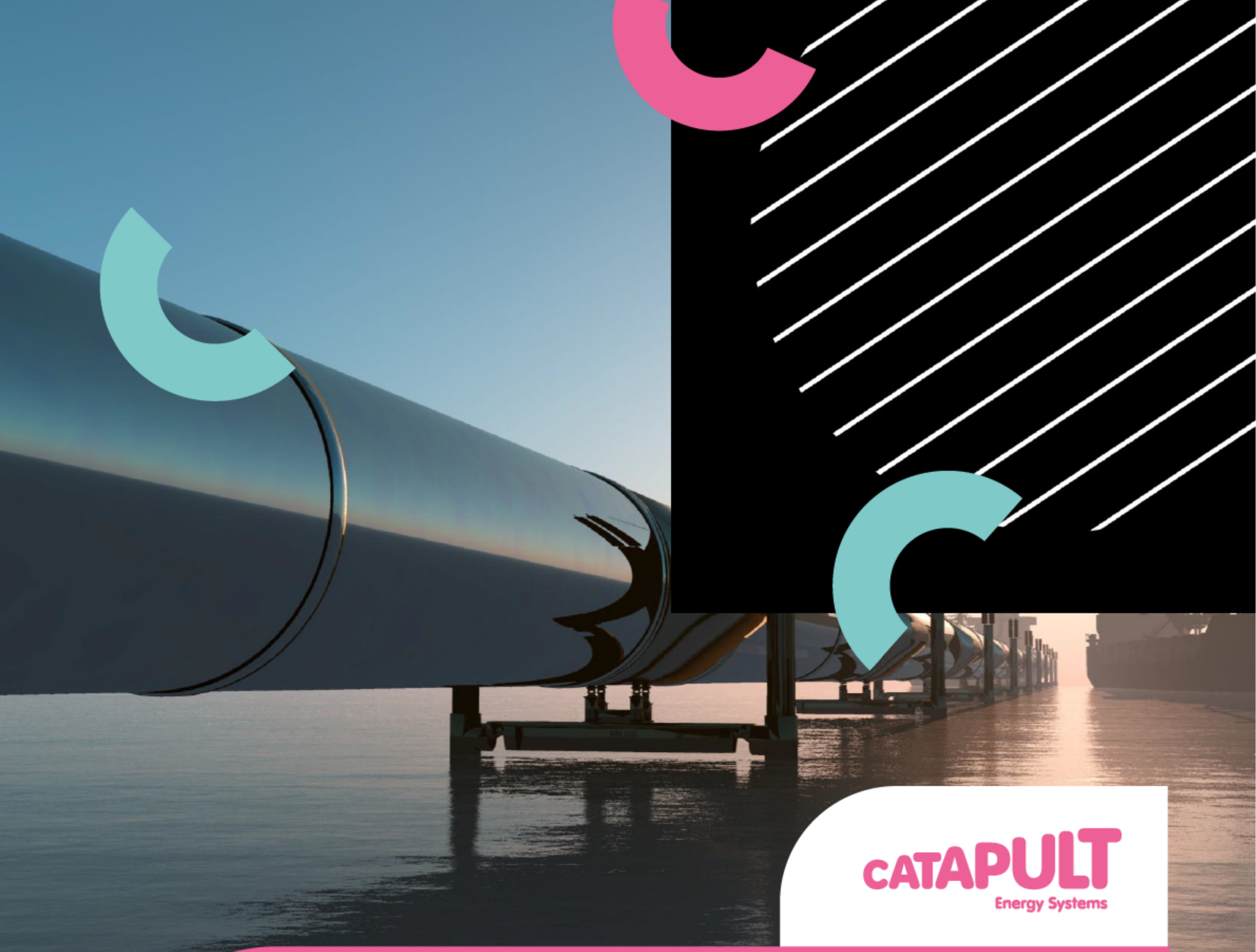

Clean Power Flexibility Investigation: Scenario and Assumptions

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Date: July 26

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1. Executive Summary

The Clean Power Flexibility Investigation (CPFI) was commissioned by National Gas Transmission (NGT) to understand how the National Transmission System (NTS) can continue to support electricity system security in a future characterised by lower average gas demand but increasing reliance on gas-fired generation during periods of system stress. The project focuses on the impact of Clean Power 2030 (CP2030) on gas network operations and seeks to identify scenarios that could create significant short-term increases in gas demand from power generation.

This report establishes the scenario framework and assumptions used throughout the CPFI programme. Its purpose is to identify credible but extreme future conditions that could stress the NTS and provide the basis for detailed gas network modelling in subsequent work packages. A systems-thinking approach was adopted to recognise the growing interdependencies between gas and electricity systems and the increasing influence of flexibility requirements on gas network operation.

The study defines network stress in terms of recognised gas security criteria, including low pressures at network extremities, breaches of power station Anticipated Normal Operating Pressures (ANOPs), Local Distribution Zone pressure limits and operating margin triggers. Scenario development focused on four key elements: future energy pathways, prevailing system conditions, trigger events and the resulting system response.

Analysis of Future Energy Scenarios and CP2030 conditions indicates that gas-fired power stations are likely to transition from relatively steady operation towards a peaking and flexibility role. As a result, future gas demand may become more volatile, characterised by rapid ramping of Combined Cycle Gas Turbines (CCGTs) in response to electricity system peak-gap events.

To explore these risks, a bespoke CPFI scenario was developed, combining aspects of the Holistic Transition and Electric Engagement pathways. The South East of England was selected as the focus geography due to its concentration of electricity demand, gas-fired generation, interconnectors and known network sensitivities. Eight stress-test scenarios were created around two representative trigger events: the sudden loss of a major generating asset and a significant reduction in electricity imports from continental Europe. These scenarios incorporate variations in supply sources, demand conditions, seasonal factors and asset availability to test the resilience of the NTS under challenging future conditions.

Together, these scenarios provide a structured and evidence-based foundation for assessing future network resilience, identifying potential operational vulnerabilities and informing future innovation activities required to maintain flexibility and security of supply in a decarbonised energy system.

2. Introduction

The Clean Power Flexibility Investigation (CPFI) project aims to understand how to sustain the gas network in a low average, high peak demand future, focusing on the interaction between gas and electricity systems (with focus on NTS connected power stations). It is an NIA funded project by National Gas Transmission (NGT), delivered by Energy Systems Catapult (the Catapult). The objectives of the project are to:

- Define Clean Power 2030 demand stress conditions (and high-level conditions out to 2050), with specific attention to peak gap events caused by weather, low renewable output or electricity supply failures.
- Assess the implications of peak gap events on the gas network and the gas network's ability to respond, using NGT's SIMONE model, identifying limits, stress points, and operational gaps.
- Identify potential technical, operational, and market issues that prevent the gas network to provide backup capacity in a decarbonised energy system
- Develop a high-level shortlist of potential interventions suitable for future innovation project(s), including simulations, prototype deployments, or market and regulatory interventions (the type of interventions may change as the transition progresses through time).

The project is focused on investigating if the gas network can reliably meet short-term spikes in gas demand from the electricity network via gas-fired generation. The approach to deliver this is through assessment of the stress points in the gas network under 2030 decarbonisation scenarios and beyond to 2050. This will provide the basis to explore market and operational processes/tools that could be used to maintain standby gas flexibility, and evaluate how the electricity network and markets could support the gas network in preparation for these events.

Five work packages:

Figure 1 - Clean Power Flexibility Investigation Work Packages

Work package 1 establishes the foundation for analysis, it provides a defined set of net-zero consistent stress conditions. Providing the input to work package two gas network simulation to be completed by NGT. This has been delivered here by outlining National Transmission System (NTS) and Energy system performance criteria for energy security; define stress conditions; identify extreme and plausible energy system scenarios, including a review existing scenario data; selection of key test parameters for the study and definition of the demand profiles and generation mix.

2.1 Approach

The approach to this work package was broadly split into three steps. First to understand how stress for the NTS is defined for this project. Then to investigate scenario options through research and discussion with NGT. Followed by design of the scenario and assumptions included here.

2.2 What can stress the NTS?

The NTS operates in an increasingly interconnected systems of systems that makes up the GB energy system ('the system') which operates in the context of the global energy system. It is broadly designed for the energy systems of the 1970s-1990s or large reasonably predictable domestic and industrial demand.

The energy system is constantly evolving, with uncertainty around the different scenarios between 2030 and 2050. The role of the NTS in these future systems could vary significantly, resulting in different operating environments and 'stress conditions' emerging on the NTS. The task of this work package is to identify potential outlier scenarios, that are both credible and extreme, which might put the most stress on the NTS. The selected scenarios, with accompanying assumptions, will inform subsequent gas network simulation in work package 2 to explore the question in more detail.

2.2.1 Energy Security

Stress in the NTS is inherently related to energy security. This work package required a definition of what criteria applies and therefore the level of stress to understand at which points the NTS was overstressed. Energy security is well defined in existing NGT standards and associated regulations and licence conditions. These provided reference to define system stress here.

The gas supply emergency standard[1] is an existing industry standard that defines supply energy security requirements for the NTS. Providing criteria for a gas supply emergency and the procedures to both avoid and mitigate occurrence. There are three types of gas supply emergency:

- a Gas Deficit Emergency (GDE) can occur when the demand on the NTS is greater than the supply available through commercial actions i.e. due to insufficient supplies;
- a Safety Monitor Breach is when storage gas levels fall below the storage safety monitor; or
- a Critical Transportation Constraint happens when an issue on the National Transmission System prevents gas from reaching a certain part of the network

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[1] "E1 - Network Gas Supply Emergency Procedure," National Gas Transmission, U.K., Rep. Version 12.1, Nov. 2024. Accessed: Dec. 9, 2025. [Online]. Available: https://www.nationalgas.com/sites/default/files/documents/E1%20NGSE%20Procedure%20-%20Version%2012.1_1.pdf

Following additional discussion with the NGT project team regarding typical triggers for gas simulation modelling failures the following performance criteria for NTS Energy security were defined as the stress conditions for this project:

- Low pressure at network extremity prompting use of Operating Margin gas.
- Pressure below supply levels required by a gas fired power station ANOP (Anticipated Normal Operating Pressure) in the SIMONE model.
- Breach of a Local Distribution Zone minimum pressure.

2.2.2 Systems Thinking

Prior to discussing the scenario detail, it is worthwhile considering this challenge with a 'systems thinking' perspective. The objective of this work package is to define a set of conditions that could generate stress on the NTS. The NTS is part of a wider UK and European and global energy system, an increasingly complex and inter-connected system-of-systems. One of the foremost academics in the development of systems thinking, D.H. Meadows notes "As systems become complex, their behaviour can become surprising."[2]. Within this work package it is intended to prompt the NTS into showing this behaviour.

Meadows proposed that all systems have leverage points, "places in the system where a small change could lead to a large shift in behaviour"[2]. Publishing a list of 12 ways to intervene to push the system in a positive or negative direction.

Here we are attempting to push the UK energy system in a negative direction in a manner that system stress manifests as stress in the NTS as a sub-system. Following discussion of stress, from the 12 options, the leverage point that was identified as having the potential to push the energy system and NTS in a negative direction was: "The lengths of delays, relative to the rate of system change."[2] This provided prioritisation and focus for scenario design as a Discovery project.

2.2.3 NTS Stress conditions 'levers'

Once stress was defined, a set of variables that could set the conditions for NTS stress were created. For this purpose, three categories were created:

Pathway (Energy Scenario): which energy system is the NTS in during the chosen time period for modelling and what does the energy system configuration mean for the role of the NTS within it. e.g. what is the electricity systems generation and storage technology mix.

Conditions: What are the energy system 'prevailing conditions' e.g. electricity system configuration or gas transmission system line pack levels. Or configuration and flows.

Event: What are the characteristics of the energy system event that is influencing the NTS and potential trigger of stress conditions. e.g. asset failures or a Dunkleflaute.

[2] D. H. Meadows, Thinking in Systems: A Primer, D. Wright, Ed., White River Junction, VT, USA: Chelsea Green, 2008.

Event Response: how will the energy system respond to the event.

To design the system conditions, extreme plausible events that could impact the NTS were considered, and a combination of Pathway, Conditions, Event and Event Response have been created. The event is considered to take place in the electricity systems and spread to the NTS. Options considered are discussed further below:

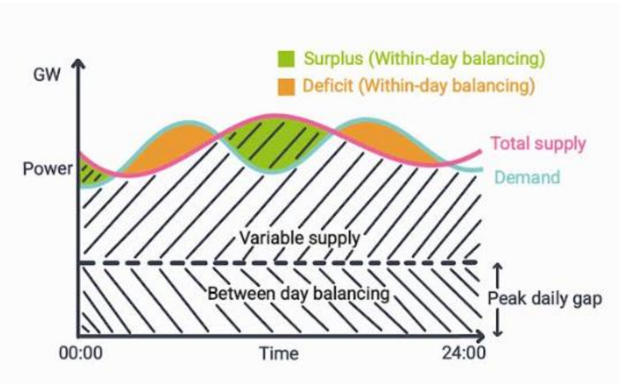
2.2.4 Potential Trigger Events

Events in complex systems typically have a trigger that combines with factors across multiple sub-systems to create a wider compounding system stress. A specific defined event will provide the trigger in the simulated scenario(s) for this project. The electricity system has been identified through discussion as one of the primary sources of the trigger event, specifically a 'peak gap' resulting in a significant demand on the gas system to close the gaps, potentially causing stress conditions.

The Catapult's Innovating to Net Zero 2026 report, "scaling flexibility to meet the five peaks challenge" identified four peak gaps in the electricity systems that need to be considered when designing the architecture of the future energy system[3]. These gaps quantify the amount of flexibility or storage we need to balance the system in both capacity (power) and volume (energy) terms. Four of these gaps were assessed for use here:

- The daily peak gap
- The instantaneous peak power gap
- The peak durational gap
- Peak energy gap.

The peak daily gap which is the maximum difference over the year between average daily demand and average daily supply of power. It represents the total need for between-day balancing capacity in GW.



[3] Innovating to Net Zero 2026: Scaling flexibility to meet the five peaks challenge. 2026 [online]. Avaliable: https://es.catapult.org.uk/project/innovating-to-net-zero-2026/

Figure 2 – Peak Daily Gap Source: ESC

The instantaneous peak power gap; the time during the year when there is the maximum difference between supply (including between-day balancing) and demand. This is likely to occur when a spike in energy demand coincides with drop in renewables and interconnector output. This peak power gap defines the maximum GW of within-day balancing that we need.

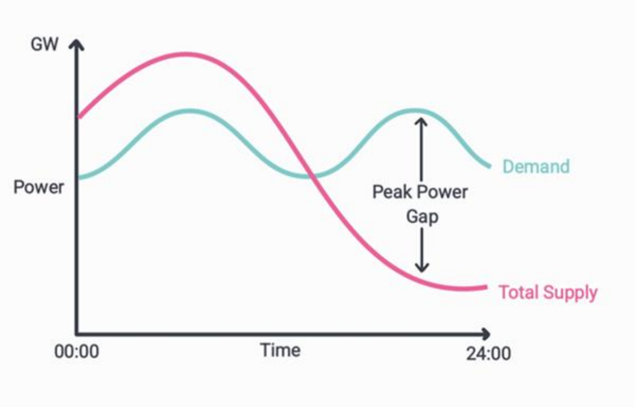


Figure 3 - Instantaneous peak power gap

Peak energy gap - this will not necessarily occur at the same time as the peak power gap and is likely to happen when a storm moves across the British Isles and the wind gradually falls or increases over the course of the day.

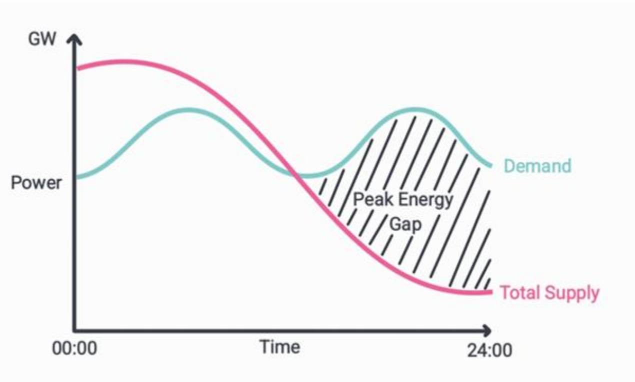


Figure 4 - Peak Energy Gap

The final gap is the hardest to predict, the total amount of between-day balancing we might need, over time. Within-day balancing assets are returned to their original state at the end of each day. But for between-day assets, one day with a shortage of generation can be followed by another and another, gradually depleting whatever energy store is being used. This is the fourth gap, the peak durational gap.

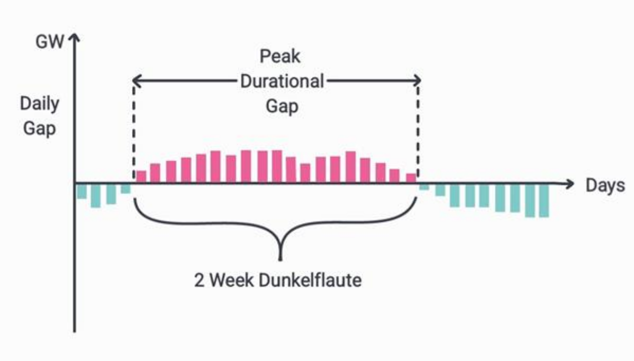


Figure 5 - Peak Durational Gap

The translation of these electricity system peak gap events to the NTS through demands on the exit points will be dependent a high number of whole systems variables. The most influential is the power generation mix and electricity system assets providing flexibility services.

In discussion with the NGT team it was determined that exploring how the NTS could respond rapidly to a large instantaneous peak could be a useful initial trigger event to explore 'flexibility response' characteristics and potential causes of stress conditions on the NTS.

2.2.5 Key parameters for the study

The energy security and NTS stress parameters translate into metrics that represent physical elements on the NTS pipelines and exist points. The key parameters identified for this study are:

- Maximum Pipeline Pressure (MOP)
- Minimum Pressure at the Local Distribution Zone (LDZ) exit points
- Ramp rates at the exit point in MW/min
- Pressure Minimum at power stations (ANOP)
- Network Geography of the trigger events and any second or third order consequences
- Operating Margin Trigger.

3.Scenario Design

The boundaries for what makes extreme and plausible gap conditions are not definitively set out. Instead, combinations of variables, have been explored to identify a scenario where they compound to amplify a peak gap and subsequent translation of this to the NTS.

3.1 Existing scenario data review

Previous work by NGT has used SIMONE to test the gas network against NESO's FES 2025 pathways (as described WP2 Previous NGT Analysis). Some of the gas demand and supply over the pathways is presented in *Figure 7*, along with an additional scenario discussed later.

	Holistic Transition	Electric Engagement	Hydrogen Evolution	Falling Behind
Pathway descriptor	Net zero is met through a mix of electrification and hydrogen, with hydrogen mainly used around industrial clusters. Hydrogen is not used for heat except as a secondary fuel for heat networks in small quantities. Consumer engagement is very strong through adoption of energy efficiency improvements and demand shifting, with smart homes and electric vehicles providing flexibility. A high-renewable capacity pathway, with unabated gas dropping sharply. Pathway sees moderate levels of nuclear capacity and lowest levels of hydrogen dispatchable power. Supply side flexibility is high, delivered through electricity storage and interconnectors. No unabated gas remains on the network in 2050.	Net zero is met mainly through electrified demand. Consumers are highly engaged in the transition through smart technologies that reduce energy demand, such as electric heat pumps and electric vehicles. Pathway with the highest peak electricity demand, requiring high nuclear and renewable capacities. It also has the highest level of bioenergy with carbon capture and storage across all net zero pathways. Supply side flexibility is high, delivered through electricity storage, interconnectors and low carbon dispatchable power.	Net zero is met through fast progress for hydrogen in industry and heat. Widespread access to a national hydrogen network is assumed. Some consumers will have hydrogen boilers, although most heat is electrified. There are low levels of consumer engagement within this pathway. Hydrogen is used for some heavy goods vehicles, but electric vehicle uptake is strong. Pathway sees high levels of hydrogen dispatchable power plants, leading to reduced need for renewable and nuclear capacities. Hydrogen storage provides the most flexibility in this pathway.	Considers a world where some decarbonisation progress is made against today, but at a pace not sufficient to meet net zero. Used in downstream gas and electricity security of supply processes – it is important that we use Falling Behind alongside the net zero pathways to consider the full range of potential demand levels for possible remaining reliance on unabated fossil fuels. With the current level of low carbon projects in the pipeline and increased policy ambition, we consider some level of progress in areas where there is increased certainty or progress.

Figure 6: Extract from Table 1 of Future Energy Scenarios: Pathways to Net Zero 2025 with Low Continent/High LNG case

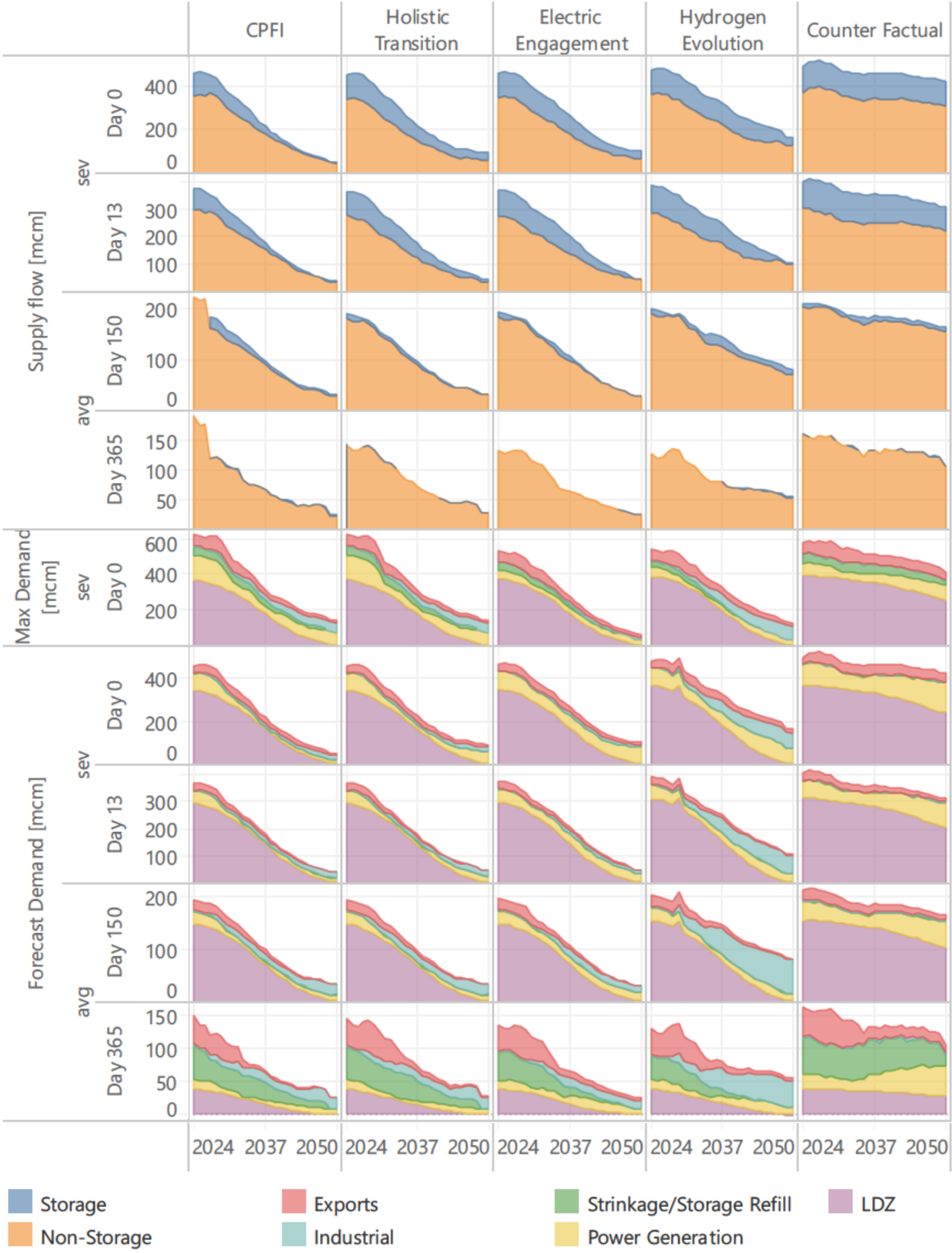


Figure 7: Comparison of supply and demand for each scenario with Low Continent/High LNG case

Each scenario provides different challenges for the system, and a number of possible studies were identified to explore various factors that could provide challenges to the gas network in a future energy system. Some of these could still form the basis of a subsequent investigation:

- Gas demand continues at a relatively high level: this could be part of a ‘Falling Behind’ type scenario where Net Zero targets are not achieved, or where high levels of CCS (and/or DACCS) are deployed such that gas demand remains high. In a future with increased intermittent renewables but low levels of storage and flexibility, dispatchable generation requirements could result in a more ‘peaky’ gas demand for electricity generation.
- Repurposed and/or decommissioned gas network: existing gas infrastructure could be converted to provide transmission assets for hydrogen and/or CCUS pipelines. This could be an economically effective way to unlock higher levels of deployment of hydrogen for industry, heating and power generation in place of natural gas, but would reduce the capacity available for gas transmission. If this were to remain in use for dispatchable generation, as in a ‘Hydrogen Evolution’ type scenario, peak demand would become an increasingly large proportion of overall gas consumption. The transition, as assets are repurposed, could also provide stress conditions when assets are no longer available for gas transmission, but also not yet operational for hydrogen or CCUS, or with hydrogen generation assets still to be deployed. Until additional electricity can be generated from new hydrogen plant, gas may still have to provide the same amount of dispatchable generation during this period, but with less transmission capacity available.
- High levels of electrification: while ‘Electric Engagement’ includes significant use of interconnectors and electricity storage, a similar scenario with high levels of electrification but more reliance on dispatchable generation could again see a more ‘peaky’ gas demand.
- Industrial clusters: both ‘Holistic Transition’ and ‘Hydrogen Evolution’ see gas demand for industrial applications increasing over the pathway to 2050. Changes to industrial processes within a decarbonising energy system could encourage sites to locate in close proximity to one another, creating a localised demand in an area which currently has a relatively small gas transmission capacity.

Building on existing work done to model the FES scenarios using SIMONE provides a more established basis for this project, and is intended to provide NGT with analysis in a more familiar context.

A ‘Falling Behind’ type scenario provides a world closer to the present day, and was therefore thought to provide less value than a scenario exploring new possible conditions that may stress the gas network in new ways.

The significantly higher proportion of gas powered dispatchable generation in ‘Hydrogen Evolution’ is most constrained when considered against the decommissioning of existing gas transmission assets. This would require more information from NGT than was readily available for this discovery project, and therefore more suitable for future work modelling future energy systems in greater detail.

The ‘CPFI’ scenario created for this work package is based on ‘Holistic Transition’ and ‘Electric Engagement’ and explores the additional challenges that may be encountered with a combination of pathways that could occur with different regional approaches during an energy system transition. The ‘Holistic Transition’ pathway forms the basis of the scenario, but with 'Electric Engagement' pathway adopted for LDZ and power generation demands in the North Thames and South East regions. The supply locations are also modified to reflect the scenarios detailed later in this document: for scenarios 1, 2, 5 & 6, the majority of supply is from Milford Haven and none is from Grain; for scenarios 3, 4, 7 & 8, imports at Bacton are increased to provide the majority of the supply.

Figure 8 provides a comparison of scenarios for LDZ demands and supply for power generation sites within these regions. *Figure 9* provides the same comparison for only the power generation sites.

The Counter Factual scenario was discounted from this analysis as the scope of the project was a focus on how the network would respond to low gas demands and large changes in demand in scenarios that would meet Net Zero. In addition, initially considered that the Counter Factual scenario was close to 'business as usual' for the NTS and that the within day demands changes would not be as potentially stressful with high DN demand. This was further reinforced with subsequent discussions between Catapult and NGT of credible extremes associated with the system intervention points and electricity system peak gaps chosen for exploration.

