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Energy Efficiency Directive: An assessment of the energy efficiency potential of Great Britain's gas and electricity infrastructure

Report

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Overview:

This report assesses the energy efficiency potential of the gas and electricity infrastructure in Great Britain (GB). This is required under the Energy Efficiency Directive (EED). In June 2014, the UK implemented certain provisions of the EED, through The Energy Efficiency (Encouragement, Assessment and Information) Regulations 2014. Regulation 6 established an obligation on the Gas and Electricity Markets Authority (GEMA) to report to the Secretary of State on GB's energy network's energy efficiency potential, and the cost-effective measures that are already in place to improve it.

A key way to improve the energy efficiency of network infrastructure is to reduce wasted energy. In the gas sector, this waste is known as shrinkage and in the electricity sector as losses. As reducing losses and shrinkage is recognised as the best way to improve energy efficiency of networks, this assessment focuses on the potential for shrinkage and loss reduction.

The report describes the measures the network companies currently adopt and their expected benefits. It also describes various potential measures that might improve energy efficiency in future but are currently not commitments of the network companies.

The requirement to report on measures to reduce losses and shrinkage comes from our RIIO (Revenue = Incentives + Innovation + Outputs) regulatory framework. Although this report focuses on these measures, there is other work being done on flexibility which may have an impact on the wider energy efficiency front.

Associated documents

Consultation document and responses:

https://www.ofgem.gov.uk/publications-and-updates/assessing-energy-efficiency-potentials-gb-energy-infrastructure

Contents

Executive Summary

The Energy Efficiency Directive (2012/27/EU) (EED) was adopted in 2012 with a transposition deadline of 5 June 2014.

In June 2014, the UK parliament implemented certain provisions of the EED through "The Energy Efficiency (Encouragement, Assessment and Information) Regulations 2014[1]". Regulation 6 put an obligation on the Gas and Electricity Markets Authority (GEMA) to report to the Secretary of State on the energy efficiency potential of the energy networks in Great Britain (GB) and the cost-effective measures to improve their energy efficiency. This document fulfils this obligation.

The report provides an overview of networks today as well as barriers and enablers to implementing loss reduction measures. This report centres on ways to reduce shrinkage in the gas sector and losses in the electricity sector. Reducing shrinkage and losses is recognised as the most effective method of improving energy efficiency of networks. At the core of the report is an outline of current measures, some with estimates of the impact (in MWh) that they will have on losses/shrinkage.

We have also described a number of potential measures which could have a positive impact on losses and shrinkage. Whilst these measures could have a positive impact, they are not yet feasible either for technical or economic reasons. These initiatives will not necessarily apply to all network operators due the differences between networks.

The requirement to report on measures to reduce losses and shrinkage comes from our RIIO (Revenue = Incentives + Innovation + Outputs) regulatory framework. Although this report focuses on these measures, there is other work being done on flexibility which may have an impact on the wider energy efficiency front.

Electricity

The total energy lost on the GB network is estimated by subtracting the volume of energy units known to be delivered to customers from the volume of units that originally entered the network.

In 2013, losses, as a proportion of demand on GB's networks were estimated to be 7.2 per cent – 27TWh.[2] Losses can be split into three components: transmission

[1] SI 2014/1403
[2] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/337649/chapter_5.pdf

losses, distribution losses and theft. The majority of electricity network losses occur on distribution networks.

Electricity Distribution

The GB electricity distribution network consists of six large incumbent companies (DNOs) that between them operate 14 networks and a number of smaller independent distribution network operators (IDNOs) which run smaller embedded networks. Both DNOs and IDNOs are regulated by Ofgem through a licence, which includes a requirement to keep losses as low as possible.

Concrete measures implemented by DNOs could lead to a reduction in losses on the distribution system of around 0.69TWh over the period 2015-2023 from a 2013 baseline of 19.6TWh. This equates to a 3.5% reduction in DNO losses and the equivalent saving of 312,772 tonnes of CO2 emissions.[3]

Electricity Transmission

Three companies own GB's onshore transmission networks. Transmission Network Owners (TOs) must publish a strategy showing how they will minimise transmission losses, and report on the implementation of this strategy as part of their RIIO price controls.

TOs have put forward measures which are currently being applied or are actively being investigated. These measures will minimise losses but only when it is cost beneficial to do so. TOs are planning a number of network reinforcements and these will have an impact on the status of losses. The impact that these reinforcements will have also depends on generation scenarios. Tables displaying the potential percentage change in losses as a result of planned reinforcements are included Appendix 2.

Currently losses from the transmission networks are equal to 6.4TWh which is nearly 25% of total system losses.

[3] CO2 saving calculated using figures from DUKES 2013 page 11: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/337649/chapter_5.pdf

Gas

Gas Distribution

Four Gas Distribution Network operators (GDNs) operate eight different networks in GB alongside several small independent gas transporters (IGTs). In 2013, Ofgem introduced the RIIO-GD1 (Revenue = Incentives + Innovation + Outputs) regulatory framework for the GDNs, who may earn incentives or face penalties based on their performance. RIIO-GD1 places obligations on the GDNs to reduce shrinkage and, separately, leakage on their networks.

Shrinkage represents the difference in volume between the gas entering the GDN systems and the total volume of gas used by customers and can be broken down into three core elements: leakage, own use gas (OUG) and theft of gas. Leakage relates to un-combusted gas emissions to the environment from GDN pipelines, OUG is gas that is used in the running of the distribution network and theft of gas includes situations where, for whatever reason, end users are unaccounted for and are using unrecorded gas.

GDNs have output commitments in place to reduce shrinkage and leakage from their networks by 15% - 20%. This equates to a baseline reduction of 542GWh from 1 April 2013 to 31 March 2021.

Gas Transmission

National Grid Gas Transmission (NGGT) is the sole owner and operator of the gas transmission system in GB. NGGT is also the System Operator (SO) for the National Transmission System (NTS). As the SO, NGGT is subject to incentives to develop a sustainable energy network, including on the level and cost profile of shrinkage gas. Special Condition 3D, Part B(i) of the NTS Gas Transporter Licence obliges NGGT to establish and publish an annual NTS Shrinkage Incentive Methodology Statement.

The largest area of energy consumption on NGGT’s system is through Compressor Fuel Usage from the operation of the compressor fleet. Under the Industrial Emissions Directive, all units that need to be replaced have to comply with a best available technology assessment to reduce their environmental impact. NGGT included a compressor replacement programme as part of its RIIO-T1 price control.

1. Introduction and overall context

The directive

1.1. The Energy Efficiency Directive (EED) was adopted in 2012 with a transposition deadline of 5 June 2014. The EED covers multiple aspects of the energy system: from supply, transformation, transmission and distribution to consumption.

1.2. The EED required Member States to set themselves a non-binding national energy efficiency target by 30 April 2013 and seeks to meet the EU's 2020 target to reduce primary energy consumption by 20% compared to a 2007 business as usual projection.

1.3. In June 2014, the UK parliament implemented certain provisions of the EED through "The Energy Efficiency (Encouragement, Assessment and Information) Regulations 2014". Regulation 6 established an obligation on the Gas and Electricity Markets Authority (GEMA) to report to the Secretary of State on the energy efficiency potential of the energy networks in Great Britain (GB) and the cost-effective measures to improve their energy efficiency. [4] A separate assessment of energy networks in Northern Ireland is being prepared by the Northern Ireland Authority for Utility Regulation.

How GB fulfilled the assessment requirement

1.4. Regulation 6 of the Energy Efficiency (Encouragement, Assessment and Information) Regulations 2014 asks for an assessment of the energy efficiency potentials of the gas and electricity infrastructure of GB. One way to improve energy efficiency is to reduce wastage. In the gas sector this wastage is referred to as shrinkage and in the electricity sector as losses. Reducing shrinkage and losses is recognised as the most effective method of improving energy efficiency of networks. The potential for shrinkage and loss reduction is the focus of this assessment.

1.5. Two industry working groups were set up in 2014, one for gas and one for electricity. The working groups helped us to compile and consult on the potential for reducing shrinkage and losses. This assessment is based on measures being carried out by the TOs, DNOs, and GDNs; we have not included data from the independent network operators.

1.6. We received nine responses to this consultation.[5] We took these into consideration in preparing this final report.

[4] http://www.legislation.gov.uk/uksi/2014/1403/regulation/6/made
[5] https://www.ofgem.gov.uk/publications-and-updates/assessing-energy-efficiency-potentials-gb-energy-infrastructure

Structure

1.7. This report has separate sections for electricity and gas. Both follow the same broad structure. A background on losses/shrinkage is provided, giving a technical overview and details of the regulatory approach we use to drive network company behaviour. This is followed by an overview of GB's networks and details current estimates of losses/shrinkage volumes. Then we explain the barriers, enablers and uncertainties which must be taken into consideration in assessing the potential for losses/shrinkage.

1.8. The main part of each section is '**current measures**'. This describes what measures are being adopted by the network operators. This is followed with a '**potential measures**' section describing measures that have been identified as potentially being effective at reducing shrinkage/losses in the future.

RIIO price control framework

1.9. The RIIO (Revenue = Incentives + Innovation + Outputs) regulatory framework, is a new performance-based model for setting the network companies' price controls which will last eight years. RIIO is designed to encourage network companies to:

- Put stakeholders at the heart of their decision-making process
- Invest efficiently to ensure continued safe and reliable services
- Innovate to reduce network costs for current and future consumers
- Play a full role in delivering a low carbon economy and wider environmental objectives.

1.11 The RIIO model includes a time-limited innovation stimulus package that builds on the Low Carbon Networks Fund (previous innovation competition). It consists of:

- The **Network Innovation Competition (NIC)** is an annual competition for funding larger-scale innovative projects that have the potential to deliver carbon or other environmental benefits to consumers.
- The **Network Innovation Allowance (NIA)** provides innovation funding for small projects with the companies self-certifying against published criteria.
- The **Innovation Roll-out Mechanism** enables companies to apply for additional funding within the price control to roll-out a proven innovation if it meets defined environmental criteria.

1.12 Examples of gas and electricity innovation projects with an impact on losses and shrinkage are listed in appendices 1 and 4.

Flexibility

1.10. Although this report is focused on measures to reduce losses and shrinkage, there is other work being done on flexibility which may have an impact on the wider energy efficiency front.

1.11. We are examining the potential for flexibility and thinking about the interactions between the different uses of flexibility across the value chain. We want to understand how market participants across all parts of the supply chain might participate in providing and using flexibility in the future.

1.12. Our strategy, due to be published over the summer, will explain what we intend to do to facilitate the use of new sources of flexibility in the GB electricity system and will set out the actions that we or other parties need to take. Should changes to policies and regulation be necessary in order to deliver the strategy, we will consider them at a later stage and develop them through normal consultation processes.

1.13. Flexibility is recognised in this EED report in the measures sections describing smart meters, DSM and various innovative projects listed in appendices 1 and 4. Concrete measures for flexibility were not reported on in this EED report as concrete plans for their implementation are still being developed. However, there is potential for flexibility measures to improve network energy efficiency.

2. Electricity networks

Background on losses

What are losses?

2.1. The amount of energy that enters an electricity network is more than the amount that is delivered to customers. The total energy lost on the GB network is estimated by subtracting the volume of energy units known to be delivered to customers from the volume of units that originally entered the network. The cost of the losses is apportioned among customers and forms part of a customer's electricity bill.

2.2. The principal reason for loss is that an electricity network consumes energy in the process of delivering power to customers. This is known as a **technical loss**.

2.3. Technical loss is made up of two elements: a fixed amount (a function of the network itself, irrespective of the usage of the network) and a variable amount which depends on the amount of energy moving through the network. The variable loss will change as demand increases and decreases. Additional factors such as the effect of network imbalance, power factor and power quality can also affect technical losses.

2.4. The fixed element of losses is the energy which is required when plant such as transformers or conductors are energised. The variable element of losses is created due to the heating effect of energy passing through conductors. High load (when an item of equipment is running near or at full capacity) produces proportionally more losses than when an item of plant or network is partly loaded.

2.5. Energy lost, not directly as a function of the delivery to customers, is referred to as a **non-technical loss**. Situations where there is no registered supplier at a connection point or no meter installed. In many cases however, non-technical losses are due to illegal activities for example, bypassing the meter.

Regulatory approach to managing losses[6]

2.6. The first RIIO price control for electricity transmission networks (RIIO-T1) and electricity distribution networks (RIIO-ED1) came into effect on 1 April 2013 and 1 April 2015 respectively.

2.7. Ofgem has placed licence obligations on the companies to ensure that losses are as low as reasonably practicable. This is combined with the requirement for all companies to justify expenditures in their business plans on managing network

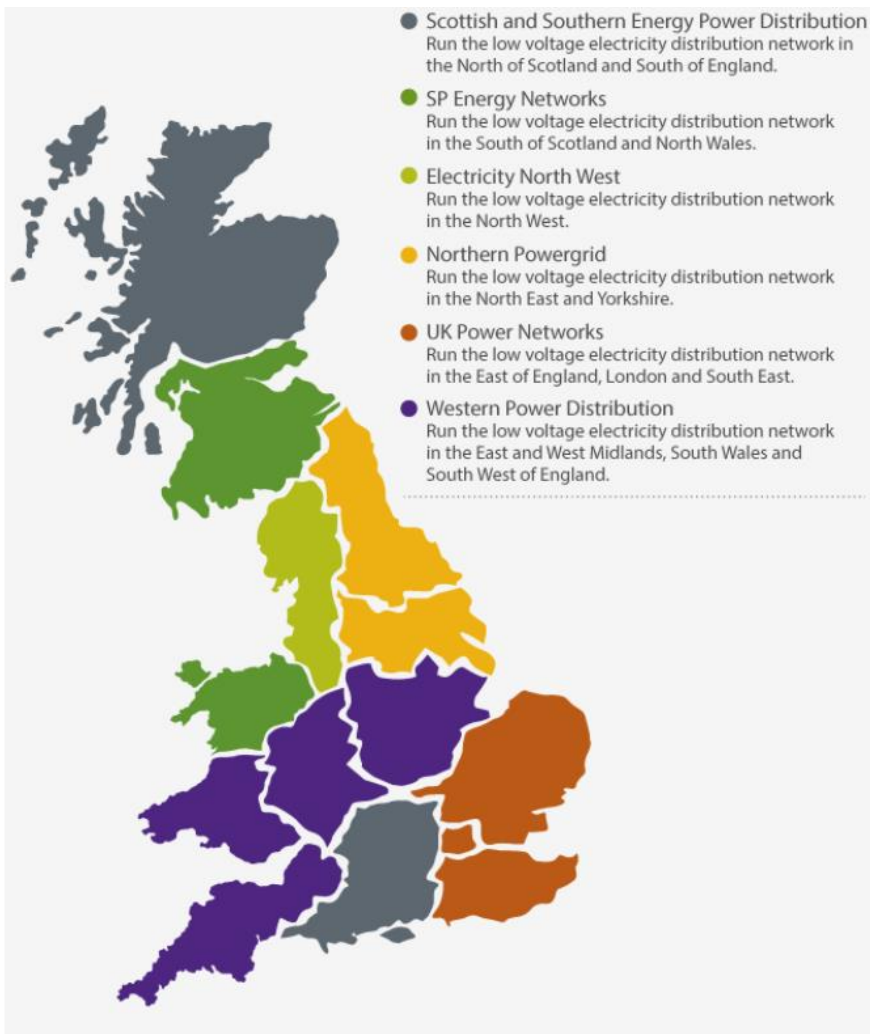
[6] https://www.ofgem.gov.uk/ofgem-publications/47067/riioed1decoverview.pdf

losses, as part of their carbon reduction methodology. The information provided in the companies' losses strategies was used as the basis for this report.

Distribution Networks

2.8. The GB electricity distribution network operators (DNOs) are six large incumbent companies shown below, and a number of smaller independent distribution network operators (IDNOs). Both DNOs and IDNOs are regulated by us through a licence, which includes a requirement to keep losses as low as reasonably practicable. Through Ofgem's regulatory mechanisms, a price control is set on the revenues that these companies can earn over a fixed period of time.

Figure 1 – Who operates GB's electricity distribution networks?[7]



[7] https://www.ofgem.gov.uk/network-regulation-riio-model/energy-network-how-it-works-you

2.9. The latest price control period, called RIIO-ED1, runs from 1 April 2015 to 31 March 2023. It introduced a losses reduction mechanism comprising:

- A licence obligation for DNOs to ensure that losses are as low as reasonably practicable
- A licence obligation for DNOs to investigate and resolve any cases of 'relevant theft of electricity' from their distribution systems
- A requirement to maintain and act in accordance with a distribution losses strategy
- Ex-ante funding for efficient loss reduction activities
- A reporting requirement on loss reduction actions taken and actions planned each year
- A discretionary reward for efficient and innovative loss reduction initiatives of up to £32m, available over the RIIO-ED1 period.

2.10. The RIIO-ED1 strategy decision also states that DNOs should set out proposals to establish a reliable losses baseline in RIIO-ED1 so that an incentive mechanism in the following price control – RIIOED2 (1 April 2023 to 31 March 2031) can be introduced.

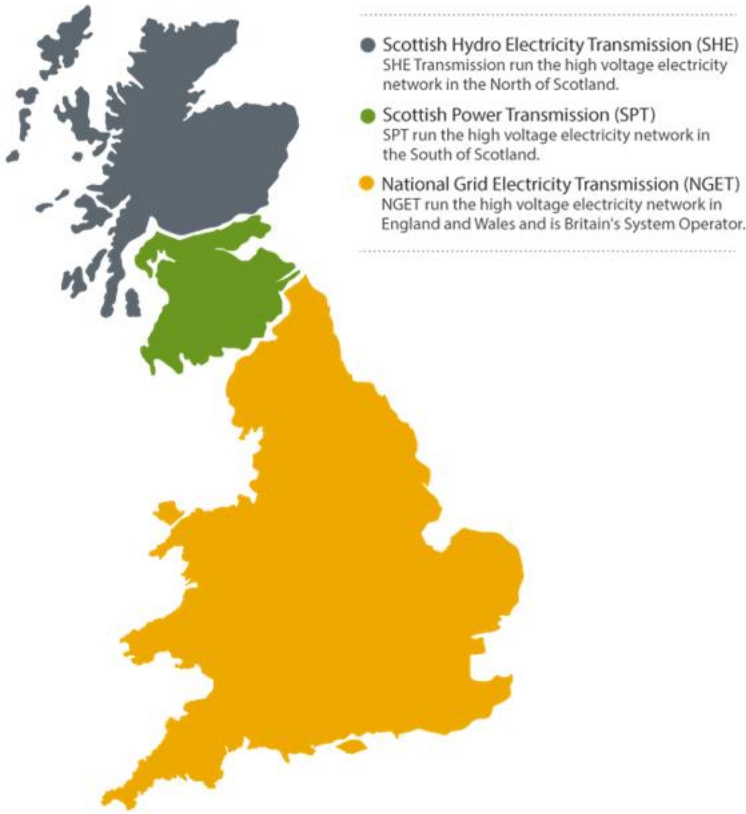
Distribution losses strategies

2.11. The first distribution losses strategies were published in 2014. These documents have been used for the basis of this report. The most recent strategies can be found on the individual distribution company websites. The information is updated annually so the strategies may not correlate exactly with the information presented in this report.

Transmission networks

2.12. Three companies own GB's onshore transmission networks, illustrated in Figure 2. Transmission Network Owners (TOs) must publish a strategy explaining how they will minimise transmission losses over the price control period.

Figure 2 – Who owns GB's electricity transmission networks?[8]



2.13. The TO licence condition on losses provides guidance on the losses strategy. It should include:

- a description of the methodology used by the licensee to take transmission losses into account when planning load related reinforcements
- a description of the licensee's methodology to take transmission losses into account when the licensee is planning non-load related asset replacement programmes
- a description of how the licensee determines the optimal specifications in relation to transmission losses arising from the on operation of new equipment in its asset procurement processes;
- a summary of key developments to the licensee's Transmission System and estimates of the impacts those developments will have on transmission losses

[8] https://www.ofgem.gov.uk/network-regulation-riio-model/energy-network-how-it-works-you

- a summary of the licensee's asset replacement programmes and estimates of the impacts those programmes will have on transmission losses on the licensee's Transmission System
- a description of the potential application of new and alternative technologies to the licensee's Transmission System during the price control period and the impact these technologies may have in relation to transmission losses.

2.14. The TOs must publish an annual losses report for the previous year. This should include details of the level of losses on its system, a progress report on implementing its strategy, and any revisions it has made to the strategy.

2.15. As the System Operator (SO) for the National Electricity Transmission System in GB, National Grid Electricity Transmission (NGET) must publish and maintain an up-to-date explanation of how it takes transmission losses into account when procuring balancing services to balance electricity supply and demand. NGET also publishes monthly data showing the total volume of historic transmission losses and an indication of the cost of transmission losses from the NETS. Additionally NGET is required to publish information or provide details which:

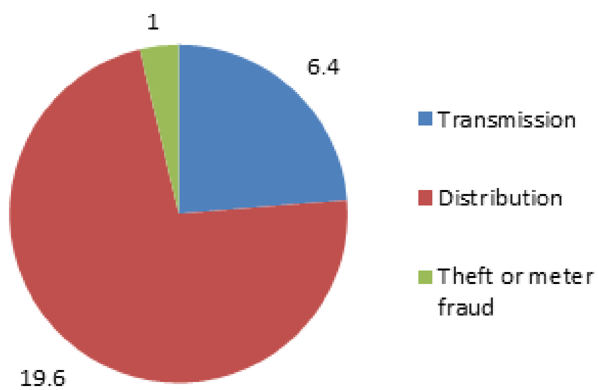
- identifies and explains the expected drivers that may impact the total volume of expected transmission losses on the NETS over the course of the next ten years
- a description of how the licensee takes expected transmission losses over the next ten years into account when undertaking its planning activities in relation to the balancing services.

3. Electricity networks today

GB system losses

3.1. In 2013 losses, as a proportion of demand on GB's networks, were estimated to be 7.2 per cent – 27TWh. Losses can be split into three components: transmission losses, distribution losses and theft, demonstrated in Figure 3. Distribution networks account for the majority of electricity network losses. Therefore the bulk of the electricity section of this report focuses on distribution losses.

Figure 3 – Total electrical losses split between transmission networks, distribution networks and theft in 2013 (TWh)[9]



Accuracy of loss measurement

3.2. While the current losses calculation is a good guide to overall performance, it has a number of limitations. For example, today's domestic metering does not record when energy is used between each reading. Meters record the volume of energy, therefore it is not possible to completely align measurements of energy entering and leaving the network. Similarly, this estimate is complicated by the use of non-metered energy, including fraudulent use (theft).

3.3. Even after smart meters have been rolled out, the accuracy of the metering for domestic properties at exit points will be [±]1.5%.[10] Due to these metering

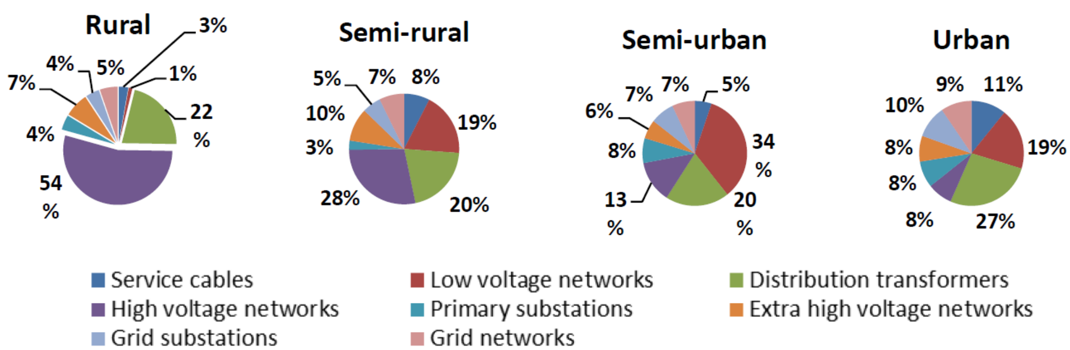
[9] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/337649/chapter_5.pdf
[10] Settlement Agreement Code of Practice 5 issue 6 section 4.2.1 (i) requires an accuracy of ± 1.5%. Therefore if this flowchart results in a CT accuracy of +/- 0.5%, then the meter and associated apparatus must not exceed ± 1.0%

inaccuracies the absolute level of losses, ie the GWh, will always be uncertain within +/-1.5%[11] of the total energy distributed.

Distribution losses

3.4. Figure 4 gives an indication of how the losses are distributed across the distribution network assets.[12]

Figure 4 – Breakdown of losses in four types of network[12]



3.5. Across these types of networks, the service cable and LV cables supplying electricity to properties account for 25% of distribution losses. The distribution transformers add another 22% with the high voltage (HV) network accounting for another 25%. The extra high voltages make up the remaining 28%.

Transmission losses

3.6. Transmission losses are calculated by NGET every year, based on metered generation and demand data. The calculation is based on the latest applicable settlement metering data currently available for generation, demand and French / Moyle Interconnector Balancing Mechanism Units (BMUs), together with operational metering for the boundaries between the Scottish Hydro Electric and Scottish Power systems and the Scottish Power and NGET transmission systems.

3.7. Overall the losses arising from the GB transmission system are calculated by taking the difference between the sum of infeed to and the sum of the offtakes from the transmission system.[13] At a GB level the total generation (sum of positive

[11] The Settlement Agreement Code of Practice requires an accuracy of ±1.5%. If a systematic bias is built into the metering then the overall margin of error will be equivalent to the meter accuracy (ie either +1.5% or -1.5%). If the meter accuracy is a product of random imperfections in the individual meter – so that some are less accurate in either direction – then the sum of the random inaccuracies would tend towards zero.

[12] http://www.westernpower.co.uk/docs/Innovation-and-Low-Carbon/Losses-strategy/SOHN-Losses-Report-Executive-Summary.aspx

[13] https://www.elexon.co.uk/data-flow/settlement-report-saa-i014-also-known-as-the-s0142/

metered active power) and total demand (sum of negative metered active power) values can be used.

3.8. The losses for the three GB transmission areas are in Table 1.

Table 1 – Annual transmission losses per region (TWh)[13]

	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14
England and Wales	4.80	5.12	5.15	4.92	5.36	4.22	5.23	4.93	4.45
South Scotland	0.58	0.69	0.74	0.67	0.49	0.53	0.55	0.44	0.49
North Scotland	0.22	0.30	0.29	0.37	0.29	0.24	0.36	0.27	0.38
GB	**5.60**	**6.10**	**6.18**	**5.96**	**6.14**	**4.99**	**6.14**	**5.64**	**5.32**

Whole system planning

3.9. The responsibility for loss management resides with the individual network operators however there is interaction between the TO and the DNO that can affect losses. Both parties are required to ensure that the operation is managed in a coordinated way, and this extends to ensuring that losses are also managed to a practical level.

3.10. When work is done that could impact either transmission or distribution networks, interaction occurs. This includes exchanging information between both parties so that planning and development can be done according to the relevant Licence Standards and to identify measures that will mitigate losses.

3.11. Loss mitigation measures are recorded against the assets such as transformers or conductors. So for this report, the loss reduction measure is also reported against the asset. For completeness, this process does not capture upstream and downstream indirect losses that may be affected by these measures.

Note that the calculation methodology and values differ from that presented in Figure 5.

4. Barriers, enablers and uncertainties

Enablers

Losses reduction mechanism

4.1. We have introduced a losses reduction mechanism into the DNOs' price control arrangements. This requires DNOs to have an up-to-date strategy on how to reduce losses on their networks, and gives them a financial and reputational incentive to reduce losses. DNOs can also apply for funding if losses benefit is over and above those set out in the losses strategy from the beginning of the price control for cost-effective loss reduction measures.

4.2. We developed a standard cost benefit analysis spreadsheet for network companies so they could take a 'whole life' approach to network reinforcement. This tool takes into account the cost of losses at £48.42/MWh (in 2012-13 prices). This approach is expected to help implement loss reduction solutions that may not have been considered previously.

Distributed generation

4.3. Generation produced and used locally can reduce the requirement to transfer energy over large distances, and hence result in a saving in network losses. There are a number of specific regulations in place to support distributed generation. In GB, there is an incentive scheme for companies to help facilitate the connection process from a customer perspective. The scheme is referred to as 'Incentive on Connections Engagement' (ICE)[14] and came into force in 2015. It requires the companies to report on their strategy for engaging with relevant stakeholders in the connections process.

Lower network utilisation

4.4. Losses are comparatively higher when the network utilisation is running near to capacity. Reducing the time that the network is near capacity will reduce losses, particularly those at LV and HV levels. So the most simplistic 'enabler' available is to increase the capacity of the network. This could be increasing conductor / transformer size and/or reducing peak power flows.

4.5. Lowering the time that the network is running at its secure capacity can be realised by installing larger or more assets, which means more initial network investment and so an initial increase in cost. However there is a balance between

[14] https://www.ofgem.gov.uk/ofgem-publications/91745/riio-ed1guidanceice041214.pdf

network investment and reducing losses. The concrete measures in this report reflect a positive total life cycle benefit.

Demand side management and smart meters

4.6. Demand side management (DSM) is when customers participate by reducing their energy consumption at particular times of need. Using DSM may depend on the implementation of suitable tariffs. The simplest example of this is the use of storage heaters, which charge overnight on a low rate tariff such as 'Economy 7'.

4.7. Too much generation, potentially leading to lower tariffs, could possibly coincide with conventional times of maximum demand and lead to a pronounced network peak above that currently experienced. This may be further compounded in an area with a lot of electric vehicles and other low carbon technologies. Smart meters will support time-of-use and dynamic tariffs, and could reduce peak demand and losses.

4.8. By the end of 2020, smart meters are expected to replace manually-read gas and electricity meters in homes and small businesses. Smart meters let customers manage their usage if they receive price signals. This potentially allows them to move their demand from traditionally high periods (which would attract a higher charge) to lower periods (attracting a lower charge). So the traditional peak periods of the day (16:00 until 19:00) could flatten. A secondary effect is that losses will be lower than they would otherwise have been. But price signals to domestic customers will likely be supplier-led and potentially outside the direct control of network operators.

4.9. In its Smart Meter Impact Assessment, the Department of Energy & Climate Change (DECC) has assumed a reduction in losses, due to the smart meter roll out. It calculates the benefit of this as £0.5 for electricity and £0.1 to £0.2 for gas per meter, per year. This equates to a total net present benefit of avoided losses of £428m for the domestic sector and £93m for the non-domestic sector, over an 18-year period.[15]

Innovation in the RIIO framework (RIIO-T1 and RIIO-ED1)

4.10. Innovation is important in GB, as electricity networks are evolving in a way they were not originally designed for. Ofgem has introduced incentive and innovation funding mechanisms to help network companies trial innovative technological, operating and commercial plans. These may be more expensive initially, but if there are positive long-term benefits, innovation is an efficient choice. There is a range of innovation projects relevant to reducing losses and increasing network efficiency in Appendix 1.

[15] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/78666/IA-Feb.pdf

4.11. The RIIO model includes a time-limited innovation stimulus package that builds on the Low Carbon Networks Fund (previous innovation competition), supplementing the other incentives to support these projects. This package consists of an annual competition, a limited funding allowance and a mechanism to fund the successful innovation trials, as described in the introduction section.

Barriers

Economics

4.12. The physical laws that govern electricity transmission and distribution dictate that there will always be losses within the network. Hypothetically, it would be possible to design a network to achieve very low electrical losses if there were no economic constraints. But to achieve economic efficiency, there has to be some compromise which considers cost versus benefit. This has implications for providing new connections at minimum cost to network users, replacing assets, and general reinforcement.

Obligations placed on the network operators

4.13. Under the Electricity Act 1989 (Section 9(1) for electricity distribution licensees and Section 9(2) for transmission licensees) each licensee is obligated to ensure that the network is designed to allow for developing, maintaining and operating an efficient, coordinated, and economic system for distributing electricity, and facilitate competition in generating and supplying electricity.

4.14. In addition, licence conditions require the licensee to operate its network in a way that ensures losses are as low as reasonably practicable.

4.15. There is a balance between these two conditions that is addressed in the losses strategies that the network companies publish every year. This shows how a network company will ensure that losses will be as low as reasonably practicable while also ensuring that an economic, efficient and coordinated system is developed.

Smart metering losses

4.16. Smart meters are designed to record consumption of energy (electricity and gas) and relay the information to the energy suppliers and DNOs. As smart meters' functionality is more sophisticated, they use more energy than non-smart meters do.

4.17. The energy used by a meter appears on the network side of the meter. This means that the energy it uses is not included as part of the meter reading and not metered. The end effect is that it appears as a loss on the network.

4.18. Table 2 shows an estimate of losses from smart meters energy against existing meters:

Table 2 – Smart meter energy consumption estimates

Meter Type	Existing Metering Losses	Smart Meter Losses	Increase in Losses
Gas meter	0W electrical (gas pressure driven)	1W	1W
Single Phase Single Element Electricity Meter	2W	3W	1W
Single Phase Twin Element Electricity Meter	2W	3W	1W
Poly Phase Electricity Meter	5W	7W	2W
In Home Display	0W	0.6W	0.6W
Communications Hub	0W	1W	1W
Total (single phase)	2W	4.6W	2.6W
Total (poly phase)	5W	8.6W	3.6W

4.19. The existing electricity meters on GB's networks are estimated to contribute around 2.5% of overall losses – 0.67TWh.[16] Table 2 shows that the energy usage from a domestic smart meter will increase power usage from around 2W to over 5W (gas meter, single phase electricity meter, in home display and communications hub). The initial effect of the smart meter rollout will increase the contribution that meters make to network losses, albeit providing additional functionality to significantly reduce peak demand, and in turn, losses. This is why smart meters feature in both the 'enablers' and 'barriers' section.

Conductor replacement strategies

4.20. High temperature, low sag conductor systems and the composite core conductors, ACCC (Aluminium Conductor Carbon Core) and ACCR (Aluminium Conductor Composite Reinforced), have been developed to handle increases in circuit capacity. Although these conductors can double the capacity of existing circuits, if this capacity is used it also increases losses.

Power quality

4.21. Power quality is an industry term that refers to the overall quality of supply that a customer experiences. This includes technical elements such as harmonics, voltage waveform quality, the rate of voltage change and reactive power quality. The power quality is usually managed through standards applied to electrical equipment by either European Commission (IEC) or British Standard Institute (BSI). One element that is not covered in the standards is the concatenation of many devices in close proximity (for example a street with solar PV on each roof). As these power quality effects are not linear (using the example above, more solar PV can exacerbate a harmonic issue to greater than the sum of its parts), this report looks

[16] From Section 3.1, 7.2% of annual energy generated is losses = 27TWh; 2.5% of losses is metering = 0.67TWh

at methods to improve power quality, that will also lead to improvements in energy efficiency.

4.22. Domestic customer loads have changed slowly over the last 20 years. Passive devices such as incandescent lamps and iron core transformers have been replaced with compact fluorescent and LED lamps and switched-mode power supplies. The switch to LED lights from incandescent bulbs has increased energy efficiency, and so reduced losses, as has moving towards switch mode power supplies which are also more efficient than the traditional iron core transformers. Compared to traditional devices, these modern devices have a non-linear effect on voltage and current waveform.

4.23. Typical domestic harmonics levels appear to be increasing because of low carbon technologies and energy efficient appliances.[17] The net effect is that losses can change due to power quality experienced on the network.

4.24. The key element of power quality is that the effects are not linear. This means that multiple devices connected at the same location can produce higher losses than the sum of the individual items.

Non-firm connections

4.25. To allow the connection of generation or demand in capacity constrained areas of the network, alternative connection arrangements can sometimes avoid reinforcement that would add additional capacity. These solutions can increase the utilisation of the network so can have a detrimental effect by increasing losses.

4.26. For customers downstream of a single network constraint, a connection can be offered which allows generation to flow when the constraint is not a limiting factor but restricts generation flow when the constraint becomes active. Losses are generally considered to be the same or increased due to an increase in overall utilisation.

Uncertainties

Low carbon technologies

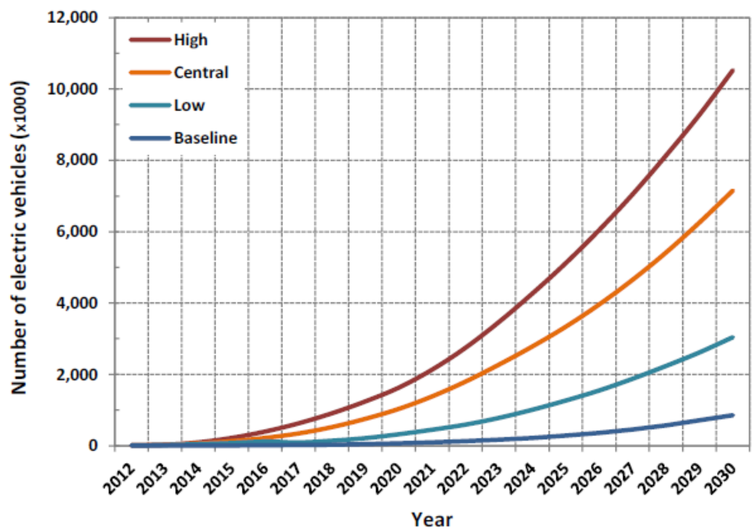
4.27. Generation on the LV and HV networks are projected to be mainly photovoltaic (PV) and wind generation. DECC has published 'low', 'medium' and 'high' trajectories for the future uptake of these technologies.[18] These show that the capacity of PV and wind installations on distribution networks alone will increase from 2012 to 2020.

[17] Two IFI projects are underway - Harmonic Detection and analysis (WPD); IFI project; Advanced Harmonic monitoring (UKPN) – to investigate and confirm that domestic harmonic levels are increasing
[18] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/370648/Final_Report_-

4.28. When an embedded generator is generating electricity, the load on the circuits supplying energy to local demand may be reduced. When local generation matches local demand, the power flow on these circuits could reduce to zero. As a result, the variable losses on these circuits and on the upstream transformer will also be reduced to zero. But this is unlikely to coincide with maximum demand on the system, where variable losses on the system are highest. Because there are many different demand and generation scenarios, there are also circumstances when embedded generation can increase losses on the network by increasing the amount of electricity flowing on the circuit.

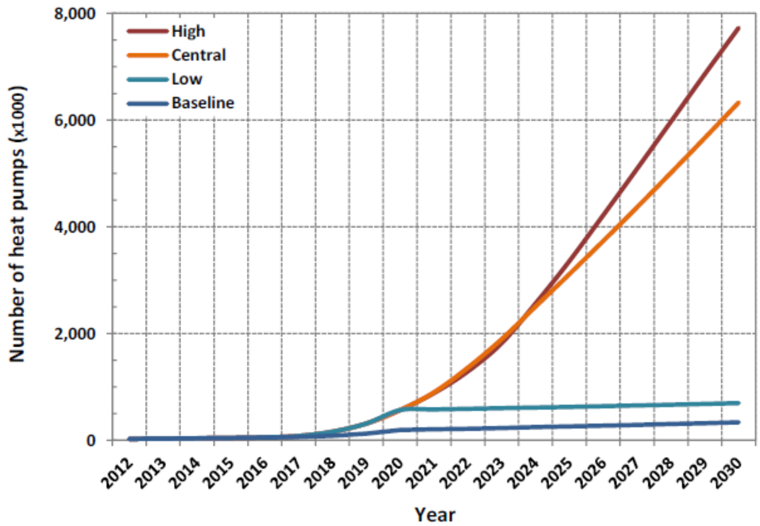
4.29. DECC projections show increased levels of embedded generation and an uptake of low carbon technologies. Energy distributed is therefore expected to increase. For instance, modelling suggests potential significant uptake of heat pumps and electric vehicles in GB (see Figures 5 and 6). If these loads are not properly managed to minimise the increase in network peak demand, they will significantly increase the load on the network and the associated variable losses will increase quadratically. This will cause the overall value of losses to increase, unless this increase can be offset by other factors, such as smart control devices that actively manage the energy use.

Figure 5 – DfT's trajectories for electric vehicle uptake[18]



_Impact_of_Policy_that_Drives_Low_Carbon_Technologies_on_Distribution_Networks_.pdf

Figure 6 – DECC's trajectories for heat pump uptake[18]



Cost of electricity and carbon

4.30. The future costs of electricity and carbon have a strong influence on the losses reduction measures that are adopted by the companies. A low cost of electricity and carbon means that measures introduced to lower losses could have a negative net present value. Conversely, a higher electricity and carbon price can make measures deliver a positive net present value. Assuming a low cost of electricity and carbon for network investment decisions can represent a major barrier for adopting low loss network design and implementation.

5. Electricity distribution network concrete measures

Measures to reduce losses

5.1. This section examines the concrete measures put in place by the DNOs. There is a brief description of each measure, with a forecast of its loss benefit. The data that supports the forecast of loss reduction is in the individual losses strategies as published by each DNO.

5.2. DNOs are required to produce a losses strategy. Each DNO strategy provides information on the measures that they have and will be introducing to manage and reduce losses. The detail in this report is an abridged and anonymised commentary on these strategies.

5.3. Each concrete measure represents the total activities of all DNOs on year-by-year. We present the following data cumulatively against the measures where appropriate:

- **£m benefit** – the monetary value shown is a product of the MWh saved and the value that we have set for deferred energy (currently £48.42/MWh)
- **MWh saved** – this is the total of all the activities forecast by the DNOs that have an influence on losses and represents the net benefit by applying the new technologies where the traditional approach would provide no further benefit.

Proactive replacement of transformers

The EU Ecodesign Directive

5.4. The EU Directive – 2009/125/EC – mandates the adoption of Ecodesign transformers for distribution networks in two phases, from 2015 and 2020. The Ecodesign requirements are for improved transformer fixed and variable losses performance in 2015 and further improved in 2020.

Replacement of old transformers

5.5. Old distribution transformers (for example those that pre-date circa 1958) were built to a range of designs and specifications which preceded the current specifications. Older transformers were produced using a core manufacturing process that resulted in efficiencies that are approximately 60% poorer than modern transformer designs. Proactively replacing these high loss transformers is more cost effective from a losses perspective than replacement based on the condition of the asset alone.

Table 3 – Electricity distribution concrete measures – replacement of old transformers

Solution		15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23
Replacement of old transformers	£m benefit	0.67	1.69	3.04	4.74	6.73	8.91	11.27	13.63
	MWh saved	13,882	34,806	62,792	97,826	139,077	184,049	232,740	281,432

Low loss transformers

5.6. The benefits of purchasing transformers that outperform the latest EU transformer efficiency directive[19] (Tier 1 & Tier 2) at Primary level (33kV/11kV) have been considered. The increase in initial capital costs to install transformers that go beyond this directive can be economically viable in some cases over the lifetime of the plant.

Table 4 – Electricity distribution concrete measures – low loss transformers

Solution		15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23
Low loss transformers	£m benefit	0.64	1.06	1.43	1.84	2.28	2.76	3.42	4.13
	MWh saved	13,266	21,962	29,567	37,951	47,066	56,904	70,593	85,360

Transformer sizing

5.7. Installing a larger capacity transformer than necessary from a thermal rating perspective reduces the use of the transformer. Over the lifetime of the asset, the higher initial cost can be offset in some cases by the long term loss reduction.

Cables and overhead lines

Replacement of conductors

5.8. DNOs replace underground cables and overhead lines primarily at the end of their lives. In the context of this report, replacement of cables to increase the capacity for customers is classified as a reinforcement activity.

5.9. Replacement is traditionally considered a 'like for like' activity which means that the capacity of the new conductor is similar to the existing asset. Usually conductors which are oversized reduce conductor resistance. This can have the

[19] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0548&from=EN

added benefit of improving network performance, ie voltage drop, current carrying capacity and earth loop impedance, and reduce losses.

Oversizing conductors

5.10. The use of larger conductors than the minimum required for the load has been adopted where the long term loss reduction is financially beneficial. Different conductor sizes are used depending on the nature of the work.

Table 5 – Electricity distribution concrete measures – oversizing of conductors

Solution		15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23
Oversizing of conductors	£m benefit	0.36	1.01	1.96	3.21	4.75	6.61	8.78	11.22
	MWh saved	7,333	20,811	40,405	66,230	98,172	136,524	181,286	231,699

Different conductor material

5.11. When a conductor needs changing, the choice of the material of the replacement conductor can affect the loss. This optimisation of a particular overhead line or cable is subject to local conditions (for example sheltered areas through valleys or exposed areas on top of moors) and this optimisation can improve losses if it is financially beneficial.

Table 6 – Electricity distribution concrete measures – optimising conductors

Solution		15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23
Optimising conductors	£m benefit	0.51	0.86	1.16	1.49	1.81	2.16	2.60	3.05
	MWh saved	10,497	17,709	24,038	30,669	37,481	44,509	53,712	63,044

Voltage control

5.12. In the past, voltage reduction was used to reduce demand during generation shortages, as much of the load has been 'voltage dependent' (eg filament lamps and resistive heating). As the resistance of these devices is largely fixed, applying a lower voltage reduces the current drawn, less power is transferred and hence overall load is reduced. For resistive heating, the energy output will be reduced but as the load is temperature-driven, the same energy will be required over a longer time. The net effect is that there is limited change in the energy requirements or loss improvement. For filament lamps the lamp will dim, thus providing less visible light.

5.13. In technical terms, generally reducing the voltage of all systems apart from the LV system will increase losses. Reducing the LV voltage will slightly reduce energy consumption by customers, but it can increase network losses on the LV network. From an overall energy efficiency viewpoint, this could be a good thing to do as the overall reduction in energy used is likely to be greater than the potential increase in losses on the LV network. However, great care needs to be exercised in assessing the benefits.

5.14. There is scope to reduce the network voltage and remain within the statutory voltage parameters. Reducing the voltage will reduce the overall power requirements at the LV level makes a small contribution to loss reduction, however it could have a minor effect on HV and EHV losses. There is a balance between the two to ensure that the most optimal solution is found. There is a trade-off with reducing the voltage as this can reduce the headroom available for connecting low carbon technologies such as electric vehicles or heat pumps. This relates to the operating range of the transformers and their ability to keep the voltage at the prescribed level.

5.15. Load is increasingly 'voltage independent', as it is fed via a switched mode power supply, which effectively changes its impedance based on voltage (such as high frequency fluorescent tubes, light-emitting diode lights, computers, variable speed drive motors).[20] So lowering voltage may not, in all circumstances, lead to the demand savings as desired and could actually increase network loading and hence losses.

Table 7 – Electricity distribution concrete measures – Voltage control

Solution		**15-16**	**16-17**	**17-18**	**18-19**	**19-20**	**20-21**	**21-22**	**22-23**
Voltage control	£m benefit	0.28	0.41	0.52	0.63	0.75	0.89	1.10	1.33
	MWh saved	5,806	8,570	10,682	13,051	15,575	18,288	22,779	27,390

Interoperability

5.16. Optimising voltage at all voltage levels will provide the best assurance of meeting statutory obligations under ESQCR[21] Regulation 27(3) (b), (c) and (d). Maintaining voltage at the lower level within the statutory limits will also ensure that variable losses (as a percentage of energy supplied) are minimised at the LV level, however they may be increased at the HV or EHV level. It is important that the trade-off is economically assessed. In practice, determining busbar voltage set points is a compromise between achieving the ideal voltage level from an energy efficiency perspective and practical considerations regarding the need to ensure adequate automated voltage control (AVC) relay operating bandwidths and operating time delays.

Non-technical losses

Theft in conveyancing activities

[20] Carbon Trust [2011] – "Voltage Management" Technology Guide (CTG045)
[21] Electricity Safety, Quality and Continuity Regulations can be found online at: http://www.legislation.gov.uk/all?title=electricity%20safety%20quality

5.17. Revenue protection activities include:

- Planning and making customer site visits and meter inspections
- Responding to tampering notifications and 'tip-offs' from a range of stakeholders
- Repairing electricity services and mains supplies
- Assessing unrecorded energy and updating information systems
- Liaising with enforcement agencies
- Participating in industry and government groups regarding energy theft
- Storing meters where interference has been identified as evidence
- Providing stakeholder training and awareness initiatives
- Preparing cases for enforcement action and pursuing prosecutions.

Conveyance and settlement inaccuracies

5.18. Situations arise where energy is delivered and consumed but is not accurately recorded in the electricity settlement system, and therefore becomes lost energy. The main causes of these non-technical losses include missing and unregistered metering points, incorrect recording of the energisation status for metering points and incorrect registration of metering system information leading to inaccurate customer consumption data. Such non-technical losses are often regarded as 'conveyance'-related. DNOs work closely with suppliers and metering service providers to improve settlement data and metering point registration accuracy. DNOs will continue to focus on reducing the numbers of metering points without a registered supplier and some operators have already implemented tighter controls on the allocation of new Metering Point Administration Numbers (MPANs) to property developers.

5.19. DNOs will also continue to proactively monitor the number (and check the status) of metering points registered as disconnected and de-energised by suppliers. They will cooperate fully in Elexon Audits to check settlement data and resolve any inaccuracies with corresponding commitments to refine internal processes to prevent recurrences.

5.20. During the roll-out of smart metering, when lots of meters will be changed within short timeframes, DNOs will work with all relevant stakeholders to develop robust industry procedures to ensure accurate settlement.

Unmetered supplies

5.21. Non-technical losses associated with unmetered supplies can be attributed to incomplete database records of unmetered customer loads, inaccurate equipment inventories and errors regarding the assumed demand characteristics. Typically, these considerations result in under-recording unmetered energy consumption.

5.22. DNOs continue to work with unmetered supplies customer groups to ensure equipment inventories are regularly updated. DNOs actively pursue customers whose inventories they have not received. They will take a proportionate approach to making unmetered supply records more accurate by targeting the largest customers, which typically include councils and local authorities.

5.23. If customers do not engage with DNOs, regarding asset inventories for their unmetered supplies, DNOs may do equipment audits to establish accurate consumption information for including in energy settlements.

6. Electricity distribution network potential measures

Potential measures to reduce losses

6.1. The potential measures in this section are in different stages of investigation. They are reported as potential measures as there is either no 'concrete measure' in place, or the measure cannot be attributed to losses reductions in particular years for the timetable of concrete measures. Factors affecting these potential measures include:

- understanding the effectiveness that the potential measure will have on losses
- understanding how the potential measure can be installed on the network in the best way
- developing the technology to a level that it can be installed on the networks
- making sure the potential measures are an economic and efficient solution for customers
- the feasibility of a manufacturer developing and supplying the equipment
- interaction between differing potential measures to ensure that the overall package is effective.

6.2. As with any list of potential measures, it is important to recognise that not all of them can be introduced immediately. The DNOs are investigating them based on the nature of their networks and the most efficient solution for those businesses. This means that different DNOs will have different strategies and priorities based on the network topology and business goals.

6.3. Because each DNO's strategy is unique, these initiatives are a summation of selective initiatives from across industry rather than applicable to all DNOs.

6.4. The contribution each of these potential measures can make to overall losses reduction on GB's distribution networks is uncertain. The estimated loss reduction potential for each of these measures has been totalled and a range to deal with uncertainty has been applied. These measures have the potential to reduce losses by a further approximately 170,000MWh to 345,000MWh[22] on GB's distribution networks.

[22] This value equates to the total of the potential measures identified by the DNOs through their losses strategies

Cables and overhead lines

Conductor type

6.5. Increasing the cross-sectional area of the conductor reduces losses. However, an alternative may be to change the conductor material from aluminium to copper. Copper has a lower resistivity and so reduces the losses on the network. The downside is that copper is more expensive than the current option of aluminium alloy and the current cost benefit analysis identifies aluminium as the preferred option. As the price of materials changes, this option may become viable.

Transformers

Reduced winding resistance

6.6. Further loss reduction over and above the current measures can be gained through transformer design and specification. A method of reducing copper losses is to reduce the resistance of the windings. This can be either by reducing the resistivity of the winding material or by increasing the cross-sectional area of the windings.[23]

6.7. There is a trade-off when reducing winding resistance, such as increasing core size to accommodate the larger windings which in turn leads to increased iron losses in the core.

Cast resin transformers

6.8. Instead of using oil as a dielectric medium, an epoxy resin is used to encapsulate the windings. The main advantages of cast resin transformers are that they are virtually maintenance-free, moisture-resistant, flame-retardant and self-extinguishing. This makes them ideal for integration within buildings, where the risk of fire is a primary concern.

6.9. The losses from cast resin transformers follow similar principles to oil-filled transformers, namely core and winding losses. However, as cast resin transformers can be placed within buildings, they can often be located closer to the load centre which reduces losses in LV sub mains cabling.

Network configuration

6.10. There has been a drive to reduce the number of customers connected to a single LV feeder. The knock-on effect of this is that the load on these circuits is also reduced, therefore reducing utilisation and the relative losses on the circuit. The

[23] Heathcote [1998] – "J&P Transformer Book"

drive of losses to reduce the number of customers on a feeder or to reduce its overall length requires analysis to establish the optimum balance, albeit at an increased cost to serve as more assets are employed.

Power quality

6.11. Power quality element is described under section 4.2.1. This section looks at the options available in more detail that may lead to reduced losses. This section examines potential opportunities to reduce losses due to power quality methods. This includes harmonics and power factor correction.

Power quality – harmonics

6.12. Consumer equipment is designed to comply with specific standards (ie relating to the impact it has on power quality), but the combined effect of multiple devices can lead to low power quality and possibly an increase in losses. The companies carry out modelling studies to ensure this does not happen.

6.13. While "power quality" is a convenient term for many, it is the quality of the voltage — rather than power or electric current — that it actually describes. Power is simply the flow of energy, and the current demanded by a load is largely uncontrollable.

6.14. Power quality is usually described as a set of values of parameters, such as:

- Variation in voltage magnitude
- Transient voltages and currents
- Harmonic content in the waveforms for AC power.

6.15. Power quality depends on the nature of the appliances that are connected to the network. Examples include air conditioning, heat pumps or solar PV inverters. These devices can cause the normal sinusoidal waveform to become distorted. Significant distortion can increase the losses on the network.

6.16. Equipment can be installed onto the network to reduce the effects of harmonics.

Power quality – phase balancing

6.17. Phase balancers, often in conjunction with voltage regulators, have historically been used selectively to maintain voltage within statutory limits on long rural LV feeders where achieving phase and voltage balance has otherwise proved to be problematic. Such traditional devices produce losses in their own right and, particularly in the case of moving-coil voltage regulators, incur maintenance costs. However the concept of balancing feeders with significant imbalance can have substantial losses savings. The simplest measure is for overhead line networks to transfer single phase customers onto a lightly loaded phase. This simplistic solution will be completed before considering regulators or power electronic solutions.

6.18. It must be recognised that phase balancing is a 'coarse setting' as imbalance is a real-time phenomenon and a perfectly balanced feeder will change as customers change their energy usage and therefore become unbalanced.

Power quality – power factor correction

6.19. Power factor is a ratio between the real power flowing through a conductor and the apparent power flowing through the same conductor. The most efficient power transfer takes place when the power factor is at unity. Power factor correction could be installed at various points of the system. The most efficient use of power factor correction is at the load. For bulk customers this is often at the customer's switchboard and at the consumer level within certain devices (such as adding a capacitor in parallel with the magnetic choke in fluorescent light fittings).

6.20. The use of power factor correction in residential installations has not generally proven to be technically or financially feasible. Most of the requirements are captured within manufacturing standards for consumer products and very low levels of correction potential remain in individual properties. The cost and complexity of individual installations would outweigh the benefit.

Legacy network design rationalisation

6.21. Some networks operating at voltage levels of 22kV and 6.6kV are being gradually replaced through investment synergies and strategies by specific DNOs. This rationalisation is specific to the topology of the network and therefore specific to each DNO.

6.22. In general, this will provide losses reduction opportunities due to the (higher) standard voltages now employed, ie 66kV, 33kV (or 132kV) and 11kV. However, there are, in addition, discrete pockets of non-standard network architecture which, due to their age and component obsolescence, are the subject of more specific asset replacement programmes. These will provide further opportunities to reduce losses, albeit subject to practical limitations inherent in their legacy designs.

Optimising network design

6.23. Networks are electrically separated at nominated points, colloquially called open points. These open points are strategically positioned to optimise customer interruptions, loading for each network section and to reduce switching operations under first circuit outages. Moving an open point to better balance customer numbers between two or more feeders usually results in the balancing of load. However, this potentially increases customer interruptions during fault conditions.

6.24. As the networks evolve, original network configurations can become inefficient. In certain cases it is beneficial to modify the existing circuits or substation configurations to enhance the operational flexibility of the substation, this can lead to loss reduction in some cases.

6.25. This optimisation can be an attractive option where network automation can also be introduced. The combined benefits can also improve reliability for customers and reduce losses.

Active network management

6.26. Some parts of the distribution network are constrained by more than a single constraint factor. One solution is a dynamic generation control system including power electronics that alter power flows and dynamically calculate circuit ratings to provide the highest generation capacity possible in the network. The net effect is that utilisation is dynamically managed, and this may increase or decrease losses compared to the traditional reinforcement measure, as the dynamic management can be set to optimise losses.

Operational measures to reduce losses

Switching out under-utilised plant

6.27. At times of low load at twin transformer substations, the combined iron and copper losses of the two transformers can be higher than the equivalent iron losses and copper losses of one transformer. At these times losses could be saved by switching out one of the transformers and re-energising it when the load increases.

6.28. The disadvantages of this would be security of supply, as if there was a fault on the single transformer, the de-energised transformer would have to be re-energised and loaded up. This would not be instantaneous and so customer supplies would be interrupted. Other disadvantages include circuit breaker wear, as they would be operated more regularly than under normal conditions.

Distributed Generation (DG) challenges and network support

6.29. DG may provide opportunities for improved network management, including managing losses. For example, DG could help optimise power flows by achieving a better overall balance between generation and demand and hence help to flatten network demand profiles. Even if a suboptimal balance between localised generation and demand causes a localised increase in losses, the overall impact might still be to reduce overall losses due to reductions in upstream power flows required to serve downstream demand. Moreover, if more of the losses are being supplied by renewable energy sources, then the overall carbon footprint of losses will be reduced. While the responsibility for dispatching generation is unlikely to fall on DNOs in the foreseeable future, this does not preclude a DNO from entering into contractual relationships with DG operators to provide ancillary services such as network support or as part of an agreed curtailment arrangement.

Measures to reduce network reinforcement

Smart meters

6.30. Smart meters will allow suppliers to offer a greater range of tariffs including more tariffs based on time of use. Where these are used to move load away from peak times, this will result in reducing overall losses because of the reduced amount of times when distribution equipment is operating at its maximum rating.

6.31. Smart meters are being fitted with a remote control function that could be used to schedule certain loads and increase the overall level of utilisation of the network. This will reduce the level of physical network reinforcement required by creating a more consistent and flatter load profile. The details of the benefits of Smart meters are in section 4.

Demand side management

6.32. There would be potential benefits such as avoided investment in capacity and reduced increases in losses if the potential increase in peak demand could be suppressed through peak-shifting. This can be achieved either through direct controls, intelligent autonomous controls (or smart appliances) or simply time-of-use tariff incentives to encourage consumers to avoid peak demand periods where practical. For example, home charging of electric vehicles could generally be restricted to night-time off-peak periods (except for consumers with electric space and water heating, or served by parts of the network which are already night-peaking such as off-mains gas areas) without loss of convenience.

Other efficiency measures

6.33. Here are some examples of things that DNOs are doing to improve energy efficiency. These activities are not counted as losses as the energy used is accounted for and paid for, ie the volumes are taken into settlement. The Energy Efficiency Directive however covers energy efficiency of which losses is one part.

Use local generation to support substation auxiliaries

6.34. It is noticeable that other public and private organisations have become more aware and active in recognising applications of local generation to support local demand. Examples are petrol stations, supermarkets, office blocks, road signs and parking meters.

6.35. Using local generation could offset the energy used by substation auxiliaries in the normal operation of the substation.

Substation ambient temperature

6.36. In major substations (primary substation, supply and grid supply points) indoor equipment rooms are temperature controlled. This is usually in the form of resistive electric heaters, controlled via a thermostat to allow switchgear and associated control equipment to function correctly.

6.37. There is an initiative being delivered to install dehumidifiers at a number of major substation sites, and this will have a variable impact due to present practice in the setting of temperature controls. When considering losses, dehumidifiers present a lower energy consumption than the equivalent electric heaters, which translates into a lower parasitic loss on the network.

7. Electricity transmission network measures

Transmission operators' approach to losses

7.1. The biggest impact on transmission losses is likely to be from the changing geographic location of generators; a move to more intermittent generation towards the periphery of England, Wales and Scotland; and more generation embedded into the distribution networks. To create more new connections, the transmission network is being developed including new and upgraded circuits. Loading patterns are becoming more dynamic as renewable generation outputs change across the country with weather patterns. A large proportion of the new renewable generation is connecting in Scotland which is increasing Scottish power flows to demand in the south, so losses increase with the increased power flows over longer distances.

7.2. Transmission losses may be seen to increase due to new generation siting away from demand, requiring greater use of the transmission network and therefore leading to higher losses. Some transmission loss reduction may happen due to growing capacities of embedded generation siting close to demand and taking loading off the transmission network.

7.3. Losses are considered as part of the transmission system development together with the asset life cycle, satisfying customer requirements and maintaining system security. Efforts are made to reduce transmission losses whenever economically viable, but reducing losses often conflicts with maximising the use of existing assets and avoiding new infrastructure build.

7.4. At transmission level, the system is already highly efficient with the optimum voltage levels being selected to best balance investment, operation and network capability. As the system has developed, parts of the network have been upgraded to ensure capability meets requirements and losses are managed for optimum efficiency. Replacing assets prematurely with modern, lower loss designs or constructing new circuits could reduce losses. But with the high cost of transmission assets, cost benefit analysis does not typically support such actions for loss reduction alone. Where losses affect investment decisions, they are assessed as part of a Whole Life Value Framework.

Losses control measures

7.5. The following transmission-related loss control measures represent actions that are currently being applied or investigated. In applying the measures, the aim is to minimise losses as far as possible in a way that balances capital investment, operational control and environmental impact.

The application of low-loss equipment

Transformers

7.6. The losses from transformer core steel have reduced significantly in the last 40 years, driven by improvements in steel alloys, processing and increasing loss capitalisation values. The loss capitalisation value, which is a calculation of capital investment against expected lifetime cost of losses, is now predominantly driving the lowest loss commonly available grade steel to be used. It is possible that market pressure will stimulate development and production of steels with losses up to 10% lower than this in the next few years.

7.7. Variable (load) losses are greatly influenced by the capitalisation value, and would therefore decrease if higher capitalisation values were used. Exceptions to this are the largest transformers (eg 1100MVA interbus transformers and Quad Boosters) that are constrained by allowable transport weights. Replacing large transmission transformers early is not typically economically feasible before the end of normal asset life.

Conductors

7.8. Specifying conductor replacement involves replacing old or low rated conductors with larger diameter conductors, which is principally driven by the need to increase transmission capacity, but also reduces line resistance and associated losses. For the same material, a smaller diameter conductor will have a higher resistance and hence, greater losses.

7.9. Transmission owner non-load related conductor replacement schemes will in general employ All Aluminium Alloy Conductor (AAAC), which was developed in the late 1980s. The transmission owners specify a lower DC resistance than the British standard to reduce system losses. DC resistance reductions are optimised while not compromising the mechanical strength of the alloy.

7.10. The AAAC alloy was developed solely to reduce transmission losses and is designated as an extra high conductivity (EHC) alloy conductor. This is the conductor type of choice for all non-load related schemes as it is relatively inexpensive, robust, easy to install and maintain.

7.11. If a significant increase in capacity is required (load-related schemes) high temperature, low sag conductor systems such as GAP and the composite core conductors, ACCC (Aluminium Conductor Carbon Core) and ACCR (Aluminium Conductor Composite Reinforced) have been developed. These conductors can double the capacity of existing circuits, but this also increases losses accordingly if the circuit utilisation is increased.

Cables

7.12. In general, transmission requirements are for cable systems with high current ratings. This will reduce losses to enable higher current ratings. For example, the requirement for increased current ratings may lead to the introduction of larger cross-sectional cables than the 2500mm² currently used. As these have a lower resistance, they will produce lower losses per MW of active power transmitted. However increases in power transfer requirement usually lead to a corresponding increase in utilisation which will also tend to increase the variable losses of a cable system. The lifetime losses are typically less than 10% of the capital cost of the cable system. The requirement to maximise current ratings and minimise capital costs of a cable system require that the losses are reduced to the optimum level.

Transmission development and reinforcement

Upgrade in voltage level

7.13. By upgrading 275kV circuits to 400kV the circuit losses may be reduced by 20% to 40% depending on loading. A joint research project between the University of Manchester, EPL Composite Solutions, SSE and National Grid has developed a new composite cross-arm design to make the overhead line part of the upgrade potentially easier and more cost-efficient.

New circuits

7.14. Load-related works that require additional circuits will potentially have a beneficial effect on losses by reducing circuit loading and therefore losses.

De-energising or removing unnecessary equipment

7.15. If equipment is found to be unnecessary and it is removed it could lead to a reduction in losses. The recently completed disconnection of Inverkip 400kV substation from the network which included the disconnection of 80 circuit-km of overhead line is estimated to have provided an annual reduction in losses of at least 2 – 3GWh.

Alternatives to network reinforcement

Demand side management

7.16. Demand side management has significant potential benefit in reducing network peak. However, it is not fully within the control of the transmission owners. Research projects completed in this area have shown positive results in reducing peak demand and hence a losses benefit. Managing demand in this way will be of interest to the system operator and supply businesses. It is as yet unclear if this can be managed from a network operator perspective or must be supplier-led.

Time of use tariffs

7.17. Smart meters will allow time-of-use tariffs to be implemented at a half-hourly level. This is a significant opportunity to reduce peak demand at different times across varying locations, and hence reduce network losses. However this is an area which will likely be supplier-driven, meaning that there could be a conflict between the interests of the various system actors.

Energy storage

7.18. SHET has completed extensive energy storage projects, and modelling energy storage purely for losses mitigation. Through this work, it has gained a very good understanding of the potential benefits. The CBA work completed from a losses perspective proved that it is not cost-effective to implement storage to reduce losses alone. Losses will however be considered in more detail when making a justification for energy storage.

Technology use

7.19. The use and effect of technology, both new and existing, will be evaluated for applying on the transmission network to look for opportunities to improve network performance in a cost-effective and reliable way.

Explanation of status of losses tables

7.20. To demonstrate the impact that transmission developments will have on losses, an assessment has been made by the transmission operators using winter peak analysis and reported in appendix 2. As the analysis is scenario-based and operating conditions can vary significantly, the suggested losses effects should be taken as indicative only and subject to variation.

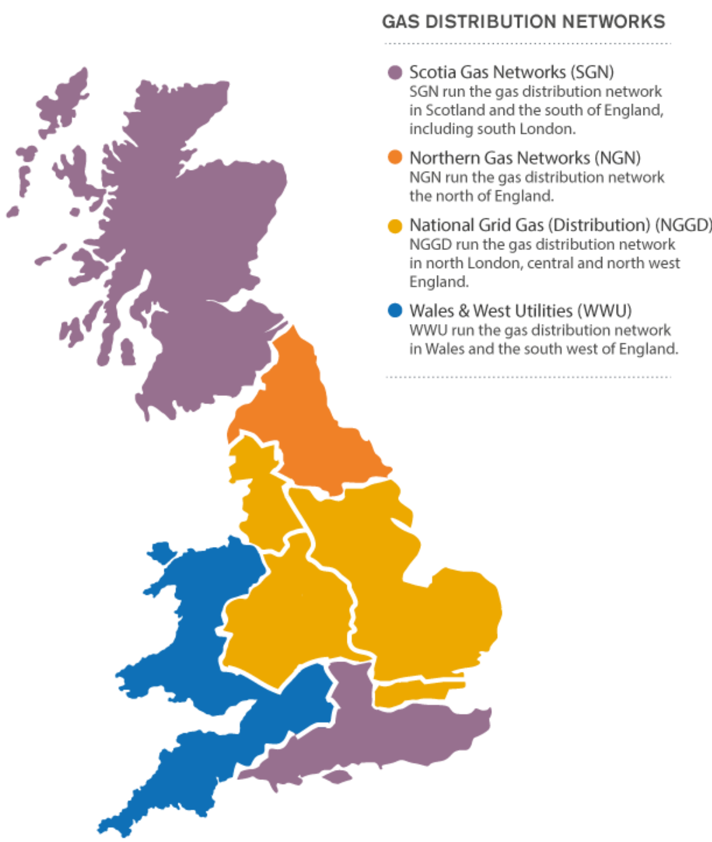
8. Gas networks

Background on shrinkage

Gas Distribution

8.1. The GB gas infrastructure[24] transports gas to approximately 21.5 million gas customers,[25] through 282,000km of pipes. The GB gas infrastructure is among the oldest in the world, and recent figures show that gas meets over 50% of GB energy demand. Four GDNs operate eight different networks in GB (Figure 7).

Figure 7: Who operates GB's gas distribution networks?[26]



[24] There is more information on GB Energy Networks on the Energy Networks Association website: http://www.energynetworks.org/modx/assets/files/news/publications/GTTN/GTTN%202013_Website%20version.pdf

[25] This figure refers to supply points and is here: https://www.gov.uk/government/statistical-data-sets/gas-sales-and-numbers-of-customers-by-region-and-local-authority#history

[26] https://www.ofgem.gov.uk/network-regulation-riio-model/energy-network-how-it-works-you

8.2. The Gas Act 1986 requires gas transporters to "develop and maintain an efficient and economical pipeline system for the conveyance of gas"[27] and the Pipeline Safety Regulations 1996 require network operators to ensure that pipelines are "maintained in an efficient state, in efficient working order and in good repair".[28]

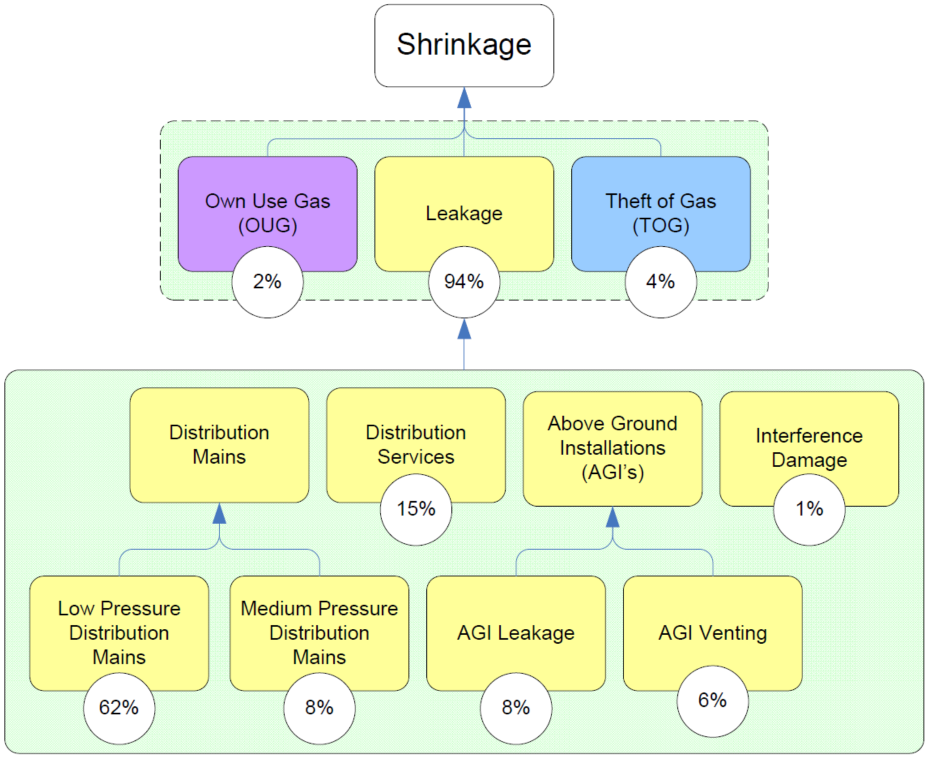
8.3. GDN shrinkage represents the difference in volume (in GWh/energy) between the gas entering the GDN systems and the total volume of gas used by customers. If this volume of gas is not quantified it would not be possible to make a true evaluation of the volume actually transported through the networks on behalf of Gas Shippers. It is the dominant element of the GDNs' Business Carbon Footprint (BCF) and accounts for around 1% of GB's greenhouse gas emissions. The three elements of shrinkage are:

- **Leakage (94% of shrinkage)** – forms by far the largest element of shrinkage and relates to un-combusted gas emissions to the environment from GDN pipelines. Emissions can be split into three groups: those from distribution mains, distribution services and above-ground installations.
- **Theft of gas (4% of shrinkage)** – includes situations where, for whatever reason, end users are unaccounted for and are using unrecorded gas.
- **Own use gas (2% of shrinkage)** – gas used in running the network, such as gas used for preheating at pressure reduction stations.

[27] The Gas Act 1986, s.9(10(a)

[28] The Pipeline Safety Regulations 1996, reg. 13

Figure 8 – Percentage components of shrinkage, average of GDNs' 2013-14 Regulatory Reporting Packs (RRP)



Gas Transmission

8.4. In GB, gas can enter the National Transmission System (NTS) through beach reception terminals, LNG import terminals, interconnectors or storage (gas that has previously been extracted and is now held in storage). Gas exits the NTS to supply power stations, large industrial customers, storage sites and the Distribution Networks. NGGT is the sole owner and operator of the gas transmission system in GB.

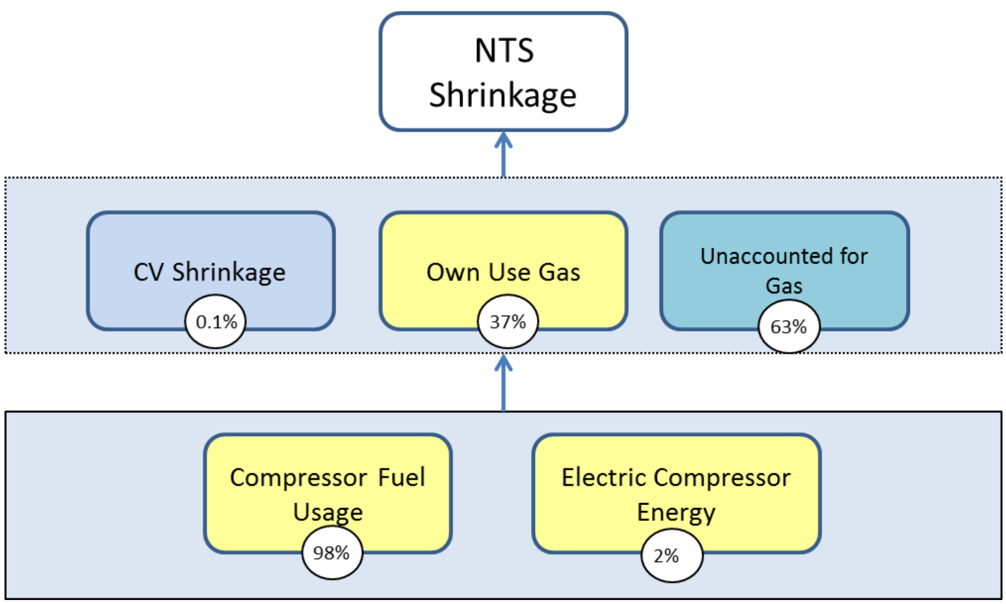
8.5. NTS shrinkage covers the gas and electrical energy which is used in operating NTS compressors, and the gas that cannot be accounted for and billed in the measurement and allocation process. Section N of the Uniform Network Code (UNC) – Transportation Principal Document, provides further details on how shrinkage is determined, assessed and notified to users.

8.6. NTS shrinkage is broken down in to three categories:

- **Own Use Gas (OUG)** – the main component of this is compressor fuel usage (CFU), which is the energy used to run gas compressors to transport gas through the NTS. There are currently 24 gas compressor sites within the NTS, each containing a number of separate units. The compressor fleet is primarily used to support four key functions:

  - ensure that gas is transported efficiently around the network based on the physical supply and demand pattern
  - provide system flexibility in meeting rapidly-changing use and conditions
  - meet agreed pressure obligations to NTS customers
  - facilitate maintenance.
- **Calorific Value (CV) shrinkage** – CV shrinkage is the energy difference between delivered and billed energy of a charging zone as a consequence of applying the Flow Weighted Average Calorific Value process, in accordance with the Gas (Calculation of Thermal Energy) Regulations 1996 (amended in 1997).
- **Unaccounted for Gas (UAG)** – UAG is the quantity of gas which remains after taking into account all measured inputs and outputs from the system, Own Use Gas (OUG), CV shrinkage and the daily change in NTS linepack. UAG is primarily a measure of the cumulative uncertainty of all individual instruments connected to the system.

Figure 9 – Percentage components of NTS shrinkage, based on 2013-14 RRP



Approach to gas networks assessment

8.7. To assess the energy efficiency potential of the gas networks, we have focused primarily on shrinkage. As shrinkage is the term used for gas both lost and used in the operation of the networks, it is a good proxy for the energy efficiency of the transmission and distribution of gas in GB. In our assessment, we decided to focus on examining the optimal balance between the costs associated with investing in measures to detect and reduce shrinkage, and the benefits through energy savings of such investments.

8.8. However, in addition to shrinkage, the GDNs have also included information on other measures that have an impact on energy efficiency more widely, for example new connections to the gas network being carried out through the Fuel Poor Scheme. We have included these other measures because, through these initiatives, the gas network is an enabler that could allow the overall energy network to become more efficient through reduced customer need for energy. We have also provided details of the GDN's Business Carbon Footprint (BCF) excluding shrinkage. Although shrinkage is by far the largest component of the overall BCF of each network, in our RIIO-GD1 price control we introduced a requirement on GDNs to report on their CO2 equivalent emissions for company transport and energy consumption. We have included BCF information because actions taken to reduce BCF could also help the companies run their networks more efficiently (eg through reduced energy consumption).

8.9. In 2013-14, NGGT's overall shrinkage volume was 4,226.8 GWh of which the majority was due to unallocated gas. Across all of the GDNs, the level of shrinkage in 2013/14 was forecasted to be 3103GWh and the GDNs have a commitment to reduce this to 2561GWh by 2020/21. The GDNs are currently on target to meet this commitment.

8.10. The network companies are currently developing a wide range of innovation projects that will result in network benefits. A list of projects which could have an impact on energy efficiency is provided in Appendix 4.

9. Gas networks today

9.1. The first RIIO price control for gas distribution networks (RIIO-GD1) and for transmission networks (RIIO-T1) came into effect on 1 April 2013.

Gas Distribution

9.2. GDN performance baselines have been set for both overall shrinkage and, separately, leakage. These baselines set out the reductions that GDNs are expected to deliver over the price control period, based on the outputs that we have set. The GDNs are incentivised and can be financially rewarded or penalised depending on their position relative to their baselines. The GDNs' baselines are based on factors including:

- The forecast of:
  - the length of live mains in a network, over the price control period, by diameter and material
  - the number of services in a network over the price control period
  - the number of above-ground installations in a network over the price control period
  - replacement activity.
- The Shrinkage Model[29] assumptions of:
  - the percentage split between metallic and plastic service pipes
  - Mono-ethylene glycol (MEG) saturation
  - the impact of replacement activity
  - average system pressure (ASP)
  - mains, services and AGI leakage rates.

9.3. GDNs have output commitments in place to reduce shrinkage and leakage from their networks by 15% -20% over the price control period (dependent on each company). The level of shrinkage in 2013/14 was forecasted to be 3103GWh and the GDNs have a commitment to reduce this to 2561GWh by 2020-21. The GDNs are currently on target to meet this commitment.

[29] The Shrinkage Model is used to estimate the level of gas lost in the operation of the network. It factors in pipe material, diameter, operating pressure, gas conditioning, service leakage, AGI leakage. This is used to complete GDNs' annual reporting requirements. Theft of gas and Own Use Gas are derived from fixed factors.

9.4. Under the UNC, GDNs are responsible for purchasing gas to replace that lost through shrinkage. An efficient level of funding has been set out in RIIO-GD1, which can be recovered through gas transportation charges. This provides the GDNs with an incentive to control shrinkage from their networks to avoid having to purchase more gas than they have been funded for. GDNs will also be able to keep a share of any efficiency savings for the remainder of RIIO-GD1.

9.5. Releasing uncombusted gas has additional environmental impacts. To target this area of shrinkage, an additional output incentive has been introduced for RIIO-GD1. The Environmental Emissions Incentive (EEI) uses the social cost of carbon set by the Department of Energy and Climate Change (DECC) to form an incentive unit value. The GDNs are then rewarded or penalised for improvements or deteriorations in leakage performance.

9.6. For the RIIO-GD1 price control, Ofgem has also introduced a rolling incentive mechanism which provides eight years of benefit or penalty for the GDNs, irrespective of the timing of investments and delivering enduring reductions during the price control period.[30]

9.7. In addition to the outputs above, the GDNs are also required to report on:

- BCF emissions (excluding shrinkage)
- connections
- fuel poor connections
- biomethane connections.

9.8. These activities may potentially affect the energy efficiency of the gas distribution network and are discussed in detail in the following sections of the report.

Gas Transmission

9.9. Under RIIO-T1, NGGT has financial and reputational System Operator incentives on the level and cost profile of shrinkage gas. Special Condition 3D, Part B(i) of the NTS Gas Transporter Licence obliges NGGT to establish and publish an annual NTS Shrinkage Incentive Methodology Statement detailing the rules used for determining forward levels of gas and electricity volume targets, cost reference prices and the method used to assess efficiency levels for CV and Compressor Fuel

[30] The rolling incentive is a means by which GDN's will receive either a penalty or a benefit for 8 years based on performance relative to the baseline. Ofgem determine the leakage & shrinkage baselines, based on a wide range of information submitted by the GDN's and previous reported performance. Further information can be found here: Section 2.23 - https://www.ofgem.gov.uk/ofgem-publications/48155/2riiogd1fpoutputsincentivesdec12.pdf

Usage (CFU) against outturn volumes. A copy of the Shrinkage Incentive Methodology Statement for the current year is available on National Grid's website.[31]

9.10. The statement is reviewed, updated and published annually. Shrinkage procurement and energy efficiency assessments are analysed against the statement. NGGT baseline calculations are then independently audited to ensure they comply with the rules in the statement.

9.11. The shrinkage incentive incorporates an assessment of energy efficiency performance for each year. This encourages continuous improvement in line with the methodology statement, where assessments are done to reward or penalise NGGT against the effectiveness of its shrinkage management activities.

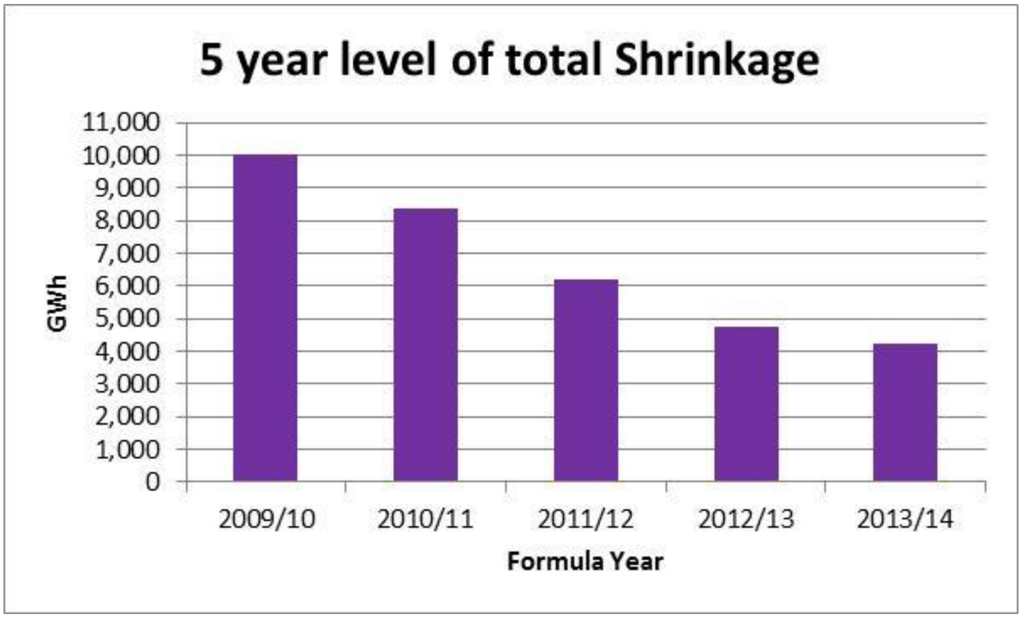
9.12. Under Special Condition 3D.23, NGGT must review of the NTS Shrinkage Incentive Methodology Statement before any modifications from April 2017. NGGT expects to start this in 2015.

9.13. Figure 9 below shows the last five years of shrinkage volumes on the NTS. This shows an overall reduction in 2013-14 of over 40% from 2009-10 levels. We can attribute this mainly to the work done by NGGT and meter asset owners to address meter asset issues, which were contributing to higher levels of UAG. In addition, the CFU has reduced because of changes to underlying supply patterns, installing new, more energy-efficient compressor units and enhancements to operational planning processes on fleet management and system configuration.

9.14. It should be noted that a significant amount of the reduction below can be attributed to a reduction in UAG. Improvements in UAG shrinkage are generally due to more accurate billing of gas usage and therefore, improvements in performance under these areas will not increase the energy efficiency of gas transmission infrastructure.

[31] http://www2.nationalgrid.com/WorkArea/DownloadAsset.aspx?id=34181

Figure 10 – Total NTS shrinkage level for last five formula years



10. Barriers, enablers and uncertainties

Barriers and enablers

10.1. Government needs to balance security of supply, sustainability and affordability. To achieve this, it will determine the appetite to tackle energy efficiency challenges. It will also influence certain aspects of the system more directly such as the connection of new gas sources, including biomethane, to the gas network through mechanisms such as the Renewable Heat Incentive (RHI).

10.2. Government direction on the balance between sustainability and affordability will then affect Ofgem in setting the regulatory framework that network companies will work within. The framework will determine the cost-effective balance/cost-benefit threshold for delivering environmental outputs and factors such as funding, incentives and innovation mechanisms.

10.3. Government and Ofgem’s regulatory policies will also drive consumer behaviour and their energy efficiency. This will ultimately limit energy networks’ ability to improve their own energy efficiency. An example of where government policy has resulted in a significant step change in consumer energy efficiency behaviour is the mandating of condensing boilers.

Uncertainties

10.4. Each year NGGT publishes its Future Energy Scenarios (FES)[32] which analyses plausible and credible conclusions for the future of energy. The scenarios flex the two variables of affordability and sustainability, giving the following four scenarios:

- Gone Green
- Slow Progression
- No Progression
- Low Carbon Life

10.5. NGGT’s 2014 FES outline the level of uncertainty expected around future gas supplies, in particular around shale gas. Shale gas will potentially be a significant new source, but, even between the two lowest carbon scenarios, the volumes differ from none under the ‘No Progression’ scenario to 32 bcm/year in the early 2030s in the ‘Low Carbon Life’ scenario.

10.6. As a result, NGGT’s network needs the capability to manage a wide range of potential supply patterns. Which pattern may occur on a given gas day is

[32] The 2014 UK Future Energy Scenarios can be found at: www.nationalgrid.com/feswww.nationalgrid.com/fes

increasingly uncertain and could increase further. The variation between the two scenarios above highlights one of the many factors that directly affect NGGT's use of compression (there is more information in the 2014 Gas 10 Year Statement[33]). These challenges make it difficult to predict compressor usage going forward and to set year-on-year targets for improvements in CFU levels.

[33] The 2014 Gas Ten Year Statement can be found at: www.nationalgrid.com/gtyswww.nationalgrid.com/gtys

11. Gas network concrete measures

Gas Distribution

11.1. Each concrete measure for the GDNs represents the activity of all networks aggregated. The benefits have been calculated using 2015-16 as the starting year. We present the following data against the measures where appropriate:

- **£m benefit** – the monetary value shown is a product of the MWh saved and the value that we have set for deferred energy (DECC's short term carbon values)
- **MWh saved** – this is the forecast of the total energy saved by all of the GDNs on a year-on-year basis.[34]

Shrinkage measures

11.2. GDNs have RIIO-GD1 output commitments against three primary outputs: shrinkage, leakage and fuel poor connections.

11.3. The GDNs have two incentives to minimise gas transportation losses over and above the baseline reductions captured in the price control:

- **Shrinkage Incentive** – incentivises the reduction in volume of gas lost from the network. Licensees receive an allowance to replace gas lost through shrinkage. If licensees need to replace less gas than they have received an allowance for, they share the savings with customers. If they need to spend more than the allowance, then they share any cost over runs with customers.
- **Environmental Emissions Incentive (EEI)** – provides an incentive to manage the leakage element of shrinkage. If the reported level of leakage is below the forecast level, the EEI allows GDNs to capture the environmental benefit associated with the reduction in carbon emissions, at the level of DECC's traded cost of carbon. Likewise, if the volume of leakage is higher than forecast, GDNs incur the associated environmental cost.

11.4. Both these mechanisms provide the GDNs with incentives to reduce the levels of gas lost from the networks. The reward or penalty applied is equal to the non-traded carbon price in the case of the EEI and a reference gas commodity price in relation to the shrinkage efficiency incentive. Baselines for both these incentives were established and agreed through the settlement of the RIIO-GD1 price control, and GDN performance is measured against these baselines with rewards for out-performance or penalties for under-performance.

[34] The data for these tables was supplied by the GDNs individually and collated.

Leakage

11.5. The GDNs are doing works to reduce leakage from their networks:

- **Replacing metallic mains and services** – over the RIIO-GD1 period, the GDNs plan to replace a significant proportion of the remaining low pressure metallic mains and services on their network. The metallic mains are being replaced with polyethylene (PE) pipes with electrofused joints. PE leakage rates are dramatically lower than metallic mains, hence replacing metallic main significantly affects the leakage of a network. Mains and services replacement accounts for over 90% of the total reduction in leakage per annum. The iron mains risk reduction programme includes the flexibility to select pipes for replacement based on criteria that provide additional customer benefits in financial value and asset performance, but also environmental benefits in terms of leakage reduction.
- **Gas conditioning** – liquid fogging agents injected into networks at strategic locations conditions the joints on ferrous mains. This swells the lead/yarn joints and restricts the leak path. Used appropriately, this method can reduce the rate of leakage from cast iron pipes by 4% relative to what it otherwise would have been. The cost benefit case for gas conditioning is based on the overall leakage reduction (measured with the Leakage/Shrinkage model) compared to the ongoing cost of carrying out the conditioning and sampling. As the length of metallic mains within a network reduces through the replacement programme the number of networks where gas conditioning continues to be cost effective will drop.
- **Average system pressure control** – reducing average system pressure to reduce the amount of gas leakage while ensuring a reliable system that meets all demand conditions, including peak winter conditions, is a major objective. Much of the UK gas distribution network is under intelligent pressure control which minimises network pressures and thus leakage. There is a programme to install new pressure control systems for further leakage reduction. There is also an allowance provided in RIIO-GD1 to maintain the existing systems to avoid an increase in pressures which would directly increase leakage.
- **Network reinforcement** – reinforcements are planned where growth in demand is forecast to avoid raising pressures and associated leakage rates. Strategic network reinforcements (non-growth-related) are also identified and justified on their ability to achieve further reductions in system pressure and deliver additional reductions in leakage and improvements in asset and network performance.

11.6. The table below shows the benefits over the rest of the RIIO-GD1 period of some of the leakage measures.[35] The benefits presented below have been calculated using 2015-16 as the starting year and are based on the investment for each individual year. For the purposes of this report the MWh saved are not cumulative.

[35] The benefits of the gas distribution measures were calculated using leakage figures in 2009-10 prices (based on the figures in the Transportation licence) and using carbon emissions figures in 2014 real prices (based on DECC's short term carbon values).

Table 8 – Gas distribution concrete measures – leakage

		15-16	16-17	17-18	18-19	19-20	20-21
Mains replacement	£m benefit	2.27	7.00	11.92	16.79	21.76	26.84
	MWh saved	64,676	66,776	64,153	63,593	63,079	62,459
Services relaid and transferred[36]	£m benefit	0.65	1.98	3.32	4.61	5.89	7.17
	MWh saved	18,424	18,524	17,147	16,607	16,021	15,541

Shrinkage (excluding leakage)

11.7. **Own Use Gas (OUG)** – This is currently measured as a percentage of annual through-put with no direct reduction commitment. The majority of the GDNs' OUG is linked to the requirement to pre-heat gas entering their systems from the NTS (pre-heating is needed to manage pressure issues). The GDNs' preheating requirements are currently delivered via ageing water bath heaters or more modern boiler package technologies. However, there are several key issues that GDNs currently face when appraising options for preheating technologies:

- the whole-life costs and, in particular, the carbon impact of currently available technologies is not understood; and
- there has been little research and development in this area resulting in limited financially viable alternatives to existing technologies.

11.8. Ofgem awarded funding for a Network Innovation Competition project to investigate the options for modernising gas preheaters in a low carbon environment (more information on this project is in the innovation section below).

11.9. **Theft of Gas** –GDNs recognise the potential for customers to be taking unmetered gas from their networks and have set up dedicated teams within their businesses to address the issue. They have been active in developing the Theft of Gas Code of Practice managed by the Supply Point Administration Agreement and have developed guidance for industry parties on how to approach theft of gas investigations.

11.10. These efforts have been focused on ensuring robust processes are in place to resolve cases of illegally taken gas (through physical tampering upstream of the ECV or through lack of supply contract), substantially reducing the number of outstanding shipperless and unregistered sites as well as implementing measures to prevent new shipperless/unregistered site creation.

11.11. In addressing the outstanding workload of shipperless/unregistered sites, GDNs implemented a project led by Xoserve[37] which during 2014 sent letters and

[36] A service transfer is where an existing service is transferred on to a newly laid main. A service relay is when a new service is laid from the new main to the customers meter.
[37] Xoserve is jointly owned by the five major gas distribution Network companies and National Grid's gas transmission business. It delivers transportation transactional services on behalf of all the major gas Network transportation companies and provides one consistent service point for the gas Shipper

then started visiting sites, and visited almost 23,000 nationally. When GDNs reported back to Ofgem in October 2014, 38% of these sites had been cleared either through data cleansing or supplier registration and work is still on-going.

11.12. In order to reduce the number of newly created shipperless/unregistered sites several measures have been implemented by GDNs and industry including Uniform Network Code and Meter Asset Manager Code of Practice (MAMCoP) modifications, amended industry processes and enhanced customer communications. All of these measure combined should greatly reduce the likelihood of new sites taking gas without a supply contract.

Activities with wider energy efficiency impacts

11.13. In addition to shrinkage we have also included information on other measures that have an impact on energy efficiency more widely, for example new connections to the gas network being carried out through the fuel poor network extensions. We have included these other measures because, through these initiatives, the gas network is an enabler that could allow the overall energy network to become more efficient through reduced customer need for energy.

Fuel poor network extension scheme

11.14. GDNs continue to support alleviating fuel poverty, where gas is the most efficient heating source. The gas network is an enabler that potentially allows the overall energy network to become more efficient through reduced customer need for energy.

11.15. According to research undertaken by Citizens Advice, there were around 4 million households without gas for heating across England, Scotland and Wales in 2008. Of this, over 0.5 million had gas in their property but were not using it for heating, over 1.3 million were identified as being within close proximity of the gas network and 2 million were fully off-grid. Extending the gas network is currently, in many scenarios, the most energy-efficient, and secure, domestic heating solution. Customers connected to the gas distribution networks under the fuel poor network extension scheme may previously have been using a more inefficient and expensive source of energy to heat their homes and cook with, so this scheme gives them an opportunity to reduce their carbon footprint as well as their energy bill.

11.16. During RIIO-GD1, the GDNs' innovative approaches will continue to deliver, low cost gas connections to vulnerable customer groups in the following ways:

- **One-off Connections**: when customers apply for a connection, GDNs identify those who are eligible for the Fuel Poor allowance (in an eligible IMD area), which helps this vulnerable customer group get gas connections. The funding is capped at the standard net present value (NPV) of transportation revenues

companies. http://www.xoserve.com/index.php/xoserve-film/

for an individual domestic connection with the customer required to pay any additional amounts.

- **Network Extensions**: working with a number of stakeholders, including local authorities, housing associations and community groups, to identify off-network mains extension schemes to qualifying communities.

11.17. Since the introduction of the Fuel Poor scheme in 2009 there have been 58,000 customers connected to gas across the UK. Over the RIIO-GD1 period GDNs have a target of 77,450 connections (in 2013-14 performance was 15,612 connections). The table below shows projected benefits over the RIIO-GD1 period.[38]

Table 9 – Gas distribution concrete measures – fuel poor connections

		15-16	16-17	17-18	18-19	19-20	20-21
Fuel poor connections	£m benefit	0.07	0.20	0.35	0.51	0.68	0.85
	MWh saved	0	0	0	0	0	0

Connecting new sources of gas

11.18. Increasing quantities of renewable gas from anaerobic digestion (biomethane) and thermal gasification (bioSNG) will efficiently facilitate continued use of gas for heating while helping to meet the 2050 greenhouse gas reduction targets.

11.19. The GDNs are playing roles in projects to inject biomethane in to the grid. Although they do not currently have an output commitment on the number and capacity of biomethane connections to their networks during RIIO-GD1, they have set a target to connect approximately 180 projects by 2021. To date, the GDNs have connected four projects supplying gas to heat over 10,000 homes on an average day (as set out in the table below). These projects are all different, and include examples of each type of anaerobic digestion feedstock: food waste, human waste and break crops. GDNs anticipate connecting higher numbers of new sources of gas during the remainder of RIIO-GD1.

11.20. The process for scoping suitable sites and obtaining the necessary permits is very resource-intensive. It is therefore critical to plan well before starting any construction works. We anticipate this work has now been completed for a significant number of sites, and this should result in more connections throughout the remainder of RIIO-GD1.

11.21. The number of connections is customer driven, however the rate of connection has increased since the 2013-14 RRP, and is expected to increase further.

[38] The benefits have been calculated using carbon emissions figures in 2014 real prices (based on DECC's short term carbon values)

Table 10 – Connecting new sources of gas

	Pre RIIO-GD1	2013-14 RRP (within year)	Total to date	RIIO GD1 Target
Number of Plant Connected	2	2	4	178

11.22. During RIIO-GD1, GDNs will monitor and report on the number of biomethane connections / capacity connected. GDNs forecast of future total capacity associated with biomethane entry connections was consistent with the central forecast from the Committee of Climate Change. The GDNs’ forecast suggested that government policy and incentives would stimulate a target of 7TWh/annum of biomethane injection by 2020 and GDNs will monitor this as a leading indicator of renewable gas connections.

11.23. Alongside these targets to facilitate biomethane connections to the networks, GDNs are also actively supporting the connection of other sources of gas, including bioSNG via the Network Innovation Competition (NIC) and hydrogen. There is NIC funded project being carried out in the Scottish town of Oban. This project is attempting to demonstrate the viability of utilising a wider range of gas sources safely and effectively in the networks.

Business carbon footprint (excluding shrinkage)

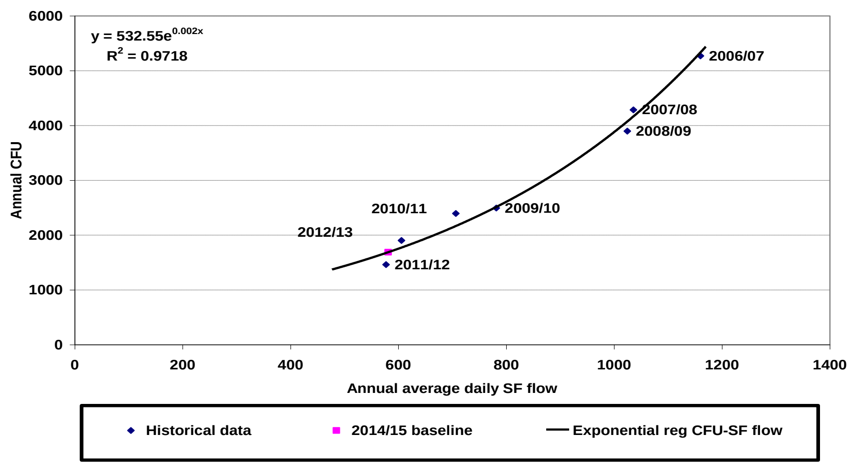
11.24. Although shrinkage volumes continue to dominate GDNs’ BCF, they will also focus on other areas of carbon emissions. The RIIO-GD1 Regulatory Framework introduced a requirement on GDNs to report annually on their carbon dioxide (CO2) equivalent emissions, using a standard framework for reporting BCF (excluding shrinkage). Two main areas of focus for BCF are company transport (scope 1) and energy consumption (scope 2).

11.25. Scope 1 emissions relate to company transport and are measured on business mileage claims for company cars and litres of fuel consumed for commercial vehicles. The majority of GDNs’ transport emissions are generated from their commercial fleet vehicles and, as such, GDNs are working to invest in more sustainable fleets that will reduce their impact on the environment. More specifically, GDNs are investigating the opportunity to participate in a Compressed Natural Gas (CNG) trial in order to explore the opportunities and environmental benefits that a wider adoption of CNG vehicles could deliver in the short and longer term. GDNs also operate a number of company cars. GDNs have introduced incentives to company car drivers who select the greenest of cars. They intend to continue with these ‘green’ incentives.

Gas Transmission

11.26. NGGT is required to meet specific measures for CFU. The level of CFU procured for an incentive year is based on its Shrinkage Methodology Statement. Under the methodology, the level is determined based on forecast flows at the St Fergus terminal against a best fit curve on actual levels of CFU since 2006-07. Figure 11 shows the current curve used to determine the 2014-15 CFU levels:

Figure 11 – Graph showing how the best fit level is determined and CFU levels



11.27. At the end of the year, the actual flow level is used to determine the associated efficient CFU level and the actual CFU is then assessed against this level. The outturn data is then added to the model to create a new best fit curve for future efficiency to be measured against. This model ensures that NGGT is penalised or rewarded against the determined efficiency criteria.

11.28. The actual levels of OUG and electricity compressor energy over the last five formula years are also shown in Figures 12 and 13. It should be noted that, although electric units were in use in 2009-10 and 2010-11, the levels were very low and do not show up clearly in Figure 13.

Figure 12 – Own use gas level for the last five formula years

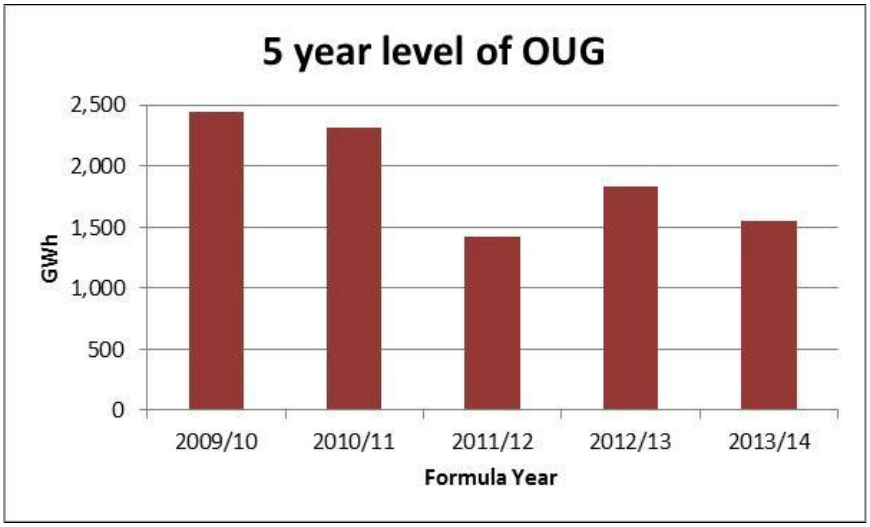
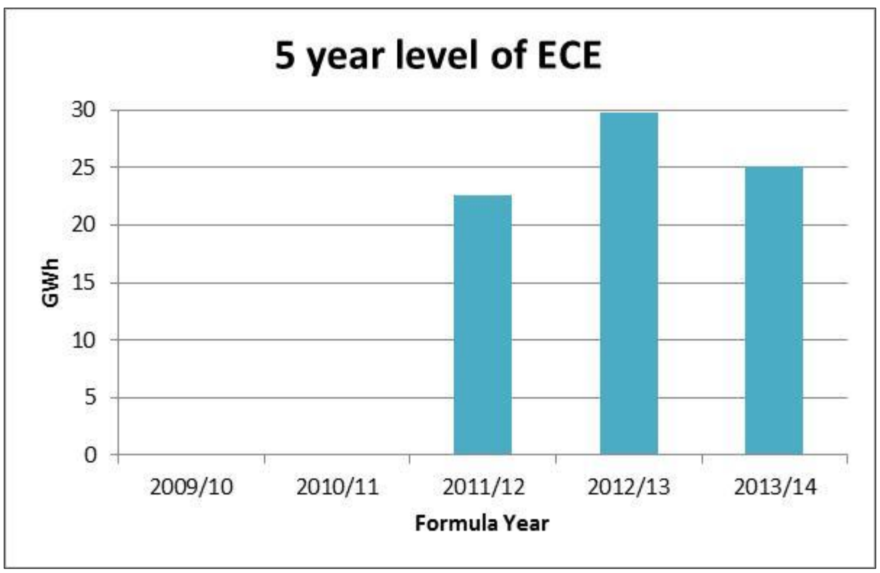


Figure 13 – Electricity compressor energy level for last five formula years



Industrial Emissions Directive

11.29. The largest area of energy consumption on the transmission system is through CFU from the operation of compressor fleet. The Industrial Emission Directive (IED) requires all impacted units to comply with Emissions Limit Values or be placed on limited lifetime derogation. All units that are required to be replaced will then need to comply with a Best Available Technology assessment to reduce their impact on the environment as a whole.

11.30. Under RIIO-T1 funding was provided under the Integrated Pollution Prevention and Control (IPPC) for replacing units at Peterborough and Huntingdon under phase 3. The new electric units installed at St Fergus, Hatton and Kirriemuir under phases 1 and 2 have been included in the baseline figures.

11.31. The table below shows the benefit seen from the installation of new gas turbine units under phase 3 from the planned commissioning date. The figures are based on assumed running hours under a central sensitivity from the Future Energy Scenarios making them uncertain and should only be used for illustrative purposes.

Table 11 – Gas transmission concrete measure – Industrial emissions directive

		15-16	16-17	17-18	18-19	19-20	20-21
IPPC phase 3	£m benefit	-	-	0.9	0.9	1.0	0.9
	MWh saved	0	0	70,285	70,285	80,093	71,334

Indirect electrical usage

11.32. NGGT will be making a targeted 5% reduction in electrical usage across above ground installations through asset health and energy improvement works. This table details the benefit from the 2014 baseline figures.

Table 12 – Gas transmission concrete measure – Electricity usage

		15-16	16-17	17-18	18-19	19-20	20-21
Electrical Usage	£m benefit	0.007	0.015	0.022	0.030	0.038	0.047
	MWh saved	247	494	741	988	1,235	1,482

12. Gas network potential measures

Gas distribution

12.1. There are several areas of potential energy efficiency improvements that the GDNs could look to introduce in the future. These include:

Infrastructure

- Development of new innovative ways to carry out maintenance and repair on existing infrastructure (Core and Vac Innovation Project, Robotics Innovation Project) (see Appendix 4 for details).

Low pressure distribution mains

- Completing the Health and Safety Executive (HSE) mains replacement programme, and then remediation of metallic mains outside of the HSE mains replacement programme
- Investigating the potential for internal joint repairs (CISBOT Innovation Project) (see Appendix 4 for details)
- Optimising average system pressure
- Design, development, manufacture, installation and commissioning of equipment to Improve MEG saturation (TouchSpray MEG Fogging System Innovation Project)

Medium pressure distribution mains

- Completing the HSE mains replacement programme
- Remediation of metallic mains outside of the HSE mains replacement programme
- Understanding the impact of pressure on Medium Pressure Mains (MP) leakage rates, capturing within the National Shrinkage model and then optimising average system pressure (Innovation Project).

Distribution services

- Replacing metallic services (Serviflex, PE Risers)

Above ground installations (AGIs)

- Understand venting and leakage rates from AGIs so reduction can be targeted (Innovation Project)
- Replacing AGI control systems with equipment that reduces venting
- Remediation of leaking AGIs

Own use gas

- Developing more efficient gas pre-heating systems (Immersion Tube Preheating Innovation Project)
- Introducing of metering OUG

Mains replacement

12.2. Replacing ageing metallic pipes continues to be the biggest contributor to reducing energy losses through the gas distribution network, totalling over 90% of the total reduction in emissions each year. By 2021, the iron mains replacement programme will be two thirds complete but there is every indication that continuing with an equivalent replacement programme will see similar levels of environmental benefit year-on-year compared to the current programme (Table 13). This is also true for the steel pipe population which continues to deteriorate at a similar rate to current replacement levels. Replacement techniques focus on lining with polyethylene pipe which demonstrates a level of emissions over 20 times less than an average metallic pipe.

Table 13 – Potential leakage reduction through continued mains replacement[39]

	21-22	22-23	23-24	24-25	25-26	26-27	27-28	28-29	29-30	30-31	31-32
Leakage (GWh)	2527.4	2411.6	2296.8	2182.1	2066.3	1951.5	1836.7	1720.9	1606.1	1491.3	1375.5
Year on Year Reduction	114.8	114.8	114.8	114.8	114.8	114.8	114.8	114.8	114.8	114.8	114.8

Further development of the shrinkage model

12.3. To make the model's assumptions and estimations more intelligent, and build upon the work already being done by the Shrinkage Forum, there are several things the GDNs are doing through the innovation mechanisms and others as possible improvements to the model.

12.4. Changes to the model will not impact real time gas leakage. The model is a method to estimate leakage based on asset data, operating pressure and independently carried out leakage tests on all material types and diameters. However, developing the model will lead to better informed investment decisions to return the greatest benefit for the cost of leakage reduction projects, such as pressure management controls. Measures that could help improve the model include:

[39] This tables assumes 100% PE LP networks (Including mains >30m proximity); no gas conditioning; flat 50mbar operating pressure across all networks; no change in customer numbers or service info (which there would be in reality); and a flat profile of replacement works.

- Including a pressure-related MP calculation considering the relationship between pressure and leakage
- Embedding / accounting for mains remediation, as well as replacement, within model
- Using new equipment[40] to identify AGI leakage.

Investigating the use of smart meter data

12.5. The Shrinkage Forum is also exploring new sources of data for the model, including an assessment of whether smart meter data could be used within the model. Of the key data inputs required in the shrinkage model, it is estimated that two could potentially be influenced and improved using smart metering data.

Average System Pressure (ASP)

12.6. Smart metering could provide usage data that might help validate network analysis models, which are used to calculate ASP. Although current network analysis validation policy already requires a high level of accuracy, smart metering could help fine-tune the process, especially in small, specific areas of networks that are proving difficult to validate. To do this, there would be a requirement for statistical load research to investigate the relationship between individual customer usage obtained via smart meter readings and the 'assumed fully-diversified' peak six-minute demand required by the Network Analysis modelling process.

12.7. Smart metering may also provide the opportunity to improve the pressure management of those networks operating on clocked or drawn profiles, ie. not on intelligent profile control, more accurately assessing demand requirements, especially through off-peak periods. This could potentially allow pressure management regimes to be refined and pressures reduced during off-peak periods, both of which would result in lower ASP.

12.8. Currently, ASP is calculated using network analysis tools that assume a specified average demand across the year for all networks. Smart metering data will allow this figure to be tested and potentially allow for network specific average demand.

12.9. To fully explore some of these potential benefits, GDNs will consider the practicalities of setting up trials on specific networks to determine if smart metering data can impact on the ASP and the likely scale of any improvement. Any trial will be affected by the smart metering rollout programme and the availability of data in specific geographic areas.

[40] Including Differential Absorption LIDAR (portmanteau of light and radar)

Service Pipe Material Data Quality

12.10. Service pipe data is estimated using a combination of mains data and service pipe populations recorded during mains replacement activity. It may be possible during the smart meter rollout to update the service type information used in the shrinkage model. This would require the support of suppliers and GDNs will raise this issue as part of supplier engagement on rollout.

12.11. There is the potential that smart metering may reduce demand, most likely during off-peak periods, allowing GDNs to operate those networks fitted with clocked or drawn profiles at lower pressures thereby reducing ASP which will, in turn, reduce leakage. The behaviour of customers cannot be forecast with any certainty and this will only be understood once smart meters are installed in significant numbers, and several years' worth of data compared.

12.12. GDNs will also investigate the opportunity to develop an improved understanding of demand patterns, following the introduction of smart metering. Smart metering may also make it easier to identify theft downstream of the Emergency Control Valve, eg via zero meter reads. The measure of OUG is not likely to be impacted by smart metering.

Other BCF measures, including micro-generation

12.13. Network companies have assets that experience changes in pressure and flows of pressurised gas across them, which could be used to produce clean electricity or store electricity as gas.[41] They also have a large amount of ground and roof space which could be used for locating micro-generation equipment such as wind turbines and solar arrays. Some network companies are restricted in their ability to take such measures to use micro-generation because of conditions in their licence. Network companies could work with DECC and Ofgem to ascertain the appetite for installing renewable micro-generation equipment on and within their assets. As a starting point network companies could undertake a desktop activity now to ascertain the potential renewable generation capability of their ground and roof space.

Facilitating gas use for transport

12.14. GDNs will work with industry stakeholders on connecting private Compressed Natural Gas (CNG) refuelling infrastructure in GB. Natural gas vehicles have up to 28%[42] lower well-to-wheel greenhouse gas emissions, rising to 65% lower if the gas is biomethane, when compared to diesel vehicles.

12.15. The most plausible applications for CNG are for Heavy Goods Vehicles (HGVs) and fleet (buses etc.) vehicles. While HGVs only account for 1.5% (550,000 vehicles)

[41] Including Pressure to Gas http://www.smarternetworks.org/Project.aspx?ProjectID=1380
[42] http://gasrec.co.uk/biogas-transport-fuel-could-cut-hgv-emissions-by-65/

of road users, they account for 20% of road transport greenhouse gas emissions.[43] Therefore, if half of all HGVs were CNG, then transport greenhouse gas emissions would reduce by between 3% and 7%, depending on the source of gas.

12.16. The table below shows the benefits from potential future biomethane connections and the GDNs' BCF work.

Table 14 – Potential energy efficiency measures and benefits

		15-16	16-17	17-18	18-19	19-20	20-21
BCF – scope 1 and scope 2	£m benefit	0.005	0.013	0.021	0.029	0.043	0.057
	MWh saved	0	0	0	0	0	0
Bio-methane connections	£m benefit	0.65	2.01	3.49	5.091	6.81	8.65
	MWh saved	2,324,673	3,156,395	3,988,117	4,819,839	5,651,561	6,483,283

Gas Transmission

Industrial Emissions Directive

12.17. During 2015 NGGT will by agreeing the options and funding for each of the compressors impacted by the Large Combustion Plant Directive and for Phase 4 of IPPC with Ofgem. Until the funding is agreed it is not possible to provide measures for the potential benefit because it is not certain which units will be retained on derogations. The actual benefit is likely to fall in within the range and the ones quoted in the concrete measure for those that already have funding. The figures are based on the same central sensitivity from the Future Energy Scenarios and should only be used illustratively.

Medium Combustion Plant Directive

12.18. The European Commission is currently developing the Medium Combustion Plant Directive which will seek to apply limits on emissions to air on sites below 50MW thermal input. While the detail and implementation/target date of the directive are still being developed, based upon the most recent draft, we estimate that about a third of our compressor units (c26 units) will need to comply with the new legislation, through replacement, decommissioning or derogation if available. Similar to IED, this will provide opportunities for NGGT to consider energy efficiency measures as part of the programme of works. We will be able to provide further information on potential energy efficiency opportunities once the legislation has been agreed and applied.

[43] http://naei.defra.gov.uk/data/uk

12.19. Other areas for potential measures will be through innovation, which could be from either those projects detailed in previous sections of the report or from new projects set up through one of the innovation mechanisms. Successful projects would then be implemented into business as usual and could form the basis of future potential measures.

13. Overall Conclusions

13.1. This report has demonstrated how approaches to minimising losses or shrinkage are based on cost benefit analysis. Only measures that can efficiently reduce losses or shrinkage with a positive life cycle cost should be targeted.

Electricity

13.2. For electricity, losses reduction will be achieved predominantly by using low loss transformers and installing larger conductors than needed to provide the energy. Typically this will be done when the assets have reached the end of their lives and a replacement is imminent or when new connections are being made and reinforcement is needed.

13.3. Electricity networks can be reconfigured to optimise network load flows. Where capital expenditure is required to enable reconfiguration, an assessment of cost v benefit is done to ensure that it provides long-term financial and loss reduction benefit. This analysis will apply to all areas that target losses and have an associated cost. It is likely that the highest value approaches will be targeted first.

13.4. Concrete measures implemented by DNOs could lead to a reduction in losses on the distribution system of around 0.69TWh over period 2015-2023 from a 2013 baseline of 19.6TWh. This equates to a 3.5% reduction in DNO losses and the equivalent saving of 312,772 tonnes of CO2 emissions.[44] Potential measures could reduce losses by a further 0.17TWh to 0.35TWh[45] approximately.

13.5. Network reinforcement within GB's transmission system is currently driven by customer-led generation connections. While these increased power flows will tend to result in a net increase of losses across the system, losses strategies are based on considering the utilisation of lower loss conductors consistent with the capability of tower structures when designing and carrying out system reinforcement to enable generation to connect.

Gas

13.6. For gas, the costs and benefits have only been quantified for measures being implemented under the current price control period. However, we have also identified innovative solutions and other future projects being investigated by the companies to identify their potential benefits and the associated costs.

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[44] CO2 saving calculated using figures from DUKES 2013 page 11 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/337649/chapter_5.pdf

[45] This value equates to the total of the potential measures identified by the DNOs through their losses strategies

13.7. Leakage comprises 94% of shrinkage on the gas distribution networks. The single biggest contributor reducing leakage over the price control period is the mains replacement work. Although this is driven mainly by safety considerations, the associated reduction in leakage will significantly improve the energy efficiency of the networks and help the GDNs to meet their target of 15% -20% reductions of shrinkage.

13.8. For NGGT, UAG is the largest contributor to shrinkage on the NTS. However, reductions in shrinkage are achieved by correcting metering errors and do not actually contribute to the energy efficiency of the network. Instead, NGGT's cost benefit analysis has focused on its compressor fuel usage, which is the energy used to run compressors to transport gas through the NTS. For gas-driven compressors, this is Own Use Gas and for electric driven compressors this is Electric Compressor Energy.

13.9. The electricity table below summarises the cumulative loss savings from the concrete measures listed in this report. The gas distribution tables summarise the year-on-year energy savings and the cumulative financial savings for the measures listed in this report. The gas transmission table summarises year-on-year benefits.

Electricity

Table 15 – Electricity distribution concrete measures and loss savings

		15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23
Replace old transformers	£m benefit	0.67	1.69	3.04	4.74	6.73	8.91	11.27	13.63
	MWh saved	13,882	34,806	62,792	97,826	139,077	184,049	232,740	281,432
Low loss transformers	£m benefit	0.64	1.06	1.43	1.84	2.28	2.76	3.42	4.13
	MWh saved	13,266	21,962	29,567	37,951	47,066	56,904	70,593	85,360
Oversizing conductors	£m benefit	0.36	1.01	1.96	3.21	4.75	6.61	8.78	11.22
	MWh saved	7,333	20,811	40,405	66,230	98,172	136,524	181,286	231,699
Optimising conductors	£m benefit	0.51	0.86	1.16	1.49	1.81	2.16	2.60	3.05
	MWh saved	10,497	17,709	24,038	30,669	37,481	44,509	53,712	63,044
Voltage control	£m benefit	0.28	0.41	0.52	0.63	0.75	0.89	1.10	1.33
	MWh saved	5,806	8,570	10,682	13,051	15,575	18,288	22,779	27,390
Total	£m benefit	2.46	5.03	8.11	11.90	16.34	21.32	27.17	33.36
	MWh saved	50,786	103,862	167,488	245,734	337,381	440,287	561,126	688,925

Gas

Table 16 – Gas distribution concrete measures

		15-16	16-17	17-18	18-19	19-20	20-21
Mains replacement	£m benefit	2.27	7.00	11.92	16.79	21.76	26.84
	MWh saved	64,676	66,776	64,153	63,593	63,079	62,459
Services relaid and transferred	£m benefit	0.65	1.98	3.32	4.61	5.89	7.17
	MWh saved	18,424	18,524	17,147	16,607	16,021	15,541
Fuel poor connections	£m benefit	0.07	0.20	0.35	0.51	0.68	0.85
	MWh saved	0	0	0	0	0	0
Total	£m benefit	2.98	9.18	15.59	21.90	28.33	34.86
	MWh saved	83,100	85,300	81,300	80,200	79,100	78,000

Table 17 – Gas distribution potential measures

		15-16	16-17	17-18	18-19	19-20	20-21
BCF – scope 1 and scope 2	£m benefit	0.005	0.013	0.021	0.029	0.043	0.057
	MWh saved	0	0	0	0	0	0
Bio-methane connections	£m benefit	0.65	2.01	3.49	5.091	6.81	8.65
	MWh saved	2,324,673	3,156,395	3,988,117	4,819,839	5,651,561	6,483,283
Total	£m	0.66	2.02	3.51	5.12	6.85	8.71
	MWh saved	2,324,673	3,156,395	3,988,117	4,819,839	5,651,561	6,483,283

Table 18 – Gas transmission measures for compressors

		15-16	16-17	17-18	18-19	19-20	20-21
IPPC phase 3	£m benefit	-	-	0.9	0.9	1.0	0.9
	MWh saved	-	-	70,285	70,285	80,093	71,334
LCP and IPPC phase 4 (Inc. IPPC phase 3)	£m benefit	-	-	2.8	3.2	2.4	2.2
	MWh saved	-	-	227,559	250,224	226,590	164,725
Electrical Usage	£m benefit	0.007	0.015	0.022	0.030	0.038	0.047
	MWh saved	247	494	741	988	1,235	1,482
Total	£m benefit	0.007	0.015	3.72	4.13	3.43	3.15
	MWh saved	247	494	298,585	321,497	307,918	237,541

Appendices

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Appendix 1 – Electricity networks innovation

1.1. The contribution of innovation is uncertain but acts as a cornerstone in tackling the issues explored in this report. Relevant innovation projects, such as those funded through Ofgem Innovation funding programmes are presented below.

Project Name	Description
Smart Network Trial - Pontypool	Equipped all HV/LV pole and ground mounted distribution substations fed from one 132/66/11 kV primary substation, with measurement facilities to capture loading information and communicate back into WPD corporate systems including SCADA. Provided the data required for site specific cost benefit analysis of loss reduction measures, such as early replacement of higher loss distribution transformers. Provided monitoring of voltage, power factor and harmonic.
Optimising System Design for Performance and Losses	Working with Imperial College the project provided an optimising tool, which can consider both performance and system losses of alternative networks under different degrees of distribution generation penetration.
Voltage Unbalance in Distribution Networks	Voltage unbalance can cause damage to equipment, increase system losses, reduce network capacity, and prevent optimal feeding arrangements. A number of monitors on a meshed HV network were installed, where it was known that voltage unbalance existed. The effect on performance and losses was evaluated.
Strategic Technology Programme (STP) Project into Energy Efficient Substations	Project (STP reference S5195_2) investigated aspects of network losses within the substation environment. This included network equipment and substation facilities.
Power Networks Research Academy Reactive Power Dispatch Using Distributed Generation	Queens University, Belfast carried out a detailed study of voltage profile and loss evaluation. The PhD student produced a paper and report into the use of DG in the reduction of power losses on the IEEE 13 Bus Model.
Technical Losses Review	Carried out by Imperial College and SOHN Associates this work developed further the research from the DPCR4 "Optimising System Design for Performance and Losses" project. It used the models previously developed to carry out a desktop cost benefit analysis of addressing losses on networks.
Carbon Tracing	The Carbon Tracing project developed a methodology to disaggregate the CO_2 and kWh elements of network losses. The methodology allows a DNO to draw a distinction between "green losses" from connecting additional distributed generation and those more normally created by demand. The project also developed a number of additional innovative metrics by with to measure the carbon impact of losses including "electricity kilometres". A follow on demonstration project is planned which will take lives feeds of network analogue data.

Voltage Optimisation – 11kV Network	The study aimed to see if it was possible to operate the whole network at a reduced target voltage, but still remain within statutory limits. It set out to identify if there were any significant energy savings to customers by operating in this fashion. This project involved reducing the voltage by 2% and monitoring the voltage and load data at both the primary and secondary substations along the feeders. The study produced some encouraging results and gives confidence that there may be benefits of demonstrating the techniques on a wider scale.
Investigating Balancing of LV Networks	Determined the benefits of LV balancing by the development of a model to optimise inclusion of interconnected star transformers (static balancers) in to typical rural and urban network designs. One of the objectives was to develop techniques to ensure that LV networks are balanced. This would allow increased LV network utilization and deliver reduced network losses.
Phasor Measurement Trial	This project aimed to demonstrate the use of field Phasor identification equipment on 33kV, 11kV and LV networks, to identify operational and safety issues and equipment limitations. The stated benefits of the project included ensuring networks are balanced to maximise utilisation, avoid circulating current and reduce losses.
Harmonic Detection and Analysis	Use of disturbance recorder information to determine harmonic levels on a rural 33kV network with a large penetration of cable connected intermittent distributed generation. Harmonic voltage distortion has been recognised as a cause of increased losses in circuits and equipment.
HV Imbalance and power factor	DNOs are developing a project with a solar generation customer that will investigate the feasibility of addressing imbalance and power factor issues on the 33kV network. It will also use local storage to set the generated power per phase to reduce overall network imbalance. The storage can also be used to manage the overall utilisation of the network.
LV Imbalance	A project is being developed which will investigate and assess methods for correcting imbalance on the low voltage network. The project will look at the relative costs and benefits of methods such as the service-by-service rebalancing of customers or the less granular approach of rebalancing whole sections of the network between joint positions.
Revenue Protection	DNOs are currently working on an Innovation Funding Incentive (IFI) project to establish if it is possible to detect the presence of heat lamps used for the cultivation of drugs such as cannabis using the specific electrical harmonic signature created by the heat lamps. This activity is often linked with illegal abstraction.
ACCC overhead conductor (Project: IFIT 2010_01)	One company has completed the assessment and trial installation of an Aluminium Conductor Composite Core (ACCC) conductor on a 132kV wood pole transmission line. The design of the ACCC maximises the area of conductive material in the conductor, providing the same power-carrying capacity at a lower operating temperature than in conventional conductor designs. The lower comparative operating temperature leads to reduced losses, as well as a high current-carrying capacity that can defer or avoid the requirement for more costly conventional network reinforcement. They are currently undertaking analysis of the trial results prior to potential transfer to business-as-usual in RIIO-T1.
Conductors	National Grid has undertaken a research and development project, in conjunction with the University of Manchester, EPL Composite Solutions and SSE, to develop and trial the application of new materials to replace existing 275kV overhead line conductor insulation and supporting arms with a composite insulated supporting arm capable of 400kV operation. The new arrangement will allow the option of upgrading of existing 275kV overhead line

	routes to 400kV operation, to increase system capacity without the requirement to build new OHL routes. If successful, this innovation has the additional benefit to reduce circuit transmission losses by 20% to 40% depending on circuit loading, for routes which can justify this investment. The research and development project is now complete, but awaiting a suitable scheme for consideration as a development option.
Capacity to Customers (C2C)	Aim is to release capacity in the network, provided for supply security, for new connections on a non-firm basis. An integral part of this project is optimisation for the network operating configuration for its loading condition. Typically, ENWL operates its HV and LV circuits in a radial configuration with alternative supply facilitated via adjacent circuits connected via a circuit breaker in the open state. The C2C project aims to reduce like-for-like power losses by 'meshing' the HV and LV networks through the closure of the normally open circuit breakers. Theoretical analysis indicates a losses reduction in the order of 0.1%. The C2C project aims to provide empirical evidence for this losses reduction technique.
The Lincolnshire Low Carbon Hub	The project evaluates reduction of losses from 33kV meshing and increase in "green losses" due to higher network utilisation.
FlexDGrid	FlexDGrid explores the saving in losses from closing bus section circuit breakers in central Birmingham to share transformer loading . This will be made possible by the FlexDGrid Fault Level modelling, measurement and mitigation techniques.
SoLa BRISTOL	Elements of SoLa BRISTOL are losses related (but on the customer side of the meter primarily) looking at round trip efficiency of eliminating AC/DC convertors within the home, schools and businesses. The project will also use the micro-grid control strategy to achieve network balancing and peak reduction using a crowd sourcing approach to battery despatch.
FALCON	The FALCON Scenario Investment Model (SIM) will include an estimation of network losses in its Cost Benefit Analysis decision tree algorithm. The SIM parameters for technique efficiency will be informed by the six engineering and commercial trials.
LV Network Templates	LV Templates investigated the impact of LV voltage reduction on technical losses. As part of the project close down a paper was produced quantifying the benefits of reducing distribution voltages within UK and EU existing standards. The project also estimated and made recommendations on the opportunities for transformer losses reduction.
Solent: Achieving Value through Efficiency (SAVE)	This project focuses on engagement with customers in order to specify energy efficiency measures which could be implemented to solve network capacity problems while saving customers money on the cost of energy and reducing network losses.
Low Energy Automated Networks (LEAN)	As previously stated this project considers the benefits case to switching out of a transformer at dual transformer Primary substations. If successful it could pay back the equipment cost between 5-10 years.
My Electric Avenue	This is only currently being used to manage constraint peaks, it can also be re-tasked to reduce peaks even when there are no capacity constraints to reduce losses – further investigation required in this area.
Thames Valley Vision	A key element of the project is looking distributed energy storage on the LV network with devices that can balance phases and hence reduce losses associated with network imbalance.

Low Carbon London	Some 1,100 domestic consumers are participating in the trial and each consumer has a smart meter which enables the project team to record their half-hourly time-series consumption. The tariff is a critical peak price tariff with three price bands. The price bands are not fixed to specific periods of the day; instead consumers are notified one day ahead of the prices and time bands that will apply over the following day. Given that a 19% increase in electricity consumption due to electric vehicles and heat pumps could give rise to a 40% increase in variable losses, the benefits of effective peak demand reduction in terms of avoided investment in network capacity and reduced distribution network losses could be considerable.
Flexible Networks for a Low Carbon Future	Aim is to provide 20% increase in network capacity headroom through a variety of innovative network solutions, including more sophisticated data analysis and network characterisation techniques, dynamic rating of overhead lines and transformers, network automation and energy efficiency measures. A key element of the flexible network control is how network reconfiguration should be done to reach a suitable compromise between losses and reliability.
Multi-terminal test environment for HVDC systems (Project: SSEEN01)	One TO is proposing to establish a collaborative facility which will enable the planning and optimisation of future HVDC systems in GB. This proposal was submitted to Ofgem in August 2013 for consideration as part of the Electricity Network Innovation Competition (NIC). This facility is known as the Multi-Terminal Test Environment (MTTE). It would allow for a detailed study of the interaction between new HVDC and existing AC networks as well as modelling of operational approaches to optimise DC and AC system performance, potentially leading to reduced losses. The outputs of the MTTE could potentially contribute to reducing losses in the latter years of RIIO-T1.
Maximising the use of existing infrastructure through new technologies: 132kV Crossarm Trial	One company is trialling innovative insulated crossarms on the towers of an operational 132kV circuit. The purpose of crossarms is to hold the wires clear of the tower body. Retrofitting the innovative crossarms to existing towers can enable the upgrading of existing lines to a higher voltage to enable higher power flows as well as reduce losses. This avoids the higher cost and greater environmental impact of rebuilding the affected lines to provide additional capacity. We are currently undertaking analysis of the trial results prior to potential transfer to business-as-usual in RIIO-T1.
Flexible Plug and Play (FPP)	A distribution network operator has completed Flexible Plug and Play, its £9.7m, 3 year innovation project to trial new technologies and commercial arrangements in order to connect distributed generation (DG), such as wind or solar power, to constrained areas of the electricity distribution network. It has delivered greater flexibility in accommodating cheaper and faster DG connections, as well as enabling previously unviable DG schemes become feasible. The Flexible Plug and Play project will deliver significant benefits for the 15 customers (over 50MW of DG) who have contracted to connect using its methods.

Appendix 2 – Status of losses on the transmission network

The tables below to show the status of losses on the electricity transmission network are separated by licence.

SHE Transmission

1.2. The methodology used to assess the impact of the reinforcement projects on transmission losses was based on a single interval of the SHE transmission network performance at winter peak demand. Power losses at peak demand in a year were compared to losses in the following year, based on the Electricity Ten year Statement (ETYS) years' format of year 1,2,3,4,5,7 and 10. The PSS/E network models used for the studies were the ETYS 2013 models from year 2013-14 to 2022-23 based on the Gone Green scenario.

1.3. The study results are shown in the table below where a negative change represents a reduction in transmission power losses at peak demand compared to previous year. Note, these are the ETYS 2013 'Gone Green' base case dates.

	Name of reinforcement	Description	Total Power Losses at Peak Demand (MW)	% Change in losses
2014	**Beauly – Denny 400/275kV OHL (part)**	Replace 132kV double circuit line Beauly – Fasnakyle – Fort Augustus – Errochty – Braco – Bonnybridge with a double circuit line Beauly – Fasnakyle – Fort Augustus – Tummel – Denny. The line to be insulated at 400kV but operating with one circuit at 400kV and another one at 275kV.	**150.3**	**-**
2015	**Beauly – Denny 400/275kV OHL (part)**	As above	**111.0**	**-26.1%**
	Beauly – Blackhillock – Kintore 275kV OHL Reconductoring	Reconductor existing 275kV double circuit overhead line between Beauly, Knocknagael, Blackhillock and Kintore substations with higher capacity conductors.		
	Fort Augustus – Skye 132kV Reconfiguration	Construct a new 132kV OHL from Fort Augustus substation to Skye Tee. This will offload the 132kV double circuit line from Fort Augustus to Fort William.		
	Keith – Macduff 132kV Reinforcement	Upgrade the existing 132kV single circuit overhead line from Keith to Macduff to a 132kV double circuit overhead line.		

2016	**Beauly – Denny 400/275kV OHL (part)**	As above	**76.9**	**-30.7%**
	Kintyre 132kV Reinforcement & Crossaig – Hunterston subsea cables	Establish a new 132 kV substation at Crossaig in Kintyre and install a subsea link between Crossaig and Hunterston (SPT). This will comprise of two 240MVA land/subsea cable circuits, connecting to two 240MVA 132/220kV transformer substation at Crossaig, and two 240MVA 220/400kV transformer substation at Hunterston. Rebuild the existing 132 kV double circuit line between Crossaig and Carradale. Install two Quadrature Booster transformers at Crossaig on the 132kV double circuit OHL to Port Ann.		
	Foyers – Knocknagael 275kV OHL Upgrade	Upgrade the existing 275kV double circuit overhead line from Foyers to Knocknagael to a higher capacity.		
	Carradale – Crossaig 132kV OHL Upgrade	Upgrade the existing 132kV double circuit overhead line from Carradale to Crossaig to a higher capacity.		
2017	**Beauly – Mossford 132kV OHL Upgrade**	Rebuild the existing 132kV double circuit overhead line from Beauly to Corriemoillie near Mossford with a higher capacity to replace the existing 2 x 132kV circuits.	**85.4**	**+11.1%**
2018	**Blackhillock Quad Boosters on the Blackhillock – Knocknagael 275kV OHL**	Install 2 x 865MVA 275kV quadrature boosters with bypass on the Blackhillock – Knocknagael 275kV circuits.	**96.1**	**+12.5%**
	Loch Buidhe 275/132kV Substation	Construct a new 2 x 240MVA 275/132kV transformer substation near Loch Buidhe, at the crossing point of the existing Beauly –Dounreay 275kV and Shin – Mybster 132kV double circuit overhead lines.		
	Beauly – Loch Buidhe 275kV OHL Reconductoring	Reconductor circuit FYL1/BFY1 of the 275kV double circuit overhead line between Beauly, Fyrish and Loch Buidhe substations with higher capacity conductor.		
2020	**Errochty 132kV Network Reconfiguration**	Split the 132kV busbars at Errochty into two separate busbar layouts and reconfigure the circuits to separate the Killin, Clunie and Burghmuir/Abernethy 132kV circuits from the rest of the 132kV circuits at Errochty substation, which are left connected to the 275kV system.	**130.1**	**+35.4%**

	Lairg – Loch Buidhe 132kV Reinforcement	Establish a new 132kV double busbar arrangement at Lairg (adjacent to Lairg GSP) and construct 20km of new 132kV double circuit overhead tower line between Lairg and Loch Buidhe.		
	Loch Buidhe – Dounreay 275kV circuit Reconductoring	Reconductor circuit DU1 of the 275kV double circuit overhead line between Loch Buidhe and Dounreay substations with higher capacity conductor.		
2023	**Beauly – Loch Buidhe 275kV OHL Reinforcement**	Upgrade the existing Beauly, Shin to Loch Buidhe 132kV double circuit overhead line with a higher capacity 275kV double circuit overhead line.	**169.6**	**+30.4%**

1.4. The SHE Transmission studies show that generally the transmission reinforcement projects helped to reduce the transmission power losses at winter peak demand in the early years. However beyond year 3, the losses increased year on year due to an increase in renewable generation connected to the network.

National Grid

1.5. Each development outlined in this section is accompanied by an estimate of its impact on total transmission losses across the transmission networks - in sections 1-6, the impact of losses are reported for key incremental wider works schemes.

1.6. The percentage loss figures outlined in the tables below are not directly comparable. The loss impact of each individual development has been assessed by considering the background pre- and post-investment. However, as developments are incrementally staged, the background against which losses are assessed continually evolves with each incremental investment. Whilst this provides an accurate reflection of transmission network development, it does not provide a consistent base for direct comparison of losses figures established at different stages of transmission network reinforcement.

Scotland – SHE Transmission to NGET

ETYS 2013 Gone Green base case	Name of reinforcement	Description	Impact on net losses (winter peak MW) (loss improvement is positive)	% Change in losses (as a percentage of losses prior to investment)
2020	**Eastern HVDC One**	A new ~2GW submarine HVDC cable route from Peterhead to Hawthorne Pit with associated AC network reinforcement works on both ends. The three onshore TOs will continue to work together during 2014 to determine the most economic and efficient design	**46,758**	**+0.59%**

		solution for the Eastern HVDC link.		

Scotland – SP Transmission to NGET

ETYS 2013 Gone Green base case	Name of reinforcement	Description	Impact on net losses (winter peak MW) (loss improvement is positive)	% Change in losses (as a percentage of losses prior to investment)
2014	**B6 NGET series and shunt compensation**	Series compensation to be installed in the Harker – Hutton, Eccles – Stella West and Strathaven – Harker routes. Strathaven – Smeaton route uprated to 400kV and the cables at Torness uprated. Reduces the impedance of the Anglo-Scottish circuits improving the loading capability of the circuits.	**3.17**	**+0.55%**
2016	**Western HVDC Link**	A new 2.45 GW (short term rating) submarine HVDC cable route from Deeside to Hunterston with associated AC network reinforcement works on both ends.	**21.42**	**+3.15%**
2024	**Eastern HVDC Two**	A new ~2GW submarine HVDC cable route between Torness and North East England with associated AC network reinforcement works on both ends.	**11,055**	**-0.12%**

North England

ETYS 2013 Gone Green base case	Name of reinforcement	Description	Impact on net losses (winter peak MW) (loss improvement is positive)	% Change in losses (as a percentage of losses prior to investment)
2014	**Penwortham Quad Boosters**	Install a pair of 2750MVA Quadrature Boosters (QBs) on the double circuits which run from Penwortham to Padiham and Daines at the Penwortham 400kV substation. They will improve the capability to control the north to south power flows on the circuits connecting the North Midlands and the West Midlands, and hence improve the transport of excess generation from the north to demand centres in the south.	**0.21**	**+0.04%**

2016	**Kirkby and Rainhill substation upgrade**	Replace circuit breakers and equipment at Rainhill so that Kirkby and Rainhill can be changed to a two-way split configuration. This will divert more power to flow into the Kirkby – Rainhill – Fiddlers Ferry route from the Kirkby – Lister Drive – Birkenhead route; as a result, loading on the Kirkby to Lister Drive circuits will be better shared. Improved utilisation of the existing 275kV Mersey ring will significantly increase the capability of the network to handle north to south power flows.	**4.74**	**+0.72%**
2020	**Yorkshire lines re-conductor (Norton – Osbaldwick hotwiring and re-conductor & Lackenby– Norton re-conductor)**	Re-conductor sections of the Lackenby – Norton 400kV circuit with higher-rated conductor and up rate the cross-site cable at Lackenby 400kV substation to a similar or higher rating. Re-conductor a small section and hotwire the remainder of the existing 400kV double circuits which run from Norton to Osbaldwick. This will help ensure the circuits will provide sufficient thermal capacity to transport the excess generation from Scotland to southern demand.	**5.18**	**+0.56%**
2020	**Penwortham – Padiham & Penwortham – Carrington re-conductor & Kirkby – Penwortham upgrade (Mersey Ring stage 1a)**	Up rate the 275kV double circuit overhead lines from Kirkby to Penwortham to operate at 400kV and carry out associated work (including construction of Kirkby 400kV substation and a new Washway Farm 400/132kV substation with two 400/132kV 240MVA SGTs). Uprate the limiting sections of the Penwortham - Carrington and Penwortham Padiham double circuit to improve overall transmission capability. This will improve the capability of the network to handle the heavy north to south power flows from the large amount of expected generation connection in Scotland.	**4.93**	**+0.53%**
2020	**Lister Drive Quad Booster Installation**	Replace the existing series reactor at Lister Drive with a Quad Booster (QB). The Quad Booster will enable flexibility to control power flows through the circuit south of Lister Drive.	**3.86**	**-0.37**

East England

ETYS 2013 Gone Green base case	Name of reinforcement	Description	Impact on net losses (winter peak MW) (loss improvement is positive)	% Change in losses (as a percentage of losses prior to investment)
2022	**Bramford – Twinstead Tee**	Re-conductor the existing Pelham – Braintree – Rayleigh Main circuit, and construct a new transmission route from Bramford to the Twinstead tee-point, creating double circuits which run between Bramford – Pelham and Bramford – Braintree – Rayleigh Main. These works will result in two transmission routes for power to flow south from the East Anglia area and hence increase the capability of the network to export excess generation from the area significantly.	**1.92**	**+0.21%**
2014	**Rayleigh – Coryton South – Tilbury re-conductor**	Re-conductor the existing Rayleigh Main – Coryton South – Tilbury circuits with higher-rated conductor. This will help ensure the circuits will provide sufficient thermal capacity to transport the excess generation from the East Anglia area to the south east demand, as an increasing amount of future wind and nuclear generation is expected to connect in the area.	**2.55**	**+0.26%**
2026	**East Anglia MSC**	Install a 225MVAr MSC to provide voltage support to the East Anglia area. The MSC will help ensure voltage compliance for local faults where power is diverted through a longer transmission route.	**1.51**	**+0.12%**

South England

ETYS 2013 Gone Green base case	Name of reinforcement	Description	Impact on net losses (winter peak MW) (loss improvement is positive)	% Change in losses (as a percentage of losses prior to investment)
2018	**Wymondley turn-in**	Modify the existing circuit which runs from Pelham to Sundon; turn in the circuit at Wymondley to create two separate circuits which run from Pelham to Wymondley and Wymondley to Sundon. This will improve the balance of the power flows on the North London	**-0.26**	**-0.04%**

		circuits, and increase the capability of the network to import power into London from the north transmission routes.		
2014	**Barking – Lakeside Tee new double circuits**	Construct a new 400kV transmission route from Barking to the Lakeside tee-point on the existing transmission route from Tilbury - Littlebrook. This will divert some power flows from the heavily loaded North London circuits to the south east transmission route to supply London demand; as a result the networks capability to import power into London will improve.	**-0.31**	**-0.05%**
2022	**Hackney – Tottenham – Waltham Cross up-rate**	Uprate and reconductor the Hackney – Tottenham – Brimsdown – Waltham Cross 275kV transmission route with higher-rated conductor to operate at 400kV, and reconductor the Pelham - Rye House double circuits with higher-rated conductor. Carry out associated work including construction of a new Waltham Cross 400kV substation, modification to Tottenham substation and installation of two new transformers	**1.39**	**+0.12%**
2019	**Wymondley Quad Boosters**	Install a pair of 2750MVA Quadrature Boosters (QBs) on the Wymondley to Pelham double circuits at the Wymondley 400kV substation. The pair of QBs will improve the capability to control the power flows on the North London circuits, and significantly improve the capability of the network to import power into London from the north transmission routes.	**0.03**	**+0.01%**

West England and Wales

ETYS 2013 Gone Green base case	Name of reinforcement	Description	Impact on net losses (winter peak MW) (loss improvement is positive)	% Change in losses (as a percentage of losses prior to investment)
2023	**Wylfa – Pentir second transmission route**	Construct a second 400kV transmission route from Wylfa to Pentir, with associated work including the modification to the Wylfa 400kV substation and extension of Pentir 400kV substation. This extra transmission route will allow the connection of generation at Wylfa beyond the infeed loss risk criterion (currently 1320MW and changing to 1800MW from April 2014). The capability of the network to export	**-0.84**	**-0.08%**

		power from Wylfa into the main transmission system will be improved significantly.		
2020	**Pentir – Trawsfynydd second circuit**	A second circuit is created by using one side of a route currently occupied by an SP-MANWEB 132kV circuit. A large single core per phase cable section is required across Glaslyn where no overhead line currently exists. A single 400/132kV transformer is teed off the new circuit to provide a connection to SP-MANWEB at Four Crosses to replace its circuit.	**2,867**	**+0.04%**
2014	**Trawsfynydd – Treuddyn Tee re-conductor**	Reconductoring the ZK route double circuit to GAP forms the first part of a suite of anticipatory investments in North Wales, designed to deliver increased transmission capacity in readiness for the first stages nuclear and wind farm generation connecting in North Wales. It is planned in 2014 as a result of asset condition drivers.	**3,711**	**+0.07%**
2021	**Bredbury – South Manchester re-conductor**	The work includes replacement of Bredbury substation cables and Bredbury to South Manchester transmission cable with two parallel single core per phase XLPE 2500mm^2. The busbars, circuit breakers and cable tower termination shall also be replaced. The reinforcement, enhances the Midlands to South power flows and ultimately, supporting the networks ability to transfer more power from the north to the south.	**11.66**	**+1.14%**
2022	**Cellarhead – Drakelow re-conductor**	Re-conductor the existing double circuits which run from Cellarhead to Drakelow with higher-rated conductor. Together with other West Midlands reinforcements, this will further increase the thermal capability from Midlands to South, supporting the networks ability to transfer more power from north to south.	**26.97**	**+2.36%**
2021	**Pentir – Trawsfynydd 1 single core per phase**	The existing cable sections of the Pentir – Trawsfynydd 1 are replaced by large single core per phase cable sections.	**3,037**	**+0.03%**
2021	**Pentir – Trawsfynydd 2 single core per phase**	The cable sections across both existing circuit and new circuit connecting Pentir to Trawsfynydd including the long sections across the Glaslyn estuary are paralleled with additional large single core per phase. The OHL will be the limiting component after this reinforcement is constructed.	**13,374**	**+0.13%**

2019	**Running Carrington 400kV substation solid and Daines 400kV rationalisation**	Having both Carrington and Daines 400kV substations split limits the boundary transfer and overloads one of the Carrington to South Manchester circuit due to poor load sharing. This is solved by running Carrington 400kV substation solid and tee-in circuits coming into Daines 400kV substation subsequent decommissioning. The scope of the project also involves extension of the Carrington 400kV that will accommodate new generation connection in the future. This reinforcement shall improve the power transfer from north to south and relaxes the thermal stress on west region boundary circuits.	**-76,483**	**-0.96%**

Scottish Power Transmission

1.7. To provide an indication of how transmission system losses are expected to change in future, the table below shows losses in the SPT network at the time of winter peak for a number of future years. These are power loss figures (for one point in time) based on analysis carried out with the 2014 ETYS model, which is based on the Gone Green planning scenario. Note that the change in losses at the time of winter peak is not only a function of the stated network reinforcements, but also of generation dispatch and demand, which can vary considerably from year to year.

1.8. To make an estimate of an annual lost energy volume is significantly more complex as it would require the construction of a significant number of network conditions (generation dispatch, demand and outages) to approximate the year-round operation of the network. By evaluating the losses for each such condition and considering the length of time it is expected to last, an annual loss estimate could be made. We are currently considering methods to make such a loss estimate.

1.9. It is difficult to estimate the impact of individual network reinforcement projects on losses as these are often related to generation connections, which tend to lead to higher network transfers and, in turn, increased losses.

1.10. The study results are shown in the table below where a negative change represents a reduction in transmission power losses at peak demand compared to previous year.

1.11. The timetable for measures reductions are presented in the tables with each concrete measure and cover the covers the current price control period to 2023.

ETYS 2013 Gone Green base case date	Name of key reinforcements	Description	Total Power Losses at Peak Demand (MW)	% Change in losses
2014	**Inverkip Disconnection**	Reconfiguration of the 400kV network associated with the Western HVDC Link will facilitate the decommissioning of Inverkip 400kV substation and the future rationalisation of the local overhead line network.	**101**	**-**
2015	**Beauly – Denny 400/275kV OHL**	The Beauly to Denny reinforcement extends from Beauly in the north to Denny. Replace the existing Beauly–Fort Augustus–Errochty–Bonnybridge 132kV overhead lines with a new 400kV tower construction which terminates at a new substation near Denny in SP Transmission's area, and carry out associated AC substation works. One of the circuits will be operated at 400kV and the other at 275kV.	**127**	**+25.6%**
	Series Compensation	Install series compensation in the Harker–Hutton, Eccles–Stella West and Strathaven–Harker routes. Two 225MVar MSCs to be installed at Harker, one at Hutton, two at Stella West and one at Cockenzie. This effectively reduces the impedance of the Anglo-Scottish circuits improving their loading capability.		
2016	**Western Link HVDC**	This is a new 2.4 GW (short-term rating) submarine HVDC cable route from Deeside to Hunterston with associated AC network reinforcement works on both ends. At the northern end it will include construction of a Hunterston East 400kV GIS substation.	**105**	**-17.2%**
	East – West 400kV Upgrade	Uprate the Strathaven–Smeaton route to 400kV and uprate the cables at Torness.		
2017	**No Reinforcements planned**	Changes in losses are due to demand and generation pattern only	**104**	**-1.1%**
2018	**No reinforcements planned**	Changes in losses are due to demand and generation pattern only	**110**	**+5.3%**

2020	**East Coast Upgrade**	A joint SHE Transmission and SP Transmission project to upgrade the existing east coast overhead line between Blackhillock and Kincardine. Includes new substations at Rothienorman, Alyth and an extension of the existing substations at Kintore and Kincardine.	**169**	**+53.6%**
2023	**Eastern HVDC Link**	A new 2GW submarine HVDC cable route between Torness and North East England with associated AC network reinforcement works on both ends.	**212**	**+25.4%**
	Denny – Wishaw 400kV Upgrade	The Central 400kV Uprate uses existing infrastructure between Denny and Bonnybridge, Wishaw and Newarthill along with a portion of an existing double circuit overhead line between Newarthill and Easterhouse. A new section of double circuit overhead line is required from the Bonnybridge area to the existing Newarthill/Easterhouse route. Together with modifications to substation sites, this reinforcement will create two new north to south circuits through the central belt: a 275kV Denny/Wishaw circuit and a 400kV Denny/Wishaw circuit, thereby significantly increasing B5 capability.		
	Dumfries & Galloway Upgrade	The transmission network in the Dumfries and Galloway Region is provided by an interconnected single 132kV circuit between Dumfries and Coylton. This circuit has a summer rating of 106MVA and was constructed in 1936 to connect the Galloway Hydro scheme. The Dumfries & Galloway Upgrade comprises the construction of a new overhead line to serve the main demand blocks, existing generation portfolios and facilitate the connection of new renewable generation in the Dumfries and Galloway region.		

Appendix 3 – Household CO2 emissions assumptions

1.12. This annex presents a methodology to estimate the carbon dioxide equivalent (CO2e) saved as a result of a consumer being connected to the gas distribution system and switching from an alternative fuel source. This estimate can be used to identify the potential CO2e savings from the fuel poor network extension scheme and for extending the gas distribution network in general.

1.13. According to research undertaken by Consumer Focus there were around 4 million households without gas for heating across England, Scotland and Wales in 2008. Of this over 0.5 million had gas in their property but were not using it for heating, over 1.3 million were identified as being within close proximity of the gas network (within the same post code) and 2 million were fully off grid. These figures are presented in the table below.

Access to Gas	**Properties (m)**[46]			**GB properties without Gas Heating**
	England	**Scotland**	**Wales**	
Gas in property but not for heating	0.489	0.053	0.026	14%
Gas within same Post Code	1.096	0.171	0.053	34%
Off Gas Grid	1.535	0.317	0.190	52%

1.14. These households currently use other less efficient sources of energy to heat their homes and to cook with, as shown in the table below. By connecting, or facilitating the connection of, these consumers to gas distribution networks it would reduce their carbon footprints and in many cases would reduce their energy bills.

Fuel	**Properties (m)**[47]			**GB properties without Gas Heating**
	England	**Scotland**	**Wales**	
Oil	0.828	0.135	0.143	28%
LPG	0.128	0.018	0.025	4%

[46] http://www.consumerfocus.org.uk/files/2011/10/Off-gas-consumers.pdf
[47] http://www.consumerfocus.org.uk/files/2011/10/Off-gas-consumers.pdf

Coal / Solid Fuel	0.240	0.033	0.037	8%
Electricity	1.919	0.354	0.063	60%

1.15. The table below shows the different fuels that consumers may switch from and the carbon dioxide factor for each fuel and the carbon dioxide savings that would be achieved if they switched to gas. This is calculated as:

Percentage savings = 1 – (Gas Carbon Dioxide Factor / Alternative Source Carbon Dioxide Factor)

Fuel	**Carbon dioxide factor ($kgCO_2/kWh$)[48]**	**Carbon Dioxide Savings if switched to gas (%)**
Oil	0.246	25%
LPG	0.214	14%
Coal / Solid Fuel	0.296	38%
Electricity	0.480	62%
Gas	0.184	0%

1.16. Therefore, assuming a household would use the same amount of energy before and after fuel switching (14,800kWh), then switching from oil to gas would save 918 $kgCO_2$ pa, LPG to gas would save 444 $kgCO_2$ pa, coal / solid fuel to gas 1,658 $kgCO_2$ pa and Electricity to Gas 4,381 $kgCO_2$ pa.

Fuel	**Calculation**	**Emissions (kg/CO_2 pa)**
Oil	14,800 x 0.246	3,641
LPG	14,800 x 0.214	3,167
Coal / Solid Fuel	14,800 x 0.296	4,381
Electricity	14,800 x 0.480	7,104
Gas	14,800 x 0.184	2,723

[48] http://www.energysavingtrust.org.uk/domestic/content/our-calculations.pdf

1.17. If we assume that:

1. the 1.32 million properties currently without gas but within close proximity of the gas network have the same current fuel split as seen across the whole population with no gas for heating;
2. each property uses 14,800kWh of energy for heating with their current fuel; and
3. they would continue to use the same if they switched to gas then almost 4MtCO2 could be saved each year if they were switched to gas for heating. This is set out in the following table:

Fuel	Properties (m)[49]	Average Household Consumption (kWh)[50]	Carbon Dioxide Emissions (MtCO2)[51]	Carbon Dioxide Emission Savings if switched to gas (MtCO2)
Oil	0.37	14,800	1.35	0.34
LPG	0.05	14,800	0.16	0.02
Coal / Solid Fuel	0.11	14,800	0.05	0.02
Electricity	0.79	14,800	5.61	3.48

1.18. **As such it could be estimated that on average switching to Gas from another fuel source saves c. 3,000 kgCO2 pa for each household**, based on those households identified as being within close proximity (same post code) of the gas network, as shown in the calculations below. Note consumption is assumed to be 14,800kWh.

Fuel	Carbon Disoxide factor (kgCO2/kWh)	Carbon Dioxide Emissions (kgCO2) per household	Properties	Total Carbon Dioxide Emissions (kgCO2)
Oil	0.246	3,641	372,144	1,354,901,029
LPG	0.214	3,167	57,538	182,233,083
Coal / Solid Fuel	0.296	4,381	104,308	456,952,169
Electricity	0.480	7,104	786,011	5,583,820,056
Average	**0.388**	**5,741**	1,320,000	7,577,906,337

[49] Based on assumptions provided within text
[50] Assumption that all properties use 14,800kWh pa DECC Gas Domestic Consumption Figure (table 3.07) as used by Ofgem in their Supply Market Indicator (p20)Supply Market Indicator (p20)
[51] Properties *X* Average Household Consumption *X* Carbon Dioxide Factor

Household[52]				

1.19. Facilitating extension of the gas network is currently, in many scenarios, the most energy efficient, and secure, domestic heating solution, GDNs are also working with stakeholders to assess the best long term heat / energy solution seeking to achieve the right balance between consumer choice (including affordability), security of supply and energy efficiency (sustainability).

[52] Average off-gas but within close proximity to gas network property

Appendix 4 – Gas networks innovation

Project Name	Description
Low Carbon Gas Preheating[53]	The objective of this project is to trial the potential of two 'alternative' preheating technologies aimed at accelerating the development of alternative technologies and increasing the level of competition in the preheating technology market. The project will provide data to allow networks to optimise investment decisions, including reducing the BCF of preheating. The project data will also be used to assess the accuracy of current estimates of GDNs' own use gas within the current shrinkage estimates, reducing whole life costs of preheating installations. (Project end date – 31/12/2017)
TouchSpray MEG Fogging System[54]	The overall aim of the MEG improvement initiative is to design, develop, manufacture, install and commission a TouchSpray MEG Fogging system for use on the Gas Distribution network, in order to achieve a major improvement in MEG saturation levels across the network, which will result in a reduction in leakage from metallic mains within the networks. This project will assess the practical and financial feasibility of the technology offered by the Project Partner, The Technlology Partnership (TTP) to significantly improve the effectiveness of the current Gas Conditioning process under Phase 2B of the project. [55] It is to produce the conceptual design of a TouchSpray MEG Fogger, produce the test capability, and understand the droplet size dynamics in the pipe flow. Under Phase 2C of the project, is to enhance the TTP air based facility built as part of Phase 2B ahead of droplet size testing occurring. [56] (Project end date – 01/09/2014)
Robotics[57]	This innovative and world-leading project has the potential to allow extensive work to be carried out on the gas network without the associated disruptive road works. Its objective is to develop new robotic technologies which operate inside the live gas main which can not only remotely repair leaking joints, but support the pipe fracture risk management process through enhanced inspection in larger our diameter pipes. (Project end date – 01/12/15)
AGI Venting and Leakage[58]	This one stage research project seeks to undertake a practical study to gain a better insight on the actual leakage rates from selected venting controllers. This study will be used to inform a potential further piece of work to develop an extended modelling approach to predict the emission rates on a regional basis and to quantify the emission savings through venting controller replacement. The expected benefits of this work will be reduced losses of natural gas at Above Ground Installations (AGIs) and reduced carbon

53 http://www.smarternetworks.org/Project.aspx?ProjectID=1319
54 http://www.smarternetworks.org/Project.aspx?ProjectID=1276
55 http://www.smarternetworks.org/Project.aspx?ProjectID=1407
56 http://www.smarternetworks.org/Project.aspx?ProjectID=1496
57 http://www.smarternetworks.org/Project.aspx?ProjectID=1321
http://www.smarternetworks.org/Project.aspx?ProjectID=1321
58 http://www.smarternetworks.org/Project.aspx?ProjectID=1281

	footprint for AGI site operations related to valve positioners and controllers. (Project end date – 01/09/2013)
Cured in Place Pipe[59]	The CIPP technique is a method whereby a host pipe is lined with a flexible tube which is impregnated with a thermosetting resin, which produces a tough pipe lining after resin cure. The scope of this project is to demonstrate 'fitness for purpose' of CIPP lining technologies for Gas distribution mains, focusing on iron mains of 8" diameter and above operating up to 2 bar pressure, as a potential alternative to pipeline replacement. (Project end date – 01/04/15)
Cast Iron Joint Sealing Robot[60]	The scope of this project is to carry out a detailed technical assessment and field trial of the joint sealing robot 'Large CISBOT', which has the potential to repair or rehabilitate a number of cast iron joints under live conditions in a more cost effective manner than existing methods. The project evaluated the effectiveness of the repair technique and associated inspection method to determine extension to asset life and to understand the potential cost benefit. This project was implemented in July 2014.
Optomole[61]	To develop a mobile, optical methane sensing system that gas distribution companies can utilise to quickly and accurately detect the location of natural gas leaks in ducts. (Project end date – 01/10/15)
Seeker Particle[62]	To carry out a conceptual study of the development of discrete particles that intelligently locates and repair leaks within the gas distribution network and various methods of introducing them into the gas network. (Stage 2 end date 01/06/15)
Opening up the Gas Market[63]	The objective of this Project is to demonstrate that gas which meets the European specification but sits outside of the characteristics of gas specified within Gas Safety (Management) Regulations 1996 can be distributed and utilised safely and efficiently in GB. For this demonstration, there is a unique opportunity an isolated network in a remote part of Scotland. This Project is based on the principles of increasing competition for network entry, improving energy security, reducing the cost of gas for customers through opening up the market to new sources and reducing the requirement for expensive processing in the future. (Project end date - 27/02/16)
Pressure to Gas[64]	The proposal is to replace the existing pressure reduction equipment with an integrated energy recovery and hydrogen electrolysis equipment package. The hydrogen gas will be generated from the power generated and immediately injected into the gas grid. The main elements to this technology are: Pre-heat (if required), Turbo expanders, Hydrogen electrolysis and Gas analysis and injection. (Project end date – 01/09/2014)
In Line Robotic Inspection of High	This project is to develop in-line inspection of below ground pipework at AGIs operating above 2 barg. Current methods of inspection for below ground

[59] http://www.smarternetworks.org/Project.aspx?ProjectID=1222
[60] http://www.smarternetworks.org/Project.aspx?ProjectID=1245
[61] http://www.smarternetworks.org/Project.aspx?ProjectID=1230
[62] http://www.smarternetworks.org/Project.aspx?ProjectID=1231
[63] http://www.smarternetworks.org/Project.aspx?ProjectID=1320
[64] http://www.smarternetworks.org/Project.aspx?ProjectID=1380

Pressure Installations[65]	pipework AGIs involve visual inspection via excavation, which is both financially and environmentally expensive. As such, it does not regularly take place and reliance on survey techniques to target excavations is favoured. This project would allow NGGT to implement an intelligent and proactive asset management strategy, reducing the requirement for inefficient and expensive excavations, extending the life of assets and reducing the likelihood of an asset failure at a high pressure installation thereby securing our national resilience. The benefits that could be provided are estimated at a saving of around 2,145 tonnes CO2e per year. The project has a target completion/implementation date of November 2018.
Renewable Power Trial and Demonstration[66]	There are over 200 block valve sites and 39 Exit Points which have locally operated valves and would require staff to visit site. During a proceeding NIA project it was ascertained that it is feasible to provide the electrical power for existing or new National Grid installations from just renewable power sources such as PV cells and/or wind turbines. This project is to demonstrate the technology in a simulated environment reviewing the factors that would determine the most practical solution for an individual site. The project has a target completion/implementation date of February 2016.

[65] http://www.smarternetworks.org/Project.aspx?ProjectID=1613
http://www.smarternetworks.org/Project.aspx?ProjectID=1613
[66] http://www.smarternetworks.org/Project.aspx?ProjectID=1577