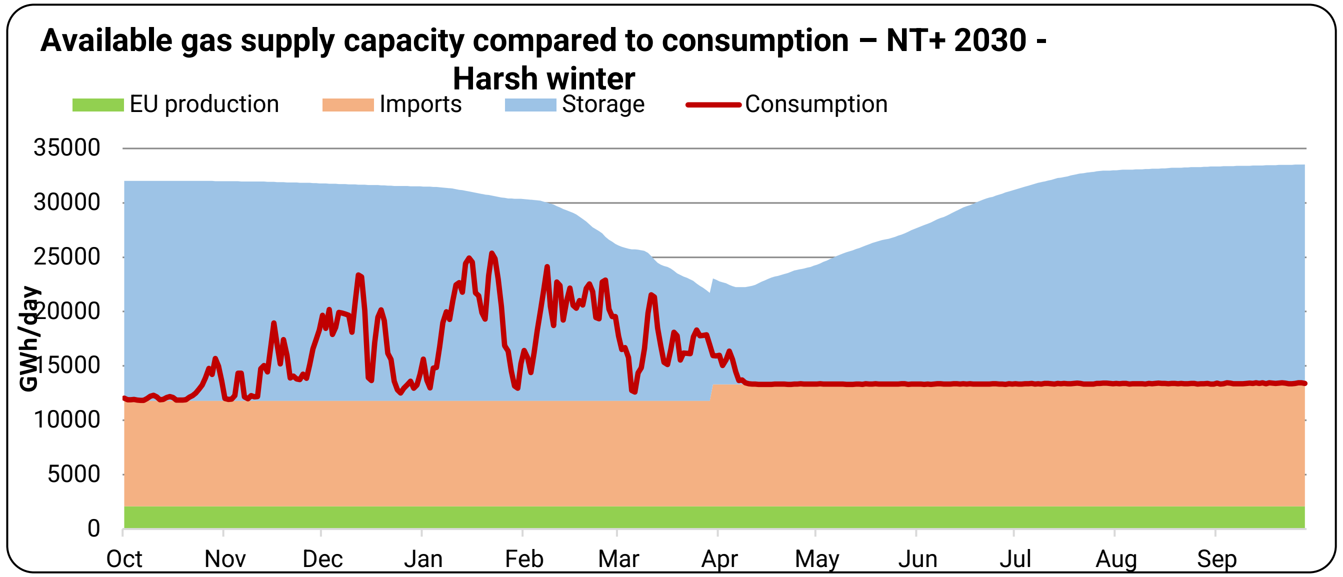
Key conclusion

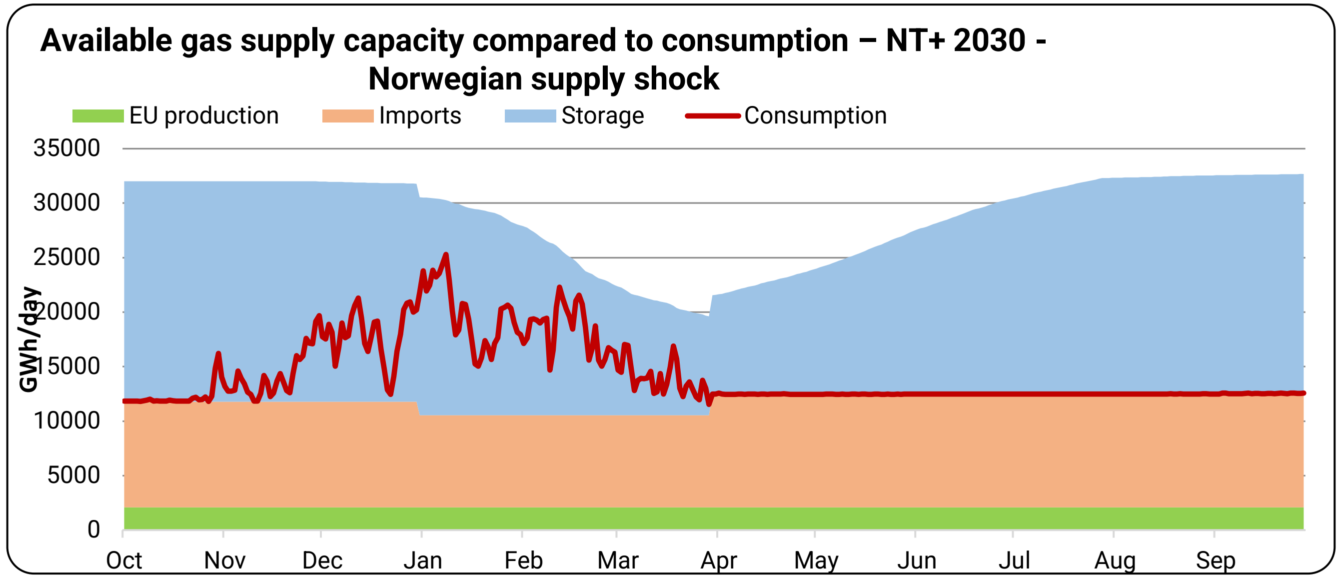
Annex – Modelling approach

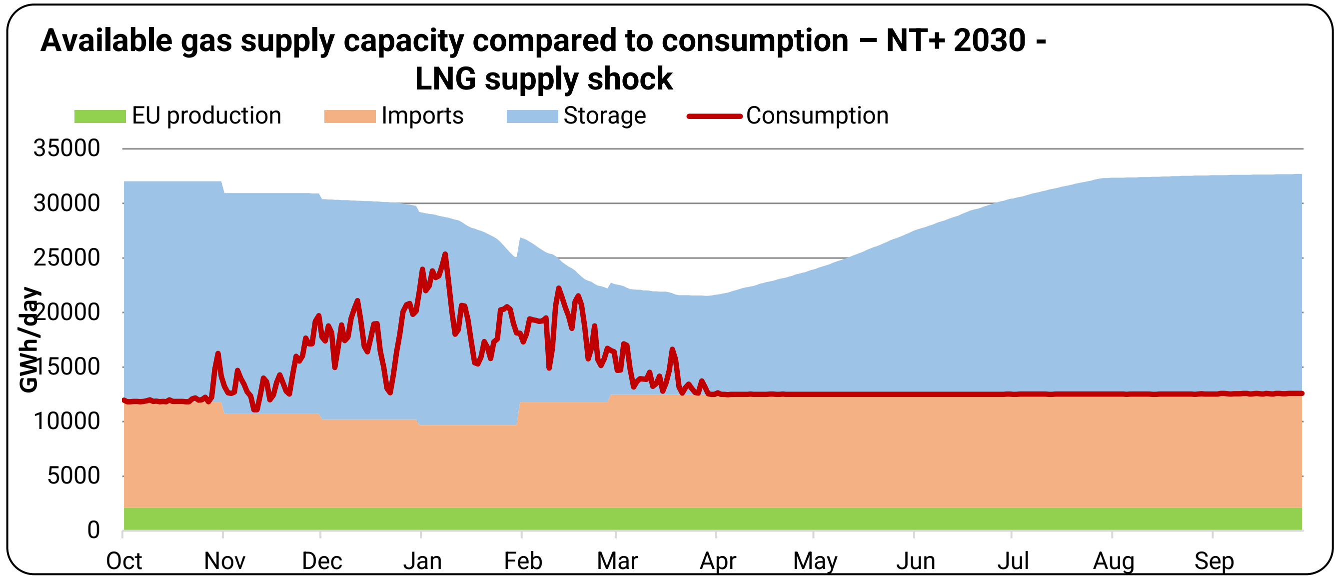
Annex – Additional modelling results

Available gas supply capacity compared to consumption – NT+ 2030



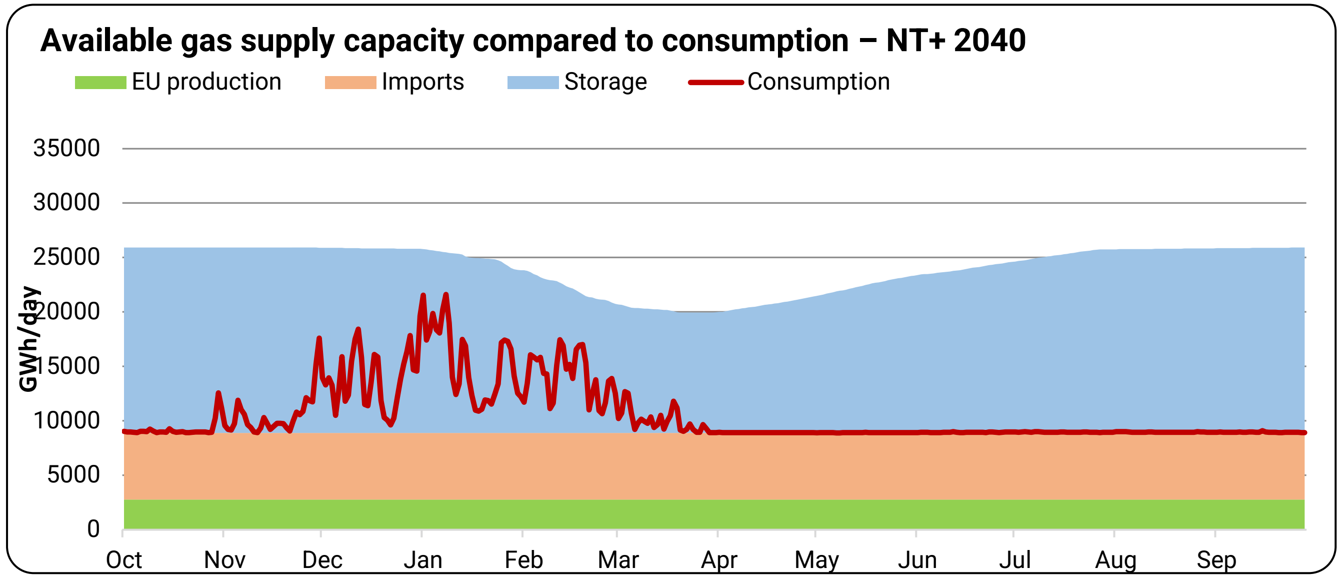


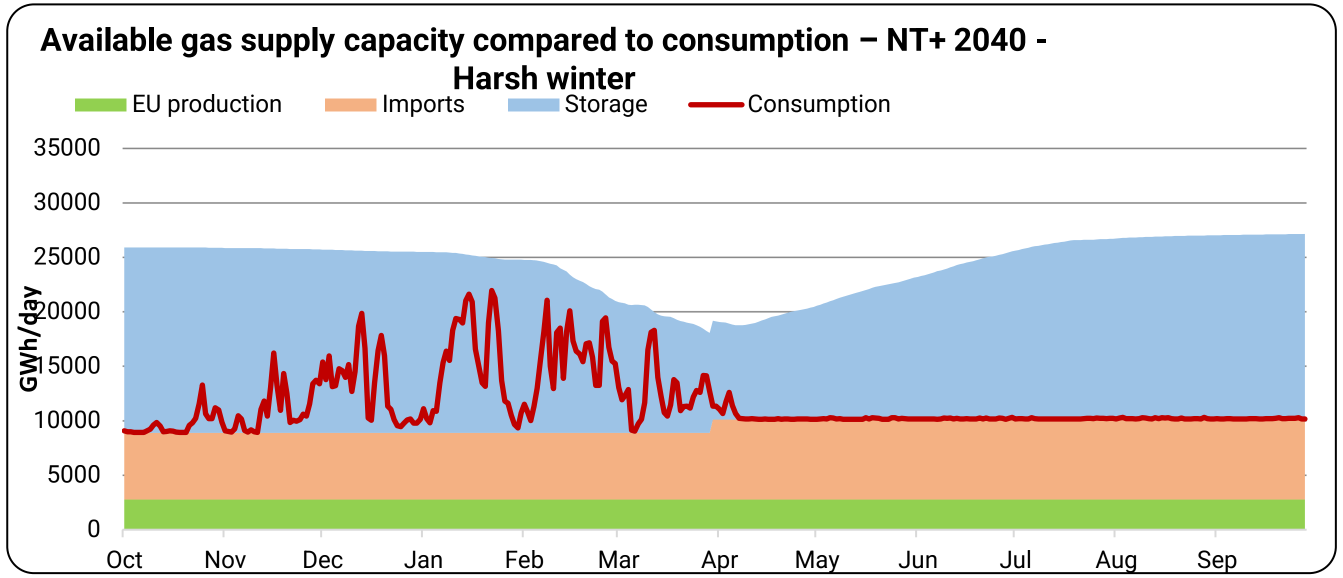


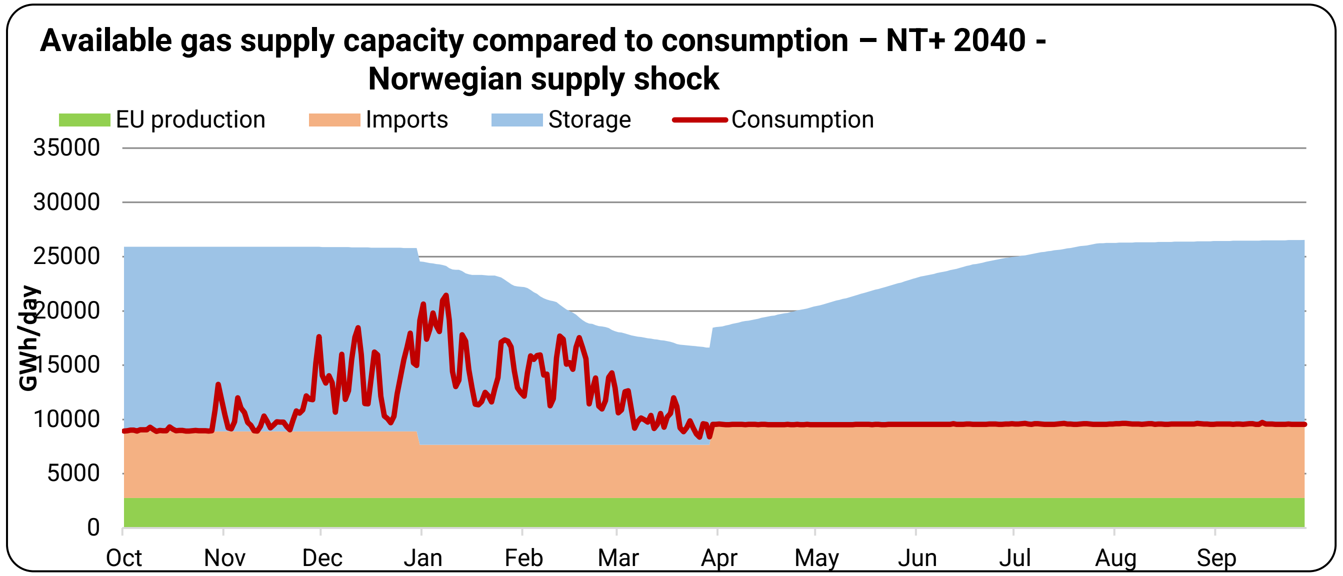


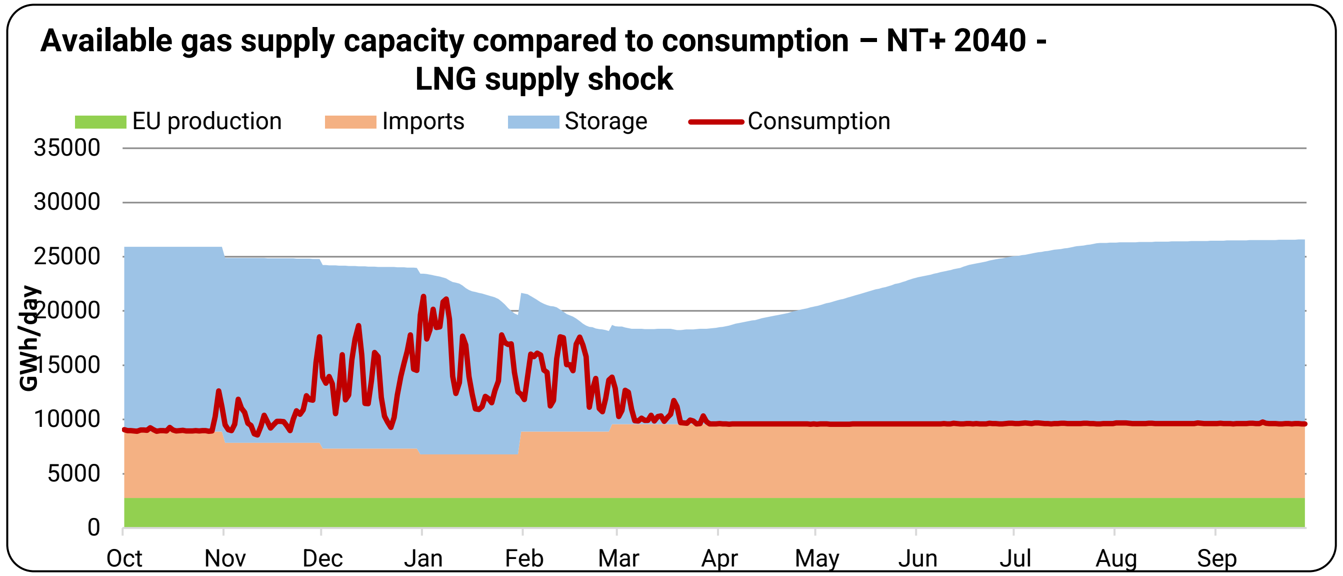
Sources: Artelys modelling based on NT+ scenarios (2030 & 2040).

