AUDIT OF NETWORK CAPABILITY ASSESSMENT

A report to Ofgem

3rd April 2020

AUDIT OF NETWORK CAPABILITY ASSESSMENT

Contact details

Name	Email	Telephone
Angus Paxton	angus.paxton@poyry.com	07766824716

AFRY is an international engineering, design and advisory company. We support our clients to progress in sustainability and digitalisation. We are 17,000 devoted experts within the fields of infrastructure, industry and energy, operating across the world to create sustainable solutions for future generations.

AFRY Management Consulting provides leading-edge consulting and advisory services covering the whole value chain in energy, forest and bio-based industries. Our energy practice is the leading provider of strategic, commercial, regulatory and policy advice to European energy markets. Our energy team of over 250 specialists offers unparalleled expertise in the rapidly changing energy markets across Europe, the Middle East, Asia, Africa and the Americas.

TABLE OF CONTENTS

EXECUTIVE SUMMARY 1

1. INTRODUCTION 4
   - 1.1 Background 4
   - 1.2 RIIO-2 5
   - 1.3 Our scope of work 6
   - 1.4 Structure of this report 7
   - 1.5 Conventions 7

2. OUR APPROACH TO THE ASSESSMENT 8
   - 2.1 Documentation 8
   - 2.2 Meetings 9
   - 2.3 Subsequent follow-up Q&A 10
   - 2.4 Commentary 10

3. NETWORK CAPABILITY PROCESS 12
   - 3.1 Overview 12
   - 3.2 Zonal consideration 13
   - 3.3 Network capability requirement 13
   - 3.4 Network analysis 14
   - 3.5 Constraint cost forecasting 15
   - 3.6 Investment optioneering 15

4. FULFILMENT OF OFGEM'S RQUIREMENTS 17
   - 4.1 Network Capability Report 17
   - 4.2 Baseline Obligated Capacities Report 18
   - 4.3 Key findings 18
   - 4.4 Other comments 19

5. MAIN FINDINGS OF AUDIT 20
   - 5.1 General perspective 20
   - 5.2 Specific findings 21
   - 5.3 Referencing RIIO-T1 performance 25
   - 5.4 Conclusions 26

ANNEX A – DETAILED INVESTIGATION 27
   - A.1 Documentation reviewed 27
   - A.2 Meetings 27
   - A.3 Zonal considerations 28
   - A.4 Network capability requirements 29

A.5 Network capability analysis 32
A.6 Constraint costs 35
A.7 Investment decisions, Cost Benefit Analyses and Network Capability Targets 37
A.8 The utilisation of the network capability assessment in the business planning cycle 39

ANNEX B – APPLICATION FOR JUSTIFYING SPECIFIC INVESTMENT OPTIONS 40
B.1 Wormington 40
B.2 King's Lynn 41

ANNEX C – AFRY INDEPENDENT MARKET REPORTS 43

QUALITY AND DOCUMENT CONTROL 44

EXECUTIVE SUMMARY

This report has been prepared by AFRY Management Consulting[1] (AFRY) for the Office of Gas and Electricity Markets (Ofgem) in relation to the Network Capability assessment undertaken by National Grid Gas plc (NGG) as part of its December 2019 Business Plan (BP) submission to the RIIO-2 process.

What is network capability?

The concept of 'network capability' refers to the ability of the system accommodate user requirements under a range of supply-demand situations. NGG has an obligation to ensure that network capability meets defined standards relating to safety and capacity, and can do this through investment or commercial constraint management actions.

An assessment of the capability of the British gas network is important for informing network investment and commercial decision-making. Ofgem has tasked NGG with undertaking an assessment of the physical capability of the GB gas transmission network (the National Transmission System, "NTS").

How does NGG assess this?

NGG has developed a process – the Network Capability process - for assessing this based on hydraulic network analysis[2] and statistical analysis of historical flow patterns. This process is used for both determining necessary investment responses (where reinforcement is less costly than commercial constraint actions) as well as the target level of constraint costs in the proposed RIIO-2 bespoke performance incentive. NGG's December BP relies on the Network Capability process developed by NGG.

The process is based on the Future Energy Scenarios work which outlines how the system might evolve and provides high-level forecasts of gas supply and gas demand against which network capability is assessed. The techniques used in the process account for the complicated nature of gas network capability including:

- the spatial nature of the capability and the differences and co-dependency between entry and exit flows (i.e. gas flowed on or off the network);
- the technical detail of stakeholders' requirements;
- planned and unplanned compressor outages; and
- pressure and flow variations around the network.

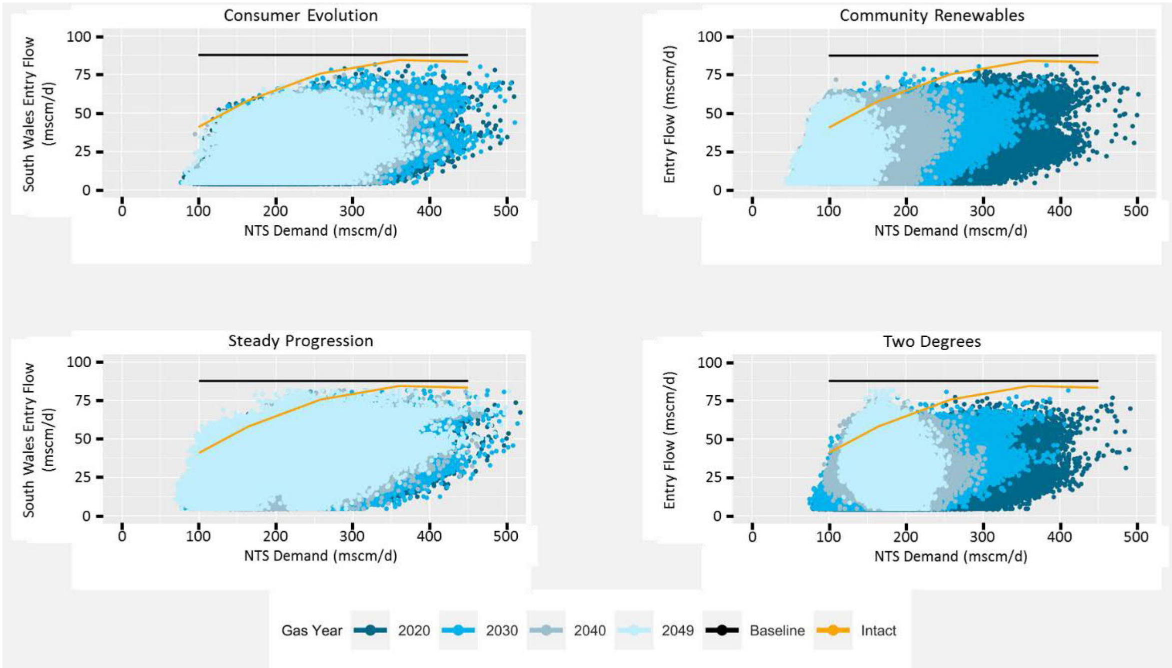
As well as providing visualisations of the various considerations involved (known as 'flame charts' - see Figure 1 below), the process outputs an estimate of the number of times per year the NTS is unable to meet the user

[1] Pöyry Management Consulting (UK) Ltd., trading as AFRY Management Consulting, part of ÅF Pöyry AB, trading as AFRY.

[2] Analysis that uses network models that respect the multidimensional non-linear thermodynamic relationships between gas flow, pressure and temperature, etc.

requirements as well as the magnitude of the constraint and resultant commercial action, which allows for an estimation of the cost of managing the constraints. This informs both the Cost Benefit Analyses (CBAs) of proposed investments, and the CM incentive target proposal.

Figure 1 – Flame charts



Our scope and approach

AFRY has been asked by the Ofgem to review the methodology and models used by NGG to assess the physical capability of the network, to assess the levels proposed by NGG for RIIO-2 network capability targets, and to consider whether NGG have met the requirements set out in Ofgem's Sector Specific Methodology Decision for Gas Transmission.

To undertake the project, we engaged NGG in a series of meetings, reviewed their RIIO-2 Business Plan submission, and reviewed additional documentation supplied by NGG. During the meetings, we requested to see the underlying models, and undertook a few 'spot checks' of underlying assumptions and code/systems, to check the models presented were consistent with documented assumptions and processes (i.e. it was not a full audit).

Our key findings

Our findings are that:

- the organisation and documentation of the process, and the visualisations, are helpful to aid transparency;
- the principles of the methodology appear to be sound;
-

- the results from the methodology are heavily dependent on underlying network analysis assumptions (e.g. relating to pressure and within-day flow patterns). The current assumptions are perhaps extreme and therefore in many circumstances may understate actual network capability;
- possibly as a consequence of this, the forecasts of the frequency, magnitude and cost of constraints appear very high compared to RIIO-T1 out-turns (78 days with costs of £238m forecast at P(50) for RIIO-2, compared with RIIO-T1 to date out-turn of two days with costs of <£1m[3]); and
- as such, there is a subsequent modification of the Network Capability constraint forecasts which is applied to derive the proposed CM incentive targets, but the modification is not applied in the investment CBA (i.e. there is an inconsistent application of Network Capability process between the investment CBA and constraint cost target applications).

[3] Excludes non-constraint costs of ~£16m, and set option contracts.

1. INTRODUCTION

1.1 Background

The NTS infrastructure allows for the transportation of gas from network entry points (e.g. terminals, interconnector and storage facilities) to exit points (including distribution networks, power stations and industrial facilities). Gas flows are physically caused by the pressure of the gas forcing it through the pipeline system although it is generally more convenient to consider as gas flow imposing a pressure drop along the pipeline, with higher flow rates leading to greater pressure differences[4]. The NTS includes compressor units which increase pressures within then network, thereby increasing the flow capability on the network.

NGG aim to meet customers'[5] needs by allowing them to flow gas on and off the network as they require. However, the network operates to strict safety standards which mean that pressures must remain within defined pressure bounds at all times. The network's physical and/or safety limitations can impose a constraint in the ability to flow gas. These constraints impact consumers' costs and can, for example, prevent the most efficient source of gas being used to meet demand. The limits to the range of customer flows on and off the network for which no constraints occur is described as the capability of the network[6].