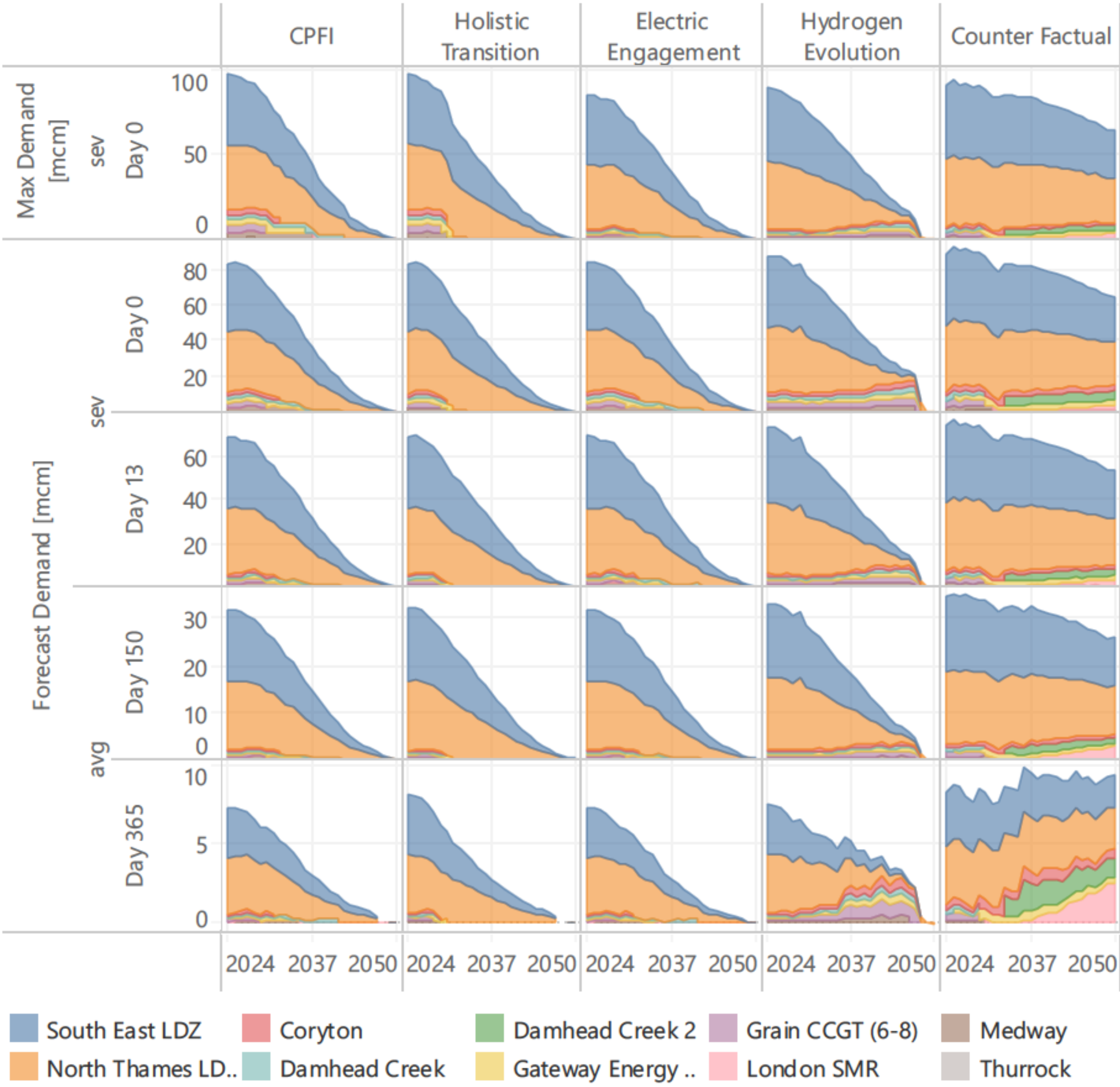


Figure 8: Comparison of LDZ and power generation demands in North Thames & South East for each scenario[4]

[4] Note that the 2029 South East LDZ values are missing (or zero) in the balance sheet data provided by NGT. The values for demand in
Figure 8 are interpolated from adjacent years, but the corresponding supply remains unchanged.

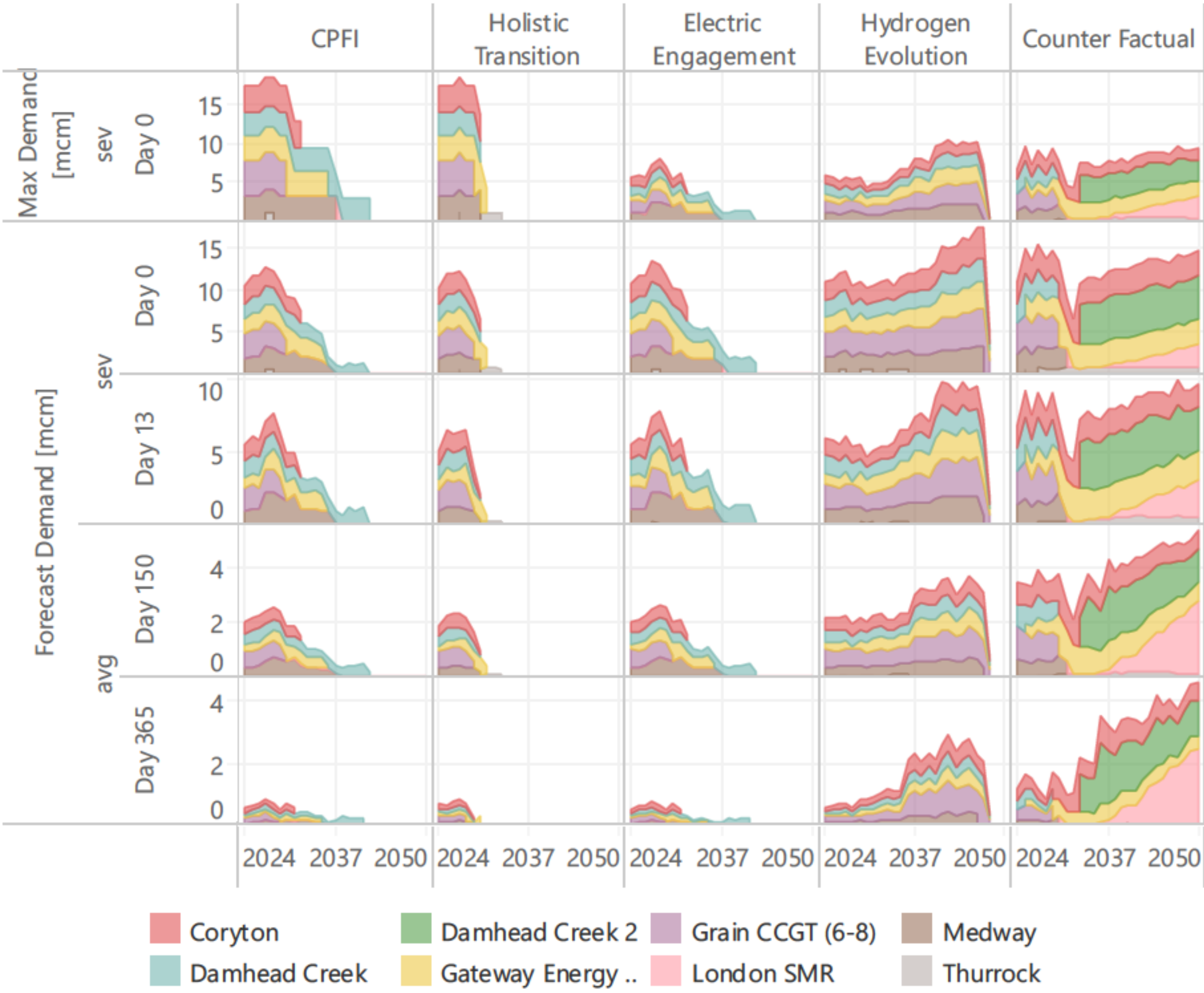


Figure 9: Comparison of power generation demands in North Thames & South East for each scenario

3.2 CP2030

Comparisons of Electricity Generation and Electricity Generation Capacity were made for the different FES scenarios and NESO CP2030 scenarios. A range of capacities exist across the scenarios but in all cases the gas generation capacities in the FES scenarios were of the same order as in the NESO CP2030 scenarios. The big difference comes in the electricity generation. Due to the requirement of CP2030 to have 5% or less of power generation coming from unabated gas, the generation profiles of CCGTs in the CP2030 scenarios all change from baseload to peak plant resulting in lower overall levels of electrical generation. It is therefore expected that to satisfy CP2030, it should be assumed that more of the CCGTs are running at minimum load factors and ramp up in response to peak demands.

3.3 CPFI Scenario Data

The new 'CPFI' scenario was created by modifying the data provided by NGT for 'Holistic Transition' and 'Electric Engagement' pathways as follows:

1. Creation of a new access database based on the 'Holistic Transition' database with *tblCWV*, *tblLDZLDC*, *tbllocationmodels* and *tblVLDMCLDC* updated to use values from the 'Electric Engagement' database for the relevant regions and sites.
2. Modification of Balance Sheet Creation Tool to include new scenario and adjusted scenario data in *DS35_Max_PS* sheet[5]

3.4 Gas Power Station Turbine Ramp Rate Profile

In order to satisfy CP2030 it is assumed that many of the CCGTs will be running at minimum load factors, only ramping up to full capacity in response to peak requirements. It is assumed that the CCGTs used in the stress scenarios are state of the art, which can have a minimum load factor of 15% and are capable of ramp rates of up to 176 MW/min, which allows the turbines to ramp up to full capacity in less than 30 minutes. For the scenarios under investigation, the stress event occurs at 18:00, ramp up starts at 18:30 meaning the CCGTs are up to full capacity by 19:00. This produces a very different profile to those currently in use which mostly assume the CCGTs to be operating more steadily during the day and ramping down overnight once the main period of demand has passed. The "event response" profile should replace existing profiles as described in the scenarios whilst other profiles remain the same.

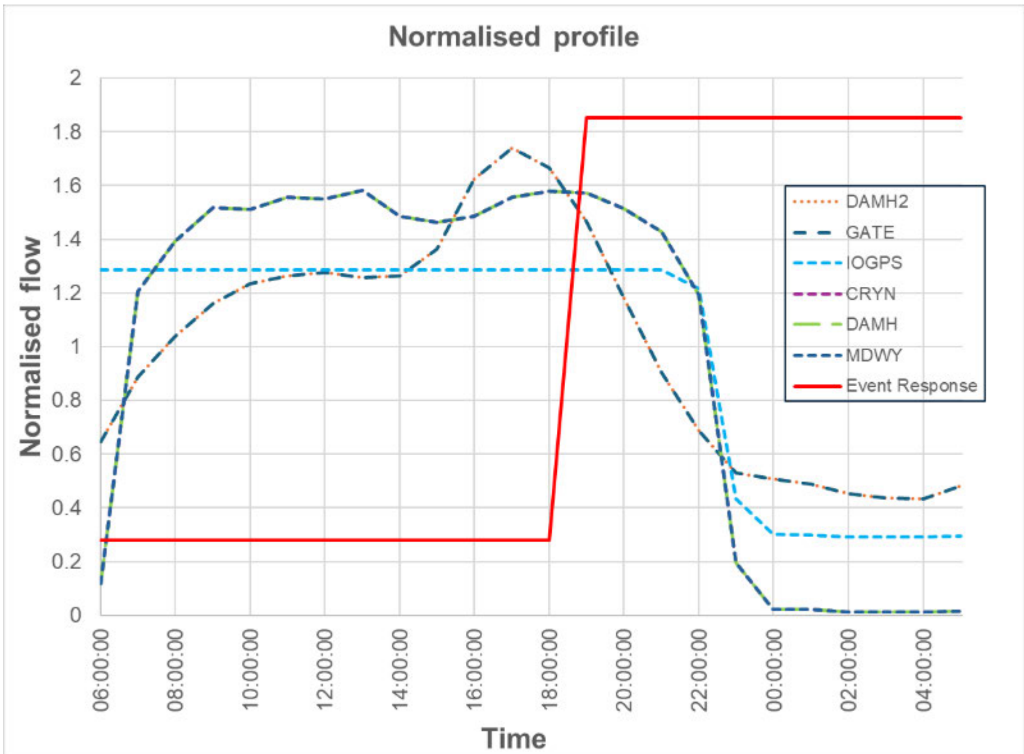


Figure 10. Comparison of existing CCGT profiles with a profile demonstrating an event response

[5] Note that when running the Balance Sheet Creation Tool, the output balance sheets for the original FES scenario implementations differed from those provided by NGT, so any additional adjustments made by NGT have not been applied to the CPFI scenario. For the FES scenarios in *Figure 7* and *Figure 8*, the data is from the balance sheets provided by NGT rather than new runs.

3.5 Scenarios and assumptions for SIMONE modelling (Work Package 2)

Discussion with the NGT project team identified that a maximum of 10 SIMONE scenarios could be accommodated, dependent on the work required to setup and adjustments required to elements such as ramp rates.

Selection of the eight scenarios below has taken this capacity, the 'levers' to explore and project time frame into account. The scenarios provided focus efforts on levers that are considered to most likely stress the NTS given the research, analysis and discussion to date.

3.5.1 Pathways

The pathway for work package 2 will be the CPFI scenario as described above.

3.5.2 Conditions

General

Two seasons will be considered in the scenarios summer, with a low 'gas' day, this assumes reduced gas flowing and in the system in the form of line pack. The winter season is captured using a high gas day. A cold day typical of the end of January, early February. Gas stores are available, but low.

The dominant weather is assumed to be a stationary anticyclone over UK and Northern European very low wind generation. For the winter day assumed outside air temperature of -10degC in the South East.

Electricity System

On the day of the event the electricity system is experiencing the following conditions:

- Norway electricity import low/unavailable.
- High interconnector flows to UK from non-Norwegian interconnectors. (Scenarios 5-8 only)
- UK supplying island of Ireland.
- Battery storage available and provides frequency response.
- No additional gas long durations storage, this has been under built.
- Demand side flexibility adoption low.
- Reliant on CCGT and OCGT for short term operating reserve.

Gas System

On the day of the event the gas system is experiencing the following conditions:

- High LNG imports from Milford Haven and low supplies from Bacton.
- Gas storage levels low.
- Linepack levels very low for low gas days.

In some of the scenarios very low or no flow from the Isle of Grain LNG terminal is assumed. Although unlikely, it was agreed that plant availability, market or maritime conditions could be considered a 'credible extreme' circumstance for which there was merit in exploring.

The potential of data centre (both gas and electricity) demand impact on the systems was considered in the scenario design process. At the time of writing there is some uncertainty of the demand profiles and how these may develop. It has been assumed that demand will be steady for this work.[6] Scenarios include some assumptions on asset availability. Network reliability and availability across the NTS is generally high. Asset management strategies are in place to deliver this performance, particularly in the winter months. However, assets can fail and whilst the combination of events are not likely there were deemed to fit a 'credible extreme' scenario and collaboratively agreed to be worthwhile testing.

3.6 Event

Specifics of the event are described to provide context and support set up. An instantaneous peak gap occurs on the electricity system triggered by the scenario in *Table 1*, it occurs at 18:00 UK time.

[6] This topic is included for further work in the enhanced early analysis proposal in the final report.

3.6.1 Geography

All scenarios are focused on the NTS in the South East of England:

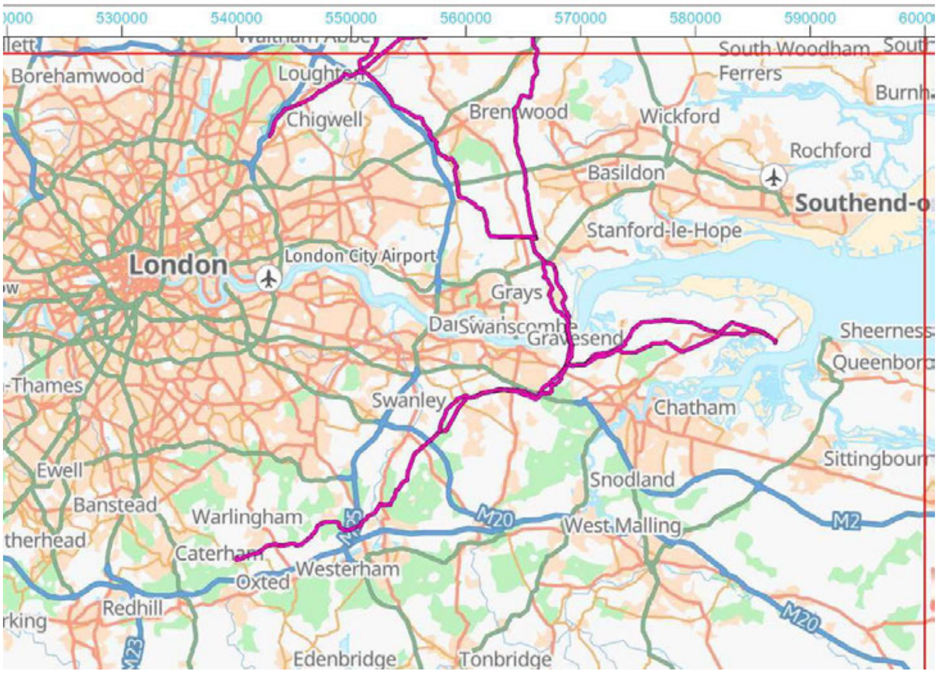


Figure 11 - Source: National Gas Transmission[7]]

The characteristics of this part of the NTS that led to it being the focus for work package two are:

- It includes an extremity of the NTS which feeds into the south east gas Local Distribution Zone, which in part supplies London.
- Large natural gas fired power stations are located in the area with known expansions planned.
- The system is known to have vulnerabilities when the NTS is in certain configurations relating to the systems intervention “The lengths of delays, relative to the rate of system change.”[8]
- The power system serves a geography with high demand, includes multiple interconnectors:

[7] "Network route maps." National Gas. Accessed: Dec. 9, 2025. [Online]. Available: https://www.nationalgas.com/our-businesses/network-route-maps
[8] D. H. Meadows, Thinking in Systems: A Primer, D. Wright, Ed., White River Junction, VT, USA: Chelsea Green, 2008.

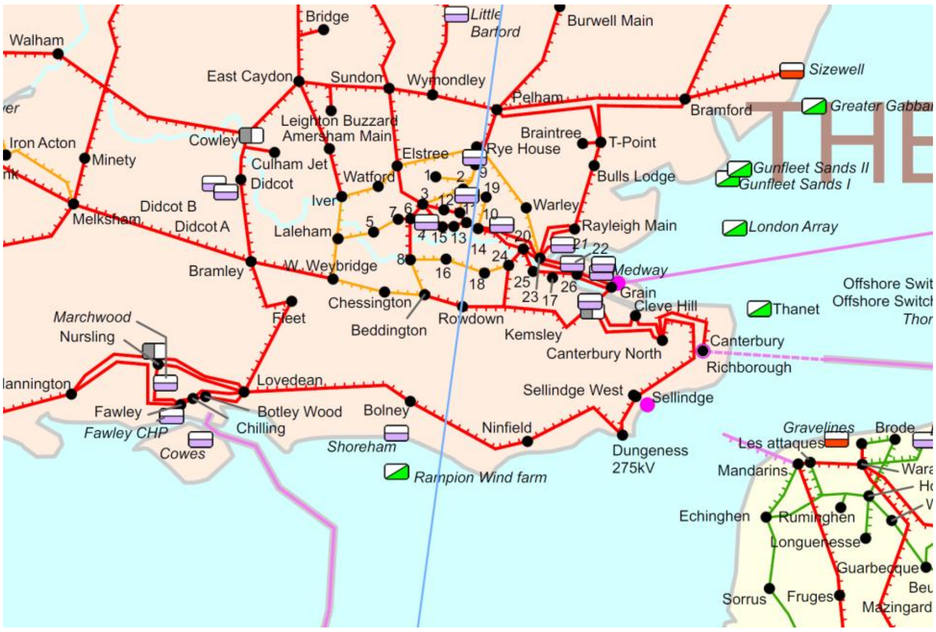


Figure 12 - Source: ENTSO-E[9]

3.7 Natural Gas Power Generation

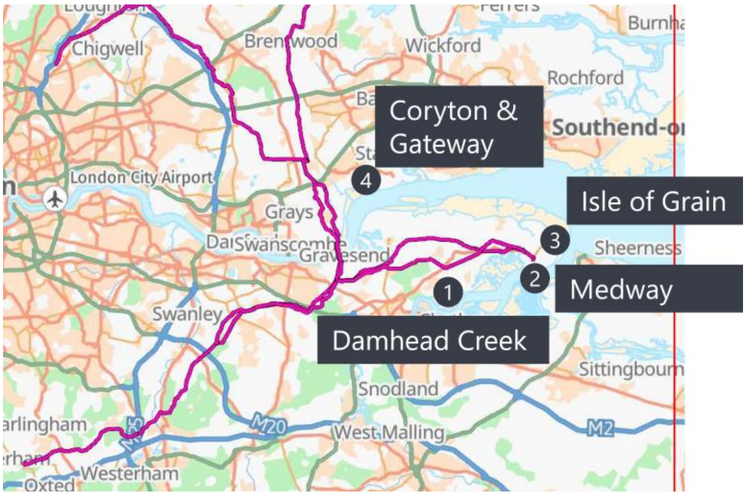


Figure 13 - Scenario Power Stations

To set this scenario up the following assumptions are applied:

- Extension of Damhead Creek PS to 2 to a total capacity of 1.8GW is complete.
- Coryton has the addition of Gateway with total capacity of 1.25GW on site.
- Grain capacity at 1.350 GW assumed existing no expansion.

Note: Expansion location and size taken from NGT and owner data.

It is assumed that these extensions have occurred with no further investment in the pipeline infrastructure which remains as is today or adjusted to repurpose pipelines for hydrogen or CCUS use.

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[9] ENTSO-E Grid Map, ENTSO-E, Brussels, Belgium, 2024. [Online]. Available: https://eepublicdownloads.entsoe.eu/clean-documents/Publications/maps/2024/ENTSOE_Grid_Map.pdf

3.7.1 Event Response

A defined event response for the NTS is provided for each scenario in *Table 1*.

4. WP2 Gas Network Modelling Scenarios

Eight scenarios have been created to stress test the NTS in the South East. Scenarios 1-4 seek to explore the loss of a large supply in the South East, with 5-8 exploring the loss of large interconnector load on the south coast.

Scn #	Event	NTS Flow Pattern	Event Response	NTS Asset Availability	Year / Gas State / Balance Sheet
1	[redacted]) generating at maximum capacity. Loses all supply due substation incident.	[redacted] taking main supply load Grain no commercial gas available in storage or ships arriving in period of incident. [redacted] power station already running	[redacted] and [redacted]) come on simultaneously rapidly 30mins after event ramping to full generating capacity with ramp rates exceeding NEXA Gas supplies ramp up to meet increased demand at [redacted]	***Low and High Gas Days:*** Electric drive compressors in east of England unavailable for first 4 hours of incident. ***High Gas Day***: Cambridge compressor station unavailable. ***Low Gas Day:*** [redacted] and [redacted] compressor stations unavailable for all.	2035 Low Gas Day 2035_NS_LC.xlsx sheet D365a_XX_LC_2035
2					2035 High Gas Day 2035_NS_LC.xlsx sheet PK_XX_LC_2035
3		Continental flows from [redacted]		**Low Gas day:** [redacted] are unavailable.	Low Gas 2035_NS_HC.xlsx sheet D365a_XX_HC_2035

4		[redacted] power station already running		***High gas day***: [redacted] Compressor unavailable on a peak day	High Gas 2035_NS_HC.xlsx sheet *PK_XX_HC_2035*
5	Major event in France, results in the country cutting exports to maintain own security of supply inter connectors cut 80% from 4GW to 0.8 losing 3.2GW of supply.	LNG – [redacted] taking main supply load [redacted] no commercial gas available in storage or ships arriving in period of incident. Already supplying [redacted] and [redacted] already running	[redacted] and [redacted] come on simultaneously rapidly 30minutes after event ramping to full generating capacity in ramp rates exceeding NEXA Gas supplies ramp up to meet increased demand at [redacted].	**All** [redacted] compressor unavailable during event. **LNG Low Gas day:** [redacted] and [redacted] are on outage. ***LNG High gas day***: [redacted] Compressor unavailable **HC Low Gas Day:** [redacted] and [redacted] Compressors are on station outage.	2030 Low Gas 2030_NS_LC.xlsx sheet *DS365a_XX_LC_2030*
6					2030 Cold winters day High gas 2030_NS_LC.xlsx sheet *PK_XX_LC_2030*
7		Continental flows from [redacted] Already supplying [redacted]			Low Gas 2030_NS_HC.xlsx sheet *DS365a_XX_HC_2030*
8					High Gas 2030_NS_HC.xlsx

		and [redacted] PS already running		**HC High gas day:** Line valve fails closed on Feeder [redacted] Somewhere between [redacted] and [redacted]	sheet *PK XX HC 2030*
Note: Figures provided in brackets for the power stations are maximum capacity electricity generated.					

Table 1 - SIMONE Scenarios

Modelling Priority for WP2

The following is based on testing a spread of conditions from across the scenarios and estimation of which of 8 are most likely to cause stress to the NTS:

Modelling Priority	Scenario	Modelling Priority	Scenario
1	5	5	1
2	2	6	3
3	4	7	6
4	7	8	8

Table 2 - Modelling Priority

4.1 Outputs from work package 2

NTS Stress Test

The NTS is considered to have been 'stressed' if the key parameters detailed previously and used here for outputs are breached.

For each scenario run provide results against the following study parameters:

- Summary of scenario implementation, including challenges, adjustments.
- Pass or fail for the modelling run and reasoning.
- Pressure Minimum at power stations (ANOP) pass or fail for the ANOP at the power stations in the scenarios provided.

- Network geography any second or third order consequences across the NTS outside the South East.
- Maximum Pipeline Pressure (MOP) if breached.
- Minimum Pressure at the LDZ exit points by AOP breach.
- Ramp rates applied at the exit point in MW/min
- Operating Margin Trigger – Yes or No.
- Supply point ramp up time (Demand to additional gas supply arriving on the network) impact.
- Local (South East) linepack change for the scenario

5. Appendix: National Gas Compressor Fleet

[redacted]

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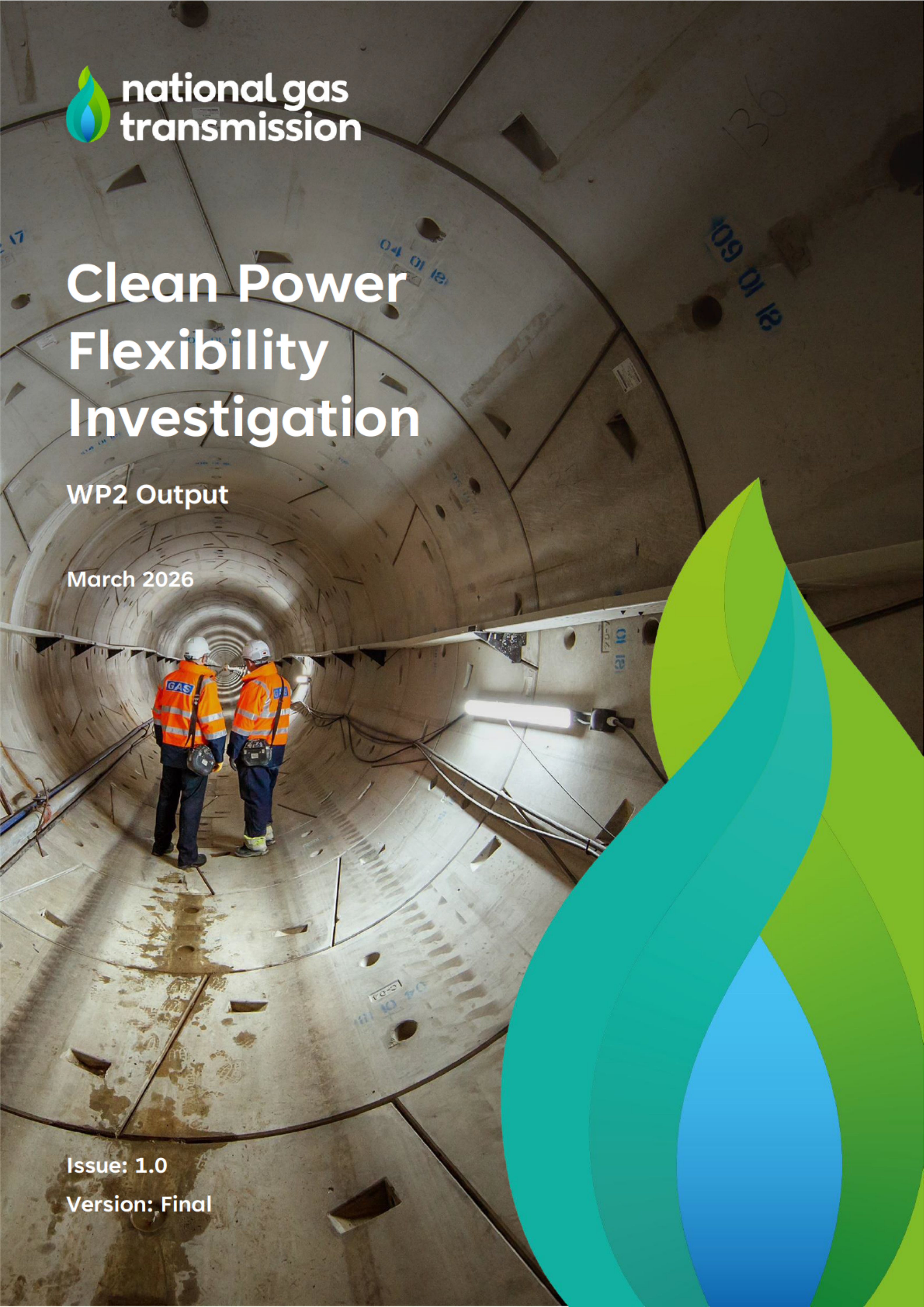


national gas transmission

Clean Power Flexibility Investigation

WP2 Output

March 2026

Issue: 1.0

Version: Final

Contents

1. Scenario Selection & WP1 Outputs

1.1. Scenario Selection

WP1 explored energy system resilience under potential stressed operational conditions, focusing on the impact of peak gaps on the electricity system and how these translate to sudden power station ramping on the gas transmission system. This work created a set of scenarios and assumptions that provided the input for this assessment in work package 2 (WP2). These are provided in the accompanying document: CPFI_WP1_Scenarios and Assumptions_v1.pdf.

The WP2 assessment:

The assessment completed in WP2 focused on the following aspects:
- Utilised power station ramping rates (MW/min) and tested the impact of sudden power station ramping due to a power event on the electricity grid network.
- Tested the impact of two distinct power system events resulting in different ramp profiles.
- Modelled both a high gas day (Peak, PK) and low gas day (D365).
- Minimized local South East (SE) demand to emphasise ramping behaviour effect on network capability.
- Tested scenarios with reduced asset availability.
- Assessed a Low Continental (LC) supply pattern in place of the High Continental (HC), to examine lower SE supplies from [redacted] and increasing supplies from [redacted] [redacted] helping to understand the effect of altered supply distribution.
- All scenarios tested achieve Net Zero by 2050.