Available gas supply capacity compared to consumption – NT+ 2040



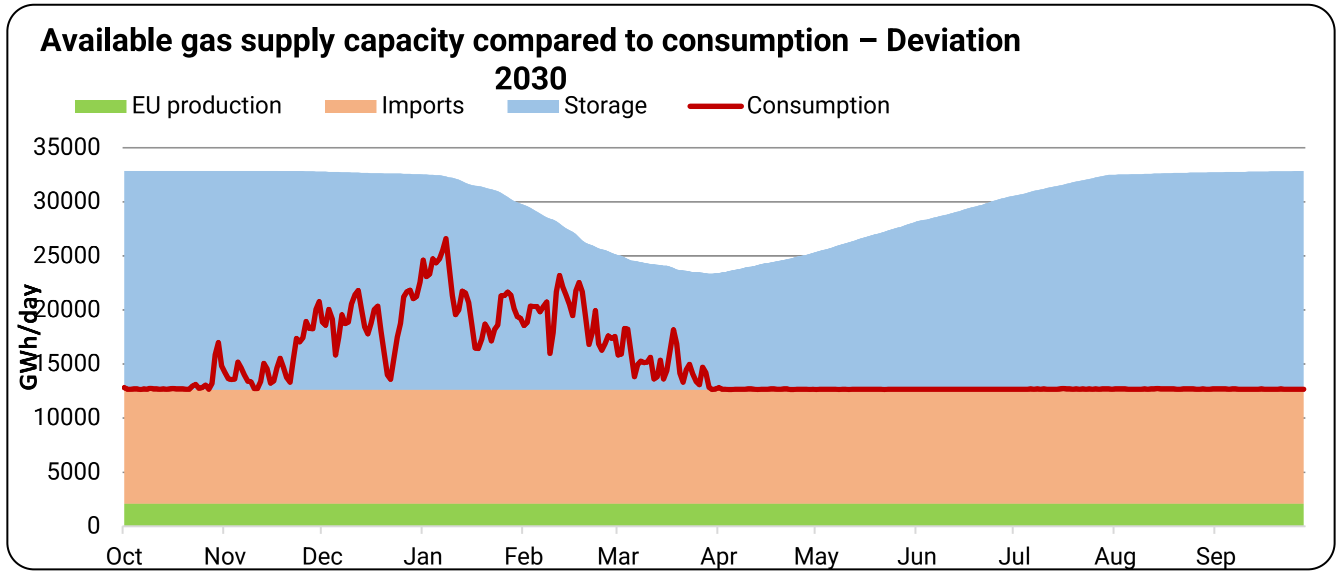


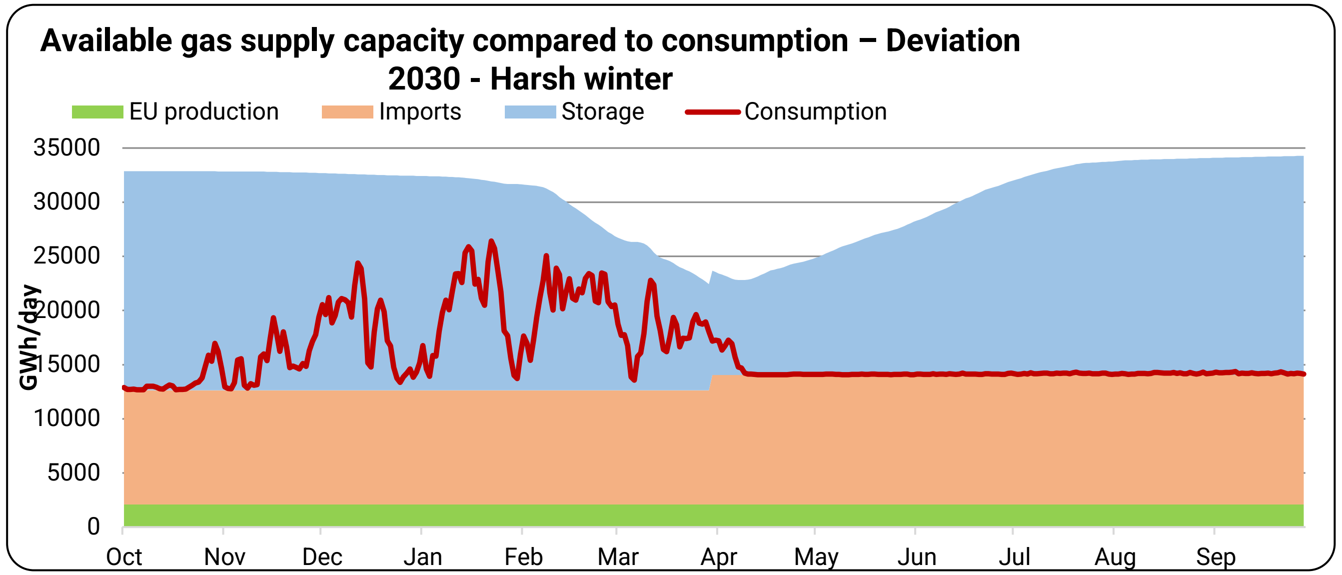


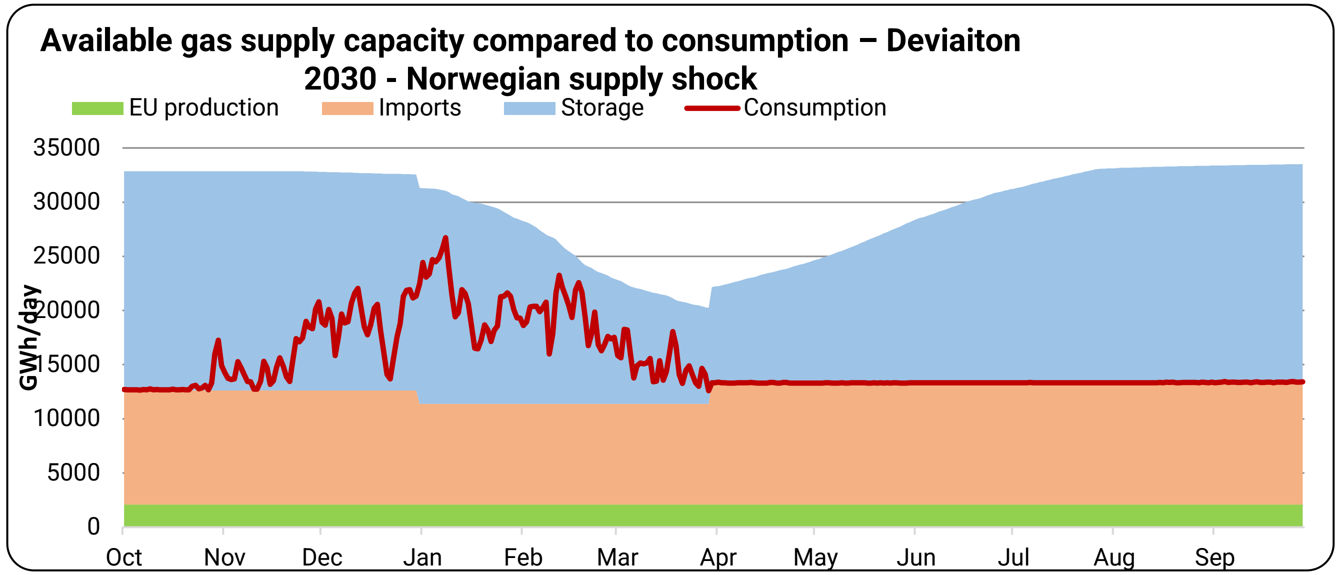


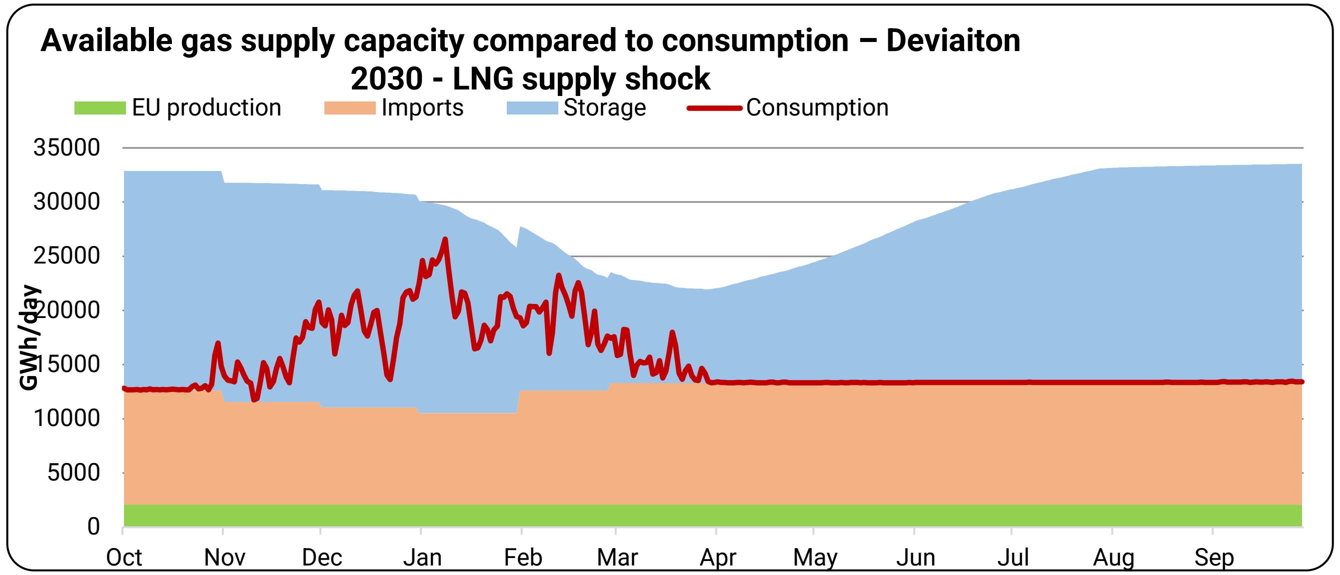
Sources: Artelys modelling based on NT+ scenarios (2030 & 2040).