The network operates with a daily balancing regime whereby users are incentivised to balance the flows onto and off the network over a 24-hour period. The nature of gas transportation means that it can take a number of hours for gas to flow from the entry to the exit point. This can lead to zonal and network wide imbalances of the entry and exit flows which are managed by changes in pressure (usually referred to as linepack) and the reconfiguration of network assets.

Customers are required to hold capacity rights to allow them to flow gas on and/or off the NTS. NGG are obliged, via their licence, to offer predefined levels of capacity for sale to the market. These predefined levels are based on 'baselines' which are defined in NGG's licence. To the extent that the day-to-day capability of the network, after reconfiguration options have been exhausted, falls short of users contractual rights to flow gas (e.g. because of compressor unavailability), a number of different within-day commercial options exist to allow NGG to manage their contractual obligation.

---

4 The precise mathematical relationship is multidimensional and inferred from the laws of thermodynamics.

5 In this document we will refer to "customers" as entities that contract with NGG for the provision of capacity (shippers, suppliers, generators, gas distribution networks, etc.), and "consumers" as entities who consume gas (or electricity, etc. as the case may be).

6 In this document we will use the lower-case, "network capability" to refer to the physical capability of a gas network (NGG's NTS being the primary focus), and the capitalised "Network Capability" to refer to NGG's specific enumeration of, and it's process of enumeration of, this concept.

NGG need to make network investment decisions (i.e. investment for growth, replacement, maintenance, mothballing, decommissioning). Such decisions require a knowledge of the prevailing capability as well as customers' current and future requirements for capability. The activity of understanding the existing and future capability of the network is undertaken with the use of models created in hydraulic network analysis software. The modelling is complicated, and takes into account the many physical parameters which influence the relationship between the markets requirements (for energy flows), physical flow and pressure.

Baselines were originally intended to reflect a contemporaneous measure of network capability when they were originally set (2007 for exit; ~2002 for entry[7]), and accompanied a 'top-down' approach to capacity release and constraint management, however the relationship between baselines and network capability has diverged over time due to infrastructure changes, and is further complicated by commercial mechanisms (e.g. long-term capacity sales) and the various licence mechanisms for funding.

More recently, there has been discussion[8] into the continuing assessment of baseline capacity and its consistency with the physical capability of the network and user needs. A re-alignment of the capability and baseline capacity is expected to account for the physical network changes.

1.2 RIIO-2

As part of its Sector Specific Methodology Decision for Gas Transmission (SSM), Ofgem asked NGG to provide:

- "an initial network capability report setting out the physical capability requirements of the NTS on 1 April 2021 based on user needs;
- a network capability target report setting out user requirements for network capability that NGGT will deliver by the end of the RIIO-GT2 price control period. It should also set out NGGT's longer-term forecast of the levels of physical capability the NTS must provide to efficiently service user needs; and
- a baseline obligated capacities report setting out the results of its assessment of the appropriateness of the current levels of baseline obligated entry and exit capacities including any proposals for revisions to baseline capacities."

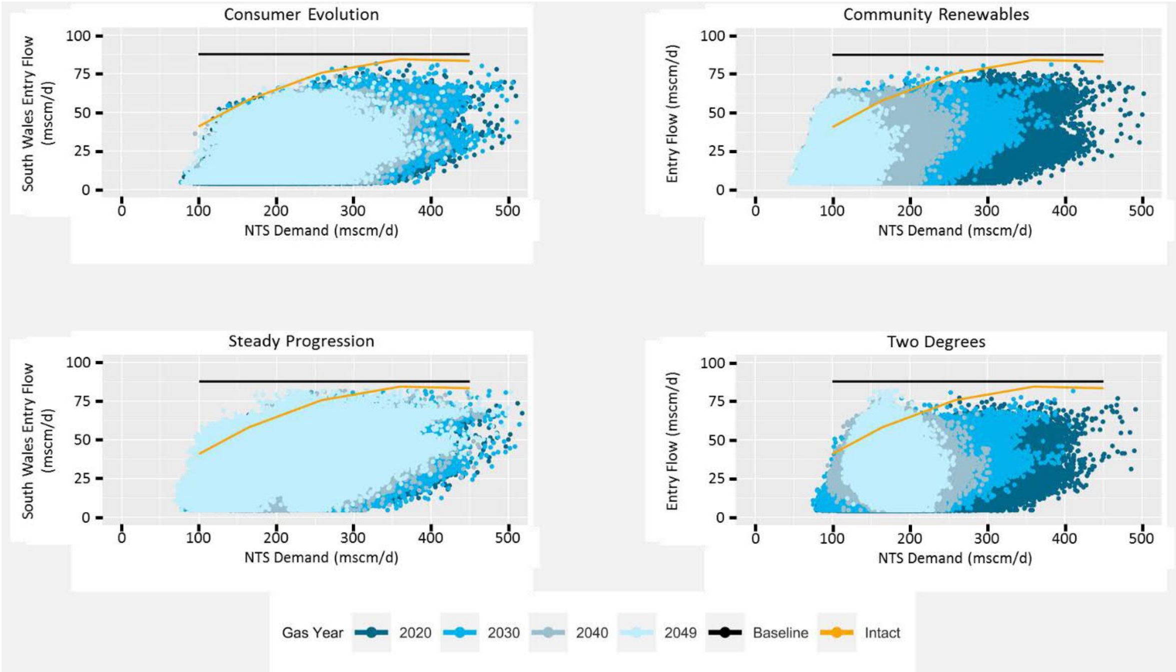
NGG has developed a methodology – the 'Network Capability' process – to evaluate the physical capability of the network under various conditions and to compare it against forecasts of users' needs. These are represented on charts for each zone, known as 'flame charts' (an example is provided in Figure 2 below). They have used the methodology to inform various parts of their

7 Ofgem, September 2001, "Transco's [NTS] System Operator incentives 2002-7 Initial proposals".

8 Ofgem, 8 November 2018, "Gas transmission. Baseline capacities and access. Options for RIIO2".

business plans, notably including numerous detailed infrastructure investment decisions and the constraint management (CM) cost incentive proposals.

Figure 2 – Flame charts



Source: NGG, Network Capability Process (v3).
Flame charts shown represent South Wales entry flows (Milford Haven). The baseline is represented by the solid black line. Physical network capability is represented by the orange curve/line. Forecast user requirements are represented as points, shown for different future gas years.

1.3 Our scope of work

AFRY has been asked by the Ofgem to review the methodology and models used by NGG to assess the physical capability of the network, and to assess the design thereof and the levels proposed by NGG for RIIO-2 network capability targets. We have assessed the appropriateness and assumptions used in the methodology, the utilisation of the methodology in the business cycle (including its role in informing the proposed constraint costs incentive and in supporting infrastructure investment decisions) and the design of the network capability targets. In particular we have been asked to review the documents requested by the SSM. We have not undertaken an examination of the source code of the models, nor tested the accuracy of the hydraulic modelling or the derivation of underlying assumptions.

The work has involved a series of meetings with NGG in January 2020, and the receipt of numerous documentation supplementary to the December BP (both detailed in Annex A). We have actively engaged with NGG during the process to obtain a detailed understanding of the process. NGG has demonstrated their various models, and we have observed a small number of specific assumptions, chosen by us, have been applied within the models as stated in NGG's documentation.

1.4 Structure of this report

This report outlines the findings of our assessment. Chapter 2 discusses our approach to the work and provides our commentary on the documentation made available; chapter 3 describes the Network Capability process; chapter 4 briefly considers whether the Network Capability process fulfils the requirements set out in Ofgem's Sector Specific Methodology decision; chapter 5 discussed out main findings from the audit. Annex A provides the detail of our investigation, whilst Annex B provides an examination of investment decisions at Wormington and King's Lynn compressor stations.

1.5 Conventions

Unless otherwise attributed the source for all tables, figures and charts is AFRY Management Consulting.

2. OUR APPROACH TO THE ASSESSMENT

Our approach to the assessment has been to engage directly with NGG to obtain a detailed understanding of the process. NGG has demonstrated their various models, and we have observed a small number of specific assumptions, chosen by us, have been applied within the models as stated in NGG's documentation. We have also received and reviewed a number of documents that have been provided subsequent to the December BP.

In this chapter, we briefly introduce each component of the documentation (chapter 3 provides a description of the elements of the process), provide a high-level summary of our meetings with NGG, and discuss potential improvements to the documentation.

2.1 Documentation

2.1.1 December BP

The December BP documentation contained only high-level description of the underlying process that had been used to populate other areas of the BP. We note that other documents, e.g. the Transmission Planning Code (TPC), already existed prior to the December BP.

Relevant BP components include the following.

- A12.01 – EY report, "Estimating the long-term economic benefits of maintain Great Britain's gas transmission network". This provides various analyses on the impact of various reductions in levels of capability on gas and electricity consumers. We have not reviewed this document in detail.
- A12.02 – Network Capability Report. This document combines the Initial Network Capability Report and the Network Capability Target Report as requested in the SSM. The document outlines the process, and includes a series of flame charts for each zone's entry and exit capabilities.
- A12.03 – Baseline Obligated Capacities Report. This contains proposals for reducing entry capacity baselines, and whilst it contains flame charts to show the reductions in the context of Network Capability, the proposals do not seem to directly rely on the Network Capability outputs.
- A12.04 – Compressor Supporting Information. This provides narrative on the impact on selected zonal network capabilities because of different assumptions on compressor station availability/configuration.
- A3.03 – Output Delivery Incentives. This provides a description of the process for generating the proposed Constraint Management Incentive cost target, which relies on the Network Capability process.

2.1.2 Additional documentation (not in BP)

During the course of our work we have been provided with the following documents:

- Cost Benefit Analysis (v3) – describing the CBA approach, and including some underlying assumptions.