1.2. Network Topology & Geography

The Clean Power Flexibility Investigation (CPFI) scenarios analysis focuses on the National Transmission System (NTS) in the South East Area of Britain shown below:

[redacted]

Figure 1. South East Area Showing [redacted] [redacted] *&* [redacted]

The South East is a risk area of the NTS because it is sensitive to supply-demand imbalances due to low linepack, high power demand, restricted local entry flexibility, and few assets to help move gas to the South East. To support this region, a minimum amount of supply is required, thus, where [redacted] supply is unavailable and [redacted] entry is reduced, the region becomes increasingly exposed to pressure drop, particularly at [redacted] which is an extremity. More information on this can be found in <u>CPFI_WP1_Scenarios and Assumptions_v1.pdf</u>

[redacted] supplies have a considerable impact on meeting our extremity pressure at [redacted] In this analysis, we have assumed no gas supply from [redacted].

1.2.1. Pressure Cover at Extremity ([redacted]

Extremities experience the fastest pressure decline during system stress due to pressure drop across the distance of the pipework, limited downstream linepack and restricted local supply. As a result, maintaining sufficient pressure cover is essential to maintain minimum operating pressures during periods of high demand or reduced supply. [redacted] is therefore the key monitoring point for this assessment, as it is expected to experience the lowest pressure compared with any other South East offtakes and serves as the primary indicator of regional resilience under ramping scenarios.

The levels of pressure cover used at the extremity are:

- LP: This is the resilience target pressure under normal operating conditions. It allows the GNCC time to manage events.
- OMP: Operating Margins Pressure, which has been used as the pressure cover in our analysis. OMP is a reduced resilience level, relying on rapid use of contractual measures to respond to events when close to operational capability.
- AOP: Assured Operating Pressure is the lowest pressure NGT is obligated to provide to the DN and represents the lowest pressure required by a GDN network to fulfil their downstream obligations.

In this analysis of the South East;

- [redacted] OMP at 06:00 = [redacted] barg
- [redacted] OMP from 07:00 - 22:00 = [redacted] barg

These values define the minimum pressures required to be met at different times of day to maintain safe and reliable operation at the network extremity in this analysis, when [redacted] compressor station is on.

1.2.2. Actions When OMP is Breached

If the pressure drops below OMP levels, we act to restore network stability by calling on Operating Margin Contracts to obtain additional gas or demand reductions from contracted sources until a longer term solution can be applied.
The OMP levels are informed from pressure cover analysis. For more information, *please refer to WP4 1.5 Problem Definition.*

1.2.3. Rationale for Focusing on [redacted] over Power Stations

[redacted] is prioritised because extremity pressures are breached earlier than those at power stations. For example, at 22:00, OMP requirement for [redacted] is [redacted] barg and [redacted] Station's Anticipated Normal Operating Pressure (ANOP) is [redacted] barg. [redacted] located downstream from [redacted] Power Station on the NTS, and requiring a higher minimum pressure, will hit its threshold sooner. As a result, a failure to meet [redacted] OMP breaches network requirements before any power station limit is reached, making it the leading indicator of system stress and the primary constraint in the region. [redacted] is also prioritised over power stations because the safety implications for maintaining the domestic network are more significant than maintaining power station pressures.

1.3. Initial Modelling

Initial modelling showed that for the low gas days, there were no significant constraints and no pressure breaches, due to the low demand. Therefore, further D365 modelling was deemed unnecessary. Nonetheless, due to the supply response at [redacted] Compressor was required to turn on or speed up alongside other compressor adjustments to manage gas distribution.

For the higher gas days, the 2030 Peak (PK) LC demand day showed lower pressures than 2035 PK LC because of high demand in the 2030 scenario. This 2030 PK LC then formed the basis for the below scenarios in this report, due to it being the most strenuous scenario that achieves Net Zero by 2050. The 2030 PK LC total demand level was 380 mcm/d, and for 2035 PK LC it was 266 mcm/d. The total level of demand for these scenarios comes from the Scenario Design in work package 1. Using a Counter Factual FES Scenario would result in a higher total demand scenario that is unlikely to meet Net Zero, though could incur more serious constraint implications.

1.4. Analysis Scope Changes

- Changes to timings for low demand scenarios. WP1 states power station ramping to start at 18:00 to 18:30. Changed to start earlier (17:00 to 17:30) for the D365 demand days, to coincide with electricity peak demand.
- Removal of some of the D365 days, due to no constraints.
- Removal of high [redacted] flows scenarios, due to lower network stress in these scenarios compared to high [redacted] scenarios. The lower network stress is due to increased regional supplies from [redacted] being able to support [redacted] pressures.
- Addition of Project Union (PU) and Carbon Capture and Storage (CCS), Exit Scenario, [redacted] reconfiguration & [redacted] alternate configuration scenarios.

1.5. [redacted] Configuration

Configuration 1 –

[redacted]

Figure 2. [redacted] Configuration 1 Set-up

This [redacted] configuration does not discharge exclusively towards the extremity at [redacted] In the network conditions as described in WP1 and WP1 Outputs, it would be unlikely that GNCC would use this configuration, likely preferring configuration 2 below. Under this configuration, [redacted] breaches OMP at 21:00, reaching a minimum pressure of [redacted] barg. This could call for an Operating Margin (OM) gas response, although as the OMP level is [redacted] it is a very small breach so the OM gas may not be called based on an anticipated pressure increase as both electricity and gas demand reduce overnight.

Configuration 2 –

[redacted]

Figure 3. [redacted] *Configuration 2*

This [redacted] configuration discharges exclusively down Feeder 27, towards the extremity at [redacted] Under this configuration, [redacted] OMP is not breached with no constraint to the pressure cover at the extremity.

In the most strenuous scenario tested (2030 PK LC), with [redacted] and Grain power stations ramping, if [redacted] compressor is running in configuration 2 before the power stations start ramping, we can meet our obligations. We meet our distribution networks' Assured Offtake Pressures (AOP), the power stations' Anticipated Normal Operating Pressures (ANOPs), while remaining in our pressure, flow and temperature limits throughout the network.

1.5.1. [redacted] Reconfiguration

This scenario evaluates whether AOP can be maintained if [redacted] compressor, initially is operating in its Configuration 1 state, discharging down feeders 3 and 27 (as shown in Fig 2.), then is put into configuration 2 (as shown in Fig 3.), discharging exclusively down feeder 27, as a reaction to the power station ramping.

To reconfigure a station, the pressure across the station must be equal. If the GNCC take [redacted] offline when power station ramping ends (18:30), the hydraulic modelling shows the station takes an hour to equalise the pressure across it. Then, the configuration can be changed, and the compressor can speed up and increase the discharge pressure.

Implementing this results in lower pressures than if the station was left in Configuration 1, but with better recovery pressures at the [redacted] This results in a lower minimum pressure as the pressure across the station equalises, but higher pressures once the station is brought back online.

Both configurations meet our obligations in nominal CP30 operations, without any power station ramping. If configuration 1 were to be used and the power stations ramp up, there would be a minor breach of our OMP Cover. Reconfiguring [redacted] compressor station from configuration 1 to configuration 2 exacerbates the breach instead of mitigates it as the pressure across the station must be equalised before reconfiguring. If [redacted] compressor station is in configuration 2 before the power station ramp up we continue to meet all our obligations.

A part of OMP cover is to provide time to respond to an unexpected increase in power station demand. GNCC may call on OM contracts, or prepare to, in the case [redacted] compressor station is in configuration 1. However, if the power station ramp-up is anticipated, the control room are likely to have pre-emptively moved to configuration 2.

1.6. Project Union & CCS Scenario

The purpose of the Project Union (PU) and Carbon Capture and Storage (CCS) scenario was to assess the impact of PU and CCS reinforcements and repurposing on a CP30 event with a ramp of 1.8 GW at [redacted] Power Station and 1.32 GW at Grain Power Station across 30 minutes. The latest PU topology is identical to our typical NTS model, except for extra valves that were introduced to the network to simulate repurposing and reinforcement of pipelines for PU and CCS operations. There is uncertainty around the exact network topology that will be used in PU/CCS, but this scenario and network reflects our most reliable information for our proposal of repurposed network at the time.

The rest of the scenario set up is the same as the previous scenarios, with the same supply and demand spread throughout the network, with the only change being the repurposed assets.

The scenario during ramp up had an instantaneous peak national demand of 465.64 mcm, a peak South East demand of 94.26 mcm and with a South East entry supply of 68.73 mcm from [redacted] only.

Results:

- No major impact to SE pressures, since no repurposed feeders impact the gas path from [redacted] to South East, which is critical for the South East to maintain its pressures.
- Increased Scotland pressures due to supply response and reduction in north to south transmission from isolated feeders.
- There were no major issues when solving the scenario, as the same strategy used for the non-PU/CCS scenario, resulting in the scenario being solved in one iteration.
- There were no pressure, flow or temperature limit breaches in this scenario (minimum pressures, maximum pressures, Assured Operating Pressure (AOP) or Anticipated Normal Operating Pressure (ANOP)).
- The OMP was met at and [redacted] with minimum pressure of [redacted] barg at 21:15. The minimum pressure at Grain Power Station was [redacted] barg at 21:15 and at [redacted] Power Station the minimum pressure was [redacted] barg at 21:15.

Based on these results it would be reasonable to assume that the control room could respond accordingly in a CP30 event with a PU/CCS network.

1.7. 'Exit', Demand level that causes an issue.

Scenario summary:
The assessment of the simultaneous rapid ramp of [redacted] and Grain power stations in the South East showed no local or system wide demand constraints on the gas network using configuration 2 at [redacted] as noted in 1.5 [redacted] Configuration. The initial scenario modelled a 3.12 GW electricity grid import loss in the South East region under a clean power condition. These initial findings led to further investigation of the exit demands from these power stations that would constrain the gas network applying a method based on NGT's Exit Capability methodology. This involves incrementally increasing the sustained (ramped) demand from both power stations until the network reaches its constraint point.

This scenario retained the setup used in the initial modelling which consists of an intact network with Peak (PK) 2030 LC demand. [redacted] Compressor in the South East is assumed unavailable. Total entry flow at the South East is 68.74 mcm/d, contributed by [redacted] UKCS and Interconnector .

Results:
- Up to 17.2 mcm/d (~4.99 GW power output) sustained (ramped) demand achieved with [redacted] and Grain power stations before reaching a network constraint. This figure reflects Grain power station flowing at its NExA-defined maximum exit rate of 6.2 mcm/d and [redacted] at an exit rate of 11mcm/d (above NEXA defined maximum of 3.99mcm/d), though the expected [redacted] 2 extension does not yet have a defined NExA. Exit demand from these power stations above combined 17.2 mcm/d results in a 06:00 OMP breach, the morning after the ramp-up. As noted in section 1.2.1, the OMP is a crucial limit to which the gas network is planned and operated. Breaching this limit signifies that the network is operating without appropriate cover to manage an unforeseen event.
- As noted above, [redacted] power station is flowing above its NEXA-defined maximum.
- While managing linepack levels during the event response, entry constraint at [redacted] was triggered as it is absorbing the main LNG supply response load. As a result, additional supply response gas was sourced from the St Fergus terminal, selected for its low level of local system interaction, to ensure that minimum supply levels in the South East were upheld. The combined supply response of both [redacted] and St Fergus was used to prevent over pressurising [redacted] terminal. This finding is important as the scenario assumes that [redacted] terminal can support the required LNG supply load during the power event. This finding supports the need case for infrastructure upgrades at [redacted] as already identified by the West Import Resilience Project (WIRP). This will enable the terminal to accommodate higher LNG entry flow as expected in the coming years. See section 4 for more on WIRP.

1.8. [redacted] Minimum Supplies

Our analysis suggests that we require a higher minimum level of [redacted] supplies (either UKCS or Interconnector) or additional infrastructure in the South East to bring gas from other parts of the network, to meet a lower level of demand, with zero [redacted] supplies, due to the unexpected ramp-up of the South East power stations.
The level of [redacted] supplies has an important impact on meeting South East demand and maintaining pressure at our extremity. This will become more important as power station behaviour becomes more volatile.

The following information comes directly from the relevant Simone scenarios.
To solve the 2030 PK LC scenario with South East power stations ramping up scenario, with zero supply from [redacted] terminal, [redacted] minimum supplies would require approximately 65 mcm/d at [redacted]

Ramping [redacted] Min:
The pre-event level of South East demand is 79.23 mcm/d, then after the power stations have ramped up their demand, the new South East demand is 88.37 mcm/d. To solve this, there must be at least 65 mcm/d of supply from [redacted] terminal. This was solved to a ±2 mcm/d sensitivity, showing that 63 mcm/d supply from [redacted] would breach [redacted] OMP.

No ramping [redacted] Min:
Similar analysis has been done to investigate the minimum level of necessary supplies for a 2030 Counterfactual, HC scenario, with zero [redacted] supply and typical power station behaviour. The results from this show that 63 mcm/d is required from [redacted] to meet a South East demand of 103.70 mcm/d.

This shows that, although the total demand is lower in the CP30 scenario compared to a typical power station behaviour scenario, the minimum required supplies from [redacted] (with the existing NTS infrastructure) is higher due to the power station ramp-up.

2. Results Summary

For the scenarios tested above, the NTS can absorb the impact due to sudden power station ramping, if there are sufficient local supplies in the South East, or low enough South East demand. It is vital to recognise the high-risk supply patterns and prepare accordingly. [redacted] compressor station is a key compressor for meeting our extremity pressure at [redacted] and the configuration choice has a significant impact.

Key Findings:

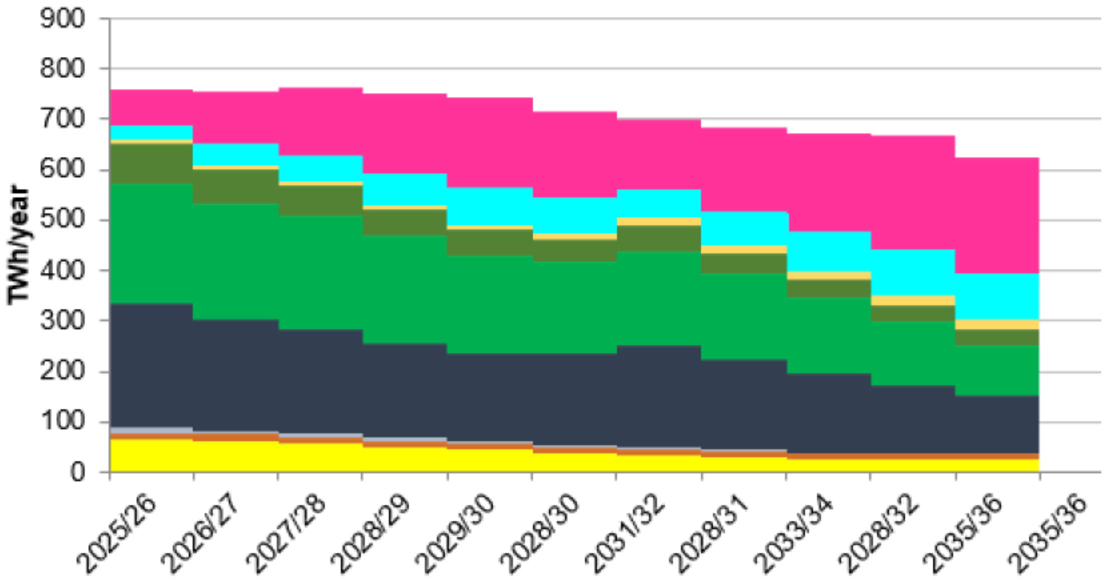
- The main contributing factor to whether we meet pressures is local supplies, which is true for the current network.
- [redacted] configuration 2 can maintain pressure at [redacted] above the OMP.
- No power station ANOPS failed from the scenarios detailed in WP1.
- [redacted] Configuration 1 breaches OMP.

- Reconfiguration at [redacted] reactively does not improve OMP in comparison to maintaining the Configuration 1 in the occurrence of the power event.
- PU & CCS topology does not greatly impact the SE.

One key point is that in the network modelling we have conducted we can take multiple tries to solve the constraints, but in the control room (GNCC) there is only one opportunity at the start of the power event to manage and obtain the best network stability. The GNCC has modelling available to them to help inform their decisions, but the decisions are also time sensitive.

In conclusion, our analysis indicates we can meet threshold pressures at NTS offtakes while remaining within the various limits across the network. The level of regional supplies is very important to the NTS' capability to meet South East demand. This is also true under current network conditions, with less volatile power station behaviour, but with more intermittent and unpredictable power station behaviour, the importance of these regional supplies increases. The impact of intermittent renewables causing unpredictable power station behaviour has the potential to exaggerate existing issues in the South East requiring a minimum level of regional supplies to meet gas demands.

Supplies from continental Europe are expected to be available primarily during periods of very high demand, when sufficient price differentials exist between the GB and EU gas markets. Figure 5 shows the expected supplies from [redacted] Interconnector ([redacted] IP) in the Gas Ten Year Forecast, low continent case, demonstrating that very few supplies are expected. Local supplies from [redacted] could support the South East, in place of declining [redacted] flows, though the volatility of the global LNG market may impact the consistency of these supplies.



[redacted]

Figure 4. Annual Supplies by terminal. Gas Ten Year Forecast High LNG/Low Continent case.

3. Previous NGT Analysis

Previous Clean Power 30 based analysis at National Gas Transmission (NGT) examined power station ramping and the NTS response under different scenarios. Key assumptions included:

- The South East accounting for 30% of total power station demand,
- reduced [redacted] supply (both UKCS and interconnector),
- supply response proportional to pre-ramp supply,
- power station ramp-up proportional to pre-ramp demand.

The Scenarios tested were:

- Peak (Cold Winter's Day) with all assets available
- D46 (Shoulder Month ~ March) with Shoulder Month level of medium maintenance
- D300 (July) with Summer high level of maintenance.

The results of the previous NGT analysis were largely shaped by the timings used, the power demand assumptions, and the sources of supply response. The level of power station ramping modelled in this analysis represents an extreme stress case rather than an expected operational outcome. The assumptions were intentionally selected to identify network constraint points and understand NTS performance under severe operating conditions. Although not representative of normal operation, the analysis provides valuable insight into network resilience and operational response requirements.

We tested an extreme level of power station ramping across the network and assessed the resulting system impacts, examining the effects of delayed supply response, modelling delays of 2, 4, and 6 hours.

Key Findings:

- Post-event pressure recovery, for example, in the D46 scenario with 6 hour delayed response caused breaches at the 06:00 pressure for some LDZ offtakes
- [redacted] maintained AOPs for all scenarios. OMPs remained within the limits outside of 06:00 breaches.
- The impact of delayed supplies had a greater effect on entry constraints than exit constraints, as shippers try to balance before the end of the gas day. The exit constraints did not greatly worsen where compression was reactively be established.
- Some power stations may not be able to flow if they are needed to come on if the pre-ramp pressures are too low, without the correct amount of notice as defined in the power station's NExA (Network Exit Agreement).

4. Other Relevant Projects

This modelling assesses the NTS as it is now, there are relevant projects that are investing into key areas of the network that will impact how the network will operate once they are complete. These are listed below, with the expected outcomes of the project.

The South East Resilience Project (SERP):
This project aims to enhance the South East's gas network for both exit and entry capacity, with expected output impact being able to boost [redacted] pressures depending on the final option chosen.

The exit investment entails an increase in Grain Power Station baseline, and as part of the preferred option for Grain PARCA. The intent is to invest to reduce the pressure drop in the region, which in theory allows us to meet the OMP at [redacted] whilst increasing exit capability in the South East.

The entry investment in this project focuses on addressing future supply shortfall in the South East during the winters of 2027/28 and 2027/29. The proposed option is a [redacted] reversal, which will allow increased flows from [redacted] terminal.

West Import Resilience Project (WIRP):
WIRP aims to upgrade infrastructure to increase capability to facilitate increasing LNG imports arriving at [redacted] The main work involves building two new pipeline sections in Warwickshire and Worcestershire (9 km [redacted] Honeybourne, 2 km [redacted] Compressor–[redacted] Multi-junction) and connecting them to existing stations with effective compression. Most work will be in rural areas with minimal disruption. The timeline for construction aims to start Autumn 2026 and complete by end of 2028, ensuring the network can meet future gas supply and demand patterns in South Wales and beyond.

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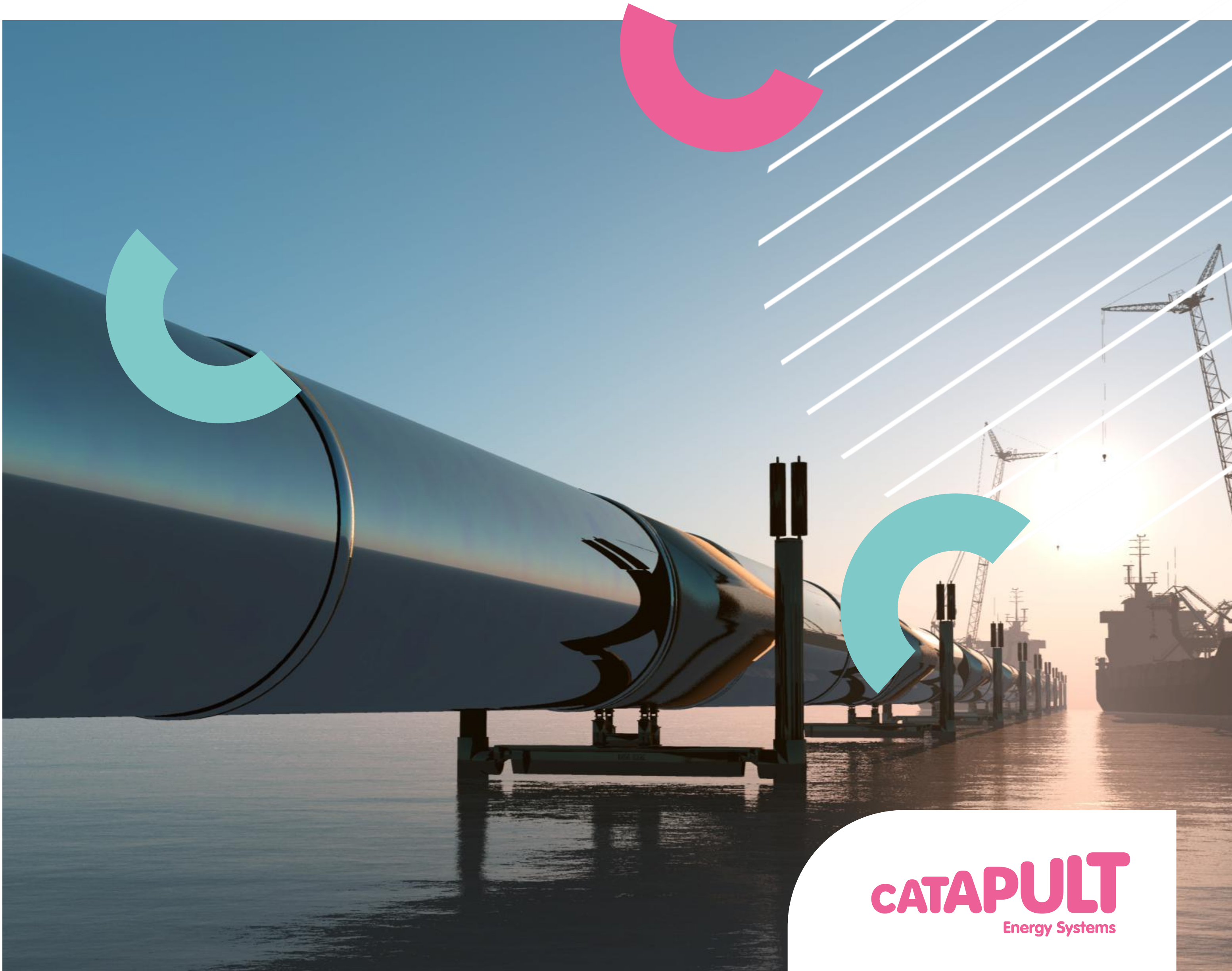

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Clean Power Flexibility Investigation: Gas and Electricity Systems Assessment

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Date: July 26

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Contents

1. Executive Summary

As part of the Clean Power Flexibility Project, the objectives of this work package were to examine the interdependencies between the gas and electricity systems under potential stress conditions defined in previous work packages[1]. The aim was to understand how evolving electricity system flexibility requirements could impact on the gas network and, in turn, impact the wider energy system.

A structured systems engineering approach has been applied to capture where the gas system is relied upon by the electricity system to meet peak gaps identified in work package one[1]. This analysis has used the peak durational gap, known as a 'Dunkelflaute', as a representative operational scenario to explore system level interactions. From this, potentially critical periods and locations for gas electricity coordination have been identified.

This analysis has used two methods: analysis of a **System of Systems Map** and **systems dynamics** analysis of a system. The former was used to identify key structural relationships between the gas and electricity systems and how interactions ripple through the systems. The latter has identified key feedback loops which helped to inform discussion of system archetypes and emergent behaviours that can be present in these system dynamics.

Combining these two approaches, identified potential constraints in four areas:

Gas transmission **physical infrastructure** elements and interfaces that could combine to result in system constraints system during periods of high energy demand and low renewable electricity generation, when reliance on gas-fired generation increases. As an example, the system dynamics analysis illustrates the chain of infrastructure, system elements, that are required to respond to a peak gap. The explicit visibility of the relationships enables a systems level assessment of the risks and mitigation options. E.g. for a Dunkelflaute this could be enhanced gas storage and compression, long-duration electricity storage, demand-side response, and increased firm low-carbon generation.

Operational constraints between gas and electricity networks limit real-time coordination between gas and electricity systems despite NESO's new dual system planning role. While NESO is responsible for strategic planning across both vectors, day-to-day system operation remains distributed across separate organisations and control rooms, with the Electricity National Control Centre balancing the electricity system and the Gas Network Control Centre balancing the gas system. Each control room operates within different operational, commercial and physical frameworks. The electricity system requires continuous balancing on sub-second to minute

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[1] This is work package 3 of 5 within the Clean Power Flexibility Project (CPFI). Outputs from all work packages have been provided to National Gas Transmission as a pack at the end of the project. Please refer to this pack for references work package outputs.

timescales to maintain frequency and system stability[2], whereas gas system balancing relies on linepack, nominations and network control actions that typically evolve over hours and across the day. These differences constrain integrated responses to fast-moving system stress events and increase the importance of forecasting, advance warning and shared situational awareness. While NESO's remit improves whole-system risk assessment and strategic emergency planning, there is not yet an updated National Emergency Plan setting out its role within coordinated gas and electricity emergency response and coordination. Further resilience gains are likely to require updated whole system emergency frameworks, shared situational awareness tools, joint exercises between ENCC and GNCC, enhanced cross-vector communication protocols, and more integrated modelling and control capabilities.

Market shortfalls arise from a heavy reliance on gas-fired generation within the Capacity Market, tightly coupling electricity security to gas supply availability. Limited gas storage capacity[3] and declining domestic production, increase exposure to prolonged stress events and import dependency. Improving resilience requires greater diversity of dispatchable low-carbon generation, more modular system design, strengthened incentives for seasonal storage, and measures identified to address infrastructure bottlenecks.

Policy and regulatory gaps mean the UK energy system is optimised for cost and performance under normal conditions rather than resilience during extreme stress events. Market frameworks undervalue assets that provide endurance and flexibility, most notably gas storage, leading to underinvestment and increased exposure to prolonged supply disruptions. While capacity and emergency arrangements ensure short-term adequacy, they do not fully address common fuel or infrastructure risks. Strengthening resilience requires clearer regulatory recognition of security and flexibility as distinct system needs, better valuation of endurance and diversity, and closer alignment between long-term planning and emergency arrangements.

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[2] The electricity system has sub-second balancing mechanisms whereas, although the gas system is monitored on a constant basis, its balancing is over hourly to daily timeframes.

[3] https://www.gov.uk/government/publications/statutory-security-of-supply-report-2024/statutory-security-of-supply-report-2024. The UK currently rely on imports and have smaller storage (relative to other European countries), In times of energy system stress (i.e. climatic conditions which might stress our energy system as well as, say that of France) Suppliers may be less likely to share their energy resources to keep their own country resilient even if there are agreements in place to do so.

2. Introduction

This report has been written to present an assessment of the system interactions between the gas and electricity networks to analyse times of potential system stress. It forms the deliverable for Work Package 3 of the Clean Power Flexibility Investigation project by the Energy Systems Catapult (Catapult) for National Gas Transmission (NGT).

The objectives of this work package were to:

- Examine system inter-dependencies between the gas and electricity systems under potential stress conditions identified in previous work packages.
- Understand how evolving electricity system flexibility requirements could impact on the gas network and, in turn, impact the wider energy system.
- A structured systems engineering approach has been applied to capture where the gas system is relied upon by the electricity system to meet peak gaps identified in work package one
- Examine representative operational scenarios such as low renewable output coinciding with high demand or sharp ramping requirements on cold days. The focus will be on identifying system-level impacts, such as capacity stress on electricity networks, risk to security of supply, and vulnerabilities in operational coordination, should the gas system be constrained or unresponsive.
- Understand how evolving electricity system flexibility requirements could impact on the gas network and, in turn, impact the wider energy system.

To deliver these objectives, the systems engineering and systems thinking approaches introduced in work package 1, shaped the approach of this work package. A structural assessment of the system interactions has been explored using a previously developed Catapult asset called the System of Systems Map. An aspect of these interactions has been selected for further exploration using the system dynamics tool of causal loop diagrams. With additional research conducted to develop a deeper understanding of these system dynamics and interactions.