Available gas supply capacity compared to consumption – Deviation 2030



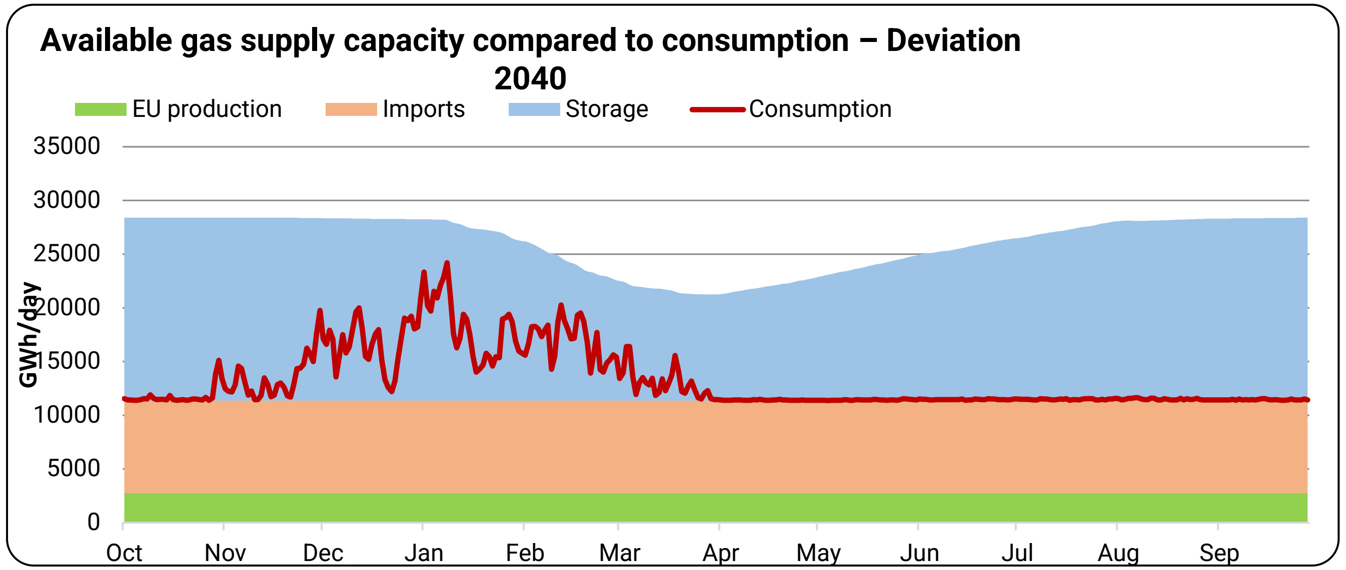


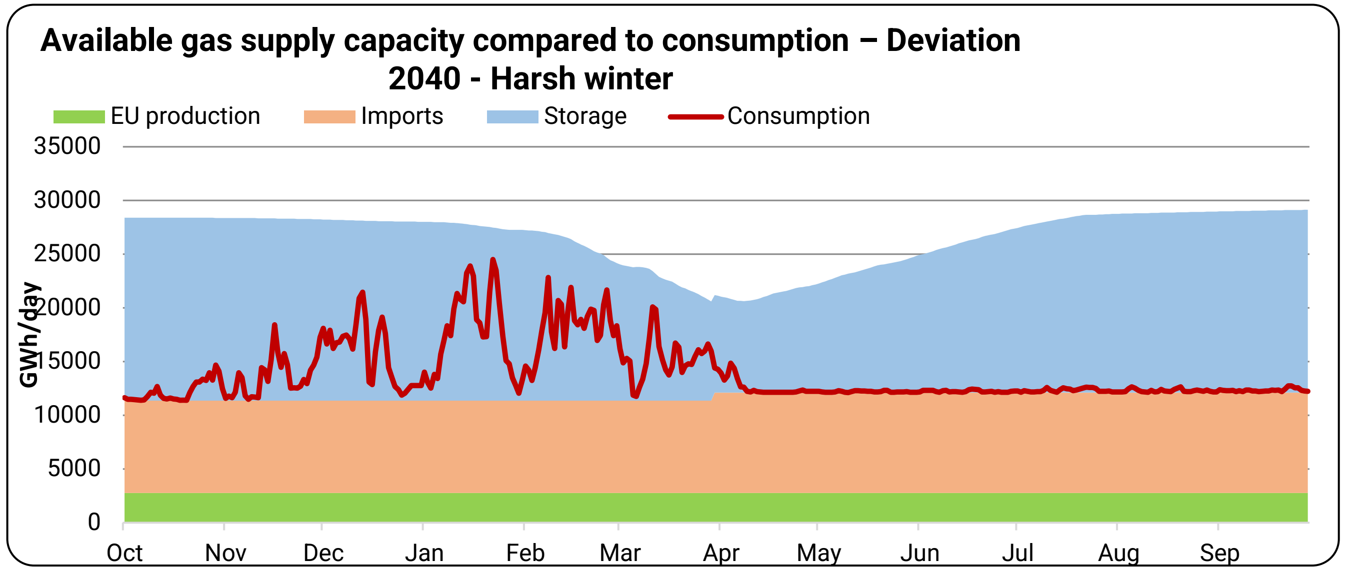


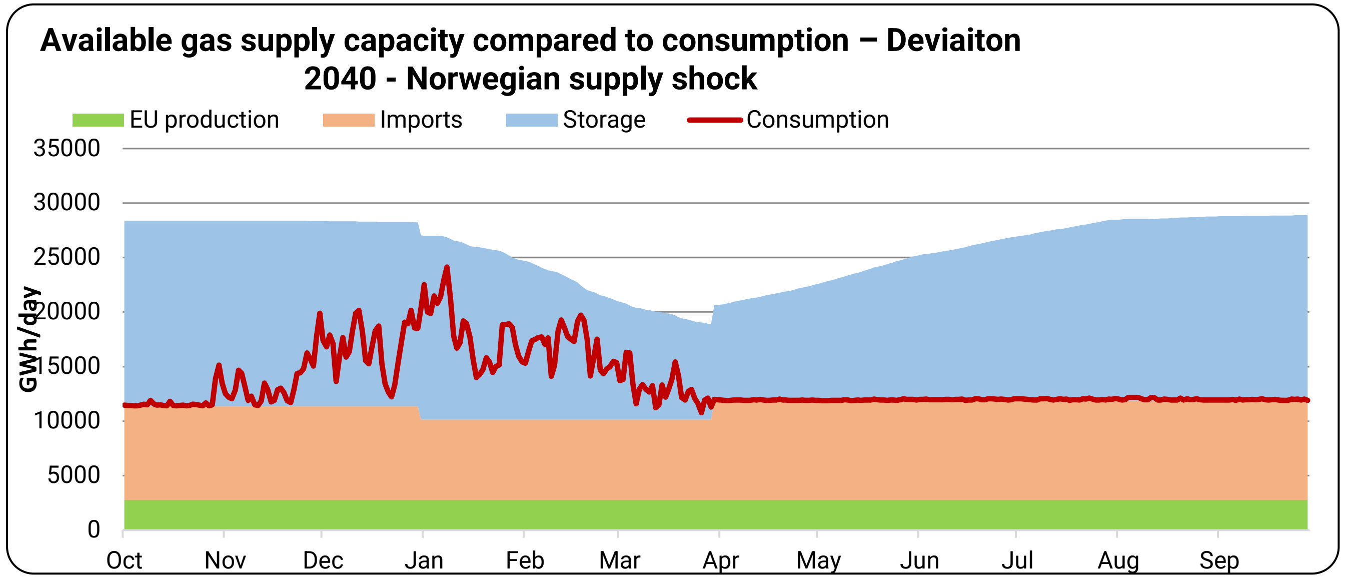


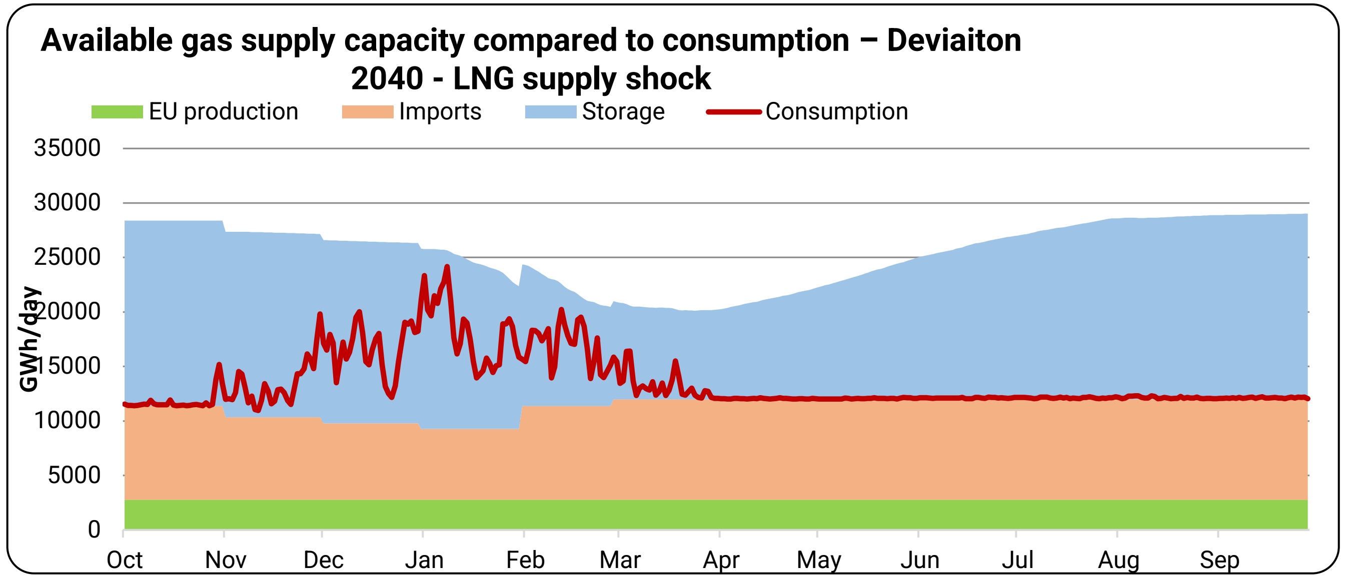
Sources: Artelys modelling based on NT+ scenarios (2030 & 2040).

Available gas supply capacity compared to consumption – Deviation 2040









Sources: Artelys modelling based on NT+ scenarios (2030 & 2040).

Annex B – Regulatory Analysis
Filling Measures – Description and Country Case Studies

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Measure type 1: **Storage filling premium**

	Description
Core principle	Storage users receive an ex-ante administratively set premium for achieving storage filling targets/trajectories[1] for a share of or the entire storage capacity; the premium might consider current market conditions (summer/winter spread); could also be implemented via a reduced transport tariff
Entity specifying technical parameter of storage to be held available (volume, rates, locations)	Government and/or energy regulatory agency; generally, in consultation with the market operator and/or the TSO(s)
Entity deciding about the usage of stored gas	▪ The commercial storage users (as the gas owner) decides about gas usage subject to the incentive provided by the premium for achieving storage filling targets / trajectories ▪ Administrative call-offs (also below the trajectory) might be permissible (against a pre-specified price)
Holder(s) of storage capacities to improve SoS?	Commercial storage users (either all or just those holding capacities subject to the premium)
Owner/buyer of gas stored?	Commercial storage users (who buy and sell gas under “normal” market prices and conditions)
Recovery of (i) storage capacity cost and (ii) cost for stored gas (and its storing)	▪ Commercial storage users obtain storage premium improving their business case for holding and filling storage capacities ▪ The premium payments are recovered via a levy (on end-users or retailers) that determines who pays for the measure (alternatively: via the state budget)[3]
Is there **commercial usage** of storage capacity or gas volumes permitted / foreseen	Yes Commercial storage users meet filling targets / trajectories to receive the premium but are otherwise free to use capacities & gas volumes; they can also choose to forego the premium

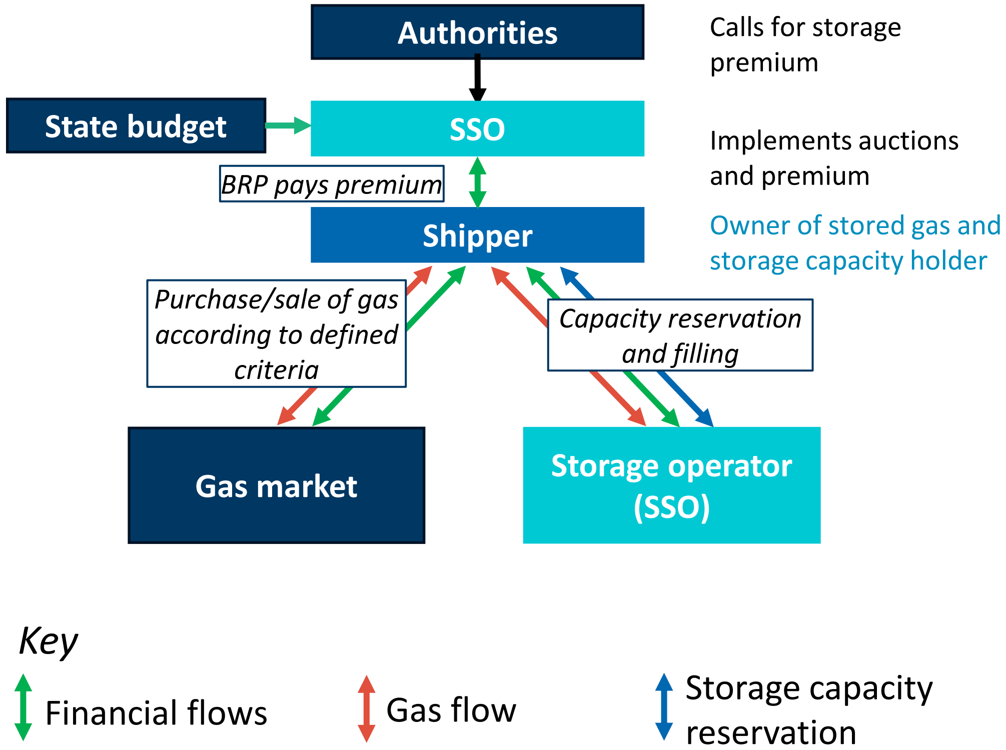
	Assessment
1. Necessity	The assessment of necessity of non-market interventions does not depend on the chosen measure
2. Effectiveness	▪ Effective only if / to the extent that the incentive from the premium is sufficient for storage users to actually fill their capacities as intended
3. Proportionality: Extent of non-market-based operation/actions	▪ Selection of storage users: potentially market-based if the premium applies uniform to all storage capacities ▪ Normal operations: fully market-based filling & withdrawals ▪ Crisis operations: optionally administrative call-offs (if implemented)
3. Proportionality: limitation of non-market-based remuneration	▪ Storage user remuneration: partly market-based (premium is not market-based and runs the risk of over-compensation) ▪ SSO-remuneration: depending on national regulatory approach (if regulated (e.g. FR) no impacted from storage filling premia; if market-based (e.g. DE) premia increase attractiveness of storage capacities, reducing – but not eliminating (not all capacities are covered) – revenue risks for SSOs.)
4. Limitation of distortions	▪ Storage market: – Distortions from uncertainty (If? When? How much?) – Depending on application for historic vs. new injections ▪ Gas wholesale market: Detailed and inflexible filling obligations may incentivise taking of opposite positions. ▪ Gas retail market: If financed via levy, the levy impacts retail gas prices and may impact gas usage (elasticity of demand)
Considerations on operational efficiency	▪ Efficiency depends on the definition of premium amount and (if not uniformly applied to all capacities) the mechanism to allocation the premium scheme to storage capacities

Notes: [1] The trajectories may stretch beyond the initial filling deep into the winter. [2] The spread(s) to be considered and the interaction between CfD tender and storage capacity allocation need to be defined as part of the detailed design; [3] These levies might be reduced based on some cross-member-state cost allocation payments. Source: Compass Lexecon analysis

Measure type 1: **Storage filling premium** – case study: **Italy** (2025)

Authorities set a financial incentive linked to storage filling targets in order to offset a negative summer-winter gas price spread.

Mechanism Illustration



Outline of the Measure

- **Context:**
  - Implemented in April 2025 by the regulatory authority ARERA[1] after Italy's storage filling level reached only 42% at the end of March 2025 in combination with negative summer-winter spread
  - Announced in April 2025 as a **temporary measure until filling level reached 90%**
  - By **mid-April** 2025, 90% of Italy's gas storage capacity for the 2025-2026 year was **fully allocated[2]**, so the premium was not applied in later auctions
- **Storage filling mechanism:**
  - Shippers holding gas in storage on 31 October 2025 are paid any negative difference between the summer and winter spread including financial costs, i.e. a proxy of the interest rate
  - BRP publishes the designated premium before each storage capacity auction
- **Cost recovery mechanism**: BRP pays the premium to storage users and is compensated by state budget
- **Volume:** About 90 TWh[3], defined as the gap to the EU's 90% filling target
- **Eligibility:** Linked to storage capacity auctions for the Thermal Year 2025/26; not available for storage capacity booked before the issuance of the relevant ARERA deliberation[1] on 1 April 2025, to prevent retroactive application

Abbreviations: BRP … Balancing Responsible Party
Sources: Compass Lexecon Analyse basierend auf Reuters [1] Arera 150/2025/R/GAS, [2] Reuters, [3] Snam 2025, Stogit 2025.

Measure type 2: **Contract for Differences (CfD)**

	Description
Core principle	Commercial storage users receive the difference between a strike price and a summer-winter spread for stored gas volumes, if they commit to filling targets/trajectories[1]; the CfD is tendered to determine the strike price[2]
Entity specifying technical parameter of storage to be held available (volume, rates, locations)	Government and/or energy regulatory agency; generally, in consultation with the market operator and/or the TSO(s)
Entity deciding about the usage of stored gas	▪ The commercial storage users (as the gas owner) decides about gas usage but may be subject to stiff penalties, if the filling trajectory/targets are not fulfilled ▪ Administrative call-offs (also below the trajectory) might be permissible (against a pre-specified price)
Holder(s) of storage capacities to improve SoS?	Commercial storage users participating in the tender
Owner/buyer of gas stored?	Commercial storage users (who buy and sell gas under "normal" market prices and conditions)
Recovery of (i) storage capacity cost and (ii) cost for stored gas (and its storing)	▪ Commercial storage users receive the difference between the strike price and the agreed summer-winter spread for stored gas volumes, improving their business case for holding and filling storage capacities ▪ CfD payments are recovered via a levy (on end-users or retailers) that determines who pays for the measure (alternatively: via state budgets)[3]
Is there **commercial usage** of storage capacity or gas volumes permitted / foreseen	Yes Storage users must meet filling requirements but are otherwise free to use their capacities and gas volumes

	Assessment
1. Necessity	The assessment of necessity of non-market interventions does not depend on the chosen measure
2. Effectiveness	Effective only if / to the extent that market participants ▪ bid for and enter into the CfD and then ▪ follow the filling targets / trajectory (the more flexible these are, the harder / later non-fulfilment can be detected)
3. Proportionality: Extent of non-market-based operation/actions	▪ Selection of storage users: Market-based self-selection ▪ Normal operations: market-based filling & withdrawals within the limits of the filling targets / trajectory ▪ Crisis operations: optionally administrative call-offs (if implemented)
3. Proportionality: limitation of non-market-based remuneration	▪ Storage user remuneration: fully market-based (as the CfD strike is determined in a tender); CfD may (depending on implementation) reduce risk of overcompensation ▪ SSO-remuneration: depending on national regulatory approach (if regulated (e.g. FR) no impacted from CfDs; if market-based (e.g. DE) CfDs increase attractiveness of storage capacities, reducing – but not eliminating (not all capacities are covered) – revenue risks for SSOs.)
4. Limitation of distortions	▪ Storage market: – Distortions from uncertainty (If? When? How much?) – Depending on alignment: CfD & capacity allocation – Depending on application for historic vs. new injections ▪ Gas wholesale market: Detailed and inflexible filling obligations may incentivise taking of opposite positions. ▪ Gas retail market: If financed via levy, the levy impacts retail gas prices and may impact gas usage (elasticity of demand)
Considerations on operational efficiency	▪ Competitive pressure from in auction may encourage efficient storage filling and limit cost for CfD payments – but this depends on the number of auction participants (e.g site specific CfDs may increase individual bidder's market power)

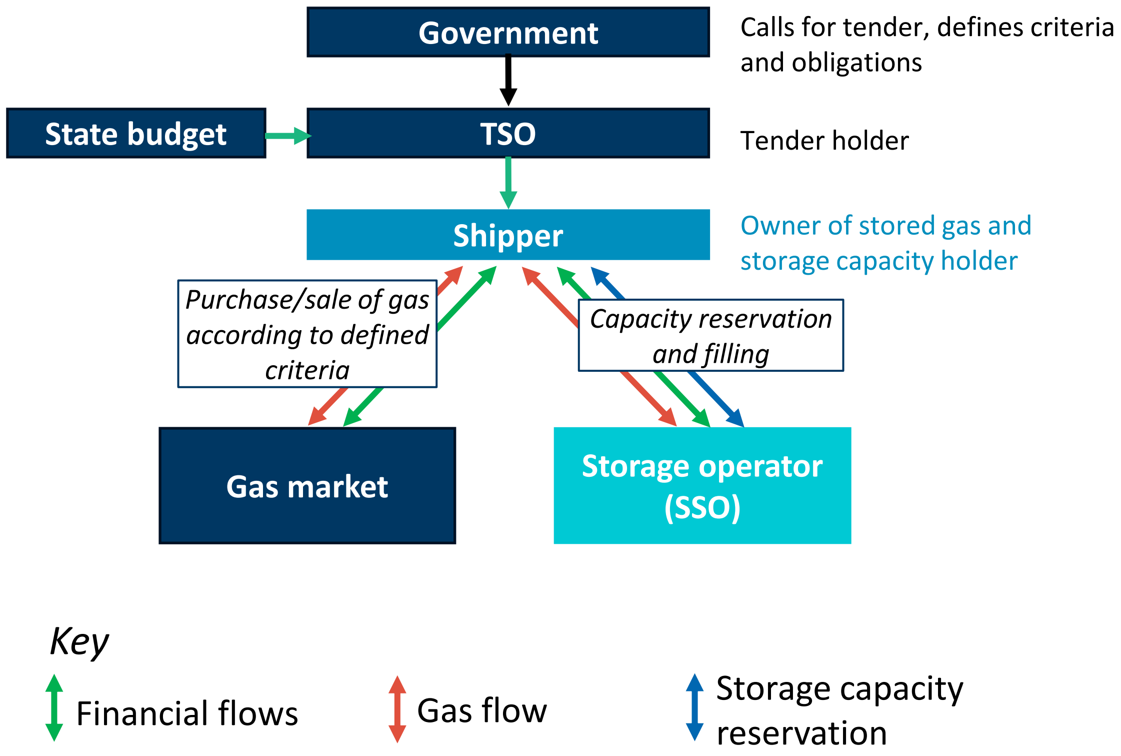
Notes: [1] The trajectories may stretch beyond the initial filling deep into the winter. [2] The spread(s) to be considered and the interaction between CfD tender and storage capacity allocation need to be defined as part of the detailed design; [3] These levies might be reduced based on some cross-member-state cost allocation payments.

Source: Compass Lexecon analysis

Measure type 2: **Contract for Differences (CfD)** – case study: **Czech Republic** (2022)

Storage users commit to a predefined withdrawal trajectory in exchange for compensation through a CfD reflecting the summer-winter spread.

Mechanism Illustration



Outline of the Measure

- **Legal context:**
  - During a state of crisis, the Ministry of Industry and Trade can impose obligations on market players (in accordance with the Crisis Act; Act No. 240/2000 Coll., as amended; Section 12a(1)(b))
  - The CfD was introduced in April 2022, when around 97% of storage capacity had already been booked
- **Mechanism:**
  - TSO (NET4GAS) organised tenders for CfDs with contractual obligations on the withdrawal of stored gas; timing set by the Ministry of Industry and Trade
  - Tender winners signed trilateral contracts between TSO, SSO and shippers
  - CfD pricing reflected summer winter spread:
    - Strike price: auction clearing price
    - Reference price: gas price during the spring/summer period
  - Trader keeps ownership of the gas, but must abide to withdrawal trajectory:
    - Until 31 October 2022: must not withdraw any gas volumes that are subject to the CfD
    - 1 – 30 November 2022: at least 80% of contracted gas volumes in storage
    - 1 – 31 December 2022: at least 60%
    - 1 – 31 January 2023: at least 34%
- **Volume:** 4.6 TWh (12% of overall Czech storage capacity)
- **Eligibility:** Storage users who already held storage capacity with RWE or MND
- **Cost recovery:** TSO was compensated via state budget
- **Control mechanism:**
  - SSOs provide TSO with information necessary to verify compliance
  - Contractual penalty corresponding to missing gas quantities and CfD price in case of non-compliance

Sources: Compass Lexecon Analysis based on MPO 2022, NET4GAS, NET4GAS – Framework Agreement, ACER & VIS (2023)

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Measure type 3: **Auctioned filling obligations**

	Description
Core principle	Obligations to meet storage targets / trajectories[1] including the relevant storage capacities are auctioned-off is against a reduced storage tariff and/or a fee paid to the storage user
Entity specifying technical parameter of storage to be held available (volume, rates, locations)	▪ Government and/or energy regulatory agency; generally, in consultation with the market operator and/or the TSO(s) ▪ Tenders are generally implemented by SSOs
Entity deciding about the usage of stored gas	▪ The commercial storage users (as the gas owner) decides about gas usage but may be subject to stiff penalties, if the filling trajectory/targets are not fulfilled ▪ Administrative call-offs (also below the trajectory) might be permissible (against a pre-specified price)
Holder(s) of storage capacities to improve SoS?	Commercial storage users participating in the tender
Owner/buyer of gas stored?	Commercial storage users (who buy and sell gas under "normal" market prices and conditions)
Recovery of (i) storage capacity cost and (ii) cost for stored gas (and its storing)	▪ Commercial storage users receive a payment for stored gas volumes, improving their business case for holding and filling storage capacities ▪ SSOs are compensated for discounted storage tariffs ▪ Total cost of the measure are recovered via a levy (on end-users or retailers) that determines who pays for the measure (alternatively: via state budgets)[3]
Is there **commercial usage** of storage capacity or gas volumes permitted / foreseen	Yes Storage users must meet filling requirements but are otherwise free to use their capacities and gas volumes

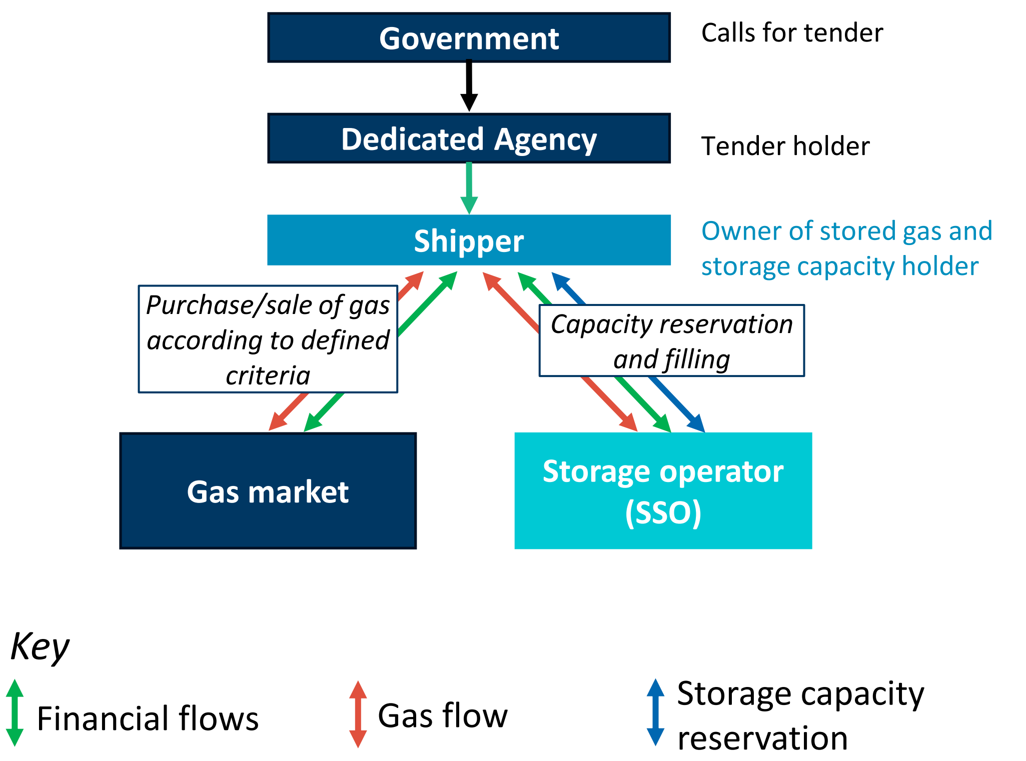
	Assessment
1. Necessity	Effective only if / to the extent that market participants ▪ bid for and enter into the filling obligations ▪ follow the filling targets / trajectory (the more flexible these are, the harder / later non-fulfilment can be detected)
2. Effectiveness	▪ Selection of storage users: Market-based self-selection ▪ Normal operations: market-based filling & withdrawals within the limits of the filling targets / trajectory ▪ Crisis operations: optionally administrative call-offs (if implemented)
3. Proportionality: Extent of non-market-based operation/actions	▪ Storage user remuneration: fully market-based (as the tariff reduction or fee paid is determined in a tender) but runs the risk of over-compensation ▪ SSO-remuneration: depending on national regulatory approach (if regulated (e.g. FR) no impacted from obligations; if market-based (e.g. DE) filling obligations increase attractiveness of storage capacities, reducing – but not eliminating (not all capacities are covered) – revenue risks for SSOs.)
3. Proportionality: limitation of non-market-based remuneration	▪ Storage market: – Distortions from uncertainty (If? When? How much?) – Depending on alignment: obligation & capacity allocation – Depending on application for historic vs. new injections ▪ Gas wholesale market: Detailed and inflexible filling obligations may incentivise taking of opposite positions. ▪ Gas retail market: If financed via levy, the levy impacts retail gas prices and may impact gas usage (elasticity of demand)
4. Limitation of distortions	▪ Competitive pressure from in auction may encourage efficient storage filling and limit cost for payments – but this depends on the number of auction participants (e.g. site specificity may increase individual bidder's market power)
Considerations on operational efficiency	Effective only if / to the extent that market participants ▪ bid for and enter into the filling obligations ▪ follow the filling targets / trajectory (the more flexible these are, the harder / later non-fulfilment can be detected)

Notes: [1] The trajectories may stretch beyond the initial filling deep into the winter. [2] The spread(s) to be considered and the interaction between CfD tender and storage capacity allocation need to be defined as part of the detailed design; [3] These levies might be reduced based on some cross-member-state cost allocation payments.Source: Compass Lexecon analysis

Measure type 3: **Auctioned filling obligations** – case study: **Denmark** (2025)

A share of the storage capacity is distributed via centrally organised tenders and linked to storage filling requirements for successful bidders.