- Compressor Availability (v3) – describing the process for generating compressor availability metrics which form an input into the CBA analyses.
- Network Capability Analysis (v3) – detailing the network analysis process for determining entry capability (the “least interactive” principle).
- Constraint Risk Forecasting (v4) – describing the statistical approaches used for estimating the number and magnitude of commercial constraints.
- Network Capability Process (v3) – providing an overview of the end-to-end process, and containing the graphic included at Figure 3.
- Stakeholder Needs (v3) – outlining the process of deriving supply-demand ‘balance sheets’ which are forecasted supply-demand situations, linking the Network Capability process to the “Gas demand forecasting methodology”[9] and FES and its related methodologies.
- Supply and Demand Scenarios (v3) – detailing the processes that produce the ‘TobySpaces’ (a statistical sample of supply/demand flows).
- Boundary Model (v3) – describes the process of importing network analysis points/boundary curve definitions, and the subsequent estimation of shortfall and buyback volumes and costs.
- Asset Optioneering (v3) – describes the approach for developing options for asset-based solutions.
- Capability Visualisation (v3) – describes the process of producing visual representations.
- Constraint Price Methodology (v4) – which explains how various prices are estimated for different types of constraint actions, though notably, stating that BEIS fossil fuel gas price forecasts are used for longer-term (>1 year) purposes at entry terminals.

In addition to the above documents, the Transmission Planning Code is a key reference document, as it sets out the approach to generating assumptions that are used in the hydraulic network analysis.

2.2 Meetings

AFRY met NGG in Warwick on 10th January 2020, with a follow-up meeting in Warwick on 16th January 2020. The agendas for the meetings included the following elements:

- Overview –a walk through the end to end process.
- Network analysis models –spot check various numbers and analysis, checking that modelling follows methodology, and models adhere to stated parameters.
- Toby spaces –general overview, and subsequent discussion to ensure detailed understanding; data examination.

9 https://www.nationalgridgas.com/document/69756/download

- Boundary models for constraint risk/cost forecasting – discussion and examination of the statistical distributions used; understanding constraint pricing; understanding sensitivities (if any).
- CBA analysis – examination of underlying assumptions.

2.3 Subsequent follow-up Q&A

Subsequent questions were raised and answered both via a formal RIIO-2 process (the SQ process), and direct correspondence with NGG.

2.4 Commentary

2.4.1 Inconsistency of documentation

It is clear that the underlying concepts, the Network Capability process and the documentation of the process have been evolving over the RIIO-T1 period, and in particular within the past year. The tools used to evaluate the network capability are diverse, have been developed at different times over a number of years, and have varying amount of historical application. Additionally, a number of aspects of the process are resource intensive making iterative recalibration difficult.

We have spotted potential imprecisions and inconsistencies across the suite of documents, although these are thought to be minor and we note that these are problems with the documentation rather than the process. In addition, some of the documentation could be clearer.

For example:

- the Network Capability Analysis document (section 5.3) explains that a “non-linear” regression is run on the individual network analysis results;
- the Network Capability Visualisation document (paragraph 5.5.2) notes that these are “typically” quadratic or linear, and the Boundary Model document notes that these “tend to be” quadratic or linear, however;
- the Network Capability Visualisation document (Figure 2gt) and the Network Capability report appear to show a piecewise-linear interpolation; and
- Annex A3.03 provides an example (Figure 15) that uses an exponential fit.

We understand from discussions that actually only quadratic or linear models are used to define the Network Capability curves. However this is not clear from the documentation, and neither does the documentation provide any insight into how the form of the model is or might be chosen (we understand it is expert judgement). Whilst, from the information provided, we cannot conclude that any particular form of model is particularly well-suited to any of the cases, we would expect that for the majority of the cases the quadratic, linear and piece-wise linear models carry similar levels of inaccuracy (we discuss this in section 5.2.2 below). As such, we do not consider that the application of the models used within the process is inappropriate, however the documentation could be helpfully tighter.

2.4.2 Transparency

Notwithstanding the potential inconsistencies and/or lack of clarity in the documentation, the construction and collation of the various documents and process has significantly improved the transparency of what is a very complicated area. In particular, the arrangement of the information into 'flame charts' should provide a casual reader with a far deeper understanding of the dynamics of network capability. Moreover, the framework should facilitate a much greater depth of analysis and lead to a far better understanding of the interaction between several elements of the gas transmission business, such as the relationships between maintenance planning and constraint management costs.

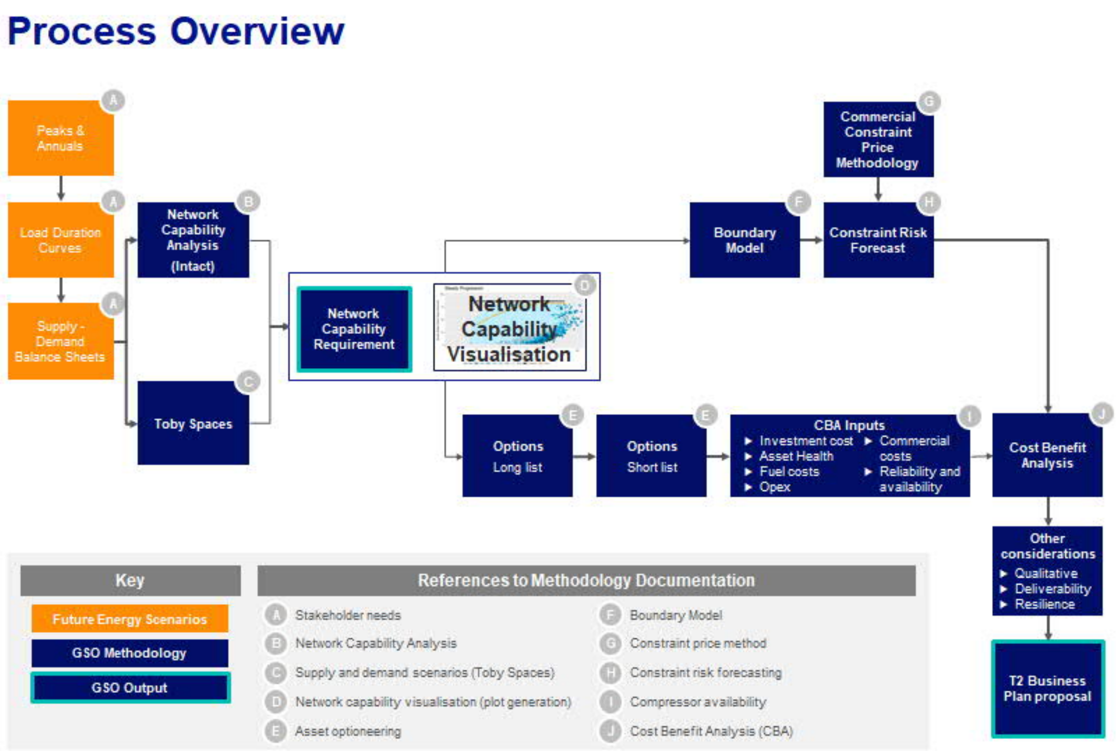
The detailed examination of the network analysis assumptions has demonstrated that there is the potential for detailed nuances to be missed in the existing documentation. We discuss this further in section 5.2.

3. NETWORK CAPABILITY PROCESS

3.1 Overview

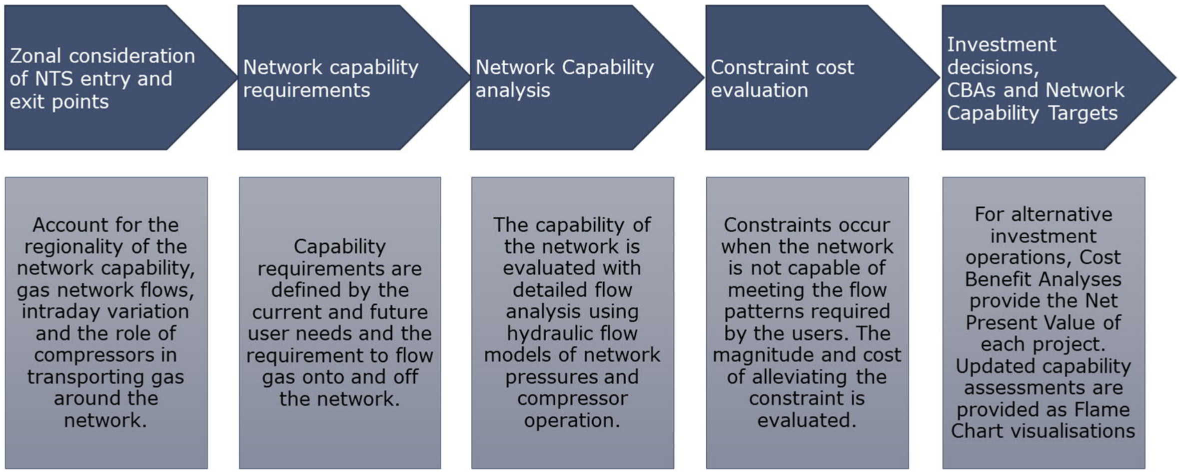
This section presents an overview of the proposed Network Capability process as presented below in Figure 3. The process relies on various models, assumptions and a wide variety of techniques which are examined in detail in following sections. Figure 4 depicts our interpretation of the stages which are involved in the process and the interdependencies between each. We describe each of these stages in the following sections.

Figure 3 – NGG overview of Network Capability process



Source: NGG, Network Capability Analysis, 07/01/2020.

Figure 4 – Overview of network capability methodology



3.2 Zonal consideration

The network is defined as a series of non-overlapping zones, and considered separately for entry and exit. The zones are used to capture the fact that different entry/exit points may use common elements of the network; zones are therefore used to approximate the boundary constraints which constrain the net aggregate flows.

The NTS is partitioned into seven zones based on the geographic and physical structure of the network, and individual entry and exit points are allocated to a single zone. An exception is made for Bacton which is complicated because of it straddles two zones and has different influences in each: it is included in the South East zone as part of the entry capacity assessment (assuming it is a net entry point), while it is treated in the East Midlands zone when it is a net exit point.

3.3 Network capability requirement

The network capability requirements are defined by the current and future users' needs. NGG has developed a methodology to evaluate these requirements based on the statistical spaces associated with the chance of a certain user requirement (defined by a set of desired network flows on and off the network). This description of the potential desired user flows over a year has been termed by NGG as the "TobySpace".