System of Systems Map

The System of Systems (SoS) map was developed using Model-Based Systems Engineering (MBSE) to provide a wide understanding of the complete Energy System in Great Britain (GB), with additional detail being added to constituent systems on a regular basis. *Figure 1* shows the systems that have been defined within the SoS Map to make up the GB Energy System. As can be seen, this is broad ranging and was based on the Climate Change Committee UK economic sectors. The map contains detailed information on the energy system and associated sub-systems. Given this depth of detail, this was used to approach identification of gas transmission system stress from the perspective of the electricity system, then trace back to impacts on the gas transmission system.

The System of Interest for this Discovery phase has been defined around the interaction between gas and electricity systems. However, it is clear that there will potentially be impacts from other systems in times of stress and further exploration into these can build on this initial assessment.

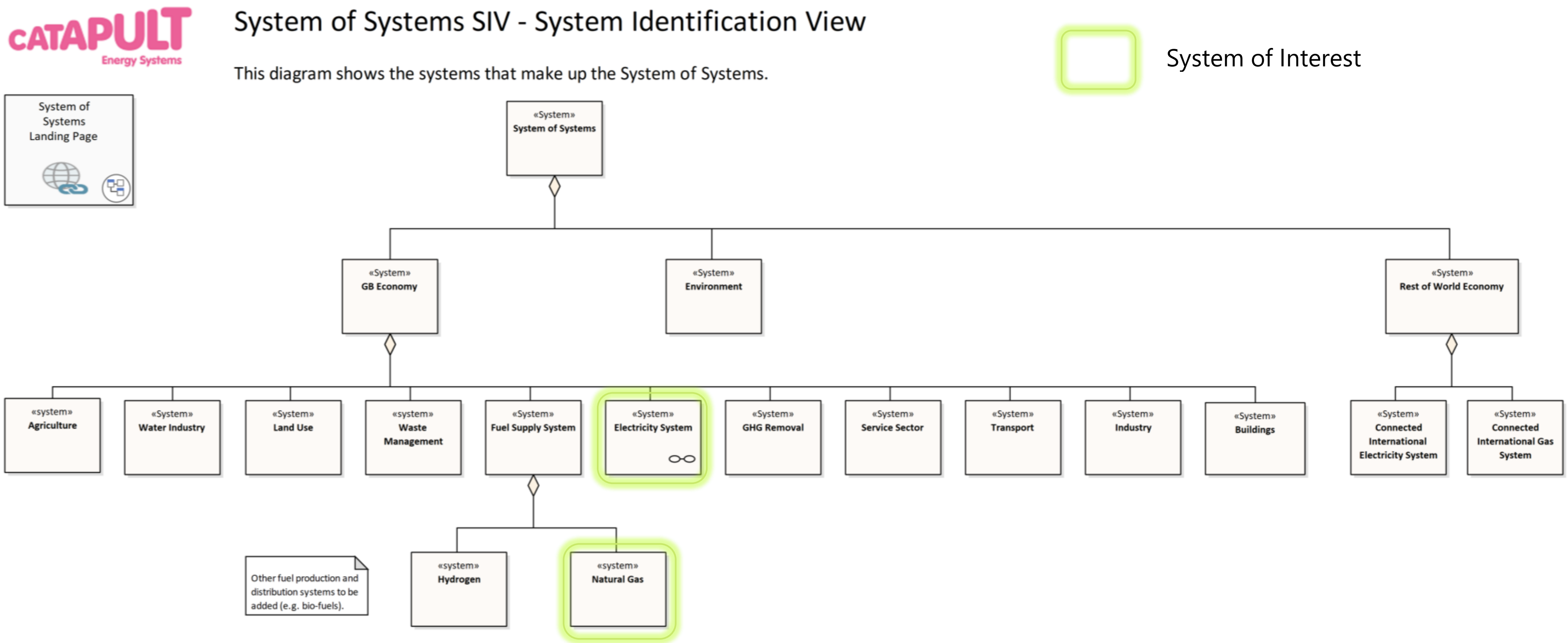

Figure 1 Diagram illustrating the systems which make up the GB Energy System defined in the SoS Map

3. System Structural Assessment

3.1 Methodology

An analysis of the Catapult's System of Systems (SoS) Map[4] has been conducted in order to understand the operational interdependencies between the gas transmission and electricity systems under stress conditions and network constraints. In addition to the challenges, areas from which potential solutions could be found have been identified. For discussion of the analysis captured in this section these have been categorised into the following aspects for each sub system: Physical assets, System operation and Market operation.

3.2 Electricity Transmission System

Diagrams from the SoS Map showing gas transmission system interactions within the electricity transmission system are provided in *Figure 9* and *Figure 10*. The areas in red highlight where there is gas demand for the electricity system and, therefore, where stress scenarios may impact on the gas and electricity systems. The areas in green highlight spaces for potential solutions.

3.2.1 System Impact

Physical Assets

On the electricity transmission system connected generation potentially affected by constraints in the gas network include supply of electricity from:

- large (100MW to 3GW) and medium (20MW to 100MW) combined cycle gas turbines.
- medium (20MW to 100MW) open cycle gas turbines. Although rare in the UK, some of these run as combined heat and power plants with a heat exchanger drawing off medium grade heat transfer fluids/gases typically for industrial processes thus having a potential impact on their operations[5].

System Operation

Whilst these stress scenarios would clearly affect electricity generation and therefore energy supply, there are also other services which gas generators can contribute to

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[4] an internal Catapult asset which maps the hierarchical and relational structure of the energy system using Model-Based System Engineering (MBSE)

[5] VPI Immingham, *Immingham solution overview*. VPI, Immingham, n.d. Available at: www.vpi.energy/solutions/immingham

stable operation of the electricity network. Prior to the 2020s, qualities of electricity supplied by the network such as stability of frequency and voltage were stable since it was a by-product of the thermal (coal, natural gas and nuclear) power plants connected to the electricity grid. As the UK decommission and retire thermal generation plants the electricity system has lost the larger synchronous machines connected to the grid. Therefore, the electricity system operator, NESO, is required to procure 'stability services'.

The types of services that gas generators, with CCGT typically being slower to respond to a service request (in the order of minutes) and OCGT (able to respond in seconds), can now offer include:

- **Energy (MWh):** bulk active power to meet demand and sell in wholesale markets / balancing mechanism.
- **Capacity (Capacity Market / firm availability)**: guaranteed deliverable capacity to meet winter peaks (Capacity Market contracts). Generators bid to provide capacity and get availability payments.[6]
- **Inertia:** The rotating mass of turbines provides kinetic energy, resisting frequency drops and stabilizing the grid, a service traditionally from fossil fuels and nuclear, now separately procured.
- **Frequency Regulation:** By quickly adjusting output (or spinning without load), steam turbines within gas generators help match supply and demand, keeping grid frequency stable.
- **Voltage Control (Reactive Power):** They supply reactive power to maintain voltage levels, crucial for overall system reliability.
- **Spinning Reserve:** Turbines can run at partial load, ready to rapidly ramp up if another generator trips, ensuring immediate backup power.
- **Grid Firming:** Gas plants can quickly fill gaps left by intermittent wind and solar, ensuring consistent power supply.
- **Short-Circuit Level:** Providing this helps grid protection systems respond correctly to faults.
- **Black Start Capability:** Some gas plants can help restart parts of the grid after a total blackout.

Other solutions may be needed to maintain this reliability of the grid if gas supply is disrupted.

Beyond the electricity transmission system, impacts can be noted to:

- Transmission connected customers such as industrial and rail sectors.
- Grid supply points for electricity distribution.

The impact on these sectors could be explored as further work.

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[6] Utility Week, *Gas turbines begin providing grid inertia service*. Utility Week, London, n.d.

3.2.2 Solution Space

Physical assets

At transmission level potential areas of technologies for mitigation of these impacts could come from the following technologies:

- grid scale batteries.
- pumped hydro with turbine.
- subsea interconnectors.
- nuclear generation.
- bio-energy generation
    - coal retrofit pulverised coal plants (GB has no operational coal plants).
    - bio-dedicated steam cycle.

Other areas not flagged in this diagram include options such as hydrogen and biomethane for electricity generation.

System Operation

Stakeholders**:**

- National Energy System Operator (NESO)'s main role is to be an independent, whole-system planner and electricity system operator for Great Britain's energy system, covering both electricity and gas. NESO have an interest in the interactions between gas and electricity system to plan for the required markets and mechanisms to support the network's operations.
- Actions that maintain grid stability will be controlled by the Electricity Transmission Network Owners e.g. National Grid, SPEN and SSEN with interactions needed with the connected market platforms.

Responses will be controlled through the:

- Electricity System Operator Control Centre (ENCC) – main function is to balance the national demand and supply of electricity and is operated by NESO.
- Transmission Network Control Centre (TNCC) – main function is to manage the transmission system assets to ensure reliable system operation and is operated by National Gas Transmission.
- Gas Network Control Centre (GNCC) – main function is to balance gas supply and demand 24/7, operating network assets to ensure safe, reliable gas delivery across the country and support the energy transition and is operated by National Gas Transmission.

Market Operation

The control centres operate through the following market platforms:

- ENCC requests services through:
    - Balancing & settlement platforms
    - Electricity wholesale market platform
    - Capacity market platforms
- TNCC requests services through:
    - Transmission network services market platform

3.3 Electricity Distribution System

Although the gas transmission network is not directly linked with the electricity distribution systems, analysis has been included here to consider how cumulative impacts on the distribution system could influence system flexibility requirements.

Figure 11 and *Figure 12* are diagrams from the SoS Map showing interactions within the electricity distribution system. The areas in red highlight where there is gas demand for the electricity system and, therefore, where stress scenarios may impact on the gas and electricity systems. The areas in green highlight spaces for potential solutions.

3.3.1 System Impact

Physical Assets

At the distribution level in the electricity system connected generation potentially affected by constraints in the gas network include:

- Reciprocating gas engines with an average size of 8MW[7]
    - Across Great Britain there are several gigawatts of non-CCGT gas generation (open cycle gas turbines and reciprocating engines) secured in the Capacity Market (around 7–8 GW), much of which consists of smaller flexible units that are likely distribution-connected. Industry data indicates existing distributed gas engine fleets of hundreds of megawatts, and embedded generation now accounts for a significant portion (~23%)[8] of overall generation capacity. Taken together, this

[7] Frontier Economics, *DECC DSR phase 2 report*. UK Government (DECC), London, 2015. Available at: https://assets.publishing.service.gov.uk/media/5a7f2868ed915d74e6228bd9/rpt-frontier-DECC_DSR_phase_2_report-rev3-PDF-021015.pdf

[8] National Energy System Operator (NESO), *What is embedded generation and transmission-connected generation?* NESO, London, n.d. Available at: www.neso.energy/energy-101/electricity-explained/how-electricity-generated/what-embedded-generation-and-transmission-connected-generation

supports an estimate of multiple gigawatts of gas engine and OCGT capacity on the distribution network."

- Small (0.5MW to 20MW) and medium (20MW to 100MW) open cycle gas turbines. More so than on the transmission network, the otherwise waste heat is utilised as Combined Heat and Power (CHP) into either heat networks or for industrial process demand.

System Operation

Similarly to the transmission network, the distribution network also now requires grid stability services to maintain voltage, constraints and local firmness with energy, frequency, inertia, reserves and black start managed by NESO at transmission level.

Other solutions may be needed to maintain this reliability of the grid as the system evolves.

3.3.2 Solution Space

Physical assets

At distribution level potential areas of technologies for mitigation of these impacts could come from the following technologies:

- Storage:
    - compressed air with turbine
    - distribution scale battery
    - gravity energy storage
    - flywheel electricity storage
- Diesel and heavy fuel oil:
    - reciprocating engine generator - diesel
- Energy from waste plant
- Close coupled gasification
- Hydrogen generation
    - small OCGT hydrogen
    - solid oxide fuel cell generator
    - reciprocating engine generator - hydrogen
    - PEM fuel cell generator

Other areas not flagged in this diagram include options such as bio-methane for electricity generation.

System Operation

Stakeholders**:**

- Action will be required from the Distribution System Operator (DSO), which is currently a specific function within the Distribution Network Operator (DNO) organisation, with interactions needed with the connected market platforms.

Responses will be controlled through the:

- Distribution Network Operator Control Centre (DNO-CC)

Market Operation

Grid services that a gas supply disruption would impact include:

- DNO-CC requests services through:
    - Distribution Network Services Market Platform
    - Local Energy Market Platform (where it exists)

3.4 Electricity system impact on the gas transmission.

Whilst the direct interaction points between electricity system and gas transmission system remain fairly straight forward in the connection points at the gas fired power station, the complexity of the electricity system is evolving rapidly. Additionally, the need for the energy system, as a whole, to decarbonise, creates a challenge for the gas system to solve. This complexity introduces emerging mechanisms by which gas transmission infrastructure, markets and system operation will need to respond to changes in the electricity system. The systems map has provided an indication of the individual mechanism, but also how mechanisms could combine to prompt flexibility demands from electricity transmission and distribution systems. As clean power 2030 is implemented and the electricity system evolves, the mapped system and interactions will evolve potentially changing where the triggers for gas fired power generation may manifest. In addition to the characteristics of that trigger.

3.5 Limitations and Next Steps

The System of Systems Map, on which this structural assessment has been based, has mainly been developed in the Electricity System to the desired depth and breadth.

Therefore, the limitation of this study is that it looks primarily at the Electricity System (gas consuming elements which produce electricity such as gas turbines are considered as part of the Electricity System and the Gas System). A next step would be to explore the Gas System to the same breadth and depth and map this out within the SoS Maps to have a clear detailed picture of the system of interest and interactions. This would give a strong foundation from which to deeply assess the cross-sector and cross-vector interactions on which to build future analyses from. Additionally, stresses from other systems (Buildings, Water, Transport, etc.) could be explored by developing the SoS Map further in these areas. Analysis of this system map has been used as the base of the system dynamics assessment that follows.

4. System Dynamics

4.1 Methodology

There are various ways of exploring system dynamics. The one we have used in this analysis is causal loop diagrams. Aspects of the electricity and gas systems alongside exogenous factors (such as weather) have been mapped to see how they interact.

The modelling methodology is 'simple' (see *Figure 2* for details) but, with considered application, can reveal fundamental system dynamics such as reinforcing feedback loops and balancing loops with the interaction of these loops forming system archetypes. These loops and archetypes can then be interpreted to understand structural system behaviours, issues and potential solutions.

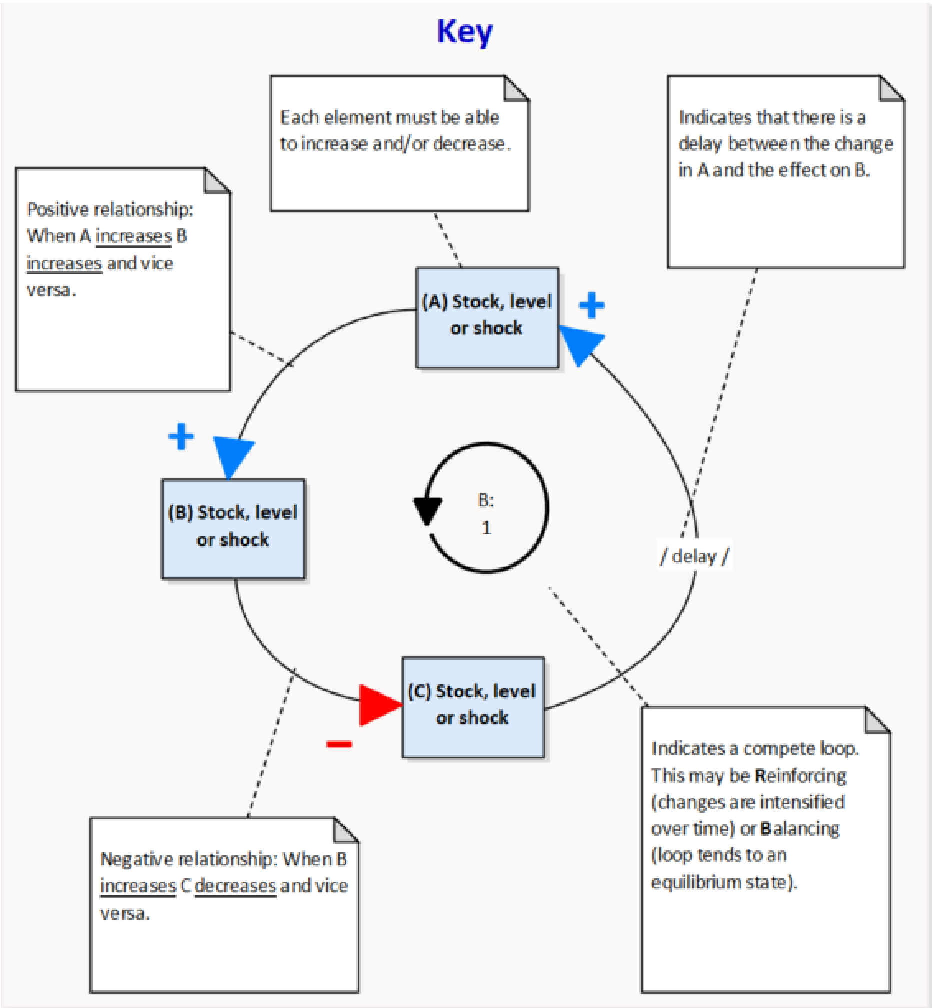

Figure 2 Key for causal loop diagrams

4.2 Causal loop diagram – Dunkelflaute scenario

Work package 1 explored the proposed four peak gaps between electricity demand and supply. The focus of that work package and the gas network modelling in work package 2 has been the instantaneous peak power gap. Another gap identified as of interest to NGT is that of the peak durational gap. To extend coverage of the peak gaps, the Dunkelflaute is explored here and illustrated in *Figure 3*.

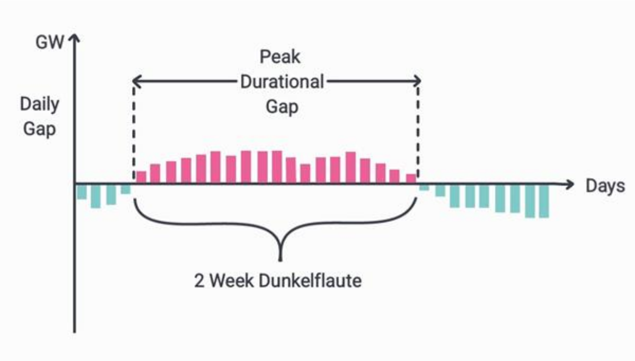

Figure 3 - Peak Durational Gap

A peak durational gap for the GB electricity system is caused by a persistent high pressure weather condition, typically found in winter. With the results shown in the causal loop diagram shown in **Error! Reference source not found.** Three main impacts to electricity and gas systems have been modelled including:

- Decreased ambient temperature (the opposite is true in summer).
- Decreased wind speed.
- Decreased solar irradiance.

Exogeneous factors such as industrial electrification and data centre growth have also been modelled.

4.2.1 Interpretation

In order to understand what emergent behaviours the system might exhibit, identification of feedback loops and system archetypes[9], an established Systems Thinking methodology has been used. The following section reports on some of the behaviours which may emerge from these system dynamics.

[9] The Systems Thinker, *Systems archetypes basics*. The Systems Thinker, n.d. Available at: www.thesystemsthinker.com/wp-content/uploads/2016/03/Systems-Archetypes-Basics-WB002E.pdf

Feedback loops

A **reinforcing loop** is a process where a change in one direction is compounded, causing more change in the same direction (e.g., compounding interest, population growth).

A **balancing loop** is a process that resists change in one direction by producing a change in the opposite direction, bringing a system to a desired state.

Three key loops have been identified:

1. A balancing feedback loop around gas plant dispatch and the impact on gas linepack.
2. A reinforcing feedback loop around reliance on gas plant dispatch.
3. A reinforcing feedback loop around electricity supply for gas compressors.

4.2.2 System Archetypes

These are patterns of feedback loops which have been found to exhibit particular behaviours and have then been formalised into these "system archetypes"[9].

Archetype - Limit to Growth

Classic "growth hits a hard limit" structure. Limiting factor and reinforcing feedback loop combining around the gas linepack, network pressure and operable gas plant capacity results in "Limits to Growth" archetype.

How this plays out:

- Gas dispatch initially stabilises the system during a Dunkelflaute scenario.
- Physical gas constraints eventually cap or reverse growth.
    - These physical constraints are more related to gas supply, rather than size of infrastructure (primarily pipes) which is ample in capacity.
- Also, moving gas around the network to meet changing demand profiles may become an emerging issue as gas has to flow through the system in a different way than would historically be typical. This is explored in detail in work package 2 by National Gas Transmission[1].
- Collapse can be abrupt due to minimum pressure thresholds
    - This is likely to be an abrupt shut-off from equipment connected to the gas network which need to operate within specific operational bands, rather than of the network itself.

There is another potential limit to growth archetype around the same linepack focal point with reduction in grid supplied electricity potentially impacting on electricity supply for gas compression units on the gas transmission system. Though many of NTS gas compressor stations have back-up electricity on site to mitigate reliance on electricity supply.

Archetype - Shifting the Burden

Short-term relief undermines long-term resilience.

The symptomatic solution in this scenario is to dispatch more gas during low-renewable periods. This potentially has the result of reinforcing the gas-dispatch loop, crowding out alternatives leading to a dependence on gas deepening over time.

Other solutions (which have not yet been included in this causal loop diagram) may include areas such as long-duration electricity storage, demand response and firm low-carbon generation (as identified through the SoS Map exploration.)

Archetype - Tragedy of the Commons

Market prices alone fail to protect the common resource.

Competing users such as gas power plants, space heating demand, industrial gas demand and residual electricity demand compete for linepack and gas network pressure. The outcome of this is that these competing individuals increase gas withdrawals and collectively deplete the pressure margin.

4.3 Limitations and Next Steps

Given the time available in this Discovery phase, only part of the system was modelled using causal loop diagrams. This was also focussed on weather conditions within the winter months driving a Dunkelflaute event.

As potential next steps:

- Exploring other stress scenarios beyond Dunkelflaute
- Too build a broader understanding of the system dynamics addition of other aspects of the interacting systems could be modelled.

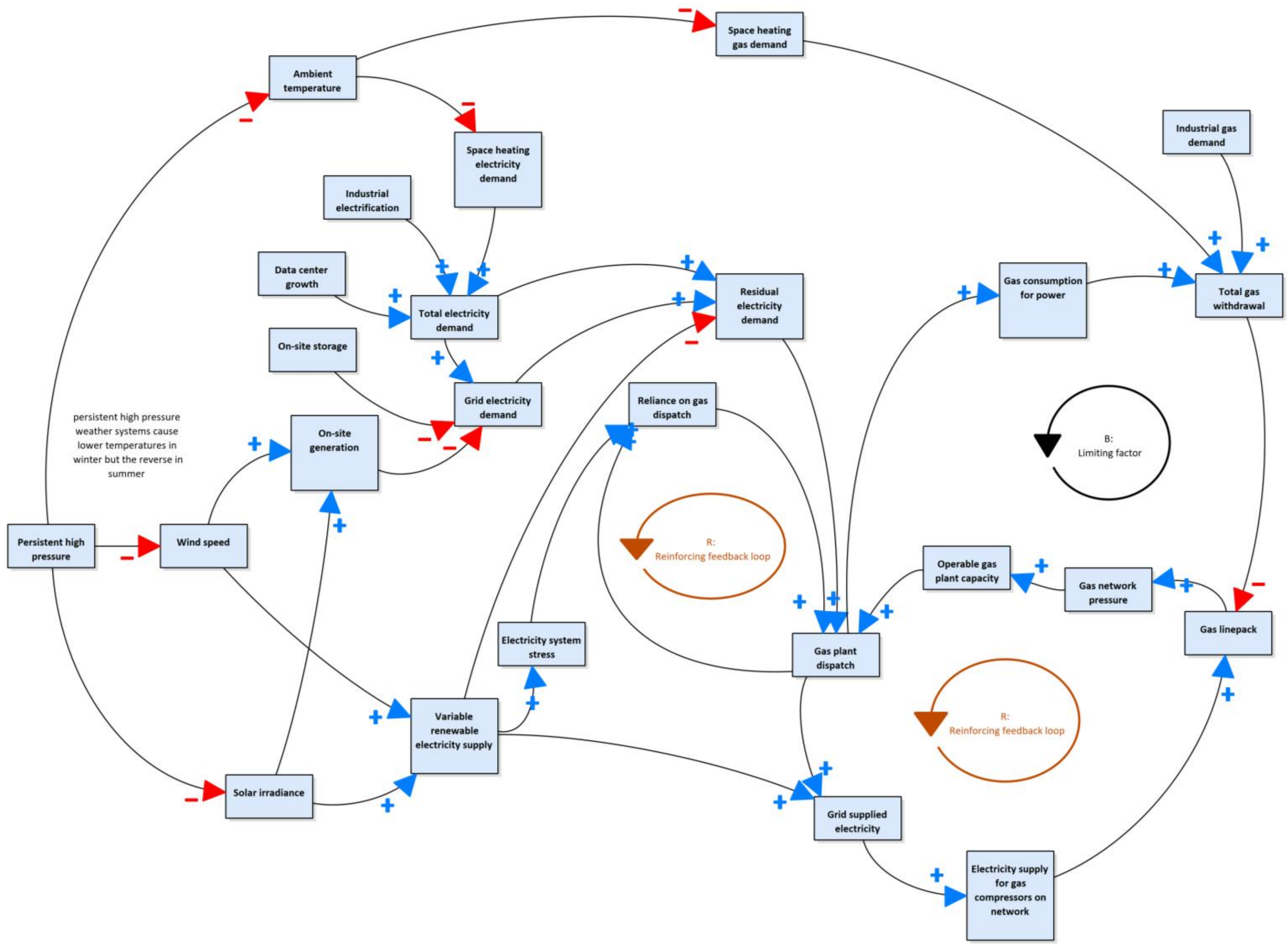

Figure 4 Causal loop diagram exploring Dunkelflaute event

5. Discussion

The following section consolidates the System Structural Assessment and System Dynamics sections and builds on them with additional research to give an overview of the risks and potential mitigations for the electricity and gas systems to provide greater resilience in high stress scenarios. This has formed the basis for the System Resilience Overview.

This overview is presented through the following perspectives:

- Infrastructure bottlenecks: regions where reduced gas infrastructure limits response to electricity system needs or correlates with renewable shortfalls.
- Operational constraints: limitations in how gas and electricity control centres coordinate responses to rapidly emerging stress events.
- Market shortfalls: lack of clear commercial signals that value fast-ramping gas generation or support maintaining readiness of dual-fuel assets.
- Policy and regulatory gaps: where existing network or market regulations disincentivise investment in assets that offer infrequent but critical resilience functions.

5.1 Infrastructure bottleneck

Risk	Mitigation
In periods of high heat demand and low renewable generation (Dunkelflaute scenario), electricity and gas demand go up and electricity supply goes down, simultaneously resulting in an increased demand of gas plant dispatch and gas withdrawal from the network. All of these effects can come together resulting in additional daily linepack use. A significant number of Assured Offtake Pressures (AOP) for Local Distribution Zone (LDZ) are set at 38barg[10]. Gas turbines, such as OCGT and CCGT, typically need fuel gas pressures from 20 -60bar[11]. As well as the higher end of this range being greater than supply to LDZs, tighter tolerances are	Potential mitigations include: • Increasing gas storage and compression capability for gas turbines • Understanding the capacity, value and cost of further utilising gas linepack flexibility • Long-duration electricity storage • Demand side response to allow time critical supply to be maintained • Firm low-carbon generation such as hydrogen, nuclear, hydropower (with storage or run-of-river with reservoirs) and bioenergy.

[10] National Grid, *Gas Ten Year Statement 2017*. National Grid, London, 2017. Available at: www.nationalgrid.com/sites/default/files/documents/GTYS%202017_1.pdf
[11] 9PDF.org, *Gas turbines – technology data for input to power modelling*. 9PDF.org, n.d. Available at: www.9pdf.org/article/gas-turbines-technology-data-input-power-modelling.y96330lw

required (+/- 1-2bar deviation can trip a turbine). If these operating conditions are not met, this could result in gas plants being unable to respond to shortfall in power supply.	

Whilst gas linepack is a potential bottleneck here, given sufficient transparency and understanding to the cost and value of this inherent storage capacity within the gas networks, its role for future electricity flexibility provision could be better accounted for. A maximum gas linepack flexibility of 690GWh was measured across the National Transmission System (NTS) and Local Gas Networks[15]. Coupling this with a low carbon fuel source or carbon capture could give the energy system a viable pathway for low carbon emergency response to stress scenarios. For example, current biomethane estimates are that approximately 8 TWh of biomethane is injected into the UK gas grid per year[12]. A wide range of between 30-120 TWh for annual biomethane utilisation per year could be seen by 2050[13,14].