Mechanism Illustration



Outline of the Measure

- **Context:**
  - Per 1 July 2025 Denmark **did not reach EU filling trajectory** (end-June filling levels at 33% vs. 60% target)
  - The Danish Energy Agency (DEA), on behalf of the government, launched a procurement process to increase storage filling ahead of winter 2025-26; Gas Storage Denmark is not involved in the procurement itself
- **Storage filling mechanism:**
  - In July 2025 a tender for "**Gas Storage Obligations**" was announced as a **temporary measure** limited to the current injection season
  - Tendered is a **payment for meeting the storage obligations** which is made per MWh stored on 15 November, penalties apply in case the obligation is not fulfilled
  - Winning bidders ensure that the agreed gas volume is stored in Stenlille or Lille Torup facilities **on 15 November** 2025
  - **No interim filling requirements**, participants are allowed to inject and withdraw gas for commercial purposes during the entire storage period (also before 15 November)
  - **No link to storage capacity auctions,** bidders without capacity can buy at a fixed price, first-come first-serve, after the tender
- **Volume:**
  - Estimated at 7.1 TWh[1] (below working gas volume still available for sale[2])
  - Defined by the need to meet EU's 90% filling target
  - Two rounds of tenders so far: 29 August – 9 September and 22 September 2025
- **Storage capacity product:**
  - Offered by Gas Storage Denmark (GSD) on **standard terms and conditions** as a yearly product.
  - GSD reserves Working Gas Volume covering 100% of the tender volume

Sources: Compass Lexecon Analysis based on Danish Energy Agency, [1] Evergabe, EU Supply, [2]Energinet.

Measure type 4: **Retailers' stockholding obligations**

	Description
Core principle	An obligation is placed on retail suppliers to hold and fill storage capacity[1] they need to meet a specified share of their (all or selected) consumers' demand (the retailers *may* be allowed to sub-contract this obligation)
Entity specifying technical parameter of storage to be held available (volume, rates, locations)	Government and/or energy regulatory agency; generally, in consultation with the market operator and/or the TSO(s)
Entity deciding about the usage of stored gas	The retail supplier (as the gas owner) decides about gas usage but may be subject to stiff penalties if the filling trajectory/targets are not fulfilled
Holder(s) of storage capacities to improve SoS?	Retail suppliers based on a rule determining their capacity holding requirement based on their end-user portfolio composition
Owner/buyer of gas stored?	Retail suppliers (who buy and sell gas under "normal" market prices and conditions)
Recovery of **(i) storage capacity cost and** **(ii) cost for stored gas** (and its storing)	No dedicated recovery but inclusion in retailers' end-user tariffs competing against other retailers
Is there **commercial usage** of storage capacity or gas volumes permitted / foreseen	Yes Storage users must meet filling requirements but are otherwise free to use their capacities and gas volumes

	Assessment
1. Necessity	The assessment of necessity of non-market interventions does not depend on the chosen measure
2. Effectiveness	▪ Effective only to the extent that retailers follow the filling targets / trajectory (the more flexible these are, the harder / later non-fulfilment can be detected)
3. Proportionality: Extent of non-market-based operation/actions	▪ Selection of storage users: Non-market-based as extend of the obligation is determined administratively (portfolio rule) ▪ Normal operations: market-based filling & withdrawals within the limits of the filling targets / trajectory ▪ Crisis operations: optionally administrative call-offs (if implemented)
3. Proportionality: limitation of non-market-based remuneration	▪ Storage user remuneration: market based via its inclusion in retail tariffs subject to competition ▪ SSO-remuneration: depending on national regulatory approach (if regulated (e.g. FR) no impacted from retailers' obligations; if market-based (e.g. DE) retailers' obligations increase demand for storage capacities, reducing – but not eliminating (not all capacities are covered) – revenue risks for SSOs.)
4. Limitation of distortions	▪ Storage market: Reduction of commercially available storage capacity potentially increasing their price ▪ Gas wholesale market: Detailed and inflexible filling obligations may incentivise taking of opposite positions. ▪ Gas retail market: – Cost-pass through to end consumers may impact gas usage (elasticity of demand) – High fixed operating cost may burden small suppliers – Cost-pass through might be hampered by supplier switching deadline shorter than storage filling cycle
Considerations on operational efficiency	▪ Complex monitoring of obligations across all retailers ▪ Retail competition should incentivise efficient filling

Notes: [1] Retailer obligations could also permit reliance on physical access to gas other than storage
Source: Compass Lexecon analysis

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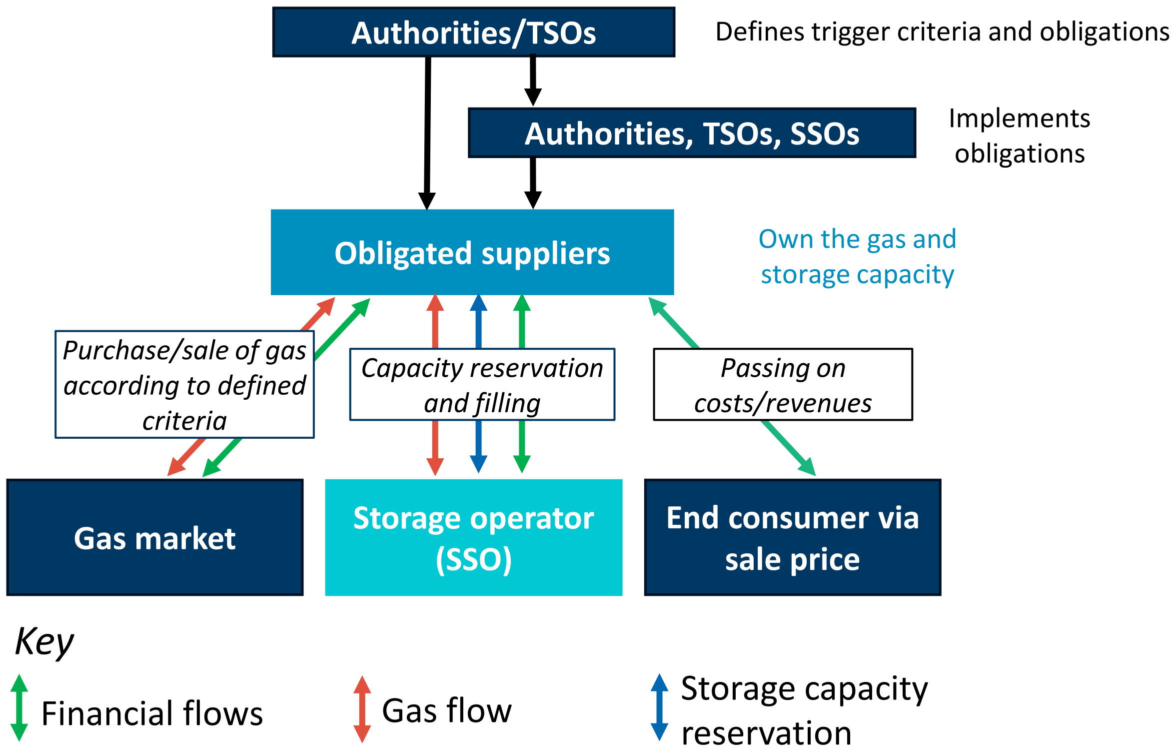
Measure type 4: **Retailers' stockholding obligations** – case study: **Austria** (2022)

The authorities define a stock obligation for suppliers, at their own expense and passed on to consumers, in addition to their commercial stock. The withdrawal criteria are linked to a minimum stock level set for each month.

Mechanism Illustration



Outline of the Measure

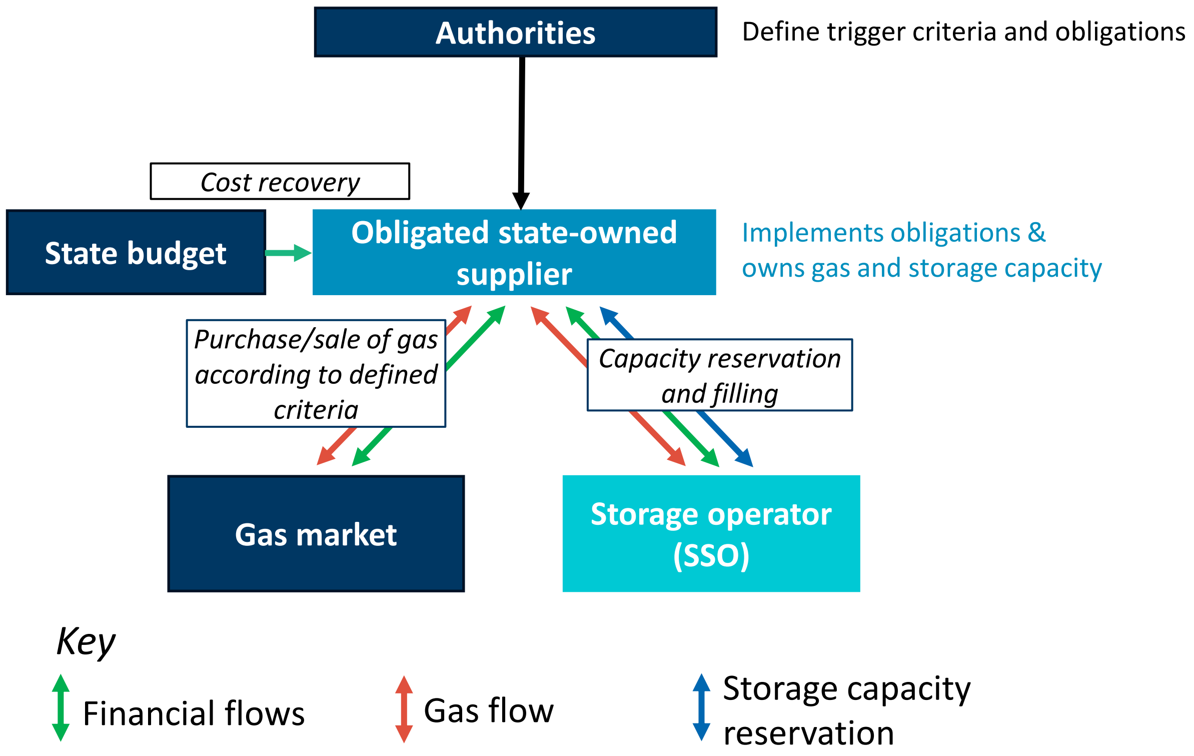
- **Legal context:** According to §121 GWG 2011, suppliers supplying protected customers are required to guarantee gas supply standards in accordance with EU regulations. The measure was initially introduced in 2011, but physical stockholding obligations were only added in 2022.
- **Volume:**
  - 4.7 TWh in 2024
  - Defined by the gas supply standards for protected customers in accordance with EU regulations
  - **Definition of protected customer:** Households, social services, district heating facilities (which are unable to switch to a fuel other than gas)
  - Calculation for each month (October to March) by AGGM based on historical data and verification by the regulatory authority (E-Control); number of suppliers' protected customer for the entire winter is based on the count as of 1 August
- **Withdrawal criteria:** stored gas may be withdrawn according to suppliers' needs, as long as the minimum storage level is maintained
- **Cost recovery:** suppliers recover their costs via the tariffs applied to end customers
- **Control mechanism**:
  - submission of storage usage contracts and proof of storage filling to the regulatory authority (may also be provided by the previous supplier)
  - Non-compliance with the obligation is punishable with an **administrative fine of up to €75,000** per retailer
- **Expansion of the supply standard to gas-fired power plants:** Supply standard for operators of gas-fired power plants (> 50 MW) was introduced in 2024. Operators must maintain sufficient gas reserves in storage to ensure supply for up to 45 days and submit storage usage contracts as well as proof of storage filling to the regulatory authority.

Sources: Compass Lexecon Analysis based on E-Control, GWG 2011, Gasversorgungsstandard-Verordnung, ElWOG 2010.

Measure type 4: **Retailers' stockholding obligations** – case study: **Slovakia** (2025)

The authorities set a stock obligation for the state-owned energy supplier; costs are recovered from state budget. The gas can only be withdrawn for domestic end consumers.

Mechanism Illustration



Outline of the Measure

- **Legal context:**
  - Imposed in **May 2025** as measure in "general economic interest" pursuant to Section 24(2) of Act No. 251/2012 Coll. on Energy and on Amendments and Supplements to Certain Acts
  - "general economic interest" is a special regulatory instrument through which, in exceptional cases, obligations may be imposed on pre-determined participants in the electricity and gas market
- **Mechanism**:
  - obligation on state-owned supplier Slovak plynárenský priemysel (SPP), SPP is also the supplier of last resort for the Slovac gas market
  - Gas must be stored in underground storage facilities on the territory of the Slovak Republic either directly by SPP or through SPP contracts with other market participants
- **Volume (for 2025/26 heating season):**
  - 5.724 TWh by 1 July 2025
  - 14.601 TWh by 1 September 2025
  - 17.754 TWh by 1 November 2025 (35% of the average consumption of end consumers over the last 5 years; around 50% of overall Slovak storage capacity)
- **Withdrawal criteria:** gradual withdrawal of gas stocks over the winter period, solely for the purpose of supplying **end consumers in the Slovak Republic**
- **Cost recovery:**
  - SPP is reimbursed by **state budget**

Sources: Compass Lexecon Analysis based on information provided by Nafta and Government of the Slovak Republic

Measure type 5: **Importers' stockholding obligations**

	Description
Core principle	An obligation is placed on importers to secure storage capacity and meet storage targets / trajectories based on e.g. a share of their imported gas
Entity specifying technical parameter of storage to be held available (volume, rates, locations)	Government and/or energy regulatory agency; generally, in consultation with the market operator and/or the TSO(s)
Entity deciding about the usage of stored gas	The importer (as the gas owner) decides about gas usage but may be subject to stiff penalties if the filling trajectory/targets are not fulfilled
Holder(s) of storage capacities to improve SoS?	Importers based on a rule determining their capacity holding requirement based on e.g. their import volumes
Owner/buyer of gas stored?	Gas importers (who buy and sell gas under "normal" market prices and conditions – or use their own gas)
Recovery of (i) storage capacity cost and (ii) cost for stored gas (and its storing)	No dedicated recovery but inclusion in importers' sales prices
Is there **commercial usage** of storage capacity or gas volumes permitted / foreseen	Yes Importers must meet filling requirements but are otherwise free to use their capacities and gas volumes

	Assessment
1. Necessity	The assessment of necessity of non-market interventions does not depend on the chosen measure
2. Effectiveness	▪ Effective only to the extent that importers follow the filling targets / trajectory (the more flexible these are, the harder / later non-fulfilment can be detected)
3. Proportionality: Extent of non-market-based operation/actions	▪ Selection of storage users: Non-market-based by applying a rule considering end-user portfolios ▪ Normal operations: market-based filling & withdrawals within the limits of the filling targets / trajectory ▪ Crisis operations: optionally administrative call-offs (if implemented)
3. Proportionality: limitation of non-market-based remuneration	▪ Storage user remuneration: market based via its inclusion in sales prices subject to competition ▪ SSO-remuneration: depending on national regulatory approach (if regulated (e.g. FR) no impacted from importers' obligations; if market-based (e.g. DE) importers' obligations increase demand for storage capacities, reducing – but not eliminating (not all capacities are covered) – revenue risks for SSOs.)
4. Limitation of distortions	▪ Storage market: Reduction of commercially available storage capacity potentially increasing their price ▪ Gas wholesale market: – Measure could deter importers from market participation – Detailed and inflexible filling obligations may incentivise taking of opposite positions. ▪ Gas retail market: Cost-pass through to end consumers may impact gas usage (elasticity of demand)
Considerations on operational efficiency	▪ Complex monitoring of obligations across all importers ▪ Wholesale competition should incentivise efficient filling

Source: Compass Lexecon analysis

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Measure type 6: **Strategic storage**

	Description
Core principle	Storage capacity is contracted and filled by a dedicated entity based on an administrative order and then held outside the market
Entity specifying technical parameter of storage to be held available (volume, rates, locations)	Government and/or energy regulatory agency; generally, in consultation with the market operator and/or the TSO(s)
Entity deciding about the usage of stored gas	Government and/or the energy regulatory agency; potentially, in consultation with the market operator and/or the TSO(s)
Holder(s) of storage capacities to improve SoS?	Special entity, market operator, TSO(s) or SSOs
Owner/buyer of gas stored?	Special entity, market operator, TSO(s) or SSOs (who buy and sell potentially subject to administrative restrictions and/or incentives for cost / risk reduction)
Recovery of (i) storage capacity cost and (ii) cost for stored gas (and its storing)	Generally, via a levy (on end-users or retailers) that determines who pays for the measure (alternatively: via state budgets)[1]
Is there **commercial usage** of storage capacity or gas volumes permitted / foreseen	No (storage capacities & gas volumes stored are held outside the market)

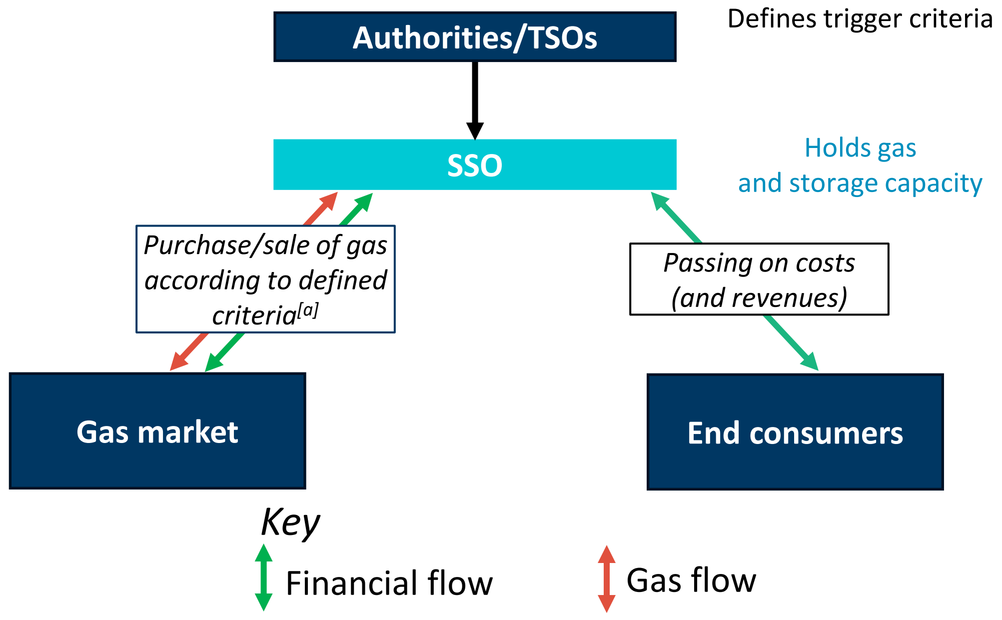
	Assessment
1. Necessity	The assessment of necessity of non-market interventions does not depend on the chosen measure
2. Effectiveness	▪ Effective to ensure gas is stored for SoS crisis as injection is mandated and executed well in advance.
3. Proportionality: Extent of non-market-based operation/actions	▪ Selection of storage users: Non-market-based as the operating entity is usually selected administratively ▪ Normal operations: partly market based as the filling of the storage follows regulatory incentives ▪ Crisis operations: Non-market-based as withdrawals are always administratively mandated
3. Proportionality: limitation of non-market-based remuneration	▪ Storage user remuneration: non-market based as dedicated entity must fall under some sort of economic regulation ▪ SSO-remuneration: generally[2] non-market-based as the SSO receives a regulated remuneration for the capacities used for strategic storage
4. Limitation of distortions	▪ Storage market: Reduction of commercially available storage capacity potentially increasing their price ▪ Gas wholesale market: – Initially filling may push up (summer) gas prices – The availability of strategic storage may impact how market participants price-in extreme events – Otherwise, limited as gas is held outside the market ▪ Gas retail market: If financed via levy, the levy impacts retail gas prices and may impact gas usage (elasticity of demand)
Considerations on operational efficiency	▪ Administrative efficiency incentives may be necessary ▪ The dedicated entity may lack experience and expertise

Notes: [1] These levies might be reduced based on some cross-member-state cost allocation payments. [2] at least in countries with a limited number of SSOs
Source: Compass Lexecon analysis

Measure type 6: **Strategic storage** – case study: **Italy** (2000)

Last resort mechanism comprising a stock held by the operator that can only be drawn on in the event of an emergency relating to security of supply.

Mechanism Illustration



Outline of the Measure

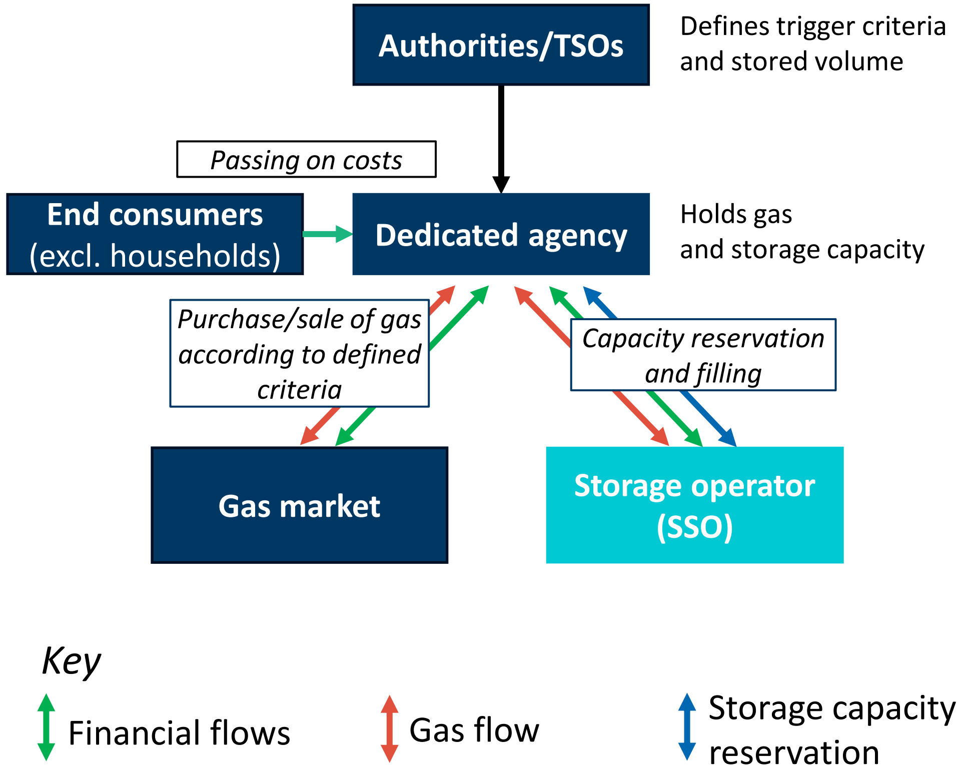
- **Legal context:** measure introduced in 2000 by Decree-Law No 164, amended in 2011
- **Filling mechanism**
  - Majority of gas currently in storage in 2000 was acquired and has been held by storage operators since then; capacity required to maintain strategic stocks is off-market
  - Eventually withdrawn gas would be refilled by the SSOs
- **Withdrawal criteria:**
  - Gas in strategic storage can only be mobilised in an emergency, upon decision of the Ministry of Energy Security, if gas import capacity is used to the maximum and all commercial storage volumes have already been exhausted
  - Italy's strategic gas reserves have not been used during the 2022/23 energy crisis
- **Volume:**
  - 50.9 TWh in winter 2025/26 (25% of Italian storage capacity)
  - the greater of the following volumes
    - a) volume needed to replace 100% of the flow linked to the most used import infrastructure during the peak season;
    - b) volume required for modulation purposes during a harsh winter, based on the coldest winter recorded in the last 20 years.
  - Calculation of the total volume for each year by the Ministry of Energy Security after consultation with the Emergency and Monitoring Committee for the Natural Gas System (relatively stable)
- **Cost recovery:** SSOs are compensated for strategic storage provision via a TSO exit tariff applied at city gates, which is therefore indirectly charged to DSO users

Notes: [a] "administrative imbalance price"
Sources: Compass Lexecon Analysis based on LEGISLATIVE DECREE 164, 23 May 2000, Legislative Decree 93, June 2011, Ministry Communiqué 02/2025

Measure type 6: **Strategic storage** – case study: **Hungary** (2006)

Last resort mechanism comprising a stock held by the operator that can only be drawn on in the event of an emergency relating to security of supply.

Mechanism Illustration



Outline of the Measure

- **Context**
  - Legal basis: established under Act XXVI of 2006 on the emergency stockpiling of natural gas ("Gas Stockpiling Act")
  - New dedicated gas storage facility (Szőreg)[1] was constructed and started operations in 2010
  - Hungarian Hydrocarbon Stockpiling Association (HUSA) acts as the owner of strategic gas stocks and storage capacity, rents the storage capacity through a long-term custody agreement with its own subsidiary (HEXUM)
- **Filling mechanism:**
  - Required storage volume, filling and withdrawal rate is determined by government decrees
  - HUSA purchases gas at market conditions and stores it long-term
- **Withdrawal criteria:**
  - Government orders sale of the strategic gas stock, determines buyers and the price of the released natural gas in a ministerial decree
- **Volume:** Since 1 November 2022: 12.7 TWh (19% of national storage capacity, 15% of projected 2025 annual demand)
- **Cost recovery:** End-user levy paid by all gas end-consumers (excl. households) to cover costs of gas and stockholding
- **Additional temporary strategic storage:** In 2022, an additional natural gas reserve was established (7.1 TWh) by HUSA; maintained only until 1 April 2026

Notes: [1] The available storage capacity exceeds the volume needed for strategic stock and is also used for commercial storage.
Sources: Compass Lexecon Analysis based on HUSA, HUSA – Budget 2025, Act XXVI of 2006, Decree 59/2021, Government 260/2022, Regulation 10/2022

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Measure type 7: **Storage filling of last resort**

	Description
Core principle	Dedicated entity purchases and stores gas after it becomes clear that market-based filling (or earlier interventions) will fall short of filling targets
Entity specifying technical parameter of storage to be held available (volume, rates, locations)	Government and/or energy regulatory agency; generally, in consultation with the market operator and/or the TSO(s)
Entity deciding about the usage of stored gas	Government and/or the energy regulatory agency; potentially, in consultation with the market operator and/or the TSO(s)
Holder(s) of storage capacities to improve SoS?	Special entity, market operator, TSO(s) or SSOs
Owner/buyer of gas stored?	Special entity, market operator, TSO(s) or SSOs (who buy and sell – usually subject to administrative restrictions and/or incentives for cost / risk reduction)
Recovery of (i) storage capacity cost and (ii) cost for stored gas (and its storing)	Generally, via a levy (on end-users or retailers) that determines who pays for the measure (alternatively: via state budgets)[1]
Is there **commercial usage** of storage capacity or gas volumes permitted / foreseen	Yes (gas is typically released back into the market as the security of supply situation improves)

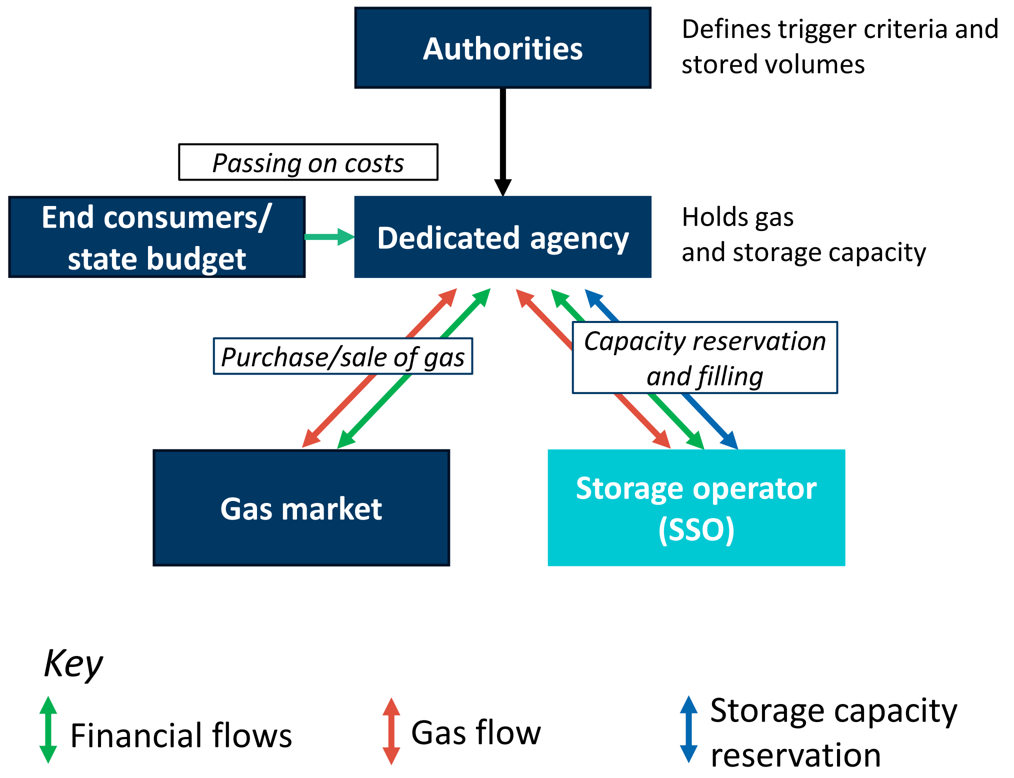
	Assessment
1. Necessity	The assessment of necessity of non-market interventions does not depend on the chosen measure
2. Effectiveness	▪ Effective to ensure gas is stored for SoS crisis as injection is mandated ▪ However, indirect effects might reduce market-based filling
3. Proportionality: Extent of non-market-based operation/actions	▪ <u>Selection of storage users / dedicated entity</u>: Non-market-based as entity is usually selected administratively ▪ <u>Filling</u>: usually strict administrative filling targets may lead to “buying at whatever price” ▪ <u>Crisis operations</u>: optionally administrative call-offs ▪ <u>Standard sell-off (after winter)</u>: “market based” but the ultimate coverage of losses (→ levy) may lead to sell-off very different to “normal” market participants following an arbitrage strategy
3. Proportionality: limitation of non-market-based remuneration	▪ <u>Storage user remuneration</u>: non-market based as dedicated entity must fall under some sort of economic regulation ▪ <u>SSO-remuneration</u>: remuneration for capacities used during filling of last resort may be set following the same principles as usually (i.e. either via regulation, auctions or posted tariffs)
4. Limitation of distortions	▪ <u>Storage market</u>: The existence of last resort filling may create inverse incentives not to book capacity or store gas ▪ <u>Gas wholesale market</u>: while rushed filling in (late) summer may increase summer prices, anticipation of release of last resort gas may depress winter prices thereby reducing summer winter spreads incentivising commercial filling. ▪ <u>Gas retail market</u>: If financed via levy, the levy impacts retail gas prices and may impact gas usage (elasticity of demand)
Considerations on operational efficiency	▪ The dedicated entity may lack experience, expertise and access to trading instruments ▪ Storage filling of last resort is typically ad hoc and short term, making it difficult to buy at the best market conditions

Notes: [1] These levies might be reduced based on some cross-member-state cost allocation payments.
Source: Compass Lexecon analysis

Measure type 7: **Storage filling of last resort** – case study: **Germany** (2022)

The market operator THE (as dedicated entity) is responsible for storage filling of last resort by buying and storing gas to cover the difference between commercial filling levels and the storage filling targets.

Mechanism Illustration



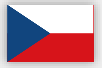
Outline of the Measure

- **Context**
  - Legal basis: established under EnWG §35 in 2022 to ensure that the filling targets are met in light of the energy crisis
- **Filling mechanism:**
  - German market area operator THE may purchase and inject in storage facilities its own gas volumes, following approval by BMWK and agreement with BNetzA
  - THE can also obtain capacities through a "use-it-or-lose-it" mechanism from storage users who hinder Germany from reaching its filling targets by not utilizing their capacities
  - If these capacities are not sufficient, THE books storage capacities for a storage fee that is the minimum of the average annual storage fees of the past three storage years
- **Withdrawal criteria:**
  - THE must sell the gas stocks from January until the end of the storage year unless these volumes are considered necessary to meet the filling targets of the next year
  - Earlier withdrawal possible upon government order for security of supply reasons
- **Volume:**
  - In 2022, 49.67 TWh (of which 12.42 TWh were sold during the winter of 2022/23; the remaining quantities were withdrawn during winter of 2023/24)
  - Price paid for buying gas: EUR 8,675.1 million; revenue from sold gas: EUR 2,408.1 million
- **Cost recovery:** originally financed by gas storage levy paid by all gas end-consumers, from January 2026 remaining cost are recovered from state budget

Sources: Compass Lexecon Analysis based on THE - Gas Purchases, EnWG

Lessons drawn from the measures introduced in 2022/23 (based on the gas storage regulation)

Following the energy crisis, the impact of national storage filling measures during the storage year 2022/23 has been reviewed by an ACER-CEER consultancy study.

№	Measure type	Measure specific lessons according to VIS	Case study specific lessons according to VIS (the selection below does not cover all countries that have implemented the respective measure)
1	**Storage filling premium**	▪ Support schemes are **effective and efficient** mechanisms to increase storage utilization by market participants ▪ However, **CfDs should be preferred** over direct subsidies, as they make more efficient use of funds.	 Both CfDs and premia were offered; market participants strongly preferred the steady subsidy of the stock premium and use of the CfD was minimal.
2	**Storage filling Contracts for Differences (CfDs)**	▪ CfDs can provide **efficient incentives** to market participants to store gas ▪ However, the mechanism should be **in place before the injection period**, to be able to react to unfavourable summer-winter spreads.	 Limited authority and timeframe in setting up auctions for CfDs resulted in a complex process involving many stakeholders and little market interest.
3	**Auctioned filling obligations**	▪ A zero-/discounted-reserve price at storage auctions provides a **strong incentive** for market participants to book capacity. ▪ **Proper planning is critical**, to achieve the targets in an efficient manner and set the right incentives.	 Zero-reserve price and filling obligations for storage users led to all capacity for the storage year 2022/23 being contracted by February, and 100% storage filling in November.  At some tenders, no filling requirements were sold, because market participants demanded a price too high for the TSO to accept.
4	**Retailers' stockholding obligations**	▪ Stockholding responsibilities of gas suppliers **should not impact the flexibility and arbitrage value** offered by storage. ▪ Gas suppliers might face **financial challenges** when requested to establish gas stocks above their commercial activities.	 Demand for storage exceeded the marketed capacity in 2022/23.  Some suppliers limited their portfolios of protected customers to reduce stockholding obligations.
5	**Importers' stockholding obligations**	*not implemented in 2022/23*	
6	**Strategic storage**	▪ Establishing strategic reserves **during a crisis** (or in anticipation of one) has **significantly higher cost**s than having established a strategic reserve in advance.	 Establishment of strategic reserves in spring/summer 2022 was very expensive.
7	***Storage filling of last resort***	▪ Storage filling of last resort should ideally be avoided but might be necessary as a last resort measure.	 Storage filling of last resort was costly and inefficient due to the need to buy large gas volumes within a short time.

Source: Compass Lexecon analysis based on ACER & VIS (2023) and ACER & VIS (2024).

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