The development of the TobySpace begins with inputs from the Future Energy Scenarios (FES) work on the future gas demand and gas supply flows. Associated to each day of the year is an average distribution network (LDZ) gas demand along with demands for the power sector and industry. Sampling is performed on statistical distributions associated with each sector, for the demand for that day, to obtain a range of demands for that day. With respect to supply terminals, storage sites and interconnectors, sampling is again performed using statistical distributions associated to each demand day.

The resulting TobySpace provides a set of sampled points describing the network flows at individual nodal level for the scenario year. The density of the points relates to the chance associated to a given set of flows occurring. These are represented on charts for each zone, known as flame charts (as shown in Figure 2 above). Each sample is represented as point in the flame chart and represents a particular supply-demand condition (the net position for the zone) which is statistically possible and fully consistent across the entire network (i.e. across all zones simultaneously). Each point in the TobySpace has a likelihood of 1 in 357700.

3.4 Network analysis

Network analysis is the primary means of assessing the capability of the network to meet users' requirements for flow. Network analysis is conducted by NGG on a comprehensive hydraulic model of the NTS using the Simone software, which allows for detailed examination of the complicated thermodynamic properties of gas. If, after extensive reconfiguration of the modelled network, the users requirements for flow are able to be accommodated within the network's pre-defined limits (a set of assumptions detailed in the Transmission Planning Code, 'TPC') then the flow pattern is considered as feasible, while if not, infeasible.

The assumptions used in the network analysis are based on approaches which are detailed within the TPC, which was last approved by Ofgem in January 2020[10]. The TPC is required to fulfil the requirements of Special Condition 7B[11], which was introduced in RIIO-T1 with the intention of improving transparency regarding the capacity planning process e.g. in relation to connections[12].

NGG establish the concept of an 'intact' network in the network analysis process. This is the assumption that any and all NTS equipment is available to be operated within the network analysis model, subject to maintaining required redundancy levels. So, for example, the network analyst will be free to choose which compressor units are assumed to be operating (they disregard anticipated outages), but sufficient standby will always be maintained to mitigate trips (which is a well-established practice that we understand is integral to the Safety Case). This approach allows the network analysis models to be created that are independent of the availability of specific assets. Deviating from this approach would necessitate the definition of a series of asset availability patterns that would each require additional network analysis with an associated manpower effort. It is not clear that this alternative approach would be more or less efficient.

---

10 https://www.nationalgridgas.com/document/129941/download

11 Covers aspects of the planning and development of the NTS that may have a material impact on users of the NTS; includes a methodology to determine the physical capability of the NTS, and includes detailed planning assumptions about likely developments in the patterns and levels of gas supply and demand on the NTS, and about the operation of the NTS under different gas supply and demand scenarios.

12 https://www.nationalgridgas.com/document/63736/download

For the assessment of the entry capability of a particular zone, the analyst increases the supply rate to the zone, balancing this with supply reductions elsewhere, (as specified in NTS Capability Brief, 2019), until the flow becomes infeasible. An equivalent analysis is conducted for exit capability. As assessment conducted in the network analysis software is labour intensive, the analysis is conducted on a series of three-to-five prototypical days per year/scenario.

These provide point definitions of the network capability at the modelled supply-demand situation. The points are mapped to the TobySpace and interpolated (using a linear or quadratic fit) to form Boundary Curves which describe the zonal network capability.

This analysis can be adapted to perform different network capability assessments including:

- limits to supply flows at entry points;
- limits to the entry and exit capacity; and
- limits to the zonal boundary flows.

Additionally, deviating from the primary 'intact' network analysis, each of these assessments can be made with different compressor units available (which is applied in the constraint cost forecasting element, discussed in 3.5 below).

3.5 Constraint cost forecasting

Constraints occur on occasions when the network is unable to meet the users' flow requirements. The forecasted costs of these constraints inform the investment decisions associated to the physical network assets (and therefore the target network capability).

This constraint cost evaluation takes as inputs results from the TobySpace and the network capability analysis. Using the Boundary Model, for each level of compressor unit availability, Boundary Curves are formed and probability distributions are associated to the number of times a constraint occurs in a year, and the size of the constraint.

The cost of alleviating each constraint is evaluated by reference to a fixed per volume cost of 60p/therm. The type of commercial action (Locational Buy, capacity buy-back, etc.) is considered only for shorter-term operational practices (i.e. less than one year ahead).

3.6 Investment optioneering

NGG stated a preliminary assumption that the network capability will not change over the course of RIIO-2.

Forthcoming changes to the network include the replacement of aging compressor units, compressor units needing adaptation due to emissions legislation and the retirement of compressor units no longer required to meet network capability.

For each investment decision, a two-stage process is used for the decision: a long-list of options is initially considered; the subsequent shortlist of options is assessed using a CBA. The costs of alternative (short-listed) investments or alternative timings are balanced against the costs of the constraints for each. The results of the CBA are used to inform the final investment decisions which are presented in the Business Plan. As part of the CBA, the benefits of providing resilience through additional compressor units is accounted for with consideration of the unavailability periods of each unit type.

The capability of the network at the end of RIIO-2 which results from the physical asset investment decisions forms the Network Capability Targets. Between the start and the end of RIIO-2, NGG do not plan infrastructure changes which change the intact capability of the network. While compressor station units are planned for decommissioning over the RIIO-2 period, it is understood that with the evolution of the network (including changes to network flows and infrastructure) their removal does not impact the change to the intact capability.

4. FULFILMENT OF OFGEM'S RQUIREMENTS

As discussed above, the SSM decision Ofgem placed a requirement on NGG to produce, as part of its BP:

- "an initial network capability report setting out the physical capability requirements of the NTS on 1 April 2021 based on user needs;
- a network capability target report setting out user requirements for network capability that NGGT will deliver by the end of the RIIO-GT2 price control period. It should also set out NGGT's longer-term forecast of the levels of physical capability the NTS must provide to efficiently service user needs; and
- a baseline obligated capacities report setting out the results of its assessment of the appropriateness of the current levels of baseline obligated entry and exit capacities including any proposals for revisions to baseline capacities."

We have been asked our opinion of whether NGG has discharged this requirement, which this chapter presents.

As part of its BP, NGG has provided the Network Capability Report (combining the requested Initial Network Capability Report and the Network Capability Target Report), as well as the Baseline Obligated Capacities Report.

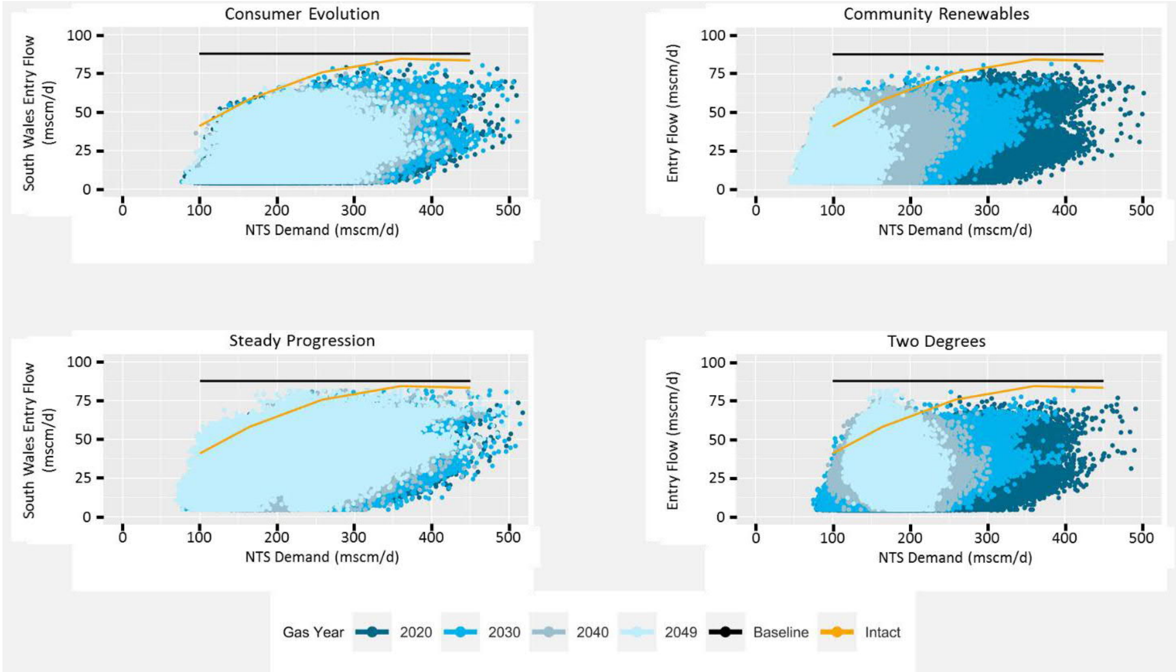
We discuss each of these documents, briefly, below.

4.1 Network Capability Report

This report presents initial, target and long-term assessments of the capability of the NTS as well as the current and projected user requirements, presented as flame charts. Each flame chart shows a collection of points representing the current and projected users' needs and either (for entry capability) a line representing the intact entry capability, or (for exit capability) a point representing the capability defined by the 1-in-20 standard. Points beneath the line/dot are considered as flows which the network can accommodate while those above the line are expected/assumed to lead to a constraint. The visualisations also presented the Licence Baselines.

The report presents a flame chart for each NTS zone and for both the entry and exit Capability. An example Flame Chart presenting the Entry Capability at Milford Haven is presented in Figure 5.

Figure 5 – Flame Charts describing South Wales/Milford Haven



Source: NGG, Network Capability Process (v3).

4.2 Baseline Obligated Capacities Report

The Baseline Obligated Capacities Report discusses the current levels of baselines (i.e. the RIIO-T1 baselines) and puts forward proposals for RIIO-2 baselines. The document does not propose any generalised methodology for determining baselines. Network Capability flame charts are used to help the discussion, but they are not used directly to derive the proposed baselines.

The proposals are to retain the current levels of baseline capacity everywhere except for:

- St. Fergus entry capacity (where a reduction from 1671 GWh/day to 1500 GWh/day is proposed); and
- Theddlethorpe entry capacity (where a reduction from 611 GWh/day to zero is proposed).

The justification for the Theddlethorpe reduction is that the terminal at Theddlethorpe is closed, and the associated NTS equipment is planned to be demolished or mothballed. The justification for the St. Fergus reduction is that it offers a balance between "reducing costs of constraints both on the day and in our investment planning process during RIIO-2, and not creating not creating [an] unnecessary perception of scarcity."

4.3 Key findings

NGG has provided Ofgem with an assessment of the current and target network capability. The capability of the NTS relies on a number of different factors and NGG have chosen flame charts to convey the results of the assessment. The flame charts highlight the evolution of NGG's forecasts of users' capability requirements, the capability at the start and end[13] of the RIIO-2 period, and how each of these can vary over the year. As such, we consider that it has addressed Ofgem's requirement in respect of the initial network capability and the network capability target reports.

The Baseline Obligated Capacities Report also appears to satisfy the requirements set out in the SSM.

4.4 Other comments

Network capability

In the course of the assessment, NGG has made a number of assumptions and simplifications. These assumptions will impact the results to varying degrees. Of particular note are assumptions regarding the hydraulic network analysis which are discussed in section 5.2. Here, single changes to the assumptions can impact the evaluated capability. Within the flame charts, these would mean the capability lines are lower than they otherwise could be, leading to more constraint days and constraint days of greater magnitude. This will have a knock-on effect to both the estimation of constraint management costs, and to the CBAs which underpin the justification of the compressor station unit replacement.

Baselines

The justification for maintaining high baselines is that it makes network capability available for capacity substitution. Ultimately the capacity substitution process provides for efficient allocation of existing capability, and serves to avoid the need for investment to provide an increase in network capability. However, we note that reducing baselines would not necessarily remove the associated network capability, and that this network capability should remain available to satisfy incremental capacity requests. As such we do not agree with the general justification for retaining high baselines.

However, we note that the constraint cost forecasting approach does not rely on the levels of the baselines. The proposals to retain baselines at current levels, even where there is clearly no forecasted user requirement, are therefore irrelevant to the other parts of the Network Capability process.

A re-alignment of network capability and baseline capacity may help to account for the physical network changes however, given the complex relationship that exists because of both commercial and funding mechanisms, we suggest that wider consultation on changing baselines is sought before using any results from the Network Capability assessments to set baseline capacities for RIIO-2.

---

13 Noting that future capability, at the end of RIIO-2, is assumed to be equal to the network capability at the start of RIIO-2.

5. MAIN FINDINGS OF AUDIT

Detailed investigations and findings are presented in Annexes A through C. This chapter provides some high-level discussion regarding what we consider to be the most significant findings.

5.1 General perspective

The Network Capability process provides input into:

- CBAs, which are used to inform investment decisions;
- CM cost forecasts, which are used to inform proposed incentive targets; and
- (indirectly) proposals for capacity baselines.

Our general perspective is that the explanation of the Network Capability process is helpful to add transparency to what is a very complex set of analyses. There are some novel approaches, in particular:

- the use of interpolation to define network capability across a range of demand;
- the presentation of network capability in defined zones;
- the population and use of TobySpaces to define forecasted user requirements; and
- the arrangement of the data into flame charts to aid communication.

Much of the underlying detail appears to be based on sound reasoning and mathematical analysis, and overall the process appears to be a good basis for investigating the relationships between forecasted user requirements and network capability.

However, as we discuss below, there are some elements that may require deeper analysis by NGG in order to provide confidence in the presented outcomes of the Network Capability analyses within the December BP. There are two areas of concern – one area around assumptions and one around methodology:

- assumptions:
  - assumptions in the network analysis models regarding within-day flow patterns;
  - assumptions in the network analysis models regarding the requirements for pressure;
  - assumptions regarding the price paid for effecting constraint management actions; and
- methodology:
  - the choice of model for interpolating between or extrapolating from network analysis results.

Moreover, we observe that the forecasts of the frequency, magnitude and cost of constraints that are output from the Network Capability process appear to be very high compared to RIIO-T1 out-turns. Annex A3.03 proposes CM incentive cost targets that take some of the RIIO-T1 findings into account.

5.2 Specific findings

We undertook spot checks on the network analysis models (pressure assumptions, flow assumptions, within-day profiles) and the TobySpace process (data files, etc.) Whilst this does not constitute a comprehensive audit of all the analysis there were no adverse findings: assumptions had been applied in the analysis as stated in the documentation.

It should be noted that, because they are computed from the tails of statistical distributions, even a relatively small increase in Network Capability is likely to result in a significant reduction in the number and magnitude of constraint management actions.

5.2.1 Network analysis assumptions

The network analysis assumptions will have an impact on the numerical output of the process, i.e. CM constraint cost forecasting and CBAs. There are two sets of assumptions where we have concerns which we discuss below. Whilst these are based on an approved document (the TPC), they may not be relevant for the reasons explained below, and it is not clear that the requirements of Licence Condition 7B should drive, via TPC, the assumptions which should be used in the Network Capability process.

5.2.1.1 Within-day flow assumptions

NGG have used a variety of approaches for creating assumptions regarding within-day flow patterns for different categories of connection. Briefly, these are:

- entry: profiles reflect historical observations on ‘backloading’[14] (only);
- power-sector: profiles for selected gas-fired power stations are created from historical observations on the days with highest linepack movements; and
- gas distribution networks: profiles are created to reflect GDNs’ NTS Exit Capacity (Flex) holdings.

The derived within-day assumptions (i.e. forecasts of within-day flow requirements) are used within the network analysis models that feed into the network capability process. In addition to the forecasted within-day flow requirements, NGG also consider a category of un-forecasted within-day flow possibilities that are subsequently included in the pressure assumptions (which are discussed below).

[14] Where the rate of delivery to the network is higher in the later part of the gas day.

We note that:

- for entry, as the approach only considers backloading and disregards any coincident frontloading, it is likely to be overstating an average requirement for within-day flow;
- for the power-sector, the approach does not filter out those situations which are otherwise considered as un-forecasted within-day change (e.g. for a sudden loss of wind generation), which may mean that some historical observations are double-counted; and
- for GDNs, the approach assumes that all GDNs simultaneously demand all of their capacity rights.

These approaches seem skewed. The network capability that is derived from the network analysis is assumed to be the expected network capability within the CM cost forecasting and CBA analyses. In discussion with NGG, they agreed that the current within-day assumptions are more extreme than might be reasonably expected.

We would expect less extreme assumptions on within-day flow patterns to yield greater levels of network capability. NGG has presented no information on why they chose the approach/assumptions they have beyond it being consistent with the TPC approach. Despite information on the magnitude of relaxing this assumption being requested from NGG we have received no information and therefore cannot say whether it has a material impact on the Network Capability assessment.

5.2.1.2 Pressure assumptions

Pressure assumptions are constructed from a number of elements:

- Maximum operating pressures (MOP) – which are specified throughout the network but are of effective significance at entry points – are ultimately defined by the pressure rating of installed equipment. As there are safety-related consequences associated with operating the network above these pressures, in operational timescales, action is normally taken to maintain pressures below the rated maxima – which is reflected in the network analysis as assuming maximum pressures are marginally below.
- Assured Offtake Pressures (AOP) are the rights to pressure that have been secured by GDNs.
- Anticipated Normal Operating Pressures (ANOP) are the pressure levels, indicated to network users, that are anticipated to be normally available.

Both AOP and ANOP are defined in the Uniform Network Code[15].

Additional elements for pressure are specified, for key points on the network, to accommodate specific uncertainties – known as ‘pressure cover’. These are to cover for both asset trips (e.g. compressor trips), and supply/demand events (e.g. sudden and unexpected changes in supply and or demand). Both elements are split into two components – a component to allow time for

---

15 Transportation Principal Document, section J.

physical network reconfiguration, and a component to allow time for 'operating margins' (additional supplies and/or demand side response) to become effective.

We note the following.

- The element of pressure cover that is used to enable reconfiguration of the network (i.e. primarily to bring a standby unit online in the event of a compressor unit trip) is designed to mitigate the effect of a compressor trip. This mitigation is disregarded later in the Network Capability process where compressor availability is taken into account, and could indicate an element of double counting.
- In day-to-day operation of the network, following request from NGG, the UNC requires that GDNs agree to receive gas at lower pressure than the AOP where it is possible for them to do so.
- Excursions from ANOP might be possible, insofar as such excursions only occur in circumstances that would be considered abnormal.

So, whilst the network analysis definitively respects the pressures defined by the TPC, the pressures do not necessarily form hard boundaries in actual network operation.

Similarly to within-day flow assumptions, we would expect relaxed assumptions on pressure to yield greater levels of network capability. Despite information on the magnitude of relaxing this assumption being requested from NGG we have received no information and therefore cannot say whether it has a material impact on the Network Capability assessment.

5.2.1.3 Price assumptions

NGG stated that they have used a fixed price assumption of 60p/therm, repeating long-term assumptions made by BEIS, for converting forecasted CM volumes into CM costs. This assumption is applied regardless of the type of action that would be required (capacity buy-back, locational actions, etc.)

We note that Locational Sell actions at Milford Haven in January 2020 have occurred at a price of 21p/therm against corresponding system average price of 28p/therm. This would imply a constraint management cost of 7p/therm. This is lost value to consumers.

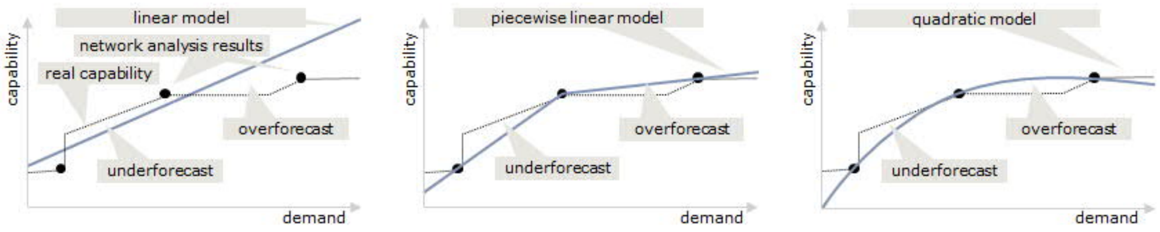
60p/therm assumption is in respect of a volume of gas. Assuming other supplies of gas would be available to replace the volumes prevented from coming to market by way of the CM action, it does not represent the opportunity cost to users/consumers of the CM action which would be marginal.

5.2.2 Choice of model for interpolation/extrapolation

In section 2.4.1 above we highlighted the inconsistency of the documentation in describing the form of model used for interpolating/extrapolating the network analysis results to define network capability across a range of demands.

The underlying simplification involved in the model is that the relationship between network capability and demand is continuous, however in practice the relationship between demand and real capability will have specific points of discontinuity associated with required plant having a minimum duty: below the minimum duty point, the specific unit must be turned off and a different network configuration used. In between any two sample points, the location of any discontinuities is unknown, which means that any model may under and over forecast network capability over a specific range. These concepts are illustrated in Figure 6 below.

Figure 6 – Network capability interpolation models



We would expect that for the majority of the cases the quadratic, linear and piece-wise linear models carry broadly similar levels of accuracy. As such, we do not consider that the application of the models used within the process is inappropriate. Obtaining greater accuracy would need much greater resolution of network analysis results to see if there is any particular bias in any of the models.

5.2.3 Additional findings

Additional findings and some recommended methodological adjustments and additional analysis are detailed in Annex A. Table 1 below lists the assumptions for which we make observations, and the anticipated magnitude that alternative assumptions might have on network capability.

Table 1 – Summary of additional findings

Area	References	Assumption	Anticipated magnitude (in isolation)
Zonal	A.3	Definition of network zones	Minor
Network capability requirements	A.4.2 (1)	TobySpace distribution selection	Moderate
	A.4.2 (2)	Utilisation of FES scenarios and scenario weighting	Moderate
	A.4.2 (3)	Uniform distribution/additional weighting for South Wales	Moderate
Network capability analysis	A.5.2 (1)	Network configuration assumptions	Moderate
	A.5.2 (2)	Consideration of compressor trips	Moderate
	A.5.2 (3)	Pressure cover & CCGTs	Moderate
	A.5.2 (4)	Within-day profile assumptions	Moderate
Constraint cost forecasts	A.6.2 (1)	Statistical distribution fitting	Minor
	A.6.2 (2)	Fitting of boundary curve	Minor
	A.6.2 (3)	Coincidence of availability and demand	Minor
CBAs	A.7.2 (1)	Constraint price assumptions	Moderate
	A.7.2 (2)	Combinatorial CBA comparison	Minor
	A.7.2 (3)	Use of expert judgement in shortlisting	Moderate
Use within business planning	A.8.1	Consistent assumptions across applications	Minor

5.3 Referencing RIIO-T1 performance

The raw constraint cost forecasts that are produced by the Network Capability process are modified to produce the CM incentive proposals for RIIO-2 by reference to RIIO-T1 experiences. To do this, they compare the number of forecasted constraint days (~12 per annum) to the number of actual constraint days (~4 per annum), and use this ratio (at 67% reduction) to modify the relevant output constraint costs.

Whilst it is right to consider the reasons for outperformance of RIIO-T1, there is no justification for the reason for adopting this particular methodology. We note that a very different adjustment would result if, for example, the ratio of actual costs to target/forecast costs were used.

The approach is not used to modify the input to CBAs.

It might be that the reasons for outperformance against target/forecast over the RIIO-T1 period can be explained, on a case-by-case basis, by the actual operational circumstances experienced (e.g. actual within-day consumption patterns) and the precise actions taken by NGG to maximise operational capability (e.g. linepack movements). Relating the actual circumstances back to the precise assumptions used in the underlying network analysis that drove the target/forecast might help to highlight the need for different assumptions to be used in the Network Capability process, and would mitigate the inconsistent approach between CM target forecasting and CBA decisions.

5.4 Conclusions

We conclude that, whilst the Network Capability process put forward by NGG provides a very useful framework to provide transparency of process, there are some key underlying assumptions that appear to be inappropriate for the primary output of the Network Capability process.

We recommend that Ofgem require NGG to undertake additional analysis to provide an understanding of the sensitivity of network capability to these underlying assumptions, and that Ofgem and NGG investigate the performance under RIIO-T1 to understand what a more representative set of assumptions would look like.

ANNEX A – DETAILED INVESTIGATION

This Annex sets out further detail of our investigations.

A.1 Documentation reviewed

The Network Capability Assessment has been evaluated based on the following reports which are either publicly available or provided by National Grid Gas:

- National Grid Gas Business Plan, December 2019.
- Annex A12.02 Network Capability Report, December 2019.
- Annex A12.03 Baseline Obligated Capacities Report, December 2019.
- Annex A12.05 Network Capability Stakeholder Engagement Report, 2019.
- Annex A16.10 Wormington Compressor Engineering Justification Paper, December 2019.
- Annex A16.14 King’s Lynn Compressor Engineering Justification Paper December 2019.
- NTS Capability Brief, 2019.
- Network Capability Analysis, dated 07/01/2020.
- Boundary Model, dated 07/01/2020.
- Network Capability Visualisation – Plots Generation, dated 07/01/2020.
- Supply and Demand Scenarios (Tobyspaces), dated 07/01/2020.
- Cost Benefit Analysis, dated 07/01/2020.
- Asset Optioneering, dated 07/01/2020.
- Stakeholder Needs, dated 07/01/2020.
- Compressor Availability, dated 07/01/2020.
- Constraint Price Methodology, dated 14/01/2020.
- Constraint Risk Forecasting Methodology, dated 07/01/2020.
- Cost Benefit Analysis, dated 07/01/2020.
- Transmission Planning Code, 2019.

A.2 Meetings

Warwick, 10 January 2020. Attendance: AFRY - Angus Paxton & Stephen Clegg; NGG - Edward Kent (TobySpaces), John Perkins (Regulatrion), Mark Hamling (Network Analysis), Mike Wassel (Constraint Management Costs), Chris Thompson (CBA), Ben Dickle (Boundary Curves), Paul Sullivan (Overview).

Warwick, 16 January 2020. Attendance: AFRY - Angus Paxton & Stephen Clegg; NGG - Edward Kent (TobySpaces), John Perkins (Regulatrion), Mark Hamling (Network Analysis), Craig Philips (Network Analysis), Chris Thompson (CBA), Ben Dickle (Boundary Curves), Paul Sullivan (Overview).

A.3 Zonal considerations

A.3.1 Assumptions

Table 2 – Zonal consideration assumptions

	Assumption	Impact of assumption	Anticipated magnitude
1.	Definition of Network Zones.	The partitioning of the network into zones is a requirement of the process and their definition is based on the network topology, geography and whether entry or exit capacity is being modelled. It is unclear how different partitions effect the results.	Minor implications to current and target Network Capability.

A.3.2 Suggested improvements

- There remains a focus on the entry and exit capability within the zones and the role of a zone in transporting gas across it (i.e. transit flow) is neglected. The development of a means to assess the zonal transportation capability is required for a fuller understanding of the capability of the network in the transportation of gas.
- Alternative entry and exit zones are considered for Bacton depending on its operation. It needs to be ensured that this isn't a special case of a wider problem which may be resolved by developing a framework for assessing the zone boundaries and considering the separation of entry, exit and transportation zones.

A.4 Network capability requirements

A.4.1 Queries

Table 3 – Summary of queries arising from the documented methodology

	Query arising from documented methodologies	Clarification
1.	In the TobySpace, how appropriate are the distributions used for the potential supply scenarios?	Historical flows have been used to form distributions associated to the terminals and storage operation for days of a give demand level. The fitted distributions are compared against historical data sets and sense checks have been applied. Commercial insight is applied for the development of South Wales flows (see 6).
2.	Why was an additional weighting applied to South Wales flows 10% of the time?	Following discussions with the operators of the South Wales terminals, there is evidence to suggest that their flow patterns will change in the future and they will flow at higher rates more often. Expert judgement has been applied and a uniform distribution is used 10% of the time.
3.	How are the offtake demands developed from the future scenarios? In particular, how are the day-to-day variation in power station demand accounted for?	These are derived from FES data. The FES analysis is performed using power system modelling to assess the gas power station electricity generation levels.
4.	How appropriate are the distributions used for offtakes?	The DN offtake distribution is based on distributions associated with each Demand Day. Truncated normal distributions based on historical observations and limits.
5.	In the TobySpace, what validation methods are performed?	Each year the TobySpace is backtested on that year's flows.

A.4.2 Assumptions

Table 4 – Network capability requirements assumptions

	Assumption	Impact of assumption	Anticipated magnitude
1.	Validity of statistical distributions used as input into the TobySpace.	Ultimately, these statistical distributions rely on expert judgement. Though, in general, the choice appear well-founded, the decision is not always supported by numerical tests. If alternative assumptions had been made, this could lead to results which may change the outcomes (i.e. changed constraint cost forecasts, changed CBA outcomes).	Moderate implications to target Network Capability.
2.	Utilisation of FES scenarios, their data and the weighting of each scenario.	Examples of the inputs include the overall supply/demand patterns and the rate of depletion of supplies from the UKCS. Different scenarios will lead to different utilisation levels of assets and a number may become redundant in different scenarios. In particular, in Consumer Evolution in 2030, the Intact Entry Capability will be ~25mscm/d above the TobySpace points, while in Steady Progression, the Intact Entry Capability line remains close to the TobySpace points. It is anticipated therefore, that there will be markedly different constraint costs in each scenario. However, in the constraint risk forecasting methodology, a probability is associated to each, leading to a single set of constraint cost forecasts for each of the RIIO-2 years. This assumption is likely to overstate requirements in the long-run and could impact the network capability requirements as well as the CBA results.	Moderate implications to target Network Capability.
3.	Additional weighting for high South Wales flows.	This assumption has been based on expert judgement. Any additional weighting will lead to increases in constraints and constraint costs. The impact of the assumption depends on the confidence of the judgement applied.	Moderate implications to target Network Capability.

A.4.3 Suggested improvements

- It is difficult to check to what extent the TobySpace is able to assess the likelihood of very rare events. One issue leading to this is the inaccuracies of the probabilities of rare events in each of the individual distributions. Moreover, while the TobySpace itself has ~360 000 datapoints per scenario, for some of the distributions (e.g., that associated with the terminal operation on an extreme day) the number of samples taken is a lot smaller, so the tails are likely not captured. Computational and statistical techniques can be employed to attempt to improve on the capturing of rare events.

- The results of the applicability of the TobySpace following the backtesting is provided.

A.5 Network capability analysis

A.5.1 Queries

Table 5 – Summary of queries arising from the documented methodology

	Query arising from documented methodologies	Clarification
1.	How have changes to the intraday flows been accommodated?	The Transmission Planning Code has been expanded upon to accommodate changes to intraday flows. This is used in the network analysis applied in forming the Boundary Curve. This update applies to supply profiles and generator profiles. See point 2.
2.	How have the demand profiles been assessed?	Analysis into the historical correspondence between linepack depletion and gas generator operation has been performed to develop a set of intraday generator profiles. Generators showing a large intraday variation are modelled as such. Moreover, evening increases in gas demand for generation is accommodated using pressure covers. See point 4. DN offtakes use the prevailing profile.
3.	How have supply profiles been assessed?	A historical survey of normalised profiles from supply points has been conducted. When a supply point has had a tendency to lead to linepack depletion (i.e., an increase in the supply-demand imbalance either locally or system wide), it is been modelled with an intraday profile which is greater in the second half of the day.
4.	How are the pressure covers evaluated?	Pressure covers are evaluated prior to the Network Analysis and depend on the demand for a given day for the offtake. There is pressure cover associated with specific asset trips and with associated with supply/demand events.

A.5.2 Assumptions

Table 6 – Network Capability analysis assumptions

	Assumption	Impact of assumption	Anticipated magnitude
1.	That network configuration continues in an analogous manner to current practises.	The Network Capability Analysis used in the assessment of the Boundary Curves follows the TPC, and the results are quite tightly linked to the pressure bounds of the network defined by the TPC. Should there by changes to pressure covers then it is expected to have direct implications to the network capability.	Moderate implications to current and target Network Capability.
2.	Consideration of compressor trips in the Compressor Availability assessment and the pressure cover.	The impact of considering compressor trips both in the pressure cover as well as in the Compressor Availability assessment used in the CBA (see Section 3.5) would lead to an underestimation of the network capability. However, the number of days of outage in a year due to Minor trips is small in comparison to Medium, Severe and Critical outages. Therefore it is expected that the implication would be small.	Moderate implications to current and target Network Capability.
3.	The correspondence between gas turbine output changes and pressure cover.	Analysis on historical data has been performed into the changes in gas turbine output. It is noted that this is more likely to happen in the morning and in the early evening. However, the pressure cover is applied throughout the day. This may over-allocate pressure cover and lead to a reduction in the assessed Network Capability.	Moderate implications to current and target Network Capability.
4.	Within-day profiles chosen in the Network Capability Analysis are indicative of constraint day behaviour.	The TPC describes the within-day flows which are used for the Network Capability Analysis. To assess the implication of within-day variations, supply flows accounting for linepack depletion (i.e., those backloading) are considered; while a proportion of those frontloading is ignored. This will reduce the network capability and impact the number of times a constraint occurs and the magnitude of the constraint.	Moderate implications to current and target Network Capability.

A.5.3 Suggested improvements

- The Network Capability depends on the detailed gas network flow analysis performed according to the Transmission Planning Code. There are implementation decisions in the TPC which can impact the Network Capability assessment. Some of these assumptions have arisen for application of the methodology to extreme events. Required is the defining of alternative assumption appropriate for its application in defining thresholds for the totality of demand and operational days.

- Related to the previous point, it is suggested that sensitivities are performed with respect to the pressure covers and the intraday profiles used in the Network Capability Assessment.
- Under current commercial arrangements, there are a number of operational tools available to National Grid Gas to increase capacity (e.g., restricting intraday flow variations or allowing for the relaxation of the pressure covers). These options may alleviate the constraints levels identified though the Boundary Curves and we would suggest a sensitivity of these options on the Boundary Curves. If significant, a more comprehensive evaluation should be taken of the trade-off in costs to consumers of using these options.

A.6 Constraint costs

A.6.1 Queries

Table 7 – Summary of queries arising from the documented methodology

	Query arising from documented methodologies	Clarification
1.	The Boundary Curves (which define the Zonal Capability) are defined by three points. Is this a sufficient number of points to define the lines and how appropriate is the line fitted to the points (i.e., quadratic or linear)?	The network analysis required to assess the boundary lines associated with the capability is resource intensive. Priority has been given to evaluating the Capability for points required for the Network Capability assessment and the CBA. It is desirable to have additional data points and developments over RIIO-2 aim to meet this need.
2.	How appropriate are the breakdown of probabilities associated with the different FES scenarios, High Continental/Low Continental sensitivity and Uniform vs Historic South Wales entry flow.	The Network Capability assessment is performed for each of the FES as well as the two sets of sensitivities. Visualisations are presented for each.
3.	How appropriate are the distributions used for the number of occasions when there is a constraint and the magnitude of the constraint?	Common statistical distributions have been fitted based on the results from the TobySpace and Boundary analysis. For example, Poisson distributions have been considered for the number of times a constraint occurs while beta distributions have been considered for the magnitude of terminal flows. The most appropriate distribution fitting the dataset is chosen.

A.6.2 Assumptions

Table 8 – Constraint cost evaluation assumptions

	Assumption	Impact of assumption	Anticipated magnitude
1.	The fitting of statistical distributions to the number and magnitude of the constraints.	These statistical distributions are fitted to the results of the TobySpace coupled with the Boundary Curve. Given the nature of the generation of the input data there can be limited data points forming the distribution. This can mean that the statistics defining the shape parameters may be inaccurate. Moreover, there is a disassociation of the number of constraints from the magnitude of the constraints. The analysts developing the method have performed sense-checks to ensure implications are minimal, however they may lead to a constant error factor.	Moderate implications to target Network Capability.
2.	Fitting of function to Boundary Curve.	There are a small number of data points associated with the Boundary Curve which makes successful curve fitting difficult. There are further assumptions such as a smooth curve is the best fit to the data points. A large discontinuity could impact the constraint costs, which may affect CBA outcomes.	Minor implications to target Network Capability.
3.	Level of coincidence between compressor availability and demand days.	The compressor unavailability assessment includes repair times and maintenance times. Each is unified in the development of the compressor units availability statistics. The Boundary Curves are defined by the number of units available and Monte Carlo simulations based on availability statistics. It is unknown how results will differ if modelling accounted for the scheduling of maintenance at times of reduced constraint risk.	Minor implications to target Network Capability.

A.6.3 Suggested improvements

- The Boundary Curves are defined by three points and this provides limited data points for interpolating the points, especially if the Boundary Curve is discontinuous in nature. Where there are large differences in the capability between points, further analysis should be conducted to fully understand the nature of the Boundary Curve.
- The gas price is a key input in evaluation the cost of the constraints, especially over the lifetime of the asset. Further price modelling is presented in the report Constraint Price Methodology and a sensitivity around the gas price is suggested.

A.7 Investment decisions, Cost Benefit Analyses and Network Capability Targets

A.7.1 Queries

Table 9 – Summary of queries arising from the documented methodology

	Query arising from documented methodologies	Clarification
1.	The Network Capability Visualizations are provided for the scenario years 2020, 2030, 2040 and 2050, however the duration of RIIO-2 is 2021-2026. Has analysis been performed over the RIIO-2 period?	Analysis has been performed for each of the RIIO-2 years (2021-2026) and for the years 2030, 2035, 2040, 2045 and 2049.
2.	One of the Scottish compressors have been removed. However, there is no reduction in the capability curve. Why?	This asset is now redundant in the providing Intact Network Capability. However, had there been a network capability assessment at the beginning of RIIO-1, then the removal of this compressor would have led to reductions in the capability against that of the Intact Network.
3.	Can motivation be provided for the utilisation of 60p/therm for the price of gas associated to all constraints?	This price is based on BEIS fossil fuel gas price forecasts and is part of an established methodology which has been used for the RIIO-2 analysis.
4.	What standards have been followed when forming the Discounted Cash Flow for the CBA? How are inputs such as the WACC and asset lifetime evaluated.	A number of these aspects have been defined by OFGEM and, in general, it is based on an established methodology which is used throughout National Grid.
5.	How are the intermediate years (i.e., those for which detailed gas network analysis hasn't been conducted) accommodated in the CBA?	Gas network analysis has been conducted for each of the years (see item 1). Between 2027 and 2048, when analysis has not been conducted, interpolation of result has been performed. Beyond 2049, the results of 2049 are used.

A.7.2 Assumptions

Table 10 – Investment decisions, CBA and Capability Targets assumptions

	Assumption	Impact of assumption	Anticipated magnitude
1.	The assessment of prices in the constraint methodology.	The cost of the constraints depends the price associated with a locational buy or capacity buy back. It is assumed that these are at 60p/them in the Business Plan. This can affect the CBA results. However, in the CBA, sensitivities around the costs are performed to inform on what investment decisions are made. Therefore changes in the assumptions on price are unlikely to effect the network capability.	Minor implications to target Network Capability.
2.	Comparative CBAs have been conducted for different options for each compressor station, though not between different options between compressor stations.	There are occasions (e.g., Felindre and Wormington and South Wales entry capacity) where alternative compressor options can interact in the reduction of constraint costs. An evaluation of the costs across stations could lead to alternative options for infrastructure developments to reach similar network capability.	Minor implications to target Network Capability.
3.	There is a balance between expert opinion and CBA results when assessing the infrastructure changes.	In developing the long and short list of options, expert opinion has been used in the choice of solutions. It has been expected that a broad range of options has been put forward. A range of sensitivities have been conducted in each CBA, sometimes without providing a clear benefit for a single option for all. Judgement has been made based on the results to decide which option has been recommended.	Moderate implications to target Network Capability.

A.8 The utilisation of the network capability assessment in the business planning cycle

A.8.1 Assumptions

Table 11 – Network capability assessment cycle implications

	Assumption	Impact of assumption	Anticipated magnitude
1.	Assumptions remain consistent across different parts of the methodology.	Minor changes to the assumptions impact the consistency of the modelling and the numerical evaluations. (An example of such a change is the updating of the capitalisation rate between the Engineering Justification Paper and the CBA). Should there be a substantial change then repeating the analysis or providing sensitivity studies would be required.	Minor implications to current and target Network Capability

ANNEX B – APPLICATION FOR JUSTIFYING SPECIFIC INVESTMENT OPTIONS

B.1 Wormington

Wormington compressor station is located in the South West of England and is important for transporting gas from the South Wales gas terminals to consumers in England. In its current configuration, it has two gas fuelled compressor and on electric variable speed drive compressor. The two gas compressors are impacted by the Medium Combustion Plant Directive (MPCD) emissions legislation. Without upgrading the compressor station, complying with the legislation will lead to a reduction in the network capability, in particular to the South Wales entry capability. Under prevailing flow conditions, the two units have limited running hours (between 2013/14 and 2018/19, the maximum combined running hours is 335). However, should there be an increase in the user requirements for South Wales gas flows, then these units may increase their utilisation, become more important to system flows, and should the capability be reduced, lead to increases in constraint costs and rises to consumer prices.

The assessment of the infrastructure options for the Wormington compressor station includes economic cost benefit analysis. This section will discuss the role of the network capability methodology in the CBA and the resulting infrastructure choices.

B.1.1 Potential infrastructure development options

The process begins with an identification of the potential constraint or network issue to overcome. For the Wormington compressor station, this is motivated by the change in legislation around its emissions. A long list of options is provided from which options which are infeasible (e.g., from an engineering perspective, or from a cost perspective) are excluded. The remaining options form a short list and for each item on the list a CBA is performed. This CBA has a cost component which includes costs of the constraints. The constraint costs evaluation is the principal role of the network capability analysis in the network infrastructure planning.

B.1.2 Evaluation of constraint costs

With respect to the Wormington compressor station, the constraint costs focus on the South Wales entry flows. The Steady Progression scenario is used as the central scenario to describe the South Wales entry flows for each year until 2049. With respect to the range in Milford Haven flows, this increases over two fold from the 2018/19 flows, thus leading to a greater number of constraint days. For each compressor unit availability combination (including alternative options and/or compressor outage combinations and/or operational running hour limits), the South Wales entry zonal capability is evaluated using the Boundary Curve. Based on Monte Carlo techniques implemented with consideration of the outage probability and statistical distributions associated with the frequency and magnitude of constraints, the expected costs of constraints for each year and each option is evaluated.

B.1.3 CBA and engineering justification

The chosen option for South Wales is '1 - Two new units'. This is the option with greatest CAPEX cost, least constraint cost and least operating costs (discounting the decommission option). The new units are able to be constructed with little interference with the existing operation, therefore, in contrast to other retrofitting choices, it does not lead to an increase in constraint costs in 2028/9 and 2029/30. For 2030/31 and beyond, the difference in constraint costs between this option and '3a-SCR unit A&B' grows from £2.96m/year in 2030 to £11m/year in 2055. The decision to have one electric units and two gas medium sized units is also motivated by the reduction in risk associated with reduced flexibility and reduced resilience.

B.1.4 Summary of the assessment of the options for Wormington compressor station

As with other aspects of the methodology, the CBA provided in the spreadsheets accompanying the Engineering Justification Paper for Wormington appears correct. However, the constraint calculation plays a dominant factor in the NPV evaluation. In the long-run (up until 2055) the chosen option ('1 - Two new units') provides the most benefits with an NPV over £100m greater than other options. Caution should be taken however with respect to the cumulative effects of the benefits in the long-term (between 2040-2055) when predictions to the system operation become more uncertain. With respect to the medium term, the year at which the chosen option and the option '3b - SCR Unit A + 500hrs Unit B' reach positive NPV is 2039 and 2043, respectively).

B.2 King's Lynn

King's Lynn compressor station lies in the East of England a plays a role in providing both entry and exit capability and its operation is tightly linked to the operation of the Bacton interconnector terminal. The Engineering Justification Paper for King's Lynn proposes options to meet the MCPD emissions legislation as well as potential changes in flows in the 2030s. Currently, there are three operational compressors at King's Lynn, the forth Unit A, being disconnected in 2017 after becoming life expired. One of the three operational compressors is impacted by the MPCD. Utilisation of the compressor is expected to increase in coming years due to higher supply flows from Isle of Grain LNG and interconnectors.

B.2.1 Potential infrastructure development options

The Engineering Justification Paper presents a number of development options including the addition of one or two new units, the uprating of the associated pipework and emissions abatement fittings.

B.2.2 CBA and engineering justification

With the prevailing network capability, the methodology estimates the constraint costs associated to King's Lynn are ~£3m/year. In the near-term (2023-29), analysis shows that ~2m/year reductions in these costs can be brought about through the uprating of the pipework. There is an expected large increase in the running hours of the units in 2025 which peaks at 2031, before falling again by 2040 (Figure 11). Where an option considers new units accommodate this, their construction will be completed by 2029. In the long-term, the differences between the constraint costs associated to 'One new unit + uprate' and 'Two new units' is comparatively small (less than £280000/year for 2030 and beyond). While, the investment cost for a new unit and uprating the piping is ~£56m and ~£30m, respectively. In these cases, it is difficult to consider 'Two new units' as a clear best option once the long-term uncertainty has been accounted for.

The chosen option '1 - Two new units' will expand the station's capability by building two new units and decommissioning of the operational Unit B. The CBA shows that this option has the greatest NPV in two out of the four sensitivities conducted. Given the changing nature of the capability in the coming years, and the associated uncertainty, a clear choice for infrastructure investment for the King's Lynn compressor station is challenging.

B.2.3 Summary of the assessment of the options for King's Lynn compressor station

There is uncertainty around which option provides the best solution for the King's Lynn compressor station. However, should changes in flow patterns begin to materialise in 2025, then this could lead to large increases in the costs of constraints should infrastructure investment not have been considered. With the timescales involved with the planning and construction of compressor units, then decisions are required now into the planning. However, this station is part of the Uncertainty Mechanism and a reopener is proposed.

ANNEX C – AFRY INDEPENDENT MARKET REPORTS

AFRY Independent Market Reports provide detailed descriptions of a country or regional energy market, coupled with market-leading price projections for wholesale electricity, gas, carbon and/or green certificates. AFRY Independent Market Reports and price projections are available for the following sectors, countries and regions. Further information on these reports and our latest additions can be obtained at afry.com/service/independent-market-reports. To order please call +44 (0)1865 722660 or email us at: consulting.energy.uk@poyry.com.

- Electricity markets:
  - Albania
  - Austria
  - Bahrain
  - Bangladesh
  - Belgium
  - Bosnia and Herzegovina
  - Bulgaria
  - Cambodia
  - Canada: Alberta; New Brunswick; and Ontario
  - Chile
  - Colombia
  - Croatia
  - Cyprus
  - Czech Republic
  - Denmark
  - Egypt
  - Estonia
  - Finland
  - France
  - Georgia
  - Germany
  - Great Britain
  - Greece
  - Hungary
  - Indonesia
  - Iran
  - Iraq
  - Ireland SEM
  - Israel
  - Italy
  - Japan
  - Jordan
  - Kazakhstan
  - Kosovo
  - Kuwait
  - Laos
  - Latvia
  - Lebanon
  - Lithuania
  - Macedonia
  - Malaysia
  - Mexico
  - Montenegro
  - Morocco
  - Myanmar
  - the Netherlands
  - Norway
  - Oman
  - Panama
  - Peru
  - the Philippines
  - Poland
  - Portugal
  - Qatar
  - Romania
  - Saudi Arabia
  - Serbia
  - Singapore
  - Slovakia
  - Slovenia
  - South Africa
  - South Korea
  - Spain
  - Sweden
  - Switzerland
  - Taiwan
  - Thailand
  - Turkey
  - UAE
  - Ukraine
  - USA: CAISO; ERCOT; MISO; NYISO; PJM; SPP; and Western Interconnection
  - Vietnam
- Renewables markets:
  - Italy[16]
  - Portugal[16]
  - Spain[16]
  - United Kingdom
- Gas markets:
  - Western European & Global Gas Supply

16 Solar and/or wind.

QUALITY AND DOCUMENT CONTROL

Quality control		Report's unique identifier: MWE/2020/XXXX
Role	Name	Date
Author(s):	Angus Paxton Stephen Clegg	3rd April 2020
Approved by:	Gareth Davies	3rd April 2020
QC review by:	Soraia Frioli	3rd April 2020

Document control			
Version no.	Unique id.	Principal changes	Date
v100	2020/0248	Final report	3rd April 2020

AFRY IS AN INTERNATIONAL ENGINEERING, DESIGN AND ADVISORY COMPANY.

We support our clients to progress in sustainability and digitalisation. We are 17,000 devoted experts within the fields of infrastructure, industry and energy, operating across the world to create sustainable solutions for future generations.

AFRY Management Consulting provides leading-edge consulting and advisory services covering the whole value chain in energy, forest and bio-based industries. Our energy practice is the leading provider of strategic, commercial, regulatory and policy advice to European energy markets. Our energy team of over 250 specialists offers unparalleled expertise in the rapidly changing energy markets across Europe, the Middle East, Asia, Africa and the Americas.

AFRY Management Consulting

King Charles House
Park End Street
Oxford, OX1 1JD
UK

Tel: +44 (0)1865 722660
Fax: +44 (0)1865 722988
afry.com
E-mail: consulting.energy.uk@poyry.com

AFRY
ÅF PÖYRY