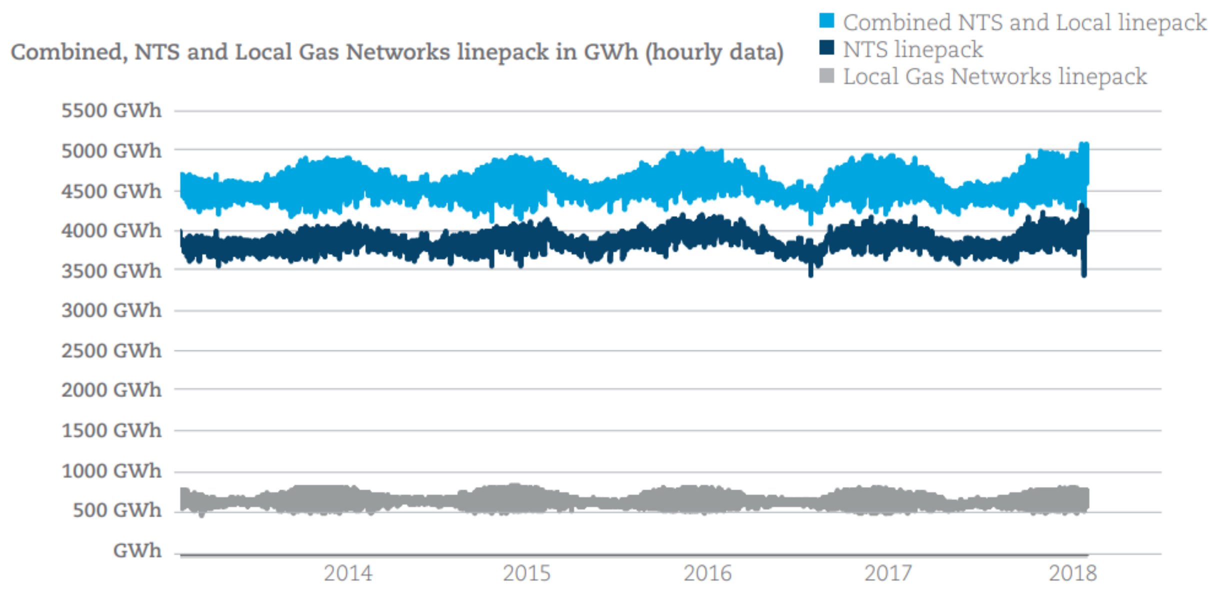

Figure 5 Available capacity in gas line pack both on the National Transmission System and Local Gas Networks[15]

[12] MCS Foundation, *Making the most of biomethane*. MCS Foundation, London, 2025. Available at: mcsfoundation.org.uk/wp-content/uploads/2025/09/2025-09-30-Making-the-most-of-biomethane.pdf
[13] UK Government, *Biomass strategy*. Department for Energy Security and Net Zero (DESNZ), London, 2023. Available at: www.gov.uk/government/publications/biomass-strategy
[14] Energy Global, *Biomethane's building momentum*. Energy Global, London, 2026. Available at: www.energyglobal.com/special-reports/15012026/biomethanes-building-momentum

[15] UKERC, *Linepack flexibility briefing note*. UKERC, London, 2019. Available at: d2e1qxpsswcpgz.cloudfront.net/uploads/2019/05/UKERC_BN_Linepack_flexibility_DOI_update.pdf

5.2 Operational constraints

Risk	Mitigation
As can be seen in Table 1, NESO now has energy system planning roles of strategic system planning across gas and electricity network, therefore having an opportunity to coordinate planning for balancing of the two systems.	The **distinct operational time-scales** between gas and electricity transmission systems reinforce the need for solutions to be found as identified in the infrastructure bottlenecks section.
However, the gas and electricity systems operate on very different physical and operation time-scales, which limits real-time coordination (electricity system requires balancing to be done sub-second to maintain frequency and stability whereas gas system dynamics evolve more slowly over the scale of hours and days[16]. Typically gas operators will use a combination of the existing conditions of the network, weather forecast and representative historical days to arrive at a linepack required for the next gas day (defined as 5am to 5am). This will charge the gas network with sufficient pressure to deal with the day's demand. This is a very different way of operating to the electricity network.	Having sufficient linepack in the gas network, will be key in achieving more aligned operational timescales. With improved forecasting, anticipation and coordination this could help sufficient gas to be present in the right areas of the network. Reactive operation to moving pressure around the network will be limited by the physical characteristics of gas flows to the minutes (10-60 minutes) timescales[17] which can enable a sustained response.
NESO's dual role strengthens whole-system coordination in principle with them: • Conducting whole-energy risk and resilience assessments,	A good first step towards integrating gas and electricity emergency planning and response has been made by having NESO fulfil both gas and electricity strategic system planning roles.

[16] Ingenia, *Balancing the energy network*. Royal Academy of Engineering, London, n.d. Available at: www.ingenia.org.uk/articles/balancing-the-energy-network

[17] R.B. Hytowitz, *Natural Gas Networks and Hydraulic Modeling*. EPRI, Available at: https://restservice.epri.com/publicdownload/000000003002024649/0/Product

• Coordinating preparation for emergency responses across gas and electricity. This indicates a shift towards a more integrated approach to emergency planning and coordination than existed previously when separate operators performed these roles. However, there is not yet an update to the National Emergency Plan[18] to show the updated framework with NESO's new role in emergency response and coordination.	To move this forward the following steps could be taken: • Review of the National Emergency Plan to reflect NESO as dual gas and electricity operator to clarify legal and procedural responsibilities • Implement shared dashboards and early-warning alert systems • Conduct joint drills and scenario simulations • Deploy shared modelling and real-time integrated control frameworks

Table 1 UK gas and electricity network roles

Sector	**Role**	**What the role does**	**Organisation(s) in Great Britain**
Electricity	ESO / SO (Electricity System Operator)	Real-time balancing of supply and demand; frequency control; system security; outage coordination	National Energy System Operator (NESO) (since Oct 2024, publicly owned) [19]
	TSO (Transmission System Owner)	Owns and maintains the high-voltage transmission assets (lines, substations)	National Grid Electricity Transmission (England & Wales); SSEN, SP Energy Networks (Scotland); Scottish Power Transmission (Scotland)
	DNO (Distribution	Owns and operates local electricity distribution	UK Power Networks, Northern Powergrid, SP

[18] UK Government, *National emergency plan – downstream gas and electricity*. DESNZ, London, n.d. Available at: www.assets.publishing.service.gov.uk/media/64c3c9cbf92186000d866760/national-emergency-plan-downstream-gas-and-electricity.pdf

[19] Institute for Government, *National Energy System Operator – explainer*. Institute for Government, London, n.d. Available at: www.instituteforgovernment.org.uk/explainer/national-energy-system-operator

	Network Operator)	networks; connects customers and generators	Energy Networks, SSE Distribution, National Grid Electricity Distribution, Electricity North West and Independent DNOs
	DSO (Distribution System Operator)	System operation functions at distribution level (flexibility procurement, congestion management, visibility)	Not legally separate – DSO functions are being developed *within* the DNOs under Ofgem policy
Gas	SO (Gas System Operator)	Balances the gas system; manages linepack; coordinates flows; emergency balancing actions	National Gas Transmission, Gas National Control Centre
	TSO (Gas Transmission Owner)	Owns and operates the National Transmission System (pipelines, compressors)	National Gas Transmission (NGT) plc
	GDNs (Gas Distribution Network Operator)	Owns and operates regional low- and medium-pressure gas networks supplying end users	Cadent, SGN, Wales & West Utilities, Northern Gas Networks
	GSO	(Conceptual / emerging) Potential future role to manage local gas system flexibility	No formal DSO role in GB gas (conceptual only, discussed for hydrogen futures)[20]

[20] UK Government, *Proposals for a future system operator role*. DESNZ, London, n.d. Available at: www.gov.uk/government/consultations/proposals-for-a-future-system-operator-role

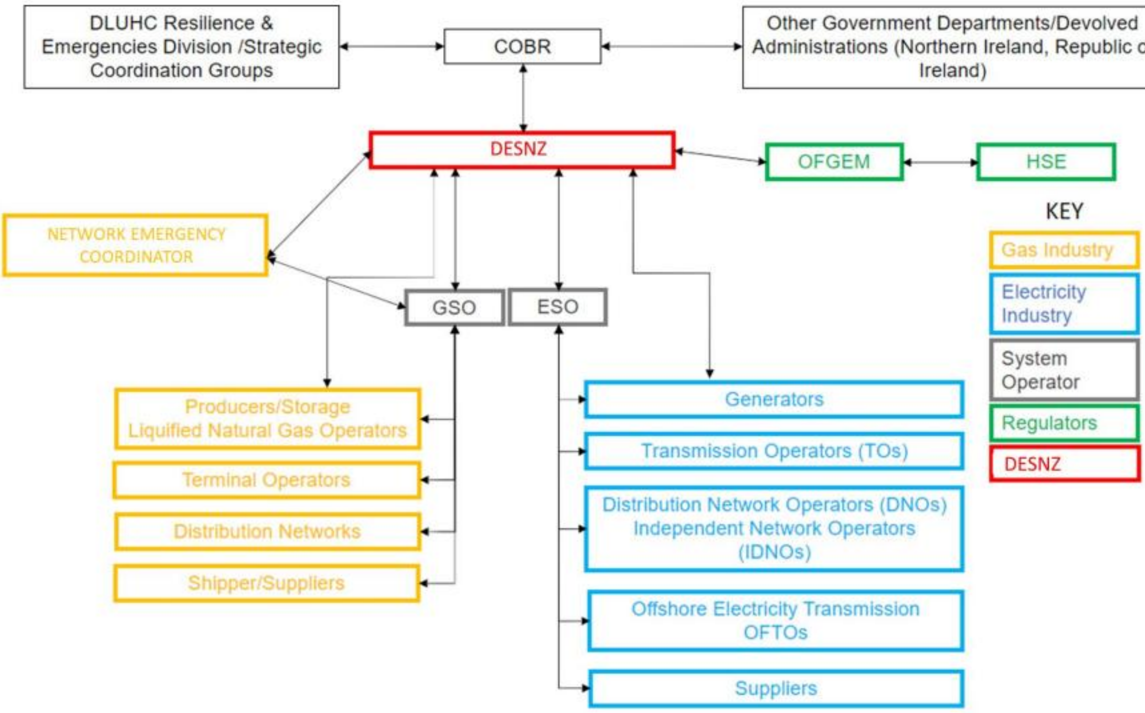

Figure 6 Key emergency response partner interactions[21]

5.3 Market shortfalls

Risk	Mitigation
The Capacity Market relies significantly on gas generation from CCGT, OCGT and reciprocating engines (see *Figure 8*) to secure sufficient electricity in advance for security in peak and emergency scenarios. This shows a strong dependency on the gas network. This leaves the electricity structurally fragile with security tightly coupled to gas supply availability.	Possible solutions include: • Increasing diversity of sources of security for electricity supply (such as described in infrastructure bottleneck section) • Introducing modularity in the network design so that the system is composed of semi-independent modules allowing failures to be contained locally.
Great Britain's gas storage capacity is small compared with many European countries; storage can help manage short-run fluctuations and peak winter demand, but today GB has only about 3.2 billion m^3 of storage spread across	Lack of deep seasonal storage and a reduction in production increased the need for the potential solutions identified in the Infrastructure bottleneck section.

[21] UK Government, *National emergency plan – downstream gas and electricity*. DESNZ, London, n.d. Available at: www.assets.publishing.service.gov.uk/media/64c3c9cbf92186000d866760/national-emergency-plan-downstream-gas-and-electricity.pdf

eight facilities. Lack of deep, seasonal storage reduces resilience more during prolonged stress events than in markets with large strategic reserves.. UK Continental Shelf (UKCS) production continues to shrink towards 2050 (see *Figure 9*); this, paired with a lack of deep seasonal storage, results in an increased reliance on imports of LNG and interconnectors.	Also, market incentives for gas storage for these periods would improve resilience of the energy system.

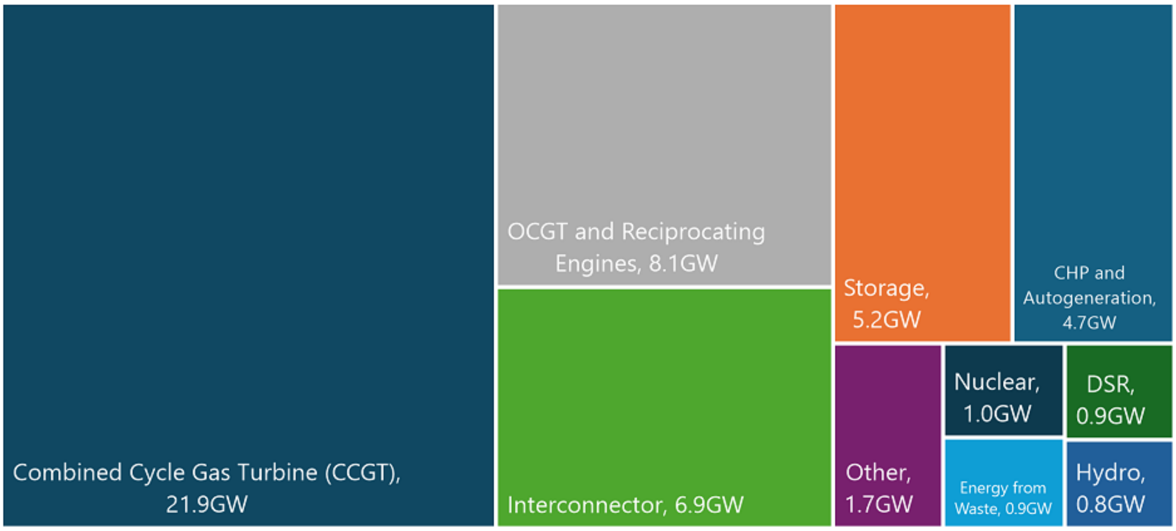

Figure 7 Derated Capacity secured for 2026/2027 delivery year by technology, in GW[22]

[22] UK Government, *Statutory security of supply report 2024*. DESNZ, London, 2024. Available at: www.gov.uk/government/publications/statutory-security-of-supply-report-2024/statutory-security-of-supply-report-2024

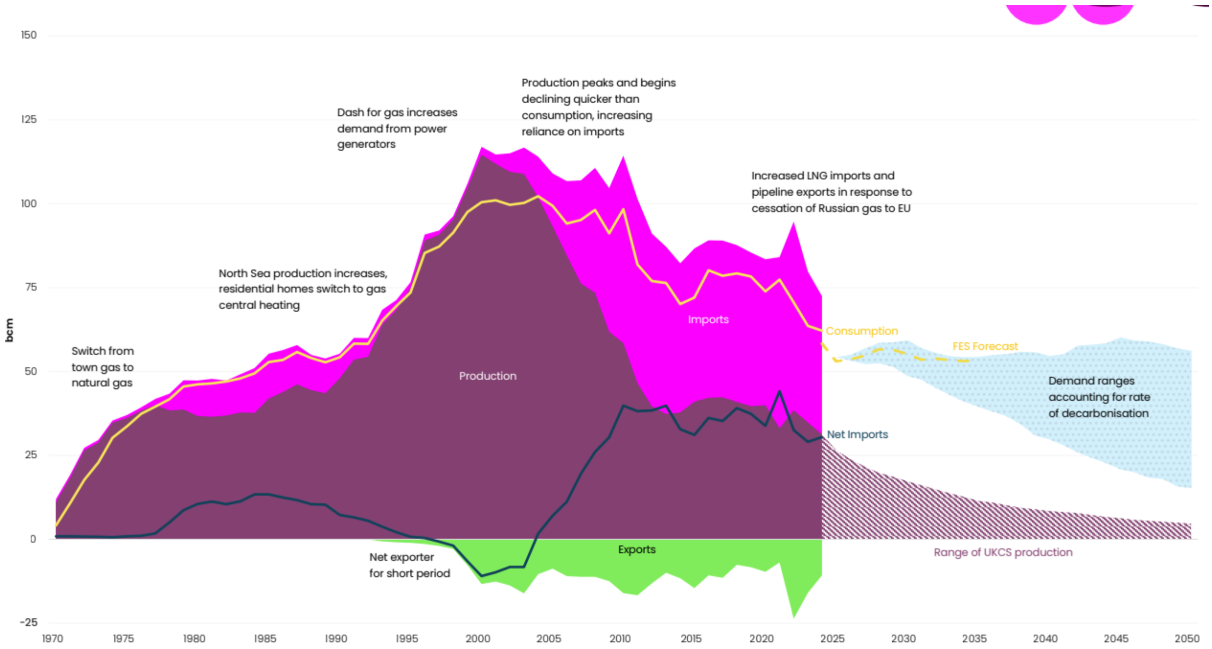

Figure 8 Total annual GB natural gas production and net imports compared with consumption, based on March 2025 North Sea Transition Authority (net) projections, including possible higher range from the FES UKCS high case.[23]

5.4 Policy and regulatory gaps

Risk	Mitigation
A key risk in the UK energy system is that market and regulatory frameworks are largely designed to optimise performance and cost under normal operating conditions (inclusive of the 1-in-20 design requirement), rather than to support assets that are rarely used but become critical during extreme system stress[22,23,24]. This creates a structural disincentive to invest in infrastructure whose primary value lies in protecting the system during low-probability, high-impact events.	Reducing this risk requires clearer recognition of resilience as a distinct system need, rather than treating it as a secondary outcome of energy and capacity markets. Government and regulatory strategies increasingly point to the need to better value flexibility and security contributions that are not captured by existing price signals. Market and regulatory mechanisms can also be strengthened by placing greater emphasis on endurance, diversity, and

[23] UK Government, *Statutory security of supply report 2025*. DESNZ, London, 2025. Available at: www.gov.uk/government/publications/statutory-security-of-supply-report-2025 (<https://www.gov.uk/government/publications/statutory-security-of-supply-report-2025>)

[24] UK Government, *Electricity networks strategic framework*. DESNZ, London, n.d. Available at: www.gov.uk/government/publications/electricity-networks-strategic-framework (<https://www.gov.uk/government/publications/electricity-networks-strategic-framework>)

This issue is most visible in gas storage. Government security-of-supply assessments recognise that gas storage provides important flexibility during periods of high demand, particularly in cold weather, but also note that commercial storage depends on short-term price signals to justify operation and investment. As a result, investment decisions are driven by market volatility rather than by the wider security value that storage provides. The UK's relatively low level of gas storage compared with some European countries reflects this incentive structure and increases exposure to prolonged supply stress.

Similar weaknesses appear in electricity market arrangements. While the Capacity Market secures sufficient capacity to meet peak demand forecasts, government analysis acknowledges that it does not fully distinguish between resources based on their ability to perform during prolonged or system-wide stress. This can result in a system that meets adequacy targets but remains vulnerable to common fuel or infrastructure constraints, particularly where electricity supply depends heavily on gas.

Broader regulatory frameworks acknowledge that flexibility services such as storage and demand-side response have not always been adequately rewarded, limiting investment in assets that could reduce system vulnerability. Emergency planning arrangements remain essential, but their role in managing crises can mask underlying fragility and reduce the perceived need to strengthen the system in advance.

independence from shared risks, particularly where electricity supply relies on a single fuel or infrastructure type. This direction is reflected in ongoing reviews of electricity security arrangements and the future role of the Capacity Market.

Finally, closer alignment between long-term system planning and emergency arrangements would help shift the focus from managing crises to reducing their likelihood and impact. By embedding resilience more clearly into regulatory and investment decisions, the system can become more robust while reducing reliance on emergency powers during extreme events[22].

5.5 Implication and Open Questions

The following implications have been noted, and questions raised from this analysis:

- Gas linepack flexibility clearly has value to the electricity/energy system in terms of flexibility and security. This value currently isn't explicitly paid for.
    - Can we cost this against other storage options (i.e. pumped hydro)?
    - How would we create an explicit valuing system for this? Could be a market mechanism or a government approved X GWh reserved payment for emergency/high stress scenarios?
- What seasonal storage capacity is required with the evolving capacity needs?
- What are the viable technologies from the "solution space sections" to pursue (WP5)?
- Does further exploration of market, regulatory and policy confirm/contradict findings in this WP? (WP4)
- What further recommendations could be suggested from this exploration? (WP4)

6.Appendix 1 - System of Systems Map Diagrams

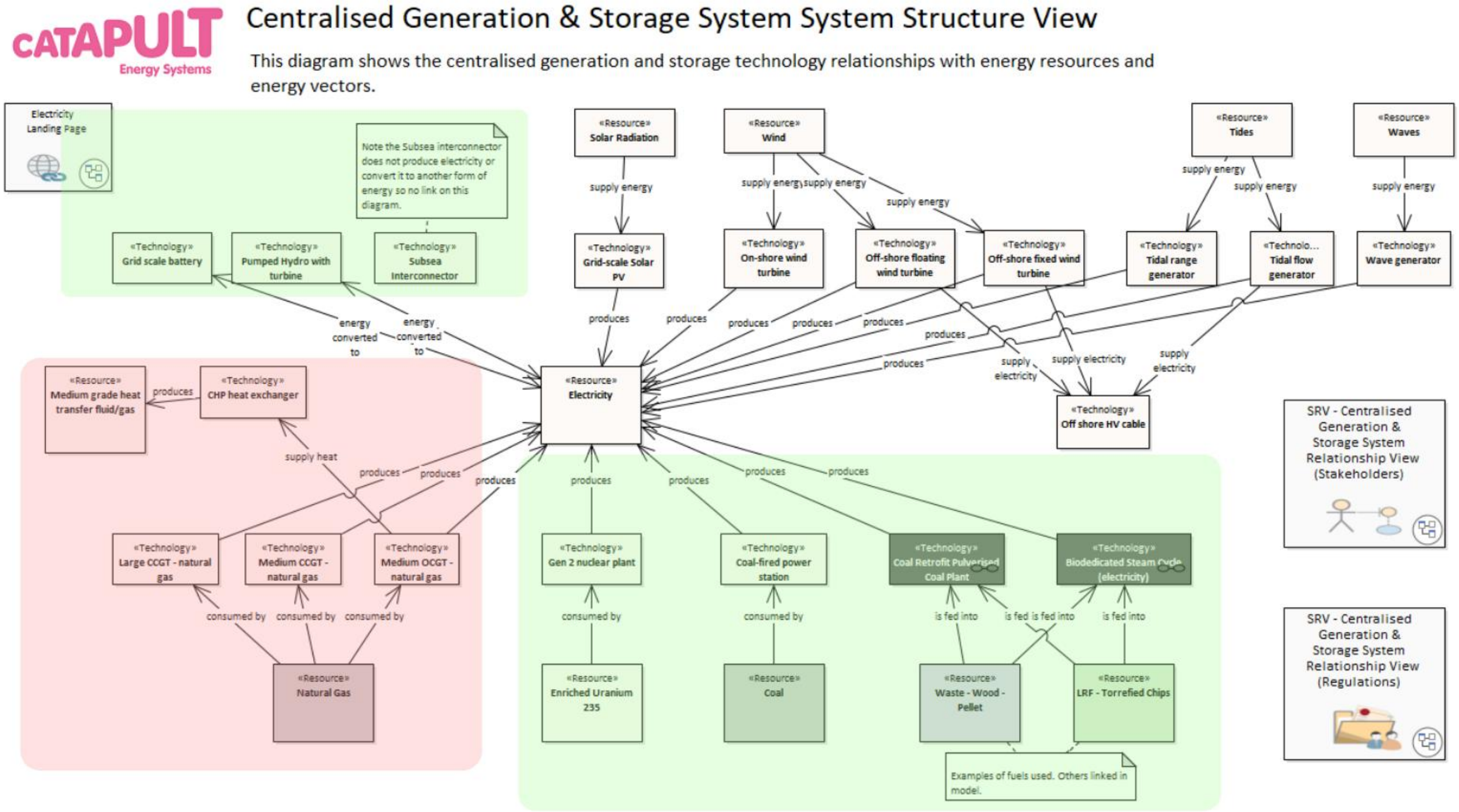

Figure 9. A relational view of the generation and storage technologies connected to the electricity transmission network from the SoS Map

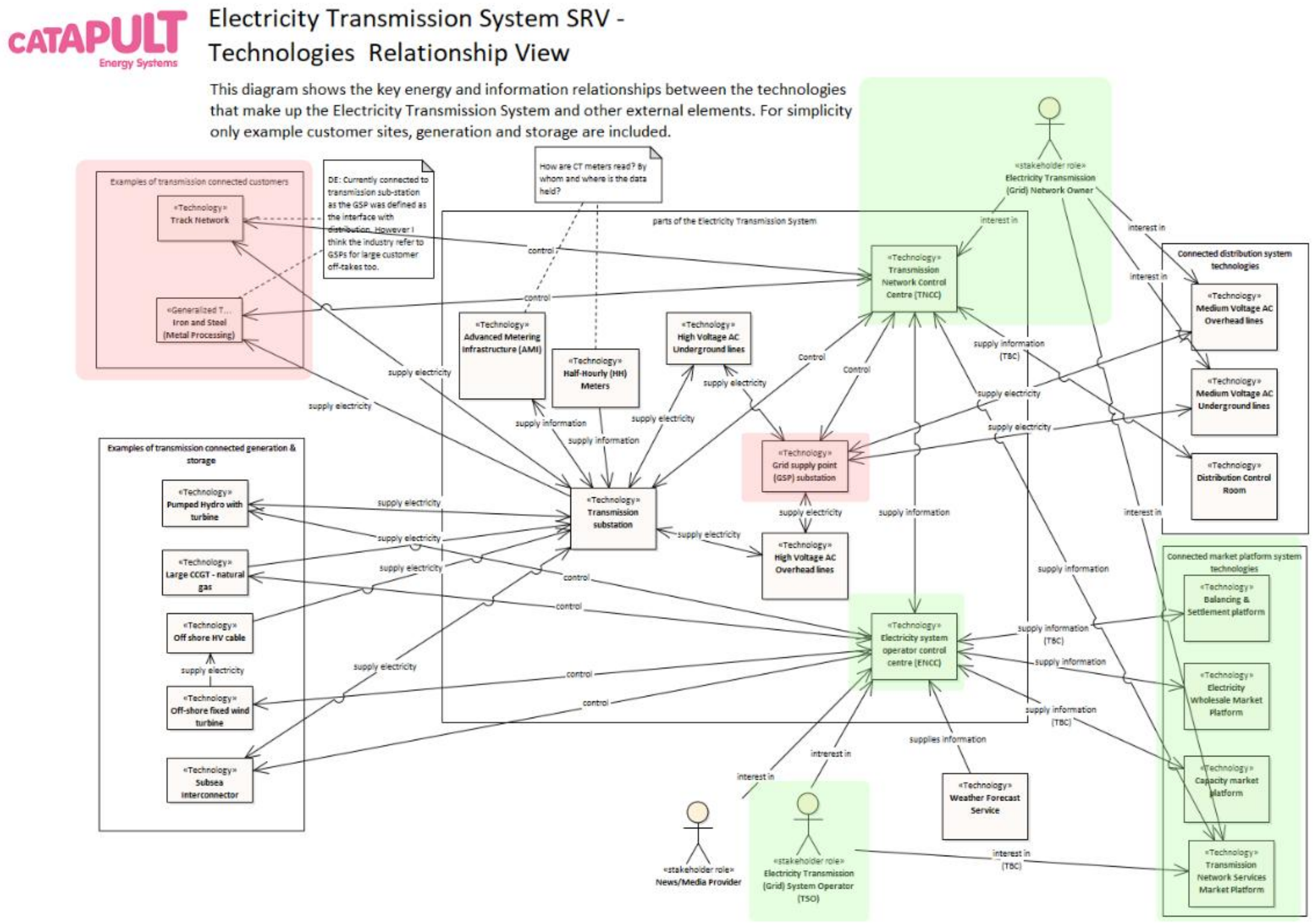

Figure 10 A relational view of the electricity transmission system with systems outside of it from the SoS Map

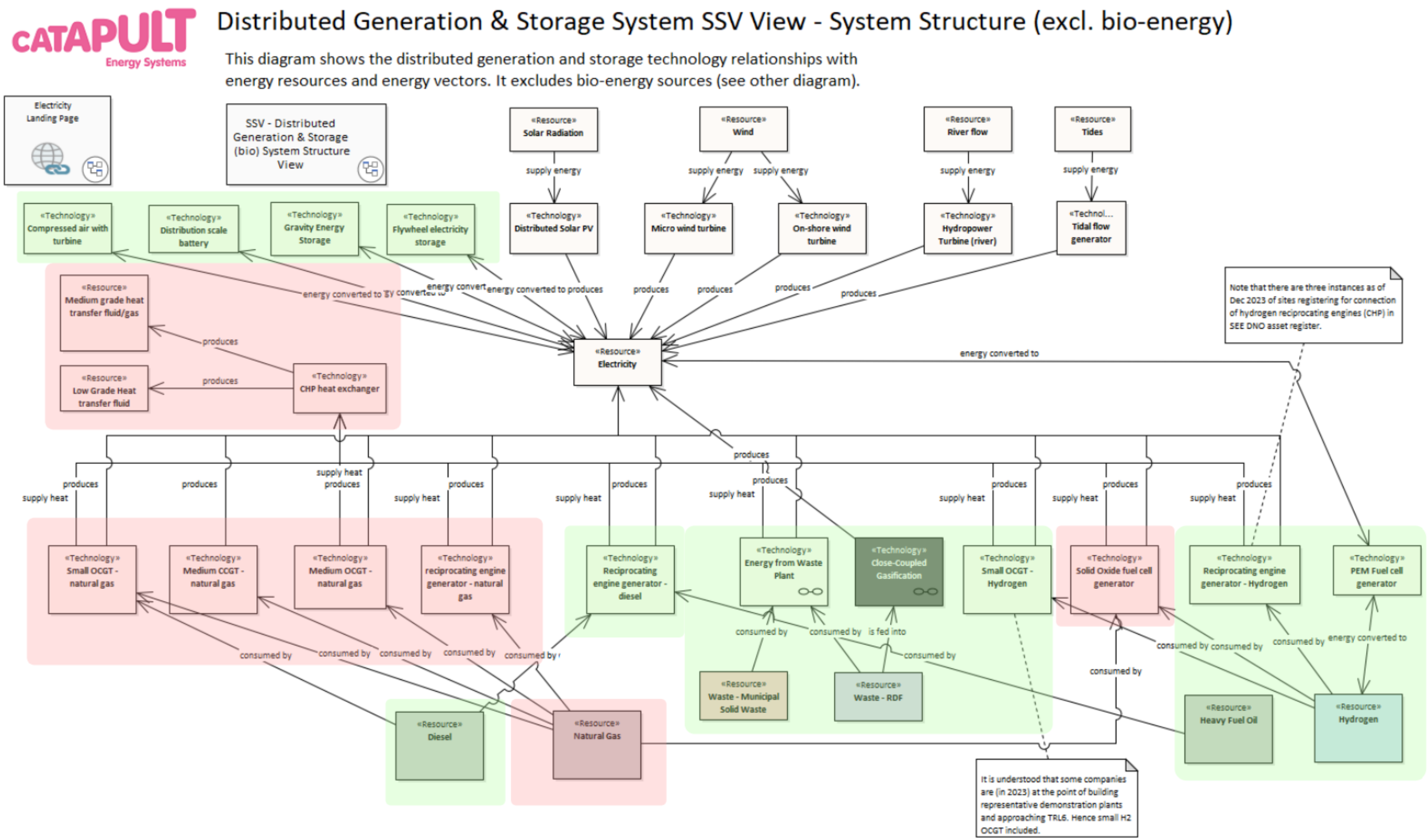

Figure 11 A relational view of the generation and storage technologies connected to the electricity distribution network from the SoS Map

Electricity Distribution System SRV - System Relationship View (detailed)

Electricity Landing Page

This diagram shows the relationships between the technologies that make up the Distribution Electricity System and other technologies. Please note that not all connected technologies are shown (only examples). Connections are only shown to the Distribution Electricity System, other connections are hidden.

SRV - Electricity Distribution System Relationships (stakeholders)

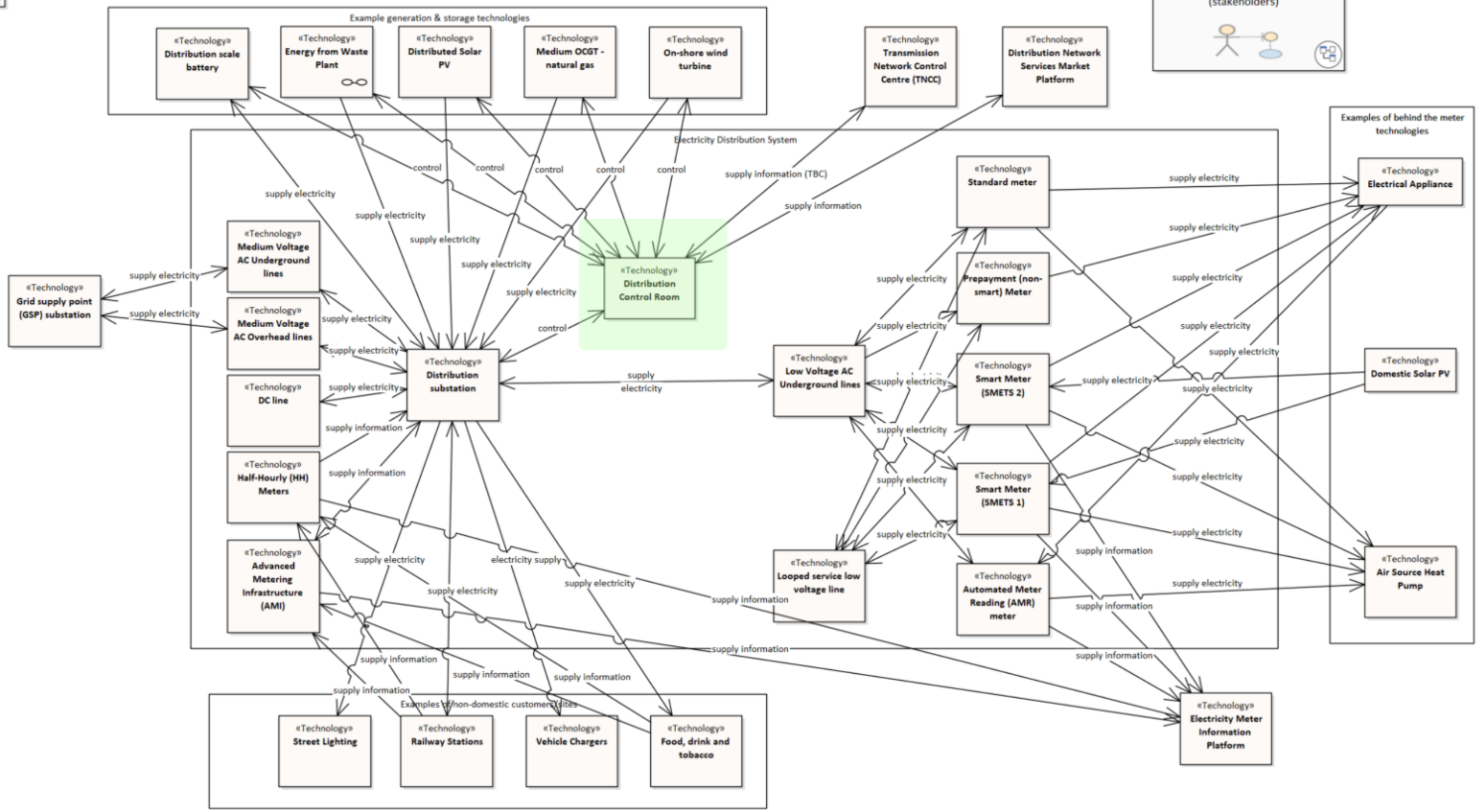

Figure 12 A relational view of the electricity distribution system with systems outside of it from the SoS Map

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Clean Power Flexibility Investigation: Options Report

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Date: July 26

Contents

1. Executive Summary

The Clean Power Flexibility Investigation (CPFI) explores how National Gas Transmission (NGT) can continue to support energy system resilience as Great Britain transitions towards Clean Power 2030 (CP2030). Building on previous work packages examining future gas network stresses, gas network modelling and whole-system interactions, this report focuses on converting identified challenges into innovation opportunities that could strengthen the role of the National Transmission System (NTS) in an increasingly electrified and weather-dependent energy system.

Analysis of future stress scenarios found that the NTS is generally capable of responding to significant electricity-system-driven increases in gas demand. However, the investigation highlighted that future challenges are likely to arise not from overall network capacity, but from the changing role of gas-fired generation, increasing operational complexity and the growing interdependence between electricity and gas systems. Key findings included the importance of local gas supplies, compressor availability, linepack management, visibility of demand changes and effective coordination between electricity and gas system operators.

From a broader systems perspective, four categories of challenge were identified: physical infrastructure dependencies, operational constraints caused by differing gas and electricity balancing timescales, market arrangements that remain heavily dependent on gas-fired generation, and policy and regulatory frameworks that do not always appropriately value resilience and flexibility.

The report develops three strategic questions to guide future innovation. The first considers how approaches to maintaining pressure cover may need to evolve under CP2030. As gas demand becomes less frequent but more volatile, the value of linepack and pressure cover as flexibility resources becomes increasingly important. Greater visibility of that value within market arrangements and whole-system planning processes may be required.

The second question examines how increasing automation and changing operational dynamics at the electricity-gas interface could affect system operation. Faster electricity dispatch, automated controls and shorter response times may reduce the warning available to gas system operators, creating a need for improved cross-vector coordination, shared situational awareness and enhanced notification processes.

The third question focuses on enhanced early analysis to anticipate peak electricity system events. Improved forecasting, whole-system modelling, linepack analytics, stress-event response frameworks and integration of hydrogen and storage data could provide operators with earlier visibility of emerging risks and more time to respond effectively.

The report concludes by identifying a range of innovation opportunities across market design, operational coordination and forecasting capabilities. These options form the basis of the CPFI innovation roadmap and provide NGT with a pathway to enhance resilience, flexibility and whole-system coordination as the energy transition accelerates.

2. Findings from gas network and system analysis

This options report collates findings from three preceding work packages that have analysed both the gas National Transmission System (NTS) and interactions with the wider energy system. Focus of analysis has been on electricity transmission connected demand and generation that interact with NTS. A 'long list' of problems was created from the results of this analysis and prioritised for further investigation. Here the problem statements are developed and options created for potential innovation projects to generate and test solutions. Work package 5[1] provides an innovation roadmap that outlines how these insights can be converted into outcomes for National Gas Transmission (NGT) through innovation projects.

2.1 Scenario Design and assumptions:

Work package 1 produced scenario and assumptions[2] for gas network planning[3] carried out by NGT in work package 2. This included identification of factors that can combine to induce stress in the NTS operation. Underpinned by systems thinking, specifically the 12 points of leverage that can influence system behaviour for positive and negative outcomes. Potential interventions were discussed with NGT and the system intervention "lengths of delays, relative to the rate of system change." prioritised for investigation in this project.

The hypothesis being that in moving physical molecules, operation of NTS has a level of inertia that can result it in taking time to reconfigure to respond to rapidly changing demands. This time to reconfigure could create vulnerabilities where the network needed to respond to an instantaneous peak gap on the electricity system.

Design of a Clean Power Flexibility Investigation (CPFI) scenario was completed between NGT and the Catapult. This included selection and definition of a set of 'stress levers' under the headings of the pathway, conditions, event and event response. Given the time constraints and prioritisation of network areas most vulnerable to stress, modelling was designed to focus on the NTS network in the South East of England.

A 'trigger event' was defined to start the change in demand in the electricity system. The Catapult's Innovating to Net Zero 2026 report, "scaling flexibility to meet the five peaks challenge"[4] described four 'peak gaps' in the electricity system that require response from flexibility services. These gaps were assessed to determine which would be most likely to create stress on the NTS:

- The daily peak gap,
- The instantaneous peak power gap,
- The peak durational gap,

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[1] Work package 5 report: Clean Power Flexibility Investigation: Final Project Report
[2] Work package 1 report: Clean Power Flexibility Investigation: Scenario and Assumptions
[3] Work package 2 report: Clean Power Flexibility Investigation: WP2 Output
[4] Innovating to Net Zero 2026: Scaling flexibility to meet the five peaks challenge. 2026 [online]. Avaliable: https://es.catapult.org.uk/project/innovating-to-net-zero-2026/

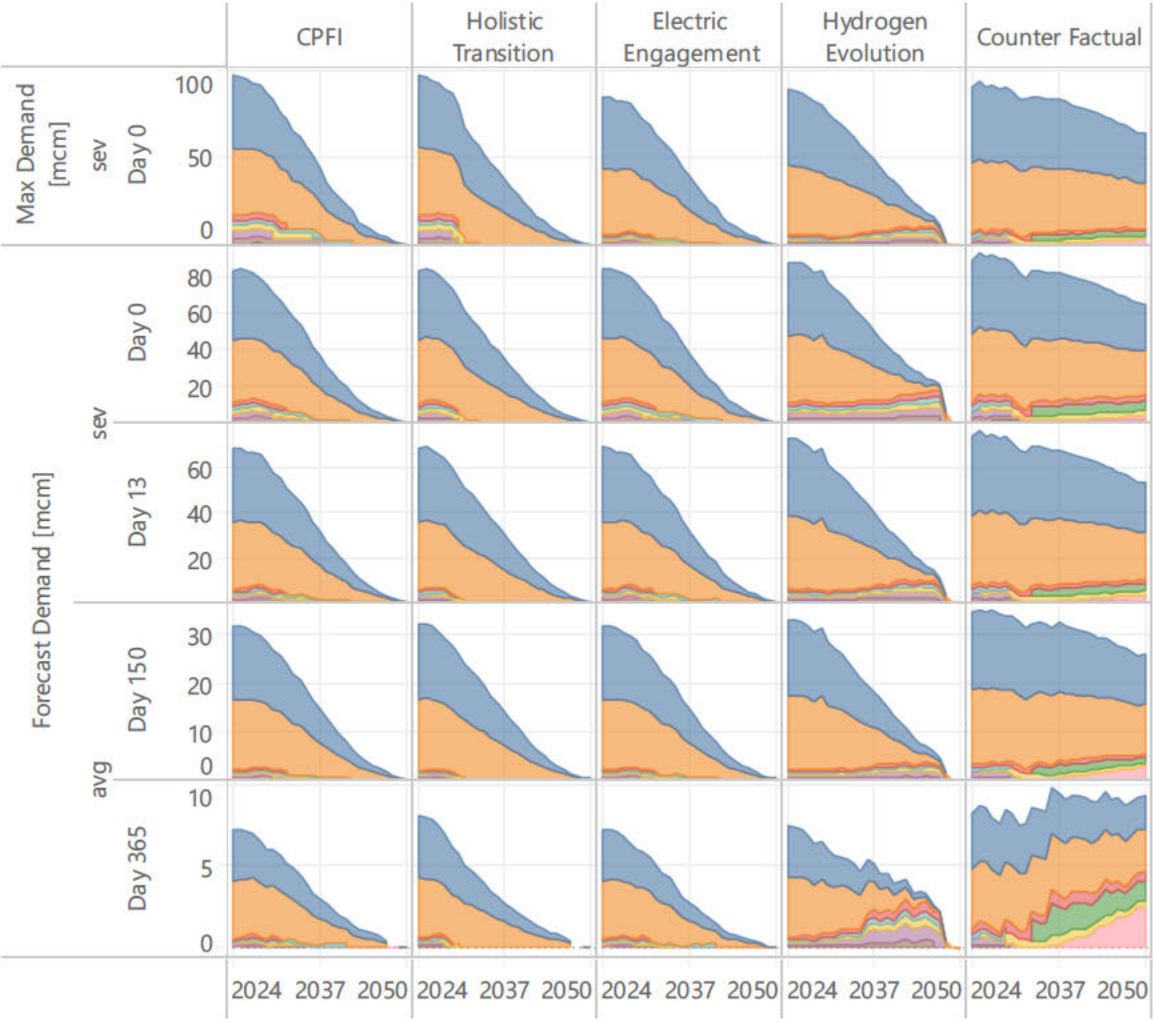
- Peak energy gap.

Given the selected system intervention, instantaneous peak gap in the electricity system was selected as the trigger event to prompt stress in the NTS. This selection was based on alignment of this peak gap with the prioritised systems intervention selected above. In discussion with NGT rapid changes of demand prompting quick NTS network reconfiguration were considered most likely to result in stress and of most interest.

Scenario design then focused on selection and modification of a FES pathway to create a CPFI pathway that presented the highest likely risk. This is based on a combination of the FES scenarios 'Holistic Transition' and 'Electric Engagement' and explores the additional challenges that may be encountered with a combination of pathways that could occur with different regional approaches during an energy system transition. The 'Holistic Transition' pathway forms the basis of the scenario, but with 'Electric Engagement' pathway adopted for Local Distribution Zones (LDZ) and power generation demands in the North Thames and South East regions.

The Counter Factual scenario was discounted from this analysis as the scope of the project was a focus on how the network would respond to low gas demands and large changes in demand in scenarios that would meet Net Zero. In addition, initially considered that the Counter Factual scenario was close to 'business as usual' for the NTS and that the within day demands changes would not be as potentially stressful with high DN demand. This was further reinforced with subsequent discussions between Catapult and NGT of credible extremes associated with the system intervention points and electricity system peak gaps chosen for exploration.

In all scenarios explored the LDZ demands is projected to be decreasing and power station demand remains low in comparison until the 2040s.



[redacted]

Figure 1: Comparison of LDZ and power generation demands in North Thames & South East for each scenario

Comparisons of Electricity Generation and Electricity Generation Capacity were made for the different FES scenarios and NESO CP2030 scenarios. A range of capacities exist across the scenarios but in all cases the gas generation capacities in the FES scenarios were of the same order as in the NESO CP2030 scenarios. The big difference comes in the electricity generation. Due to the requirement of CP2030 to have 5% or less of power generation coming from unabated gas, the generation profiles of CCGTs in the CP2030 scenarios all change from baseload to peak plant resulting in lower overall levels of electrical generation. It is therefore expected that to satisfy CP2030, it should be assumed that more of the CCGTs are running at minimum load factors and ramp up in response to peak demands.

Discussions between the Catapult and NGT during scenario design identified a ~17GW generation national level swing event in December 2024. The swing in demand was driven by low wind and low electricity imports. It was noted that larger demand swings of 20-30GW was anticipated for the future.

Figure 2 – National (GB) gas demand swing graph from power generation. 10th December 2024

The eight scenarios provided variation by trigger event, NTS Flow patterns, event responses, NTS asset availability and scenario year[5] . Each was designed to test for NTS stress in the South East of England, agreed to be a representation localised version of the national level events highlighted in *Figure 2*.

2.2 NGT Gas network modelling

Using the scenario design and assumptions provided by the Catapult, NGT completed a series of gas network modelling runs using their SIMONE software. Following testing of the initial scenarios provided by the Catapult, the network models solved, no issues in the South East beyond stress at [redacted] Compressor station, see below, were found. The wider NTS response required [redacted] Compressor to increase speed to support the supply response and increased supply from LNG at [redacted]

This prompted a revision to the approach to include exploration of:

- the planned hydrogen and CCS network topologies.
- ramping exit demands at power stations to the point where it created an issue.
- Explore to the timing required to change configuration at [redacted] Compressor station.

[5] Work package 1 report: Clean Power Flexibility Investigation: Scenario and Assumptions Document

The findings from the complete set of gas network modelling can be summarised in the following points:

- The main contributing factor to whether the NTS meets pressures is local supplies, which is true for the current network.
- [redacted] compressor station ([redacted] configuration 2 can maintain pressures at Tatsfield Offtake above Operating Margin Pressure (OMP), though configuration 1 breaches OMP in the most stressed scenario. Reconfiguration at [redacted] reactively from configuration 1 to 2 does not improve minimum pressures in a worst case timing of a power event.
- While managing linepack levels during one scenario event, it was noted that entry constraint at the [redacted] LNG terminal was triggered as it is absorbing the main LNG supply response load.
- A need for a minimum amount of supply at [redacted] to support the South East was identified in a scenario where there is no supply at [redacted]
- No power station Anticipated Normal Operating Pressure failed from the Catapult scenarios.
- Project Union (PU) & Carbon Capture and Storage (CCS) network topologies do not greatly impact the South East of the NTS, though Scotland saw an increase in pressures because current repurposing is focused on the northern sections of the NTS.

NGT analysis points towards the NTS meeting pressures, and the ramping has a lower impact than the level of local supplies and South East demand. This is true under current network conditions, without ramping, but with more intermittent and unpredictable power station behaviour, the importance of these factors increases. Increasing the emphasis on the decision making and response in GNCC (Gas Network Control Centre).

Whilst the modelling solves in these simulation conditions this is not wholly representative of the real world operating environment in which the control room operates. In this work the modelling had multiple chances to solve and time to setup the scenario. GNCC will have only one try in the advent of the power event to manage and obtain the best network stability. The GNCC has modelling capability available to them to help inform their decisions, but the decisions are also time sensitive which can discount this support capability. There may be future scenarios as total gas demand decreases where compressors will require to be started from longer times of not being used, which may increase the time it takes to start.

In addition to analysis completed for this project NGT have shared findings from previous work that examined power station ramping and the NTS response under different scenarios. The outcomes were shaped by the timings used, the power demand assumptions, and the sources of supply response. While the level of power station ramping, being forecasted is beyond the reasonable worst case to design around, investigating the impact on the NTS gave valuable and insightful results including post-event pressure recovery, LDZ AOP pressures, impact of shipper behaviours on entry constraints and identification of power stations where ANOPs were breached pre-ramping.

NGT have a number of existing projects for network interventions:

- [redacted]
- [redacted]

The findings from CPFI gas network modelling add further evidence to the needs the case for these projects.

One of the the key findings from CPFI project is an increased emphasis on GNCC system operation decision making and increased need to operate the network in a way that positions it to respond to large demand swings. This could indicate a need for additional operational support for GNCC situational awareness and decision making support in the form of enhanced early analysis.

2.3 The Gas and Electricity Systems Assessment identified four main constraints:

The gas and electricity systems assessment has taken a systems engineering approach with a structural assessment and review of systems dynamics. Findings are grouped into physical infrastructure, operational constraints, market and policy and regulatory categories.

Gas transmission physical infrastructure elements and interfaces that could combine to result in system constraints system during periods of high energy demand and low renewable electricity generation, when reliance on gas-fired generation increases. As an example, the system dynamics analysis illustrates the chain of infrastructure, system elements, that are required to respond to a peak gap. The explicit visibility of the relationships enables a systems level assessment of the risks and mitigation options. E.g. for a Dunkelflaute this could be enhanced gas storage and compression, long-duration electricity storage, demand-side response, and increased firm low-carbon generation.

Operational constraints between gas and electricity networks limit real-time coordination between gas and electricity systems despite NESO's new strategic planning role. The two networks operate on fundamentally different timescales, constraining integrated balancing during fast-moving system stress events. While NESO's remit improves whole-system risk assessment and emergency planning, an integrated National Emergency Plan was not found at the time of writing. Further resilience gains require updated emergency frameworks, shared situational awareness tools, joint exercises, and more integrated modelling and control capabilities.

Market shortfalls arise from a heavy reliance on gas-fired generation within the Capacity Market, tightly coupling electricity security to gas supply availability. Limited gas storage capacity and declining domestic production, increase exposure to prolonged stress events and import dependency. Improving resilience requires greater diversity of dispatchable low-carbon generation, more modular system design, strengthened incentives for seasonal storage, and measures identified to address infrastructure bottlenecks.

Policy and regulatory gaps mean the UK energy system is optimised for cost and performance under normal conditions rather than resilience during extreme stress events. Market frameworks undervalue assets that provide endurance and flexibility, most notably gas storage, leading to underinvestment and increased exposure to prolonged supply disruptions. While capacity and emergency arrangements ensure short-term adequacy, they do not fully address common fuel or infrastructure risks. Strengthening resilience requires clearer regulatory recognition of security and flexibility as distinct system needs, better valuation of endurance and diversity, and closer alignment between long-term planning and emergency arrangements.

2.4 Long List of Insights:

Assessing the outputs from the previous 3 work packages created a 'long list of issues'. These were reviewed between Catapult and NGT to prioritise for further exploration of both problem definition and solution options to provide the basis of the innovation roadmap.

Priority	Insight	Description
1	[redacted] **Compressor station reconfiguration.**	It is vital to recognise high-risk supply patterns on the NTS and prepare accordingly. [redacted] compressor station is a key compressor for meeting the extremity pressure at Tatsfield, and the configuration choice has a significant impact on maintaining minimum pressure. In one scenario it was found to breach the Tatsfield OMP due to reconfiguration time.
2	[redacted] **Pressure Support**	While managing line pack levels during one scenario event, it was noted that entry constraint at the [redacted] LNG terminal was triggered

		as it is absorbing the main LNG supply response load. As a result, some supply response was moved to the [redacted] terminal from [redacted] To prevent entry constraints or high pressure. [redacted] was selected for its low level of local system interaction, to ensure that minimum supply levels in the Southeast were upheld. This finding is important as the scenario assumes that [redacted] terminal can support the required LNG supply load during the power event.
3	[redacted] **Minimum supplies.**	A need for a minimum amount of supply at [redacted] to support the South East was identified in a scenario where there is no supply at [redacted] In the CP2030 world, if we were in a similar scenario, even with less SE demand, we would need more supplies from [redacted] to support that.
4	**Lack of demand change visibility of system constraints or demand change for the Gas Network Control Room. (GNCC)**	It was identified that GNCC sometimes have a lack of visibility of in day demand changes. This can be caused by automation of electricity generation response, delayed notifications, differences in penalty regime in electricity and gas markets; and lack of visibility in gas distribution networks.
5	**Pressure cover of changes on the electricity side and gas distribution offtakes.**	Positioning the NTS for demand changes uses an approach called pressure cover. This results in maintenance of high pipeline operating pressures for a greater number of days per year to ensure demand is met when needed, i.e. for approximately 15 days per year.
6	**Cross vector coordination of system operation.**	Visibility of the current status of cross vectors co-ordination was limited for the project due to the emerging role of NESO. But results from completed analysis indicate an opportunity to implement systems based approach to realise whole system benefits
7	**Systems and market design for capacity not flexibility.**	The market is fundamentally incentivised for capacity not flexibility, responsiveness and resilience.

8	**Credible extreme events definition**	Treatment and assessment of system risks, resilience and high consequence low probability events is subject to human judgement. This work raises the question as to the psychology behind selection of scenarios and influence of bias within the process. E.g. what is considered normal and extreme in the gas industry may be influenced by past norms, not future conditions given shifting variables.

To focus efforts the 'No regrets' actions or those where existing projects within NGT are in in progress were filtered from the list:

- [redacted] configuration – share findings as input to the existing [redacted] project
- [redacted] – share findings as input to the existing WIR project.

This long list was prioritised to a short list in discussion with NGT. Issues 4, 5, 6 and 7 were combined into three questions for exploration in this work package and to form the basis of the innovation roadmap:

1. How will the market aspects of maintaining pressure cover change following CP2030?
2. How are the dynamics at point of interaction between electricity system and gas system changing with CP2030 and plant automation? How does this impact on system operations?
3. What could an enhanced approach to early analysis, to pre-empt electricity peak gaps provide and look like?

The remainder of this report explores these questions in additional detail to clearly define the problem and high level options for incorporation into an innovation roadmap in the fifth and final work package.

3. How will the market aspects of maintaining pressure cover change following CP2030?

3.1 Problem Definition

Work package 3 identified potential challenges to maintaining pressure cover in the gas network as the system progresses towards the government's Clean Power 2030 (CP2030) goal.

Pressure cover is defined as a margin applied to the lower pressure limits at extremities of the network and to upper pressure limits at Entry points, which accounts for unforeseen within day events e.g. CCGT demand increase, compressor trips, supply losses, and supply increases.

Linepack – the total volume of gas stored within high-pressure transmission pipelines – is one of the key tools that the network operator currently uses to ensure maintenance of pressure cover. NGT manages linepack by buying and selling gas in response to changes in demand on the gas system to maintain pressure cover.[6]

CP2030 affects maintenance of pressure cover due to increased volatility in demand for gas, with gas-fired power stations playing a less frequent but more significant role in the electricity system in response to peak events.

The following market, policy and regulatory challenges were identified in WP3 report sections 5.3-4:

- The Capacity Market relies significantly on gas generation from CCGT, OCGT and reciprocating engines to secure sufficient electricity in advance for security in peak and emergency scenarios. This shows a strong dependency on the gas network. This leaves the electricity system structurally fragile with security tightly coupled to gas supply availability.
- Great Britain's gas storage capacity is small compared with many European countries; storage can help manage short-run fluctuations and peak winter demand, but today GB has only about 3.2 billion m^3 of storage spread across eight facilities. Lack of deep, seasonal storage could reduce resilience during prolonged stress events compared with markets with larger strategic reserves.
- GB market and regulatory frameworks are largely designed to optimise performance and cost under normal operating conditions, rather than to support assets that are rarely used but become critical during extreme system stress. This creates a structural disincentive to invest in infrastructure whose primary value lies in protecting the system during low-probability, high-impact events.

[6] National Gas Transmission (2023) Linepack Presentation

3.2 Insights

GB takes a significantly different policy approach to gas storage in comparison to most European countries. There is no statutory obligation on government or market participants to maintain minimum gas storage volumes beyond limited safety minimums. Ofgem's regulatory role focuses on third-party access, transparency and competition.

DESNZ acknowledges the role of gas storage in delivering energy security and as a flexibility source. DESNZ's position is that gas system resilience is supported by market flexibility and dynamic price signalling, including flexible sources of gas supply, primarily in the form of geological gas storage, LNG, and interconnector imports.[7] To date, the government has not seen a case to intervene in the market to guarantee gas storage levels.

By contrast, the European Union (EU)'s policy approach regulates members states' gas storage. As part of a response to volatile and high energy prices in 2021-22, the EU introduced the Gas Storage Regulation (EU/2022/1032) adopted in June 2022, which included the following requirements:

- A mandatory storage filling obligation of 80% of capacity by 1 November 2022 and 90% of capacity by 1 November in 2023, 2024 and 2025 and intermediary targets to establish a filling trajectory throughout the year.
- Mandatory certification of storage operators.

The Regulation initially applied until the end of 2025 and was extended until the end of 2027, with some relaxation to the mandatory storage filling obligations on member states.[8] While this is a temporary regulation it is possible that it could become a permanent instrument as part of the ongoing review of the EU energy security framework.[9]

In GB, although a mandated level of gas storage is not required by legislation, key regulatory requirements on NGT as Gas Transporter require it to ensure pressure cover is maintained:

- Under Section 9 of the Gas Act 1986,[10] NGT is legally required to "maintain an efficient and economical pipe-line system for the conveyance of gas" including maintaining sufficient pressure cover.
- Gas Safety (Management) Regulations 1996[11] require Gas Transporters to prepare a safety case setting out the arrangements in place to safely manage its gas network, including ensuring adequate pressure.
- NGT's Gas Transporter Licence

[7] Department for Energy Security & Net Zero (2023), The role of gas storage and other forms of flexibility in security of supply
[8] European Commission (2026), Gas Storage
[9] The Oxford Institute for Energy Studies (2025), EU Gas Storage Regulation: a journey from crisis-induced rigidity to increased flexibility
[10] Gas Act 1986
[11] Gas Safety (Management) Regulations 1996

    - Standard Special Condition A9: Pipe-Line System Security Standards sets out the security standard including that the pipeline system must meet the peak aggregate daily demand for the conveyance of gas to supply premises, ensuring that the system can meet a 1-in-20 year weather event.
- Pipelines Safety Regulations 1996, the principal health and safety legislation in the UK concerning the safety and integrity of pipelines and set out requirements to ensure that relevant onshore UK pipelines are designed, constructed, operated, maintained and decommissioned safely. Natural gas pipelines are categorised as Major Accident Hazard Pipelines under these regulations.

These requirements, unless amended, will continue to apply to 2030 and beyond, therefore creating a continuing duty for NGT to maintain pressure cover.

Lower utilisation of the gas network, leading to lower revenues to finance pressure cover maintenance, may create additional challenges for the Gas Transporter. The role of gas in the electricity system after CP2030 will be significantly changed, shifting from commodity supply to resilience provision.

Proposed Capacity Market reforms aim to bring forward more low-carbon dispatchable capacity e.g. Long-Duration Electricity Storage, Hydrogen-to-Power units, which could mean less need to call on CCGTs during system stress, therefore fewer sudden spikes in gas demand that would threaten gas transmission pressures. However, unless the spikes are completely eliminated the need for pressure cover remains. The reduced frequency makes management of these more challenging, because pressure cover would be needed for less days but rarely used, making financing more challenging. Delays to bringing these technologies onto the system could lead to longer dependence on CCGTs.

In recognition of the changing pattern of supply and demand for gas, DESNZ is exploring future options to ensure security of supply in the gas system and held a consultation on this topic closing in February 2026.[12] This includes consideration of revenue support mechanisms and regulatory reform to increase flexibility.

With regards to intraday storage, linepack may provide a low-cost method of storing energy overnight. One analysis calculated a cost of 0.023 pence to store a kWh of natural gas as overnight linepack flexibility (based on a simple cost estimate based on ratio of cumulative daily linepack flexibility to the total gas transported annually, if all of the cost of maintaining linepack was allocated to linepack flexibility this would equate to 0.2 pence per kWh).[13] Flexibility provided by the gas system requires better visibility and discussion around its costs and value to the wider energy system.[14]

The challenges identified around the maintenance of linepack were primarily locally specific, centred on the South-East of England and particularly the [redacted] compressor.

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[12] DESNZ (2026), Gas System in Transition: Security of Supply

[13] Wilson, G (2022), Estimated cost of Great Britain's linepack flexibility per kWh of natural gas

[14] Wilson, G (2022), Setting the scene of the energy system dynamics of today and considerations for tomorrow (the scale of linepack), IGEM Policy Conference July 2022

The main contributing factor to whether NGT meet pressures is local supplies, which is true for the current network.

The value provided by linepack in maintaining pressure cover and therefore enabling the gas system to respond to peak events therefore needs to be visible at the local and regional levels.

3.3 Solution Options

The insights explored above suggest that making the flexibility value provided by the maintenance of pressure cover in the gas system more visible is important to the future resilience of the system to peak events.

Options include the revision of the pressure cover process to incorporate CP2030 based events of the type modelled in this project. This would require changes to the calculation methodologies used by NGT to determine required levels of linepack to maintain pressure cover in the system. Further exploration of the changes this would require would be beneficial.

Another option is to incorporate the role of linepack in maintaining pressure cover into whole-system planning to ensure that the potential value and costs can be assessed against the options available. Linepack is not the only flexibility tool available to enable the electricity system to navigate peak demand. Other sources of within-day flexibility could support the electricity system e.g. deployment of thermal energy storage at a district heating or household level, electric vehicles, behaviour change and technology choices could smooth demand, in addition reduction of overall energy demand by efficiency measures.[15]

Regional Energy Strategic Planning (RESP) has been introduced to take a whole-system view of regional energy needs across electricity, gas and emerging vectors. To ensure that regional investment decisions account for the value of linepack in maintaining pressure cover, RESP modelling could incorporate the availability and limitations of linepack when modelling gas supply resilience at local level. This would enable regional planning to accurately estimate local flexibility needs and potential risks to security of supply.

The RESP methodology commits NESO to undertaking Network Planning Assurance (NPA) after the creation of the RESPs "to conduct a targeted review of distribution networks' strategic and load-related investment plans to assure alignment with the direction of the 11 RESPs". The approach is based on alignment of network planning with RESP, resolving misalignments, and a targeted review by NESO of each network's load-related plans which will feed into Ofgem's business plan evaluation.

Incorporating consideration of local linepack requirements to provide sufficient pressure cover for the gas system to respond to peak events would raise visibility of its value for flexibility in long-term whole-system planning, informing network investment decisions.

[15] UK Energy Research Centre (2019), Flexibility in Great Britain's gas networks: analysis of linepack and linepack flexibility using hourly data

4. How are the dynamics at point of interaction between electricity system and gas system changing with CP2030 and plant automation? How does this impact on system operations?

4.1 Context

This part of WP4 focuses on the operational coordination strand, while referencing infrastructure considerations only where they materially change operational options (for example compressor criticality and linepack constraints).

The report uses:

- Public sources covering CP2030, system operation, gas balancing, and emerging market and dispatch reforms led by Department for Energy Security and Net Zero, Ofgem, and NESO.
- Public documentation of gas balancing and linepack concepts from NGT materials.
- Public documentation of electricity balancing and dispatch from NESO and Elexon
- Selected whole-system governance and resilience material (for example the national emergency plan for downstream gas and electricity) to contextualise what already exists in "true emergencies" versus what is missing for "pre-emergency peak events".

4.2 Changing dynamics at the point of interaction

CP2030 is defined in policy terms as clean sources producing at least 95% of Great Britain's generation, implying around 5% of generation from unabated gas by 2030[16]. NESO's CP2030 advice similarly frames gas-fired generation as used only rarely, primarily in sustained periods of low wind, and quantifies "less than 5%" unabated gas in a typical weather year. In parallel, NESO's FES 2025 highlights continued electrification, with electricity supplying a much larger share of final energy demand across net zero pathways[17].

This policy and system trajectory changes the electricity-gas interface in three material ways.

First, transitioning from being load-following to dealing with shock responses. Historically, gas-fired power stations have provided a significant portion of flexibility on the power system, but in a CP2030-consistent system their role shifts toward a resilience backstop[18]. Operationally, this means fewer running hours but greater dependence on the ability to

[16] Clean Power 2030 Action Plan: A new era of clean electricity – technical annex
[17] Future Energy Scenarios: Pathways to Net Zero – November 2025
[18] Clean Power 2030

start and ramp under stress conditions, including during prolonged low-renewable periods and cold spells that drive high demand and reduced renewable output.

Second, the electricity system is accelerating its operations through digitalisation and dispatch reform. NESO describes the Balancing Mechanism as the primary tool used in the Electricity National Control Centre (ENCC) to balance supply and demand in real time, with a continuously open auction and 30-minute trading periods[19]. NESO is also deploying the Open Balancing Platform and bulk dispatch, explicitly enabling control room engineers to send large volumes of instructions to smaller balancing units rapidly[20]. This matters for gas because faster and broader dispatch capability can produce sharper changes in aggregate gas-fired generation demand and reduced "time-to-instruction" can reduce the warning window available to gas system operators.

Third, gas network operations remain situated in different physical and commercial timeframes. Gas moves slowly through the transmission network, NGT gives an illustrative example that gas delivered in one part of the country may take on the order of tens of hours to reach distant demand and therefore changes in demand are often managed by compressing or expanding gas already in the linepack. A UK Energy Research Centre briefing note[21] shows that linepack provides significant within-day flexibility in Great Britain, with significant within-day variation and hundreds of GWh of within-day flexibility across many days in the winter season. Gas balancing is designed around the gas day, and the regulatory framing itself recognises a longer balancing timeframe for gas than electricity.

Automation sits across both vectors. On the electricity side, certain balancing and frequency services require rapid delivery, which in practice depends on automated control systems. For example, Dynamic Containment is designed as a fast-acting service delivering proportionally to frequency deviations outside operational limits.[22] Reserve services such as fast reserve specify short response times from dispatch instruction. As CP2030 increases reliance on flexibility and reduces average thermal generation, the operational conditions under which gas plants are started, stopped, and ramped are likely to become more driven by near-real-time signals and automated operational patterns.

In combination, these changes increase the probability of gas demand discontinuities, meaning large and rapid swings in gas offtake for power generation occurring within timescales that are challenging for gas system control if notice is insufficient.

4.3 Problem Definition

Under CP2030, rare but high-impact peak-gap events will require rapid and sometimes synchronised dispatch of gas-fired generation. If gas network preparations and electricity dispatch are not coordinated with sufficient notice and shared situational awareness, the gas system may be unable to deliver the required offtake without unacceptable pressure

[19] What is the Balancing Mechanism?
[20] First stages of Open Balancing Platform go live
[21] Flexibility in Great Britain's gas networks: analysis of linepack
[22] Dynamic Containment

impacts or may require expensive and disruptive interventions that reduce whole-system resilience.

Within this, key barriers to maintaining energy system resilience during extreme peak events fall into four categories.

Gas balancing and many gas scheduling processes are structured around the gas day and the management of end-of-day linepack. While gas nominations can be updated intra-day, NGT's own balancing guide notes[23] that nominations and their changes are part of a process chain designed to inform and incentivise accurate forecasting rather than instantaneous control. This creates a persistent warning gap, the electricity system can change dispatch quickly, while the gas system's best control actions (for example pre-pack, entry adjustments, compressor configuration) work better with earlier notice.

Maintaining adequate pressures during rapid offtake changes depends on linepack and compressor operation. NGT explicitly describes linepack as analogous to average network pressure and highlights that increasing linepack increases flexibility but raises "entry risk", indicating a trade-off [24]. NESO's Gas Network Capability Needs Report framing highlights that resilience assessment emphasises compressors and that stakeholders highlighted the availability of these essential components as a concern, indicating that compressor availability and operability are a credible critical dependency. In CPFI delivery discussions, a practical example has already been observed where the modelled scenario could not balance during an issue with reconfiguring a compressor at [redacted] while that specific event is an internal observation, it is consistent with the general evidence that compressor availability is a central resilience factor.[25]

Electricity market parties face imbalance prices per settlement period, and Elexon explicitly describes imbalance prices as used to settle the difference between contracted and metered quantities, creating a short-timescale incentive to match physical position to commercial position[26]. In addition, balancing mechanism units can be subject to non-delivery charges when accepted bids or offers do not deliver. Gas shippers face daily imbalance charges based on system marginal prices under the Uniform Network Code framework, plus scheduling charges based on differences between nominated values and actual flows. GNCC escalation tools such as a Gas Balancing Notification[27] are explicitly intended to stimulate market response to projected end-of-day physical imbalance and have no predefined trigger formula. This combination can make it rational for a generator to prioritise immediate compliance with ENCC dispatch instructions, even if gas-side notifications and nominations lag. The result is a whole-system risk: a short-run physical imbalance and local pressure stress in the gas system, most acute during high-impact peak-gap events.

Automation increases synchronisation risk and reduces effective notice. NESO is explicitly moving toward more automated and bulk dispatch capability through platform change.

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[23] End to End Balancing Guide
[24] What is Linepack?
[25] Gas Network Capability Needs Report (GNCNR)
[26] Imbalance Pricing
[27] Gas Balancing Notification Operational Guidance Material

Frequency and reserve services include products that require rapid response, which are typically achieved via automated control loops. As these capabilities scale, "manual notification" processes can become the limiting factor. If a plant's electricity-side response is automated but its gas-side notification pathway relies on a manual step (for example telephoning GNCC or triggering a nomination change via a shipper desk), the lag becomes structural rather than incidental.

The opportunity is to treat operational coordination as a resilience product, and to design protocols, data exchange, and incentives that allow the gas system to provide backup energy reliably and cost-effectively without reverting to emergency posture. The national emergency plan for downstream gas and electricity already recognises that there can be close interactions between gas and electricity and that in pre-emergency contexts the GSO and ESO may share information on proposed response plans to avoid undue stress across the energy system.[28]

4.4 Insights

The practical system-operational insights in this chapter are best expressed as "what is structurally changing" and "what this means for system operations".

The control philosophy mismatch is increasing i.e. the two control rooms are effectively running different types of control loops which are optimise for different purposes and physics. Electricity is controlled centrally in real time, with ENCC dispatch described as second-by-second and the Balancing Mechanism (BM) operating as a continuously open auction whose gate opens 60 to 90 minutes before real time. Gas is controlled through a combination of physical buffering (linepack), compressor operation, and commercial incentives that are evaluated and reconciled across the gas day. As CP2030 reduces the routine coupling between the vectors (less average gas generation), shared steady-state is replaced by "shared stress-state", making mismatches more pronounced when they do occur.

Linepack is both the buffer and the constraint in this context. NGT treats linepack as the key mechanism to manage slow gas transport dynamics (if gas is needed in Plymouth but has been delivered in Scotland, theoretically it would take a minimum of 23 hours to reach its destination). The End to End Balancing Guide[29] emphasises that linepack relates to average pressure and that increasing linepack increases flexibility, but with higher "entry risk". The UKERC analysis[30] illustrates that linepack provides substantial within-day flexibility, with predictable within-day patterns. Under CP2030, the operational importance of linepack is likely to increase, because it becomes the short-notice reservoir used to meet peak gas-offtake surges from power stations.

However, pre-pack (actively increasing the amount of gas being stored in the NTS) is not free. Increasing linepack implies higher pressures and potentially different entry and compressor operating decisions, and it interacts with incentive regimes. National Gas is

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[28] National Emergency Plan
[29] End to End Balancing Guide
[30] Flexibility in Great Britain's gas networks: analysis of linepack

incentivised via a linepack performance measure to minimise differences between start and end of gas day linepack, reflecting an operational objective to resolve imbalances within the gas day. This can create an operational and governance tension as pre-pack for electricity resilience may deliberately move linepack away from "typical" targets and could increase costs or risks unless explicitly recognised as a resilience action with agreed triggers and cost recovery. [31]

The electricity side already operates in anticipatory mode for severe weather, providing a model for peak-event protocol design. NESO describes a practice of monitoring weather warnings closely, developing a plan of action two days before a storm, identifying weak spots, and taking defensive measures including managing outages. This is conceptually similar to what GNCC would need for pre-pack i.e. a clear trigger, a lead time, and a defined set of operator actions. The gap is that electricity severe-weather planning is not yet translated into a formal, standardised gas readiness signals under CP2030.[32]

Penalty and incentive asymmetry can produce predictable operational behaviours. On the electricity side, imbalance pricing is applied when contracted and metered volumes differ at the settlement period level, and BM non-delivery charges exist where accepted bids or offers do not deliver.[33] These mechanisms, together with operational instruction culture, support rapid compliance with ENCC dispatch.

On the gas side, NGT's balancing guide describes daily imbalance charges using system marginal buy and sell prices, plus scheduling charges aiming to incentivise accurate nominations, with the balancing neutrality mechanism redistributing net costs.[34] These are suitable for daily balancing, but they do not inherently guarantee that gas offtake for power generation will be accompanied by timely operational notice to GNCC when dispatch changes on short timescales.

Automation, across the electricity operating system, shifts the weakest point to cross-vector communication rather than physical plant response. NESO is expanding dispatch capability and digitisation through the Open Balancing Platform (OBP) programme.[35] Some balancing products are explicitly designed to deliver very quickly and proportionally to frequency outside operational limits. If gas-fired units participate in faster services or are increasingly controlled by automated bidding and dispatch processes, output and therefore gas demand can change quickly, leaving cross-vector communication as the limiting step. This makes it more likely that the ENCC sees immediate response while GNCC sees delayed information and delayed nomination adjustment.

Finally, governance is moving toward whole-system planning, which creates an enabling context for system operational coordination reform. Ofgem's review of GB energy system operation argued that net zero requires a step-change in whole-system coordination and that electricity and gas systems are likely to become more integrated through new technologies and digitalisation. NESO's gas planning obligation and publications such as

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[31] Residual Balancing
[32] How does the ENCC handle severe weather?
[33] Imbalance Pricing
[34] End to End Balancing Guide
[35] The start of the balancing mechanism revolution

the Gas Network Capability Needs Report framing reinforce that the institutional ecosystem is already shifting toward multi-vector strategic planning. Operational coordination protocols between ENCC and GNCC can be treated as a practical delivery component of that broader whole-system direction.[36]

4.5 Solutions Options

Here we propose high-level potential interventions that address the identified challenges. These are high-level ideas to help structure discussion. They are not operational instructions, a commitment to implement, or a full assessment of compliance with codes, licences, safety, or cyber requirements.

1. Peak event coordination protocol between ENCC and GNCC.

This involves defining a formal protocol for "peak-gap readiness" that is explicitly distinct from emergency arrangements. The protocol should specify trigger conditions, lead times, message content, operator actions, and deactivation criteria. The ENCC severe-weather approach provides a precedent for acting on warnings days ahead and taking defensive measures, which can be adapted to energy shortfall and renewables drought warnings rather than storms.[37] [38] The national emergency plan also confirms that information-sharing in pre-emergency stages can be used to avoid undue stress across the energy system, indicating that cross-vector coordination is already recognised as appropriate in principle.[39]

A practical protocol could include three escalating states with increasing operational action:

- **Advisory** - probabilistic indication that gas-fired generation may be required at scale (for example day-ahead, centred on low-wind or cold scenarios).
- **Watch** - high confidence of substantial gas generation ramp requirement in a defined time window.
- **Action** - active pre-pack and readiness actions, aligned to risk thresholds and constrained by safety and entry considerations.

2. Automated dispatch-to-gas notification.

Establish a digital link where certain ENCC actions that change gas-fired generation dispatch automatically create a standard notification to GNCC. This is a coordination change, not necessarily a market reform. The content could include the unit or aggregated location, expected ramp magnitude, expected duration, and confidence bounds. The rationale is that the ENCC already operates at second-by-second timescales and is scaling

[36] Review of GB energy system operation
[37] How does the ENCC handle severe weather?
[38] Riding the storm: how our control room handles severe weather
[39] National Emergency Plan

bulk dispatch capabilities. If cross-vector notification remains manual, automation increases the risk of delayed GNCC awareness.

3. Joint situational awareness data exchange.

Create a minimum viable shared data set between ENCC and GNCC for peak event operation. A plausible initial set would include:

- **From ENCC to GNCC:** forecast gas-fired generation requirement ranges by region and time window; constraint-driven dispatch risk; intended use of reserve products likely to activate gas units.
- **From GNCC to ENCC:** linepack margin indicators; compressor availability and constraints; emerging pressure risk at critical offtakes; risk level of issuing Gas Balancing Notifications (GBN), margins notices, or approaching emergency tools.

This option utilises the fact that gas system operational status is already tracked and made visible in near real time and that GNCC decision-making draws on forecast demand, supply, and linepack. It also utilises NESO's direction toward data and digitalisation and modern balancing platforms.

4. Codified notice obligations for gas-fired generators and shippers, with automation-safe design.

A high-level policy and code option is to harden notice requirements so that gas-fired generators do not materially increase offtake without GNCC visibility, except in clearly defined circumstances (for example immediate frequency events). The key is to recognise the real-time electricity imperative and design obligations around predictable envelopes rather than rigid pre-notice for every dispatch change.

One workable approach is "pre-approved nomination envelopes" for designated strategic gas power stations, so shippers and plants maintain a nominated headroom band for peak days, allowing ENCC dispatch within that band without additional notice, but with automatic notification when headroom is consumed or when ramp rates exceed declared limits. This directly addresses the mismatch between second-by-second electricity control and daily gas nomination constructs, without requiring the gas system to adopt electricity-style instantaneous balancing.

5. Penalties and compensation alignment for cross-vector actions.

The misalignment where rapid ENCC response can coincide with delayed GNCC notification, is not only technical but it is behavioural and commercial, driven by penalty regimes and responsibilities. It can be proposed as a high-level intervention in which:

- failure to provide required gas-notice signals incurs a defined consequence (for example a specific charge or compliance mechanism),
- but where compliance with ENCC instructions is protected and the penalty is placed where control sits (for example on the party responsible for notification and nominations rather than on the real-time operator following instructions).

This option should be designed with existing gas balancing tools in mind, such as GBNs which are used to stimulate market response to projected physical imbalance. The intended outcome is not punitive. It is to make it commercially rational to automate and prioritise cross-vector notification to the same extent that electricity dispatch has been automated and prioritised.

6. Operationalising pre-pack as a recognised resilience action.

Another option involves pre-packing the network with extra gas and higher pressure as a coordination option. Turning this into an operationally credible option requires two additions:

- a trigger protocol that justifies pre-pack action (covered earlier), and
- a governance and cost-recovery concept that recognises the trade-off between linepack flexibility and operational risk.

NGT sources frame linepack as an acceptable range and highlight the flexibility versus risk trade-off, implying that a “pre-pack action” needs explicit rules to ensure safety and manage entry risk.[40] A follow-on trial could test what lead time and magnitude of pre-pack meaningfully reduces the probability of pressure issues under peak-gap events, and what is the operational cost and risk of doing so.

7. Infrastructure adjacent operational option - Critical compressor readiness for peak events.

If compressor availability is a key determinant of deliverability, then operational coordination must include compressor readiness and reconfiguration planning as part of peak-day, NESO’s own framing emphasises compressors in resilience assessment. An operational option is to create a “critical gas assets for power resilience” list (to be align with WP2 Simone outputs) and embed it into joint outage planning and peak-event readiness rules, comparable to ENCC practice of managing outages and defensive measures as severe weather certainty increases.

[40] NTS Linepack

5. What could an enhanced approach to early analysis, to pre-empt electricity peak gaps provide and look like?

5.1 Problem Definition

Work Packages 2 and 3 identified several operational constraints that limit how the gas and electricity control centres coordinate their responses to rapidly emerging stress events. At its core, this problem is about how both control rooms can act early, and in a coordinated way, to minimise any impact during peak events.

The National Energy System Operator (NESO) launched in October 2024.[41] The NESO is now responsible for planning Britain's electricity and gas networks and operating the electricity system. This creates a stronger opportunity for whole-system coordination when balancing the electricity and gas systems.

However, as mentioned in Section 5.2 of Work Package 3, there are limitations in how the gas and electricity control centres coordinate responses to rapidly emerging stress events. There are two main operational constraints:

- They operate on different timescales. The electricity system requires second by second balancing while the gas system balances over several hours.
- NESO is responsible for the whole-system emergency coordination across gas and electricity, but national plans have not yet been updated to reflect NESO's new role.

Timescales differ significantly between the systems

On the electricity side, supply and demand must be balanced in real time. NESO uses mechanisms, such as the Balancing Mechanism, which provides "minute by minute and second by second" balancing.[42] Alongside new tools, such as the Open Balancing Platform, which automates the dispatch of smaller storage assets simultaneously to allow for faster response.[43]

On the gas side, the system has more inherent flexibility. Physical linepack provides security, and the system is commercially balanced across the gas day, with nominations and imbalance charges focused on end-of-day outcomes.[44] These differences in how each system balances make it harder to act in a coordinated way across both networks during fast-moving events.

The gas network needs better visibility of the whole-system

While NESO is already taking on a coordinating role, the gas network requires improved insight and modelling capability to understand interactions across the wider system. This

[41] https://www.neso.energy/news/national-energy-system-operator-neso-launches-1-october
[42] https://www.neso.energy/what-we-do/systems-operations/what-balancing-mechanism
[43] https://www.neso.energy/news/first-stages-open-balancing-platform-go-live
[44] https://www.nationalgas.com/sites/default/files/documents/End%20to%20End%20Balancing%20Guide%20Oct%2023.pdf

would help identify when gas-side action is needed in response to rapid changes elsewhere.

Looking towards a CP2030 energy system, the GB energy system will change significantly. CP2030 sets an ambition for at least 95% of Great Britain's electricity generation to come from clean sources, leaving around 5% from unabated gas by 2030.[45] As outlined in Section 4.1, gas-powered peaking plants are likely to play a less frequent, but more significant role during peak events. In parallel, increased deployment of battery storage (23-27 GW) and long-duration storage (5-8 GW) will also shape how gas contributes during peak events.[40] Battery and long duration storage can be used to mitigate challenges around immediate response and the scale of response. Potentially changing the role of natural gas power generation to one of support when batter storage is exhausted.

5.2 Insights

Early identification and anticipatory action to peak events is essential

The differing timescales across the gas and electricity systems mean that early identification of stress events is critical. Electricity stresses can emerge within seconds, while meaningful gas-side actions typically take place over several hours. The earlier a potential peak event is recognised, the easier it is for both systems to take coordinated, proactive action rather than relying on more dramatic last-minute interventions.

These limitations become more pronounced during peak events, when it is crucial for both systems to work in tandem as stress builds. Looking towards 2030, the nature of peak events is also expected to change. A more weather-dependent electricity system and tighter margins may increase either the frequency or the severity of peak conditions.[46] This reinforces the need for better anticipatory signals and improved visibility of early system stress, allowing actions to be taken sooner and with less disruption.

Whole-system visibility is increasingly important

As the energy system evolves, the gas network will need a clearer understanding not only of electricity system behaviour, but also of emerging whole-system interactions. Future gas demand and system flexibility will be influenced by whole-system interactions, such as hydrogen production swings, the behaviour of storage and distributed energy resources, the impact of electrified heating and transport and changes in interconnector flows.

Understanding the role that gas can play in supporting system resilience is also becoming more complex. Gas-powered peaking plants, CCS-enabled generation, linepack, and the potential use of gas storage to support prolonged low-renewables periods all offer different forms of flexibility. However, the gas network currently does not have sufficient visibility across the wider energy system to model its behaviours accurately or to anticipate how they may change over time. Improved whole-system insight will therefore be essential for responding effectively during future peak events.

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[45] https://www.neso.energy/publications/clean-power-2030
[46] https://www.theccc.org.uk/wp-content/uploads/2025/02/Reasonable-worst-case-stress-test-scenarios-for-the-UK-energy-sector-in-the-context-of-the-changing-climate-Bloomfield.pdf

Peak events are complex and multi-factor

Peak events are becoming increasingly complex, driven by a wider range of interacting factors across the whole energy system.[47] Several conditions can increase risk during periods of system stress. These include the potential for multiple stress events to occur at the same time,[48] such as a daily peak coinciding with a prolonged period of low renewable output. Delays to liquefied natural gas (LNG) deliveries, weather-related impacts on renewable assets, interconnectors and pipelines, failure on power supply or electricity interconnectors, and variations in hydrogen production or industrial switching all add further uncertainty. Global market conditions can also shape domestic system risk, with international gas prices and supply patterns affecting the volumes available to the UK. Shifts in consumer behaviour during cold spells, and competing gas demand across electricity, heating, and industrial sectors add further complexity. As the energy system becomes more interdependent and dynamic, peak events are likely to involve a wider range of interacting factors, making them more challenging to forecast and manage in real time.

5.3 Solution/Options

Here we propose a set of high-level innovations that address the challenges identified above.

1. **Develop an enhanced cross-vector forecasting and modelling framework**

Peak event coordination is hindered by limited visibility across vectors and timescales and the absence of tools that capture how changes in one part of the system propagate through other parts. One option is the development of a whole-system forecasting framework that integrates gas, electricity and other vectors, such as weather and hydrogen.

This framework would include both enhanced inputs and system-wide outputs:

- Integrated data and modelling on weather forecasts, renewable generation output, interconnector flows and constraints, LNG market signals, gas-fired generation dispatch, storage states/behaviour (batteries and hydrogen), heat-driven electricity demand and industry consumption patterns.
- Cross-vector balancing projections to forecast the expected movements between electricity, gas, hydrogen and storage assets in response to specific stressors.
- Representation of key feedback loops (such as low wind increasing gas-fired generation, which then reduces available linepack, affecting later system flexibility).
- Automated early warning outputs to generate alerts for conditions likely to produce major gas swings or high residual demand.

This framework would improve early detection of stress events by enabling a dynamic whole-system view of how stress events evolve over time. It would provide both gas and

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[47] https://assets.publishing.service.gov.uk/media/65e3a3323f694514a3035fbe/5-exploring-reliability-standard-metrics-in-net-zero-transition.pdf
[48] https://arxiv.org/pdf/2307.13520

electricity control rooms with a shared and potentially automated view of emerging risks and create underpinning modelling for real-time decision support.

This framework would depend on access to consistent, real-time and forecast data from across electricity, gas, hydrogen and storage sectors, including NESO, NGT, storage operators, renewable generators, hydrogen producers and relevant market and interconnector actors.

2. **Improved linepack modelling for stress event response**

Linepack is a critical tool to provide flexibility and forms part of a wider, interconnected flexibility ecosystem alongside electricity storage, hydrogen and interconnectors. An enhanced modelling tool could evaluate how effectively linepack can respond during specific stress events and identify when it is insufficient without complementary assets.

What this looks like:

- Linepack modelling should be coupled with electricity forecasts to allow linepack behaviour to be linked to expected renewable generation, battery storage level, interconnector constraints and gas-fired generation ramping needs.
- Dynamic response-time estimation to quantify how quickly linepack can deliver additional pressure support. Specifically, a focus on response-times compared to alternative flexibility sources, such as batteries, hydrogen, long duration energy storage, to ensure effective integration.
- Integrated 'flexibility modelling' to determine the level of linepack most suitable mitigation in each stress scenario or in the context of the wider market and system technologies status given the changing role of the NTS and gas fired power generation in CP2030.

This innovation would support operational decision making on when linepack can meaningfully mitigate stress events and provides evidence to support decision making on other storage assets under these events. Embedding linepack in a whole-system perspective ensures operators can understand not just its standalone value, but how its effectiveness changes as electricity, hydrogen and market conditions shift.

3. **Framework for cross-vector stress event response**

While peak events do vary, there is value in developing a repeatable, scenario-based response framework for classes of stress events that consistently occur, especially as the energy system becomes more connected.

This could include scenarios such as:

- Low-wind, cold-weather events with prolonged reduced renewable generation
- Generation outages combined with high industrial demand
- LNG import delays during high-demand conditions
- Hydrogen-production swings coinciding with low-flow periods on the gas system
- Outages or extended maintenance on the National Transmission System

The framework would outline:

- Situation definition and trigger indicators
- Required cross-vector information flows
- Actions for gas and electricity control rooms
- Communication steps and responsibilities
- Criteria for standing down the response

This framework would provide faster, clearer and more consistent operational decision making during predictable stress events.

However, some work would be needed to further develop the typical characteristics of stress scenarios to support development of standardised responses to be possible.

4. **Enhanced real time data access from hydrogen and storage assets**

Hydrogen production, electrolysis demand, storage charging behaviour and industrial switching have growing influence on gas flows and residual electricity demand. Innovation could help to create a minimum viable dataset for these assets.

This could include:

- Electrolyser operating mode forecasts (such as importing electricity vs. shutting down vs. switching to gas feedstock).
- Hydrogen storage state-of-charge and ramp potential.
- Expected industrial switching behaviours under market or temperature signals.
- Battery and long duration energy storage dispatch profiles, including in adverse weather scenarios.

This would give the gas control room better visibility of when there is the potential for major gas side swings or electricity peaks.

5. **Short-term stress-event simulation**

Alongside the development of whole-system modelling tools, there is value in strengthening short-term simulation capability using existing modelling platforms (e.g. Simone). Current Simone stress-event analysis could be extended to evaluate CP2030-type scenarios, with risky supply distribution forecasts. Simone could be used to simulate the evolution of a predicted high-risk supply mix, identify the point at which system stress is likely to materialise, and test a suite of anticipatory operational actions.

This option enables testing of CP2030-type stress events in faster timescales, before whole-system modelling is mature. It can offer immediate benefits to improving readiness to responding to uncertain supply conditions.

6. Conclusion

Work packages 1 to 3 generated a long list of findings that present challenge and subsequent opportunity for further innovation to NGT. These were filtered to move 'no regret actions' into existing NGT projects. This included findings associated with [redacted] [redacted] and [redacted]

From the remaining prioritised issues three questions were developed to support problem definition and options ideation:

1. How will the market aspects of maintaining pressure cover change following CP2030?
2. How are the dynamics at point of interaction between electricity system and gas system changing with CP2030 and plant automation? How does this impact on system operations?
3. What could an enhanced approach to early analysis to pre-empt peak gaps?

From these questions, the following topics for the innovation roadmap emerged:

Q1 - Identified innovative market options of maintaining pressure cover change following CP2030.

- Market reforms are needed to better reflect the flexibility value provided by the maintenance of pressure cover in the gas system.
- Increased requirements and market incentives should be considered for gas storage.
- Assess if existing regulatory requirements sufficient to maintain a safe network in more dynamic scenarios.

Q2 - Options for innovation in the cross-vector system operations:

- Development of peak event coordination protocols between ENCC and GNCC.
- Establish automated dispatch-to-GNCC notification.
- Develop joint situational awareness data exchange between NESO and GNCC.
- Codified notice obligations for gas-fired generators and shippers, with automation-safe design.
- Penalties and compensation alignment for cross-vector actions.
- Operationalising pre-pack as a recognised resilience action.
- Infrastructure adjacent operational option - Critical compressor readiness for peak events.

Q3 - Innovative options to enhance early analysis to pre-empt peak gaps that impact on the NTS:

- Improved whole systems cross-vector forecasting/modelling approach.
- Improved linepack modelling for stress events.
- Develop framework for peak event response.
- Develop forecasting capability of other flexibility technologies. E.g. from hydrogen/other storage.

These topics have been carried forward to the final work to develop an innovation roadmap for NGT's consideration.

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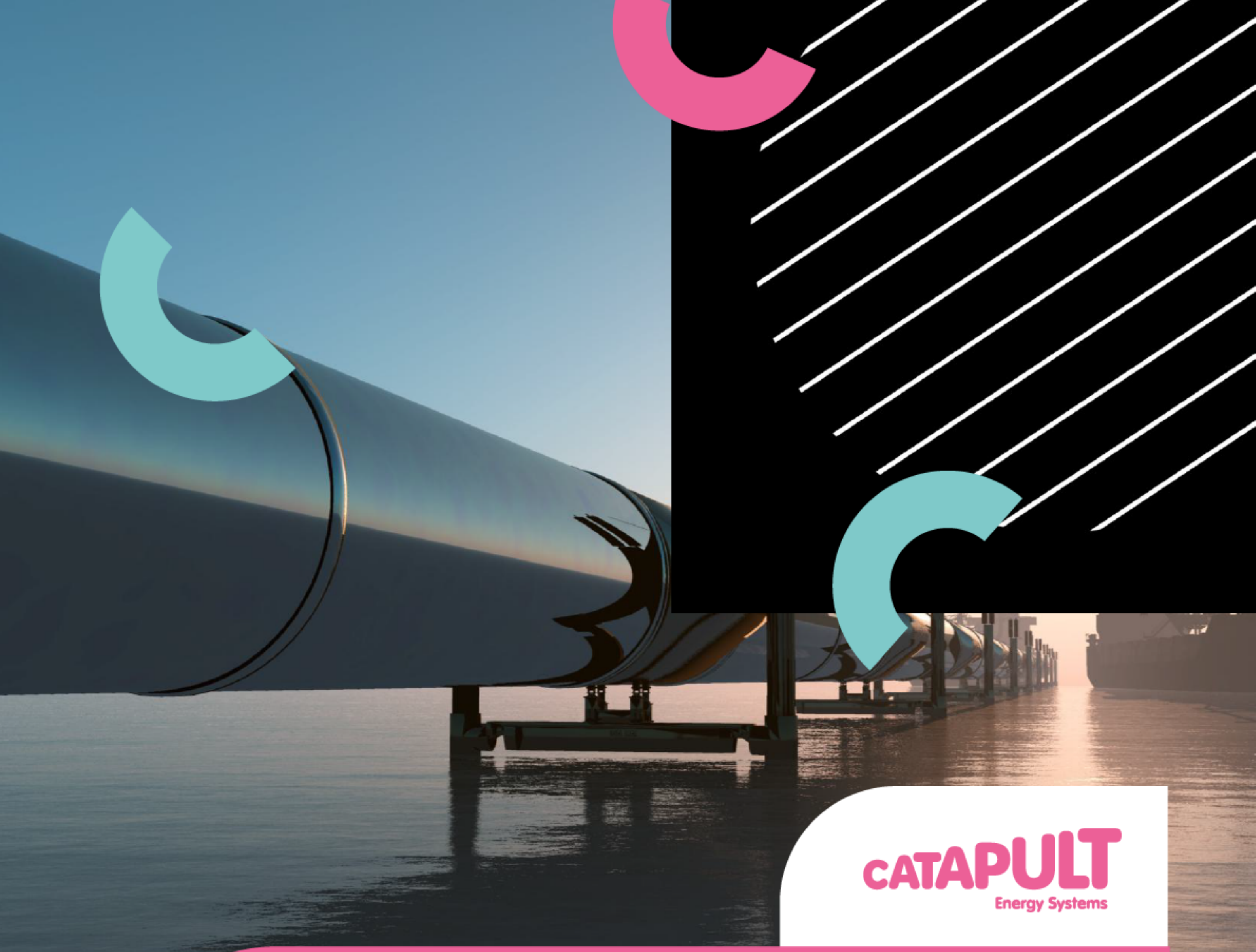

Clean Power Flexibility Investigation: Final Project Report

Author: Nathaniel Bottrell, Richard Waine

Date: July 26

Contents

1. Executive Summary

The Clean Power Flexibility Investigation (CPFI) was commissioned by National Gas Transmission (NGT) to understand how the National Transmission System (NTS) can continue to support electricity system security in a future characterised by lower average gas demand but increasing reliance on gas-fired generation as a flexible resource. The project focused on Clean Power 2030 (CP2030) scenarios and the capability of the gas system to respond to electricity system peak-gap events resulting from generation outages, reductions in renewable output and other system stresses.

The project combined whole-system scenario development, gas network simulation and systems engineering analysis. Eight stress scenarios were developed, with detailed modelling focused on the South East of England, where significant electricity demand and gas-fired generation create the potential for localised network stress.

Gas network modelling demonstrated that the NTS remains resilient under the conditions examined. No power station supply pressure limits were breached, indicating that existing linepack and operational strategies are capable of meeting the flexibility requirements associated with significant electricity system events. However, the analysis identified several important sensitivities, particularly relating to minimum supplies from [redacted] compressor station configuration at [redacted] and LNG import capability at [redacted] These findings reinforce the importance of planned infrastructure upgrades and continued operational readiness.

While physical network constraints were limited, the project highlighted wider challenges associated with growing interactions between gas and electricity systems. These include infrastructure dependencies, different operational timescales between the two systems, market arrangements that rely heavily on gas-fired generation, and regulatory frameworks that may undervalue resilience and flexibility during periods of stress. Future challenges are therefore expected to arise from operational coordination and whole-system decision-making rather than network capacity alone.

The project identified three strategic questions to guide future innovation: how pressure cover requirements may evolve following CP2030; how increasing gas-electricity interactions will affect system operations; and how enhanced forecasting and decision-support capabilities could improve responses to future peak-gap events. To address these challenges, an innovation roadmap was developed covering market innovation for flexibility provision, enhanced cross-vector operational coordination, improved early analysis and decision support, whole-system linepack modelling, stress-event response frameworks, and future integration of hydrogen and storage data into operational planning.

Overall, CPFI concludes that the NTS is well positioned to support Clean Power 2030. However, maintaining resilience in an increasingly integrated energy system will require greater emphasis on operational responsiveness, cross-vector coordination, forecasting capability and whole-system decision-making. The proposed innovation roadmap provides a practical pathway for NGT to address these emerging challenges.

2. Introduction

This document provides a summary of the four preceding reports produced in the Clean Power Flexibility Investigation (CPFI) project and proposes an innovation roadmap inclusive of interventions to innovation project outlines for National Gas Transmission (NGT) to consider in next steps.

The aim of the CPFI project was to understand how to sustain the gas network in a low average, high peak demand future, focusing on the interaction between gas and electricity systems. It is an NIA funded project by NGT, delivered by Energy Systems Catapult.

The objectives of the project were to:

1. Define Clean Power 2030 demand stress conditions (and high-level conditions out to 2050), with specific attention to peak gap events caused by weather or low renewable output
2. Assess the implications of peak gap events on the gas network and the gas network's ability to respond, using NGT's SIMONE model, identifying limits, stress points, and operational gaps.
3. Identify potential technical, operational, and market issues that prevent the gas network to provide backup capacity in a decarbonised energy system
4. Develop a high-level shortlist of potential interventions suitable for future innovation project(s), including simulations, prototype deployments, or market and regulatory interventions (the type of interventions may change as the transition progresses through time).

The focus was investigation of gas network reliability to meet short-term increases in gas demand from the electricity network via gas-fired generation. Five work packages, each with their own deliverable have been completed to deliver the stated objectives:

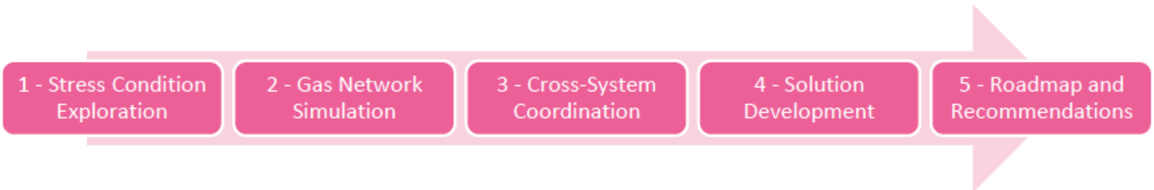

Figure 1 - Clean Power Flexibility Investigation Work Packages

2.1 Scenario development

The initial work package designed scenarios specifically to stress test the National Transmission System (NTS) using systems thinking and Catapult knowledge of emerging electricity system flexibility needs. An adapted Future Energy Scenarios (FES) scenario was created, with accompanying network condition assumptions to test stress associated with a peak instantaneous gap – rapid and large increase in electricity system demand. Eight scenarios were developed to provide test coverage across different potential stress levers.

In discussion with NGT it was identified that network constraints and stresses on the NTS can have different characteristics from national level gas deficit or supply emergencies to localised in specific geographies. Given the scope of this project it was agreed to focus on a constraint in a specific geography, the South East of England. This coincides with large demands on the electricity system in the South East of England and multiple supply points from power generation and interconnectors. As such, the focus of scenario and analysis was on this region. The instantaneous peak gap was triggered by localised loss of supply (~3GW) in the electricity system from either domestic supply (loss of a single power station) or from substantial (80%) interconnector supply reduction. The subsequent need for rapid response from the natural gas-powered generation to meet the electricity demand is driving the increase in gas demand from the NTS and potential stress. Modelled time periods focused on the early 2030's given the retained high local distribution network gas demand in the scenario developed.

2.2 Gas network modelling and system coordination

The scenarios and assumptions provided the input to the gas network modelling carried out by NGT. The initial analysis of the first two 'high stress' scenarios found minor challenges to the gas network and limited stress. Network analysis was refocused to investigate the role of [redacted] compressor station configurations, the minimum required supplies to under configuration 1, maximum power station loads, and CP30 risks in a repurposed network using a proposed Project Union (PU) and Carbon Capture and Storage (CCS) network.

Gas distribution network (GDN) assured offtake pressures (AOP) are typically higher, due to (GDN security of supply requirements), and more challenging to maintain that other exit connections (Power Stations) on the NTS, where contractual minimums are significantly lower. Extremities experience the fastest pressure decline during system stress due to limited downstream linepack and restricted local supply. As a result, maintaining sufficient pressure is essential to meet minimum operating pressures during high demand or reduced supply.

During gas network modelling GDN AOPs provide a reference point to identify initial issues with modelled scenario and indications or potentially wider issues. Given the focus of this project, power station connection pressures were included in the modelling. Modelling results found no power station supply pressures were breached in the scenarios modelled, or the scenarios modified to induce further stress. Low or unavailable local supplies ([redacted] LNG and [redacted] Terminal) were confirmed as the main factor that influence local pressure failures, as in the network today. Challenges in specific scenarios were found around [redacted] minimum supplies, [redacted] compressor reconfiguration and [redacted] Specifically, while managing linepack levels during the event response, entry constraint at [redacted] was triggered as it is providing the main LNG supply response load. This finding is important as the scenario assumes that [redacted] terminal can support the required LNG supply load during the power event. This finding supports the need case for infrastructure upgrades at [redacted] as already identified by the West Import Resilience Project (WIRP). This will enable the terminal to accommodate higher LNG entry flow as expected in the coming years. See section 4 for more on WIRP.

Although the majority of the modelling scenarios could be resolved, the analysis and results emphasise the critical role of the Gas Network Control Centre (GNCC) in any response to peak gaps in the electricity system requiring natural gas power generation. GNCC need to make rapid decisions in a real-world environment. The GNCC has modelling available to them to help inform their decisions, but the decisions are also time sensitive. Understanding the situation and making the correct decision and actions become increasingly important as the demand profiles become more volatile.

The third package of work delivered by the Catapult took a systems thinking and engineering approach. This analysis identified where the gas system is relied upon by the electricity system to meet peak gaps[1]. Using a 'Dunkelflaute' (Peak Durational Gap) as a representative scenario, two methods were applied:

- Analysis of a System-of-Systems map to identify structural relationships and how interactions ripple through both systems,
- a systems dynamics analysis to surface feedback loops and emergent behaviours.

Together, these identified critical periods and system locations for gas electricity coordination. Four areas of potential constraint were identified.

- Physical infrastructure elements and interfaces that could combine to create gas system constraints when reliance on gas fired generation increases. The systems dynamics analysis made the chain of infrastructure required to respond to peak gaps explicit, enabling assessment of mitigation options.
- Operational constraints driven by fundamentally different balancing timescales across gas and electricity networks, limiting real time coordination despite NESO's gas planning licence for strategic planning role and requiring updated emergency frameworks and integrated modelling.
- Market shortfalls from heavy Capacity Market reliance on gas fired generation, compounded by limited storage and declining domestic production.
- Policy and regulatory gaps where market frameworks optimise for normal conditions rather than resilience, undervaluing assets that provide endurance and flexibility during prolonged stress events. This is a key point that highlights the fundamental difference in design philosophy between the Gas and Electricity systems.

2.3 Development of the innovation roadmap

Work packages 1 to 3 generated a broad set of findings including opportunities for further innovation by NGT. These were split into two groups, separate 'no regret actions' for inclusion in established NGT projects, including the findings associated with [redacted] and [redacted] from the gas network modelling. For the second, to address the remaining issues, three questions were developed to support problem definition and options ideation:

- How will the market aspects of maintaining pressure cover change following CP2030?

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[1] Innovating to Net Zero 2026: Scaling flexibility to meet the five peaks challenge. 2026 [online]. Avaliable: https://es.catapult.org.uk/project/innovating-to-net-zero-2026/

- How are the dynamics at point of interaction between electricity system and gas system changing with CP2030 and plant automation? How does this impact on system operations?
- What could an enhanced approach to early analysis, to pre-empt electricity peak gaps provide and look like?

From these questions, options for the innovation roadmap have been identified.

Market options focused on reforms to better reflect the flexibility value of pressure cover, linepack, increased requirements or incentives for gas storage, and assessment of whether existing regulatory requirements are sufficient to maintain a safe network in more dynamic scenarios.

Cross-vector system operations options included peak event coordination protocols between Electricity Network Control Centre (ENCC) and GNCC, automated dispatch-to-gas notification, joint situational awareness data exchange, codified notice obligations for gas-fired generators and shippers with automation-safe design, penalties and compensation alignment for cross-vector actions, operationalising pre-pack as a recognised resilience action, and critical compressor readiness for peak events.

Options to enhance early analysis covered improved whole systems cross-vector forecasting and modelling, improved linepack modelling for stress events, development of a peak event response framework, and forecasting capability for other flexibility technologies such as hydrogen and other storage.

These options have been developed into an innovation roadmap.

3. Innovation Roadmap

The objective of this roadmap is to provide a path from the analysis completed in this project to action. It recognises the constraints of this project and the wider breadth of systems interactions that influence gas and electricity coordination. It also recognises the emerging and evolving role of NESO in navigating these cross-vector challenges.

Four principles guide the approach:

- Application of a systems approach to support operation of the NTS;
- focus on the operation of the NTS;
- modularity to allow flexibility of scope for NGT to shape and sequence projects;
- an assumption of collaboration with NESO throughout.

3.1 Market and Regulatory aspects of maintaining pressure cover will change following CP2030

Findings from work package 4:

- Highlighted the need for better visibility of the flexibility value provided by pressure cover in the gas system, particularly at a local level.
- Highlighted the potential for this to be incorporated into future Regional Energy Strategic Planning (RESP) methodologies.

Options to test through innovation:

- Operating strategies to maintain system pressure have typically been used to cover large demands in the Local Distribution Zone (LDZ). However, as these demands decline and demand profiles change there is some uncertainty around how the needs driving pressure cover will change out to 2050.
- Power generation demand has been shown to be more intermittent with higher peaks and in certain geographies of the NTS. e.g. in the South East potential for network stress appear to be more acute.
- Pressure cover has traditionally been about delivering a level of pressure that is resilient to unforeseen events on the network that could impact GNCC's ability to delivery pressures that meet NGT's obligations.
- There is a need to review if the current methodology for calculating the level of pressure cover remains suitable through the energy transition.
- Given the regional nature of the pressure cover, it is proposed that this project might benefit from working with NESO RESP and respective GDNs.

Outline Innovation Project 1: Gas market innovation for energy system flexibility provision

Type: NIA or SIF

Collaborators: NESO (RESP), SGN, Cadent, Catapult, Electricity Distribution?

Geography: South East England.

Outline Scope:

- Analyse pressure cover drivers (Electricity, Electricity Distribution, Gas Distribution)
- Deep analysis of regulation, legislation, licence to include review of policy and regulatory gaps where market frameworks optimise for normal conditions rather than resilience, undervaluing assets that provide endurance and flexibility during prolonged stress events
- Model evolving pressure cover needs scenarios from 2030-2060.
- Develop a value assessment of the pressure cover to the energy system and comparison with flexibility options. Note: Valuation of pressure cover are considered separately.
- Design market innovations
- Model and test market innovations
- Carry out stakeholder engagement

3.2 System operations for more dynamics interactions between the electricity and gas systems after CP2030

Identifying firm and processing options into an outline innovation proposal is challenging for this question given the limited visibility of current work within NESO and between NGT and NESO. As such an exploratory collaborative discussion between NGT and NESO, facilitated by the Catapult is proposed to cover the following options as topics of discussion:

Automated dispatch-to-gas notification.

This area of further innovation could involve:

- Specify the notification triggers
- Map how this interacts with NESO dispatch platform evolution
- Build a working prototype that generates structured notifications and delivers them to GNCC systems.
- Expand to more event types

Joint situational awareness data exchange.

This area of further innovation could involve:

- Define use cases and derive the minimum dataset requirements
- Build a prototype data product and dashboard

Penalties and compensation alignment for cross-vector actions.

This area of further innovation could involve:

- Map current incentive and penalty exposure across electricity response, gas nominations, gas imbalance, and operational constraints.
- Identify where "good system behaviour" is financially punished, and where bad coordination is not penalised.
- Introduce a shortlist of implementable mechanisms
- Prototype a reconciliation method

Operationalising pre-pack as a recognised resilience action.

This area of further innovation could involve:

- Translate "pre-pack" into a decision framework
- Identify constraints and risks
- Define KPIs that reflect resilience value
- Prototype a GNCC decision-support tool and stress
- Test logic across multiple events

3.3 An enhanced approach to early analysis to support GNCC decisions making relate to electricity system peak gaps.

Findings from work package 4:

- Highlighted that electricity and gas operate on different timescales with electricity balancing required in seconds while gas system actions typically unfold over hours.
- Highlighted that the gas network needs improved whole-system visibility, across electricity, hydrogen, storage and demand sectors, to anticipate peak events early and respond effectively.

Outline Innovation Project 2: Enhanced early analysis

Type: SIF

Collaborators: NESO, Catapult, Technology provider

Geography: Start with South East England, Extend to National as required.

Scope:

- **Discovery:**
    - Analyse existing early analysis for gaps associated with Clean Power and Energy Systems flexibility and resilience needs.

    - Analyse assumptions around compressor reconfiguration times and modelling of risks associated with reliability of this.
    - Develop gas transmission system map element to include hydrogen and potential sources of peak gaps to identify interactions.
    - Develop cross vector modelling approach.
    - Develop early analysis architecture and decision-making support.
- **Alpha:**
    - Identify cross-vector data set requirements.
    - Minimum Viable Product of data models and infrastructure.
    - Develop autonomous peak gap scenario identification and mitigation response strategy support.
    - Develop GNCC simulations and training scenarios.
- **Beta:**
    - Deploy fully enhanced modelling capability to operations.

This project is positioned as a SIF, there is the potential for an initial or bounded version of this project where the focus is purely on the NTS. This would include emphasis on inclusion of CP2030 events into existing short term SIMONE modelling capabilities. It is considered worthwhile to include datacentres in the scope of this initial element.

Outline Innovation Project 3: Whole-system linepack flexibility modelling

Type: SIF

Collaborators: NESO, Catapult, Flexibility provider (BESS operator)

Geography: Start with South East England, Extend to National as required.

Scope:

- **Discovery:**
    - Review current linepack modelling and identify gaps in how cross-vector effects (renewables, hydrogen, interconnectors) are represented.
    - Develop conceptual models for integrating linepack response with electricity stress-event forecasts.
    - Assess comparative response times of linepack vs alternative flexibility assets.
    - Assess timeframe differences for long term planning vs day ahead and within day.
- **Alpha:**
    - Build an MVP tool that couples linepack behaviour with electricity demand, storage, flexibility, renewable output forecasts.
    - Create an optimisation model to test linepack against other flexibility options under different scenarios.
    - Validate using historical stress-event data.
- **Beta:**
    - Deploy integrated linepack modelling into an operational setting.

Outline Innovation Project 4: Cross-vector stress event response framework

Type: SIF

Collaborators: NESO, Catapult, DNOs

Geography: Start with one DNO region then extend to national

Scope:

- **Discovery:**
  - Identify potential system-stress archetypes through analysis of historical GB stress events, whole-system modelling and predicting potential evolution of theses.
  - Define cross-vector indicators, triggers and escalation pathways for key stress archetypes (e.g., low-wind cold spells, LNG delays, industrial switching surges).
  - Map required data flows between gas, electricity, storage and hydrogen actors.
  - Develop response framework structures.
- **Alpha:**
  - Build MVP stress-event frameworks with defined triggers, operator roles, communication pathways and de-escalation criteria.
  - Create simulated training scenarios to validate framework effectiveness under various multi-factor conditions.
  - Test early versions of the framework with ENCC/GNCC operators in sandbox environments.
- **Beta:**
  - Deploy the framework in operational modes.

Outline Innovation Project 5: Hydrogen and storage data integration for whole-system operation

The focus of CPFI has been the interactions between the natural gas and electricity system for a CP2030 scenario. As the hydrogen system develops it has a potential role of provision of flexibility to the electricity. On this basis, and to support a whole system view, the following innovation project is proposed:

Type: NIA

Collaborators: NESO, Catapult, Hydrogen producers, Storage operators, Data platform providers

Geography: Start with regions with a hydrogen focus, extend to national as required.

Scope:

- **Phase 1:**
  - Identify the minimum viable dataset required for hydrogen and storage assets to support whole-system operation (electrolyser modes, ramps, dispatch profiles).
  - Map cross-vector impacts (e.g., electrolysers responding to price signals; storage charging increasing residual demand).
  - Define data-sharing and digital interface requirements.
- **Phase 2:**
  - Build MVP API service for hydrogen and storage assets.
  - Implement basic forecast models for production, consumption and switching behaviours.
  - Integrate MVP dataset into existing NESO/NGT forecasting environments for testing.
  - Validate operational benefit in simulated peak-event scenarios.
- **Phase 2:**
  - Deploy full data integration service nationally.
  - Include real data from hydrogen and storage asset operators.
  - Test end-to-end data flows during live operational periods.

4. Assumptions and Limitations

This project was a discovery project with focused time and resource to explore a complex problem cutting across multiple systems within the UK energy systems. The project was designed to take a qualitative risk-based approach in collaboration between the Catapult and NGT with focused efforts on scenarios, conditions and parts of the network which were considered most vulnerable to stress.

Practically, this approach resulted in the focusing on a single system intervention point from a possible list of twelve. Out of the four gaps identified, two peak gaps 'durational' (Dunkelflaute) and instantaneous (large supply failure) were explored. Geographically the South East was the only region explored. The scenarios focused on a combination of two FES scenarios Holistic Transition and Electricity Engagement[2].

This approach has resulted in some interesting insights, both adding evidence to known needs and identifying new areas to consider for innovation. In addition to this, the project has introduced an initial version of a systems-based approach to a challenge that crosses gas and electricity systems that could form the basis for further development and embedding of systems engineering approaches in scenario development as the dynamics of gas and electricity network interactions evolve.

The project team was comprised of a majority of people with current or previous gas transmission experience with National Gas Transmission. A key part of the project was to define 'credible extreme' scenarios. Whilst existing emergency procedures were used as the basis of this definition, there is likely to be biases towards what is considered 'normal' for the UK gas and electricity systems within the scenario developed.

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[2] Note: The reasons for scenario selection is included in work page 1 scenario design.

5.Conclusion

Analysis conducted in this project found the NTS to be reliable in response to increasing demand swings. From a system perspective, the NTS was designed to transport high volumes of gas, and power station demand represents only a relatively small share of that volume. The network was not designed for rapid responsiveness. When considering this change in functional requirement, NTS linepack to provide pressure cover and the strategies to deploy this selected by GNCC were found to meet the majority of flexibility demands from the NTS in the scenarios tested, with the exception of some interesting edge cases related to [redacted] minimum supplies, [redacted] Compressor reconfiguration and [redacted]

These findings, wider systems analysis and discussion with NGT resulted in three priority questions:

- How will the market aspects of maintaining pressure cover change following CP2030?
- How are the dynamics at point of interaction between electricity system and gas system changing with CP2030 and plant automation? How does this impact on system operations?
- What could an enhanced approach to early analysis, to pre-empt electricity peak gaps provide and look like?

Further analysis to respond to these questions has produced the following proposed next steps for the NGT innovation team:

- Gas market innovation for energy system flexibility provision.
- Collaborative cross vector systems operation exploration.
- Enhanced early analysis with AI decision support.
- Whole-system line-pack flexibility modelling.
- Cross-vector stress event response framework.
- Hydrogen and storage data integration for whole-system operation.

These projects could be configured to suit NGT evolving operational needs and strategic innovation priorities.

From a broad range of options the following are suggested prioritisation of immediate next steps to inform further innovation discussion with NGT:

1. As part of knowledge sharing from findings of this project, explore collaborative cross vector systems operation innovation opportunities with NESO and NGT. Integration with existing NESO and NGT activities not visible to this project should form pre-requisites to this discussion.
2. Work with Catapult to further scope an 'Enhanced early analysis with AI decision support' Innovation project
3. Work with Catapult to further scope a 'Gas market innovation for energy system flexibility provision' innovation project with initial focus on making the regional value of flexibility provided by NTS line-pack visible.

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