



Progressive energy

Green City Vision

Summary Report

Report for Wales & West Utilities, UK Power Networks and Scottish & Southern Electricity Networks

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GLOSSARY OF TERMS

ASHP	Air Source Heat Pump
CCGT	Closed Cycle Gas Turbine
CHP	Combined Heat and Power
CNG	Compressed Natural Gas
Consumers	Domestic energy consumers
DfT	Department for Transport
DNO	Distribution Network Operator
EV	Electric Vehicle
FES	Future Energy Scenarios
GDN	Gas Distribution Network
H-ASHP	Hybrid Air Source Heat Pump
HP	Heat Pump
ICE	Internal Combustion Engine
MtCO _{2eq}	Million Tonnes of Carbon Dioxide Equivalent
NIA	Network Innovation Allowance
OCGT	Open Cycle Gas Turbine
Ofgem	Office of Gas and Electricity Markets
Opex	Operational Expenditure
PEL	Progressive Energy Ltd
RHI	Renewable Heat Incentive
RIIO	Revenue = Incentives + Innovation + Outputs
SSEN	Scottish & Southern Electricity Networks
SN	Swindon
TOUT	Time of use Tariff
UK	United Kingdom
UKG	United Kingdom Government
UKPN	UK Power Networks
WWU	Wales & West Utilities

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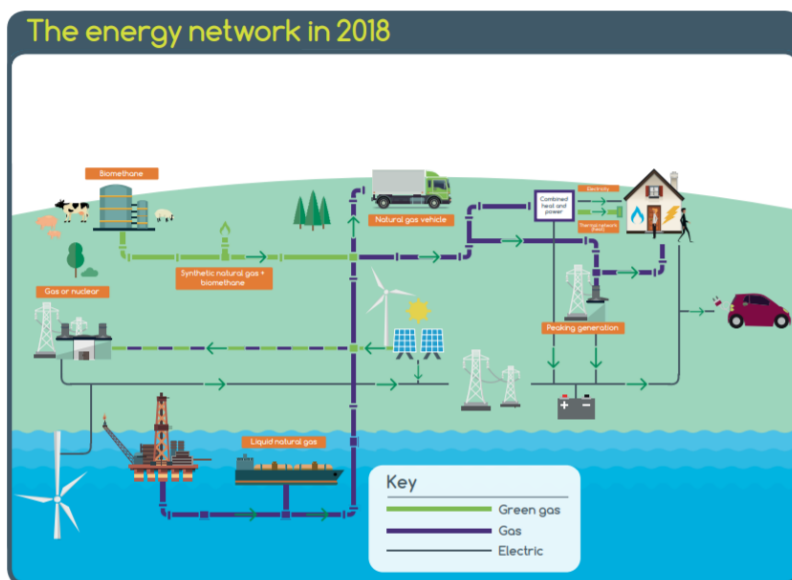
1.0 INTRODUCTION

Green City Vision is a collaborative project funded via the Ofgem Network Innovation Allowance (NIA). The project partners consist of:

- 1) Wales & West Utilities: Gas Distribution Network;
- 2) UK Power Networks: Distribution Network Operator;
- 3) Scottish & Southern Electricity Networks: Distribution System Operator; and
- 4) Progressive Energy: Low-carbon energy project developer and consultancy.

The purpose of the Green City Vision project is to create the initial evidence base to better understand system decarbonisation within the context of an integrated gas-electricity system. A number of decarbonisation strategies have been applied to a reference scenario to understand the requirements of any given strategy to achieve compliant region with respect to the UK's carbon emissions reduction target of 80% relative to 1990 by 2050.

Figure 1-1: UK Energy System



To date, analysis of the implications of decarbonising technologies and solutions have tended to focus on a single network. As the UK's energy systems have become more deeply decarbonised, they have also become more complex and interlinked. The structure of both the gas and electricity networks as isolated, top down infrastructure, is being challenged by the drive for decarbonisation. Both systems are becoming more fluid as a greater level of generation sources are connecting to the distribution networks, such as biomethane plants and embedded wind farms. The two systems are also becoming more integrated, as decarbonising technologies impact upon each, such as gas-fired flexible generation. The objective of the Green City Vision project is therefore to view decarbonisation strategies from a wider, more holistic perspective, by understanding the implications of any given strategy on the both the gas and electricity systems and focusing

on the interface between the two. By integrating both supply-based and demand-based solutions across both networks, the outcome of Green City Vision project is to understand an optimum solution for decarbonisation with feasibility level investment implications to achieve such a solution.

2.0 KEY CONCLUSIONS

The main outcomes from the analysis undertaken were:

- 1) The scenarios modelled indicated that continued operation of both the gas and electricity network will provide the least disruptive pathway to compliance – as evidenced from the necessary investment implications and changes that resulted from the single-vector Electrification and Green Gas scenarios;
- 2) All decarbonisation vectors have their role to play, however to achieve a given level of carbon emissions reductions, ‘top down’ supply-driven strategies were determined to be more deliverable than ‘bottom up’ demand-driven strategies. An example of such deliverability is where, in a 2050 energy system, a 10 MW biomethane plant would yield the same decarbonisation as 8000 ASHPs, and would require 45% less subsidy to incentivise the same decarbonising output, at current support prices;
- 3) The expected adoption of electric vehicles (minimum 90% of cars and vans by 2050) alone will require investment to facilitate a resulting compound peak demand growth rate of 5% each 5-year RIIO period until 2050. Therefore, the delivery of further decarbonisation will be made more achievable by leveraging the gas network to achieve compliance, given that a full Electrification compliance scenario yielded an 11% compound peak demand growth rate each 5-year RIIO period until 2050;
- 4) The decarbonisation of heat is a necessary condition for compliance given that current Swindon heat emissions are 15% greater than the 2050 total emissions target. Focusing on low-carbon gas, supported by efficiency improvements and hybrid heat pumps, followed by other measures, is seen as the least disruptive pathway to compliance, given the advantages of leveraging the gas network and the deliverability advantages of supply-driven strategies over demand-driven strategies;
- 5) Integrated demand forecasting between the gas and electricity network will be essential in ensuring reliable supply to the collective energy system. Particularly with reference to gas network diurnal storage – as flexible capacity for electric vehicle charging will dominate gas demand in the summer months, where generation requirements will be determined by the availability of intermittent renewable electricity;
- 6) Consumer choice will play a major role in achieving compliance, given that maximising energy efficiency to the technical upper limit could reduce overall emissions by 28% and optimising electric vehicle charging patterns could reduce additional peak demand by up to 15%. Therefore, incentivisation of consumer

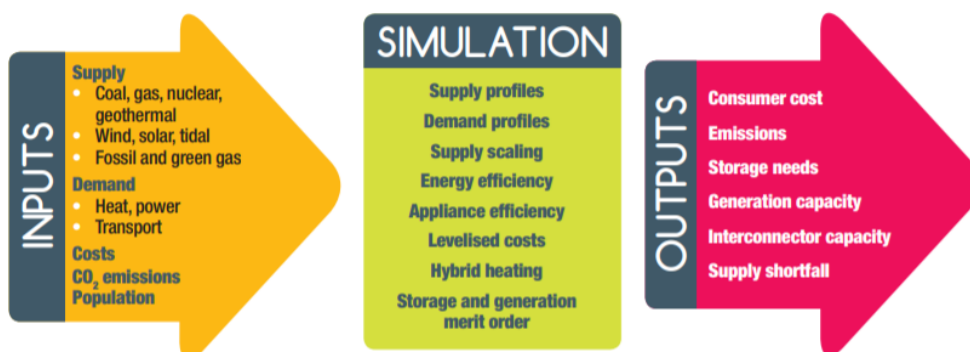
investment will be an important factor in determining the ultimate compliance pathway;

- 7) Based on the scenarios modelled, the average reduction in both annual and peak gas demand by 2050 was 35%, relative to current operation, which is in line with an average reduction of 32% across the National Grid future energy scenarios by 2050¹;
- 8) The main investment foci for the gas network within the SN area should be; facilitation of at least 80 MW of biomethane capacity along with investment in hydrogen transmission infrastructure, as well as investment to reduce opex and ensure a low-cost operation in a reduced utilisation environment;
- 9) Based on the scenarios modelled, the average increase in annual and peak electricity demand by 2050 was 50% and 45% respectively, relative to current operation;
- 10) Annual average electricity generation inertia is forecast to reduce from 70% to 50% by 2050, which is broadly in line with the 2018 National Grid future energy scenarios which on average yield 40% inertia by 2050². The minimum-inertia hour calculated from the scenarios modelled was 20%;
- 11) The main investment foci for the electricity network within the SN area should be; regional investment to facilitate a minimum compound peak growth rate of 5% each 5-year RIIO period, as well as investment to accommodate a much more dynamic system given that the average increase in peak demand change rates was found to be 60%.

3.0 PATHFINDER MODEL

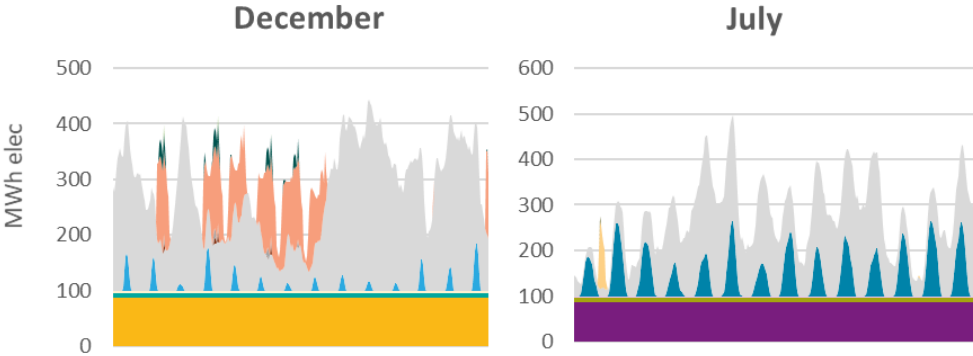
The Pathfinder model was developed by WWU in collaboration with Delta-EE. The model is a highly sophisticated engineering tool which allows the hourly balance of supply and demand across the gas and electricity network to be viewed, over the course of a year. Pathfinder takes account of the direct inputs to, and outputs from, each network, for domestic users, commercial users and any transport. This balancing of supply and demand is carried out predominately within the electricity network, given the large variety of generation sources available. An overview of the model is presented in Figure 3-1.

Figure 3-1: Pathfinder Model Overview



The purpose of the model is to allow the user to understand how both the electricity and gas networks would operate given a defined scenario, along with the interface between the two networks. Pathfinder’s sophistication allows the user to target periods within the year of particular interest, such as the winter months for peak gas demand, or the summer months for peak solar supply. By specifying the periods of interest, Pathfinder will then generate 2-week charts to graphically represent the energy balancing process on an hourly basis. **Error! Reference source not found.** 3-2 provides examples of such charts.

Figure 3-2: Electricity Supply Curves



The outturn results of the model principally indicate the overall emissions arising from the balancing of supply and demand across both networks, and if there are any periods in the year where blackouts could occur due to demand exceeding supply on the electricity network. A basic cost model is also included within the analysis; however, the overarching value in the model is in the technical insight it provides when assessing the system implications of any given energy strategy.

4.0 SWINDON CARBON TARGET

The UK’s total emissions in 1990 were 794 MtCO_{2eq}³, therefore the UK target for emissions in 2050 is 160 MtCO_{2eq} (based on an 80% reduction). The following provides a breakdown of the UK emissions in 1990. There are a number of emissions sources which are unrelated to the scope of calculation within Pathfinder, such as; agricultural emissions; waste management emissions; and land use.

The emissions that Pathfinder models are those associated with:

- 1) Power generation;
- 2) Commercial heat and power;
- 3) Road transport; and
- 4) Domestic heating.

In 1990 the above four categories of emissions totalled 510 MtCO_{2eq}. A compliant 2050 UK scenario, as modelled by Pathfinder, would result in calculated emissions equal to 20% of the 1990 UK figure – 102 MtCO_{2eq}. assuming emissions reductions were spread evenly across the economy in line with the ratio of emissions in 1990.

The carbon target for the SN area in 2050 was formulated by scaling the UK target for Pathfinder emissions (102 MtCO_{2eq}) based on populations and per capita emissions within the SN region.

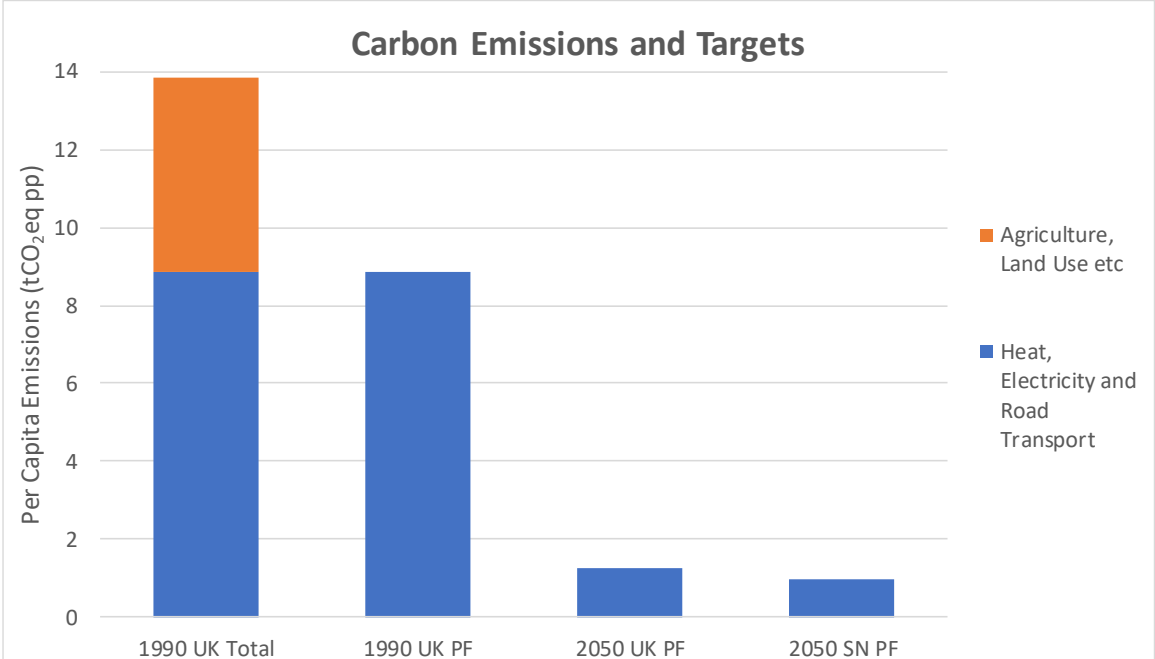
The UK Government (UKG) published in 2014 a review of region emissions from 2005 – 2012⁴. The average emissions from a resident in the SN area over the course of this period, inclusive of transport, domestic and commercial/industrial emissions, was 7.7 tCO₂pp. The average UK residents’ emissions over the same period, based on UKG total emissions data and population figures, was 10 tCO₂pp. Therefore, the per capita emissions over of a resident in the SN area was 77% of the average UK resident. The primary reason for this difference being the lack of heavy industry within the SN area. Data from the 2011 UK census indicates that the proportion of UK nationals living within the SN area was 0.7% of the total population.

The 2050 emissions target for the SN area was calculated using the formula:

$$SN\ Target_{2050} = UK\ Target_{2050} \times Population\ Fraction \times Emissions\ Fraction$$

Figure 4-1 provides a graphical representation of the logic applied to derive the SN area carbon target.

Figure 4-1: SN Area Carbon Target Derivation



The resulting 2050 carbon target for the SN area was therefore found to be 0.55 MtCO_{2eq} given that the per capita target was calculated as 1 tCO_{2eq} and the estimated population of the SN area in 2050 is 0.55 million. The 0.55 MtCO_{2eq} figure was used to determine the success criteria of the scenarios modelled, as it provides a quantitative target to determine compliance of any given scenario for the SN area.

5.0 SCENARIO MAP

The technical tool used to analyse the scenarios modelled was the Pathfinder model. The modelling methodology employed consisted of:

- 1) Defining a reference point for the SN energy system in 2050, based on 2018 National Grid Future Energy Scenario (FES) data⁵;
- 2) Applying a decarbonisation strategy to this reference scenario until compliance was achieved;
- 3) Analysing the calculated actions necessary to achieve compliance from each scenario; followed by,
- 4) Undertaking an overall comparison of necessary conditions for compliance between all scenarios to inform decarbonisation strategy recommendations.

The decarbonisation strategies were defined as being either ‘top down’ supply-driven or ‘bottom up’ demand-driven. Starting with single-vector strategies and incrementally introducing more decarbonisation levers to quantitatively understand the system advantages of applying holistic decarbonisation strategies. The following table outlines the scenarios modelled and their rationale.

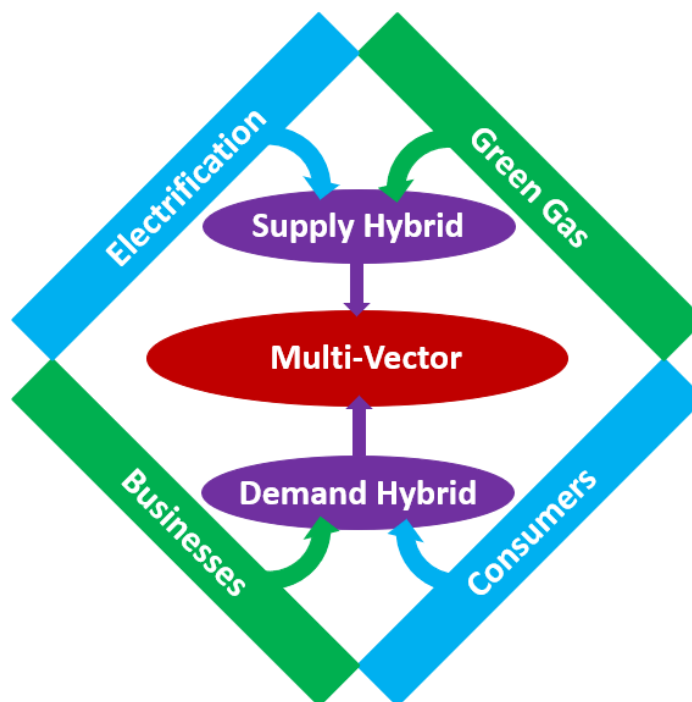
Table 5-1: Scenarios Modelled

Strategy	Scenario	Description
N/A	Reference	Baselining a possible ‘status-quo’ of the SN area in 2050, based on 2018 National Grid FES.
Supply-Driven	Electrification	Achieving compliance by solely leveraging low-carbon electricity use.
Supply-Driven	Green Gas	Achieving compliance by solely leveraging low-carbon gas use.
Supply-Driven	Supply-Hybrid	Achieving compliance by balancing the deployment of low-carbon electricity and low-carbon gas, minimising disruptive impact where possible.
Demand-Driven	Consumer Led	Achieving compliance by consumers taking full ownership via modifying behaviour and personal investment.
Demand-Driven	Business Led	Achieving compliance by businesses taking full ownership via modifying behaviour and investment.

Strategy	Scenario	Description
Demand-Driven	Demand-Hybrid	Achieving compliance by balancing the modification of consumer and business behaviour as well as investment, minimising disruptive impact where possible.
Combined Supply and Demand-Driven	Multi-Vector	Achieving compliance by balancing supply-driven and demand-driven approaches, maximising low-regrets solutions and highlighting engineering trade-offs.

Figure 5-1 demonstrates a conceptual compliance map, with single vector solutions defining the boundary compliance solutions where optimum solutions lie within the map. Analysis of the system implications of each scenario was undertaken once each scenario achieved compliance. The advantage of the reference point scenario was in the fixed nature of the inputs due to them being specified. The modelling principals utilised for the subsequent scenarios to achieve compliance was to select fixed and variable parameters within a given decarbonisation to understand inherent engineering trade-offs.

Figure 5-1: Conceptual Compliance Map

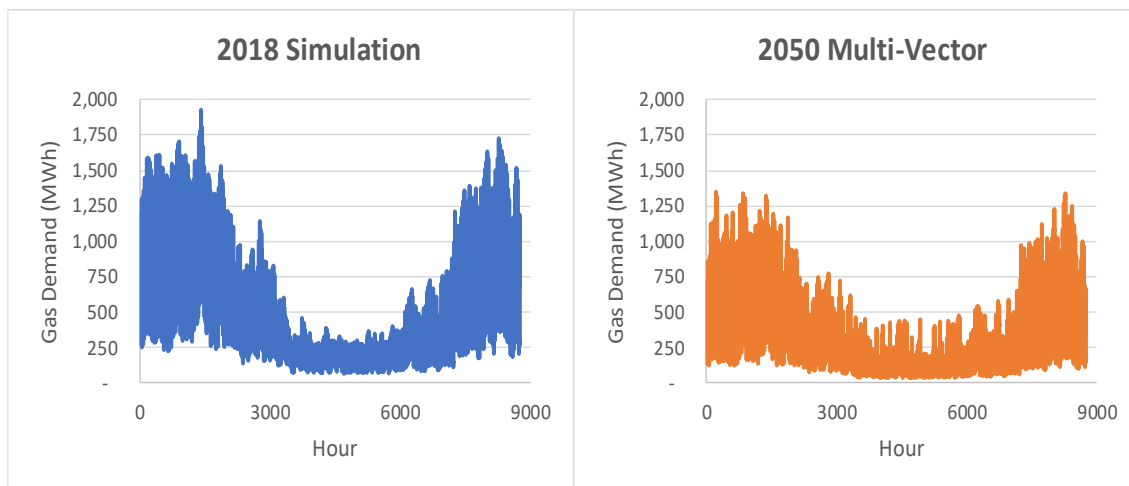


The above diagram provides a graphical visualisation of the technical process undertaken to define each scenario, starting with single-vector solutions and incrementally hybridising to capture more vector options to achieve compliance.

6.0 EXAMPLE SCENARIO OUTPUT

The output of each scenario consisted of a methodical analysis of implications for consumers, both networks, and an investment profile necessary to deliver the scenario. The Multi-Vector scenario will be used as an exemplar to illustrate the technical findings from the scenario modelling. The hourly gas demand profile of the Swindon area that resulted from the Multi-Vector scenario is shown below.

Figure 6-1: Gas Demand (SN Area): Multi-Vector Scenario



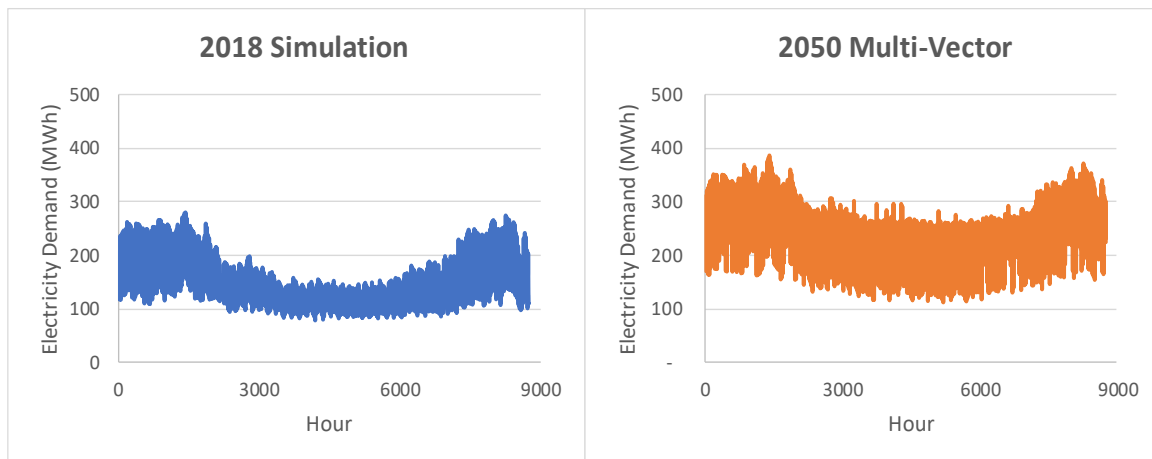
The operational envelope required to achieve the forecast hourly profile can be achieved within the current envelope. The forecast system characteristics that define that envelope, in comparison to today's system characteristics, is provided below.

Table 6-1: Gas Network Operational Metrics

Operational Parameter	2018	2050 (Multi-Vector)	Change (%)
Average Demand (MW)	500	340	- 30%
Peak-hour Demand (MW)	1,920	1,350	- 30%
Peak rate of Change (MW/h)	560	420	- 25%
Average Diurnal Storage (MWh)	1,720	910	- 45%
Average Diurnal Storage (% of daily use)	14%	9%	- 5%

As well as gas demand, electricity demand profiles and implications were equally analysed and understood. The hourly electricity demand profile of the Swindon area that resulted from the Multi-Vector scenario is shown below.

Figure 6-2: Electricity Demand (SN Area): Multi-Vector Scenario



The operational envelope resulting from the above demand profile would require an investment programme to ensure sufficient capacity is available to satisfy the forecast demand. The resulting profile can be characterised by the following key metrics.

Table 6-2: Electricity in Gas Demand (SN Area): Multi-Vector Scenario

Operational Parameter	2018	2050 (Multi-Vector)	Change (%)
Average Demand (MW)	150	230	+ 55%
Peak-hour Demand (MW)	280	390	+ 40%
Peak rate of change (MW/h)	55	90	+ 65%
Annual Inertia	70%	55%	- 20%
Minimum-Hour Inertia	45%	20%	- 55%

Taking the sum total of necessary changes to supply, distribution and use across both the electricity and gas networks within the SN region for the Multi-Vector scenario, compliance targets in 5-year increments can be developed – which align with forthcoming RIIO periods. Based on the Pathfinder model outputs, until 2050 the following targets would need to be met every 5-years within the Swindon area:

- 1) Construction of 55 MW of low-carbon electricity capacity;
- 2) Construction of 20 MW of low-carbon gas capacity;
- 3) Investment to facilitate a 5% compound peak electricity demand growth rate;
- 4) Installation of 3,600 hybrid heating systems; and
- 5) Purchasing of 42,000 electric vehicles.

By providing summarised investment profiles for each scenario, a comparative analysis of deliverability can be undertaken to inform wider policy and optioneering. This quantitative analysis allows the lowest-cost and least disruptive pathway to be understood to provide potential pathways to achieve carbon compliance.

7.0 SCENARIO COMPARISON

The impact of each scenario on consumers is primarily dependent on the nature of the strategy, be it a top-down ‘supply-driven’ strategy or a bottom-up ‘demand-driven’ strategy. The table below summarises the investment required of consumers and businesses within the SN region and necessary lifestyle changes required to achieve compliance. All scenarios included a minimum 19% increase in home efficiency gains and a minimum 90% EV adoption, as these were contained within the reference scenario.

Table 7-1: Scenario Comparison for Gas Network Implications

Compliance Strategy	Technology Investment	Lifestyle Changes
Electrification	60,000 ASHP conversions + 40,000 hybrid installations + 100% adoption of EVs	Adoption of Time of use Tariff (optimise electricity use) + Heating use expectations change due to ASHPs
Green Gas	No technology investment for biomethane + hydrogen blending, or 100% gas boiler replacement for hydrogen conversion	No lifestyle changes
Supply-Hybrid	Between 60,000 – 90,000 ASHP installations (based on stand-alone vs hybrid) + 100% adoption of EVs	Adoption of Time of use Tariff (optimise electricity use) + Heating use expectations change due to ASHPs
Consumer Led	Increase home efficiency gains to 28% technical limit + Installation of energy efficient appliances + 100% adoption of EVs	Adoption of Time of use Tariff (optimise electricity use) + Reduction of home temperatures to between 12 – 15 °C
Business Led	CHP investments + 100% electrification of LGVs + 100% HGV CNG conversion	Energy use reduction of 45% for both gas and electricity
Demand-Hybrid	Increased home efficiency gains to 23.5% + 95% electrification of personal transport and LGVs + 50% HGV CNG conversion	Adoption of Time of use Tariff (optimise electricity use) + Energy use reduction of 25% for both gas and electricity for all consumers + Reduction of home temperatures to between 14 – 16 °C
Multi-Vector	58,000 hybrid installations + 100% adoption of EVs (cars)	Adoption of Time of use Tariff (optimise electricity use) +

Compliance Strategy	Technology Investment	Lifestyle Changes
	and vans) + Conversion to CNG HGVs + Increased CHP usage	Reduction of home temperature to 17 °C + Heating use expectations change due to ASHPs

It is clear from Table 7-1 that the potential impacts for consumers and businesses of decarbonisation is wide ranging. Decarbonisation strategies that rely on consumers to make changes to their lifestyles or invest in technology will require aggregate decision making and are likely to require support mechanisms which allow individual consumers to invest. Any policy which promotes a reduction in home temperatures would need to be balanced with studies to understand the potential implications for consumer health.

The impact on the gas network that results from the decarbonisation strategies reviewed through this study all face in the same direction – reduced average and peak demand. This is primarily due to the assumed increase in home efficiency within each scenario (minimum 19% gains). Clearly if this gain in home efficiency does not materialise then the forecast reduction in gas usage, as per the Pathfinder modelling, would be lower.

Table 7-2: Scenario Comparison for Gas Network Implications

Compliance Strategy	Average Demand (MW)	Peak Demand (MW)	Average Diurnal Storage (MWh)
2018	500	1,920	1,720
Electrification	240	1,140	680
Green Gas	410	1,560	1,140
Supply-Hybrid	300	1,150	770
Consumer Led	250	950	980
Business Led	330	1,230	710
Demand-Hybrid	280	1,100	710
Multi-Vector	340	1,350	910

Table 7-2 indicates that all compliant scenarios result in a reduction of gas demand, however the gas network does not become obsolete. Based on the Pathfinder modelling, both average and peak demand would reduce by 20 – 50% relative to current operation, based on the chosen compliance strategy. Although the absolute quantity of diurnal storage is forecast to reduce, the daily pattern of use is forecast to become much more variable due to overnight charging EVs requiring flexible generation capacity.

The impact on the electricity network supplying the SN region of achieving compliance from each of the strategies is shown below in Table 14-3. Directionally all of the scenarios increase both average and peak demand and reduce the average inertia of generation.

Table 7-3: Scenario Comparison for Electricity Network Implications

Compliance Strategy	Average Demand (MW)	Peak Demand (MW)	Average Inertia (%)	Peak Demand Change increase (%)
2018	150	280	70	N/A
Electrification	300	520	50	170
Green Gas	220	380	50	25
Supply-Hybrid	230	430	53	25
Consumer Led	190	320	50	45
Business Led	210	360	50	55
Demand-Hybrid	210	430	50	25
Multi-Vector	230	390	55	65

There is a high degree of variation in the forecast implications for the electricity network, based on the results presented above. From the output of the Pathfinder model, average electricity demand from the SN region is forecast to increase by 25% – 100%. Strategies that favour ‘decarbonisation through electrification’ have a greater resultant impact on the electricity network. Based on the scenario specific peak demand forecasts, the range of compound peak demand growth rates each RIIO period is 2% – 10% with the Multi-Vector scenario requiring a 5% compound growth rate per 5-year RIIO period.

The average inertia of generation is fairly consistent between scenarios, this is because the generation mixture remains largely unchanged from the reference scenario. The Pathfinder model estimates a reduced average inertia from current operation from 70% to 50%, with the most common minimum-hour inertia of 20%. To accommodate such a reduction in inertia, it is likely that a stability service market would be required to ensure the electricity network remains reliable and stable. The establishment of an inertia/stability market by 2022 has been identified by National Grid ESO as a necessary tool to achieve operation of a zero-carbon electricity network⁶.

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- 1 National Grid. *Future Energy Scenarios – Data Workbook (Tab GD1)*, July 2018
 - 2 National Grid. *Future Energy Scenarios – Data Workbook (Tab 5.2_5.3)*, July 2018
 - 3 Department for Business, Energy & Industrial Strategy. *Final UK greenhouse gas emissions national statistics*, 2016
 - 4 Department of Energy & Climate Change. *UK local authority and regional carbon dioxide emissions national statistics*, June 2014
 - 5 National Grid. *Future Energy Scenarios – Data Workbook*, July 2018
 - 6 National Grid ESO. *Zero Carbon Operation 2025*, April 2019