Science Museum Group

Heat Decarbonisation Plan

28 March 2022

Contents

Table of Tables

Table of Figures

Glossary

Term	Definition
AHU	Air Handling Unit
ASHP	Air Source Heat Pump
BMS	Building Management System
DHW	Domestic Hot Water
eTRV	electronic Thermostatic Radiator Valve
GSHP	Ground Source Heat Pump
GIA	Gross Internal Area
GWh	Gigawatt hour
HDP	Heat Decarbonisation Plan
HVAC	Heating, Ventilation and Air Conditioning
kWh	Kilowatt-hour
LTHW	Low Temperature Hot Water
NCC	National Collections Centre
NRM	National railway museum
NSMM	National Science & Media Museum
PPA	Power Purchase Agreement
PV	Photo Voltaic
PIR	Passive Infrared Sensor
POU	Point Of Use water heater
REGO	Renewable Energy Guarantees of Origin
SM	Science Museum
SMG	Science Museum Group
SIM	Science & Industry Museum
tCO_2	Tonne of carbon dioxide
UKGBC	UK Green Building Council
WHB	Wash Hand Basin

1 Science Museum Group Plan on a Page

The target set for zero carbon across the Science Museum Group is 2033. To achieve this, significant investment is required over the coming years.

The delivery of the proposed pathway will require dedicated internal resource and significant long-term planning. As decarbonisation projects begin, the next tranche of buildings should be planned and financed. The energy saving priorities set out here will assist in generating this prioritisation.

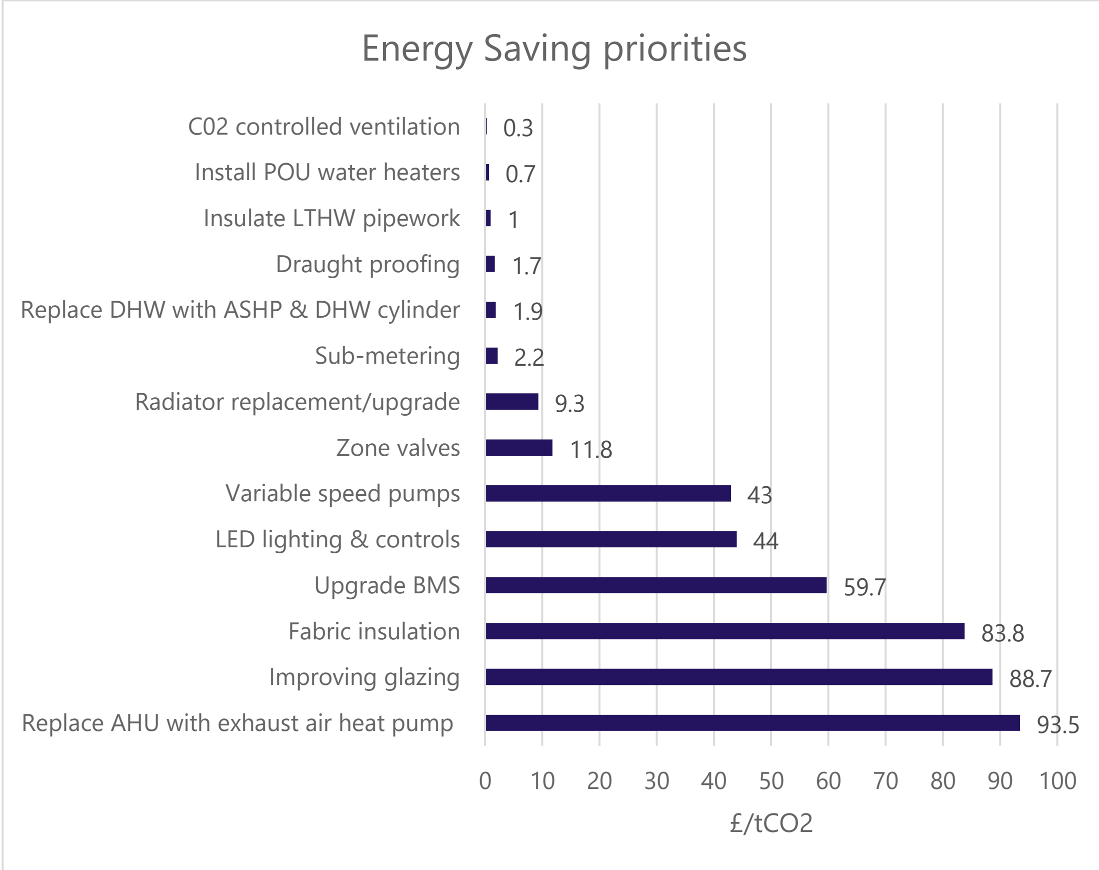
Emissions projections do not reach zero by 2033 because not all gas fired boilers are expected to have reached the end of their life by then. A carbon offset payment will therefore be necessary.

Existing Estate Summary	SMG
Number of buildings	56
Total annual energy consumption (kWh)	26,369,251
Total annual carbon emissions (tCO_2)	4,265

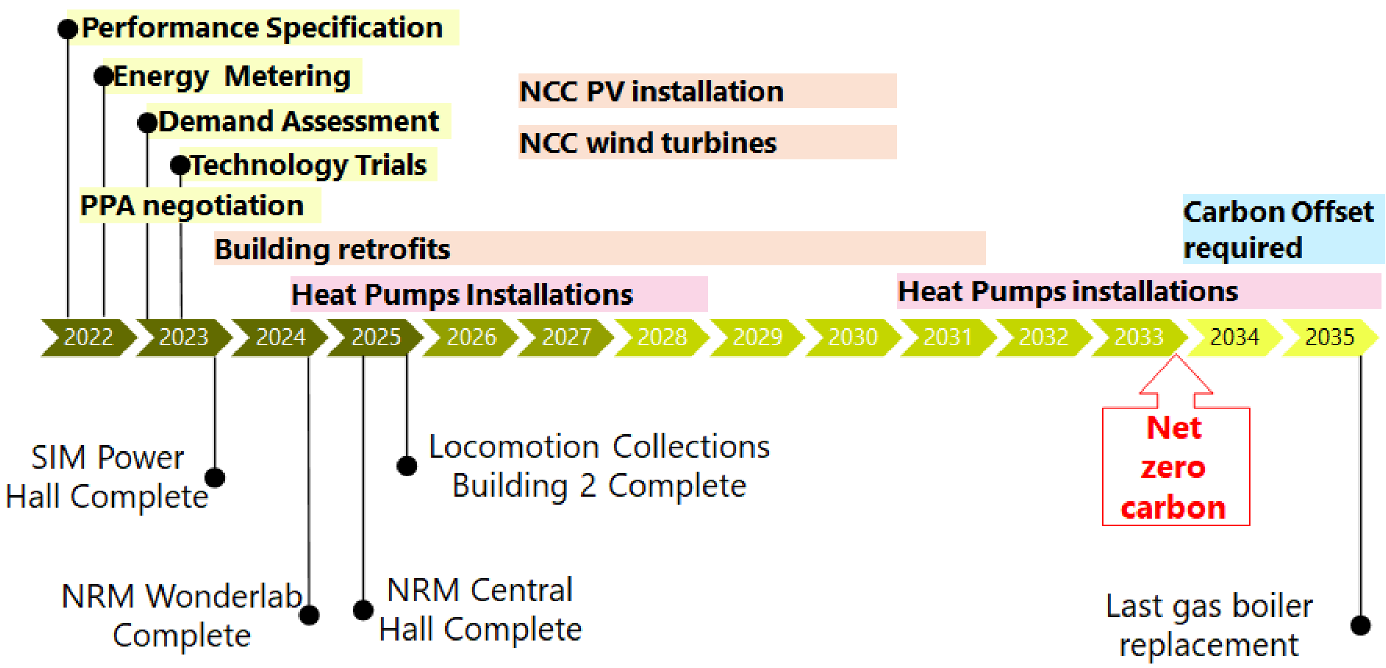
Potential Decarbonisation Projects	SMG
Total carbon saving per annum (tCO_2)	4,101
Total capital cost	£94.9M
Estimated energy consumption intensity reduction by 2033	34%
Potential site based renewable electricity generation	100%

Detailed Short Term Action Plan

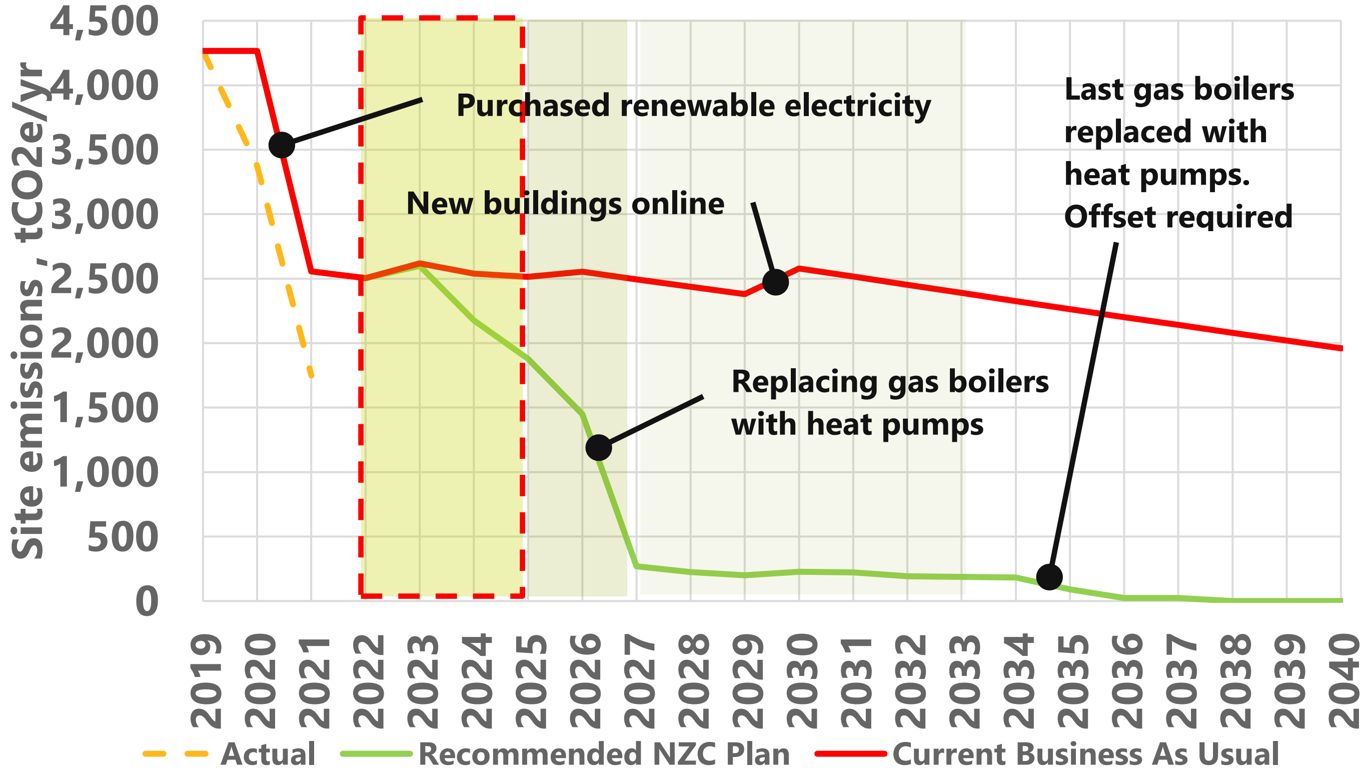
- Review and amend performance specification for building projects
- Create a common performance specification for BMS and controls
- Create a common submetering and energy consumption monitoring specification
- Start the process for negotiation of an SMG Power Purchase Agreement
- Support site heating/cooling demand assessment
- Establish trials for evaluating the potential of new technology.



Energy Action Plan Timeline



Science Museum Group carbon emission projections (tCO2e/yr)



2 Introduction

2.1 Purpose

The purpose of this Heat Decarbonisation Plan is to overview the decarbonisation pathways set out for the portfolio of buildings owned by the Science Museum Group. This plan will align with the decarbonisation targets set by the Science Museum Group as well as the targets of the UK government. This overview will be occupied by specific frameworks which will be adopted by the sites owned by SMG to guide and structure future investment on the site such that the carbon targets can be achieved.

This energy decarbonisation overview describes the state of the SMG's current energy use and its plans for reducing and/ or decarbonising it further. The plan outlines what SMG has already done, what it is currently doing, and what it plans to do in the future. The plan explains what actions are going to be taken, over what timescales, and the intended outcomes.

Energy efficiency improvements have been identified and are in line with the following themes

- Accurate recording of building energy consumption breakdown requiring building sub-meters and an automatic data collection system accessed remotely. This will help to firm up the potential energy savings identified where assumptions had to be made and enable actual energy savings to be quantified.
- Appropriate control of building plant to maintain comfort only during building occupancy. The ability to monitor comfort and operate plant remotely using smart building controls has been identified as important in making any operational and setpoint adjustment savings permanent as well as enabling proactive maintenance.
- Energy saving measures have been identified that reduce both necessary installed system capacity and annual energy consumption have focussed first on improving the building fabric where possible as although on their own they usually result in relatively long paybacks; they enable heat decarbonising technologies to be introduced in future at a lower cost as well as enabling them to operate more efficiently.
- Finally, the retrofit of LED lighting and renewable energy technologies (ASHPs, GSHPs, Solar Thermal and PV) have been identified to complete the decarbonisation and energy efficient changes.

This report focuses on scope 1 and 2 emissions and does not account for scope 3 emissions. And follows the UKGBCs route to Net Zero Carbon.

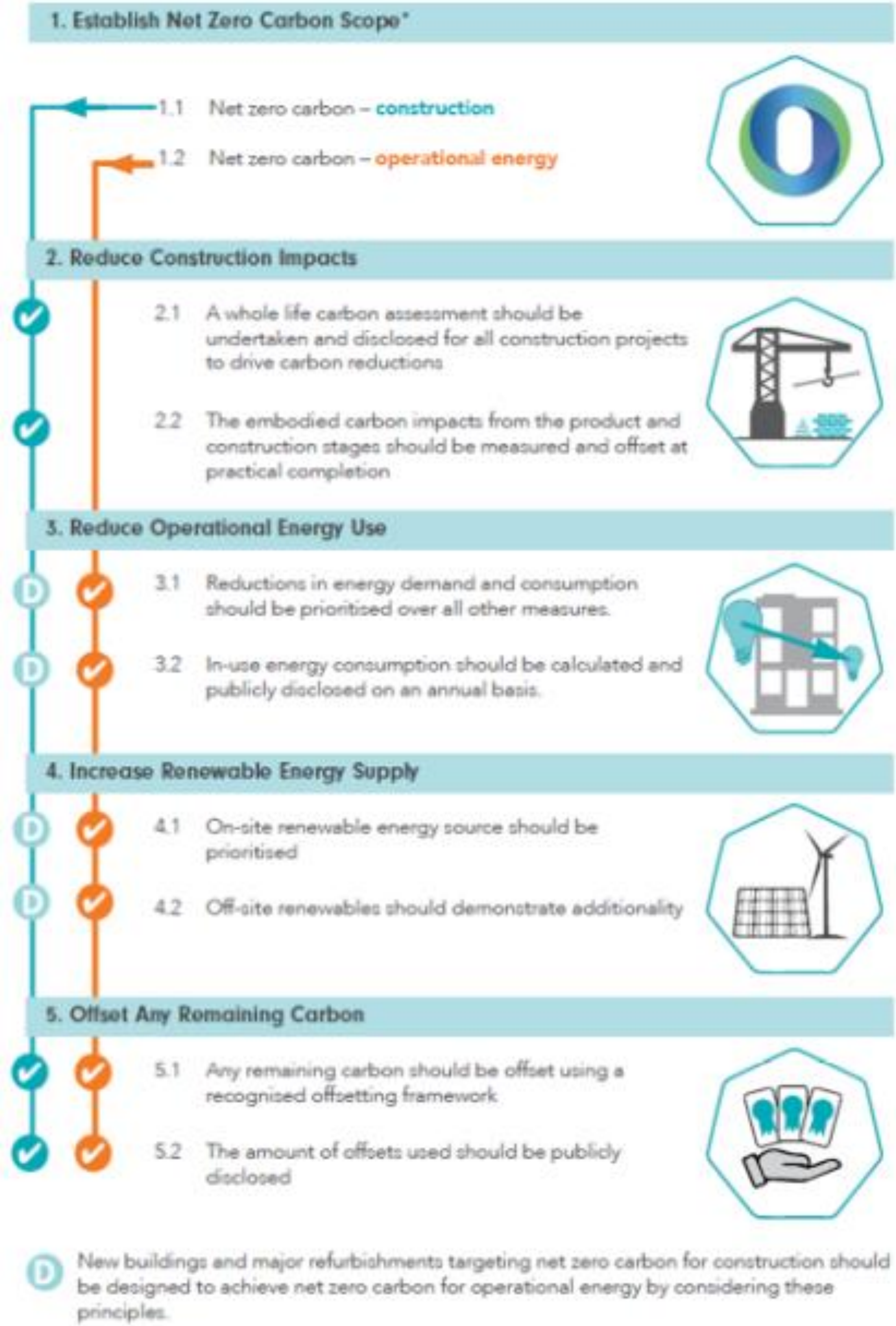


Figure 2—1 –UKGBC route to Net Zero Carbon

2.2 Context

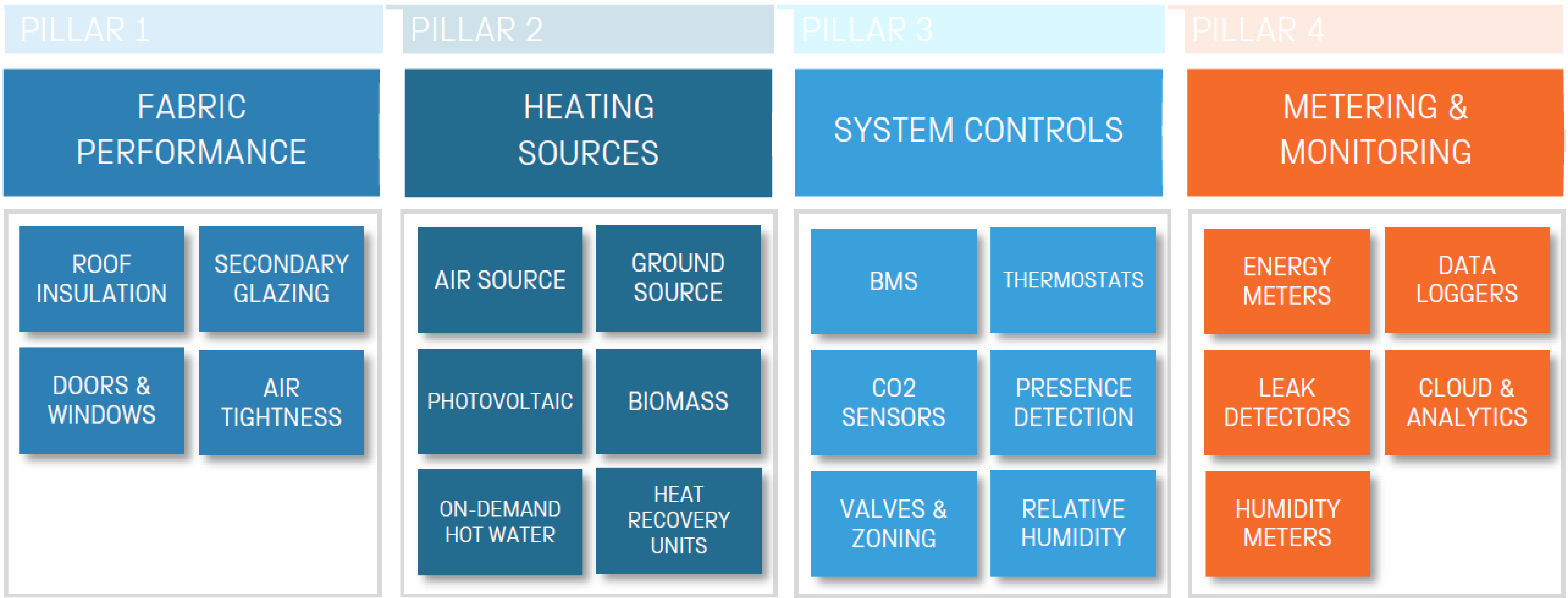
The UK government targets are to achieve net zero carbon by 2050, with an interim target of achieving 78% reduction by 2035 (vs. 1990 baseline levels). Both of these targets are legally binding.

The Science Museum Group Net Zero Carbon Strategy has the following key objectives:

- Develop and design a decarbonisation scheme covering all building services for each site which aligns with the attributes of the buildings present and the strategic masterplan for the site as a whole. This will be delivered no later than July 2022 and identified by the presence of the schemes themselves.
- Develop a funding strategy for decarbonisation which aligns with masterplan programmes, estate capital programmes, estate asset management plans and external funding opportunities such as net-zero and DCMS grant in aid. This will be delivered no later than September 2022 and identified by the presence of the strategy itself.
- Reduce the level of energy consumption against the 2019 benchmark on a per kWh per m2 basis. Targeting a 20% reduction by 2033 and confirmed by measuring the total energy (kWh) consumed by SMG against the total size of the estate (GIA).
- Increase the level of local renewable energy generated on site as a percentage of the overall per kWh energy consumed by the estate and as a percentage of the electrical energy purchased (sustainable or otherwise). Target 20% of energy consumption to be met from local renewables for the estate. This will be confirmed by comparing the total kWh consumed from local renewables as a percentage of the overall kWh consumed.
- Work with the estate term maintenance provider to reduce the level of Scope 3 emissions attributed to the estate from this and other supply contracts. Target a reduction of 15% in these emissions by 2033. This will be confirmed by measuring the total carbon emissions (CO_2e) for estate operational expenditure in 2032/33 in comparison to 2021/22 levels.
- Achieve a position of net-zero carbon for the operation of the Estate by 2033. This will be confirmed by measuring the total carbon emissions for the Estate (Scope 1, 2 and 3 emission data) inclusive of any applicable carbon offsetting for the 2032/33 financial year.

SMG is creating a site wide masterplan for energy and carbon reduction and focuses on four key pillars:

- Fabric performance
- Heating sources
- Systems controls
- Metering and monitoring



3 Your Heat Decarbonisation Plan

The Science Museum Group Heat Decarbonisation Plan consists of an Estate Heat Decarbonisation Plan (this report) and a separate Local Energy Action Plan with supporting site audit report for each of the six sites.

Table 3—1 Plan summary

	Heat Decarbonisation Plan	Local Energy Action Plan	Site Audit
Formal	PDF Report (this report)	PDF Report	PDF Report
Purpose	Provides a summary of the Heat Decarbonisation Plan covering the whole estate setting out projections of emissions, energy consumption, and operational cost against an outline investment projection to deliver the SMG sustainable objectives.	To guide and structure future investment in each site such that the site carbon and energy objectives can be achieved. This sets out an action plan for the next 12 years at the time of writing and thus provide a point-in-time assessment. The plan provides direction as to the order in which improvement measures should be prioritised. The implementation of the Local Action Plan will change in response to the development of collections and exhibitions.	To provide a record of the site audit for reference from the Local Action Plan
How to use	This plan is intended to allow the SMG to have oversight of and support the local team's delivery of the plan.	The plan is intended to allow each site to plan investment going forward. A short, medium, and long-term strategy can be developed using this plan as a starting point.	As a reference for each energy saving measure identified.

3.1 Resourcing

The Science Museum Group will be ultimately responsible for overseeing and delivering the decarbonisation plan. The roles and responsibilities at central and local level are shown below.

Oversight
- Sustainabilty Manager - Steering role for the plans, reporting on carbon and providing support to the Estates Manager to deliver the plans.

Local Energy Action Plan Delivery
- Estates Manager - Ownership of providing energy consumption data and context for trends identified, with support from the Sustainability Manager. Site knowledge to inform projects.

Project Delivery
- Projects Team - Delivery and resourcing for project implementation.

Support
- Local Action Plans (by Sustainability Guiding Groups)
- Net Zero Carbon Committee

3.2 Key Challenges

The key challenges for delivery of the plan are expected to be:

- Allocation of resilient and consistent resource to manage the process
- Allocation of sufficient resource to plan and deliver required decarbonisation projects through design, procurement, and delivery
- Availability of revenue for the required works, from feasibility studies, to design, procurement, and installation
- Collection of accurate information regards the performance of existing buildings
- Generation of accurate information regards the prediction of post project building performance
- Electrical utility infrastructure to enable the move to electricity powered heat pumps and support the export of renewable energy generation. It is understood that extensive upgrades will be required by the electricity utility at the National Collections Centre
- Negotiating a Power Purchase Agreement to allow generation of electricity for the whole estate from the National Collections Centre

3.3 Governance

The Site Heat Decarbonisation Plans are documents commissioned by the Director of Estate Operations, following a successful bid to the SALIX 2 fund. Accordingly, both the Group and Local plans are owned and managed by Estate Operations.

Delivery of the plans is a collaborative endeavour making use of a number of existing SMG committees and groups including: the Masterplan and Estate Committee, Estate Program Board, Masterplan Review Group, SMG Net Zero Committee, Project Review Group and Site Sustainability Groups.

Large scale infrastructure works will be governed under Masterplan Estate Committee and delivered through Estate Program Board

3.4 Funding and finance models

The decarbonisation of buildings requires significant investment. The required level of capital investment to achieve the carbon savings required are described within this report, with the intention that this will inform planned investment and management of available funds going forward.

There are currently a number of different models for financing decarbonisation projects, which aim to remove some of the financial barriers to decarbonisation.

- Innovation Loans
- Public Sector Decarbonisation Scheme (PSDS) - The PSDS scheme provides grants for public sector bodies to fund heat decarbonisation and energy efficiency measures. The scheme aims to support the public sector in taking a 'whole building' approach when decarbonising their estates. The next round of funding is anticipated in …, which is expected to be heat led and will not fund feasibility studies.
- Invest to Save
- Energy Performance Contracts
- 3rd party building based PV installations

4 Approach to decarbonising your estate

4.1 The Process

It is important when considering decarbonisation of buildings, to ensure that efforts are made to reduce energy consumption of buildings prior to introducing active decarbonisation technologies such as heat pumps or photovoltaic panels, as shown in the following diagram.

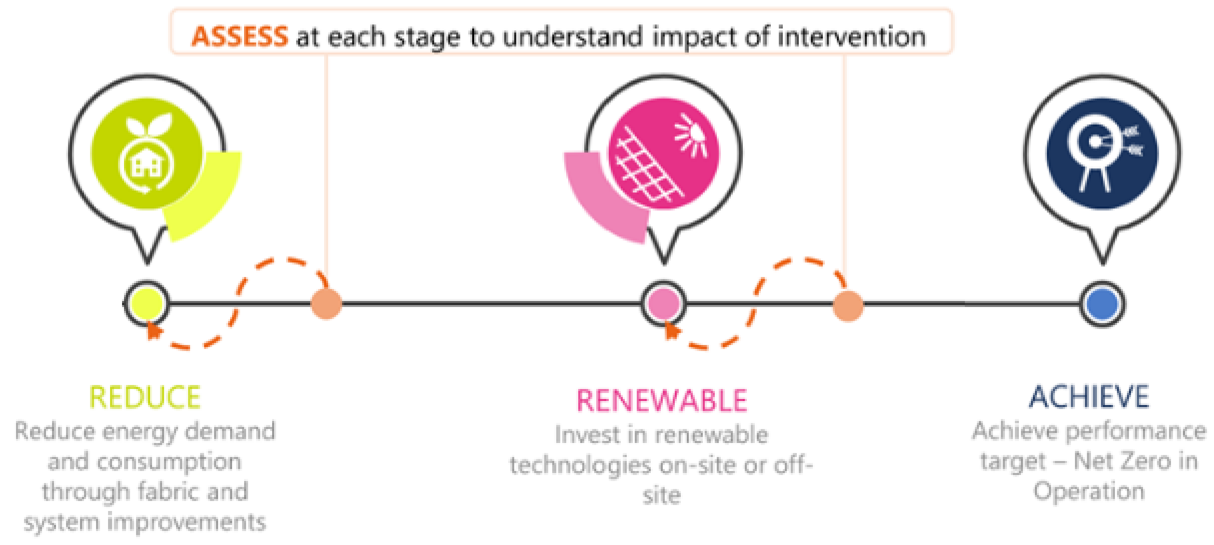


Figure 4—1 Process to Net Zero

Reduce operational energy supply

Following initial operational energy assessment, where energy demand can be reduced, it should be. This can be done through a number of intervention measures such as:

- Improve fabric efficiencies, thereby reducing building loads. This could be done by, for example, applying insulated cladding to the walls or replacing single glazing with double glazing to reduce heating demands.
- Improve system efficiencies such as reducing heating systems water temperature, utilising heat recovery in the ventilation system and increasing lighting efficiencies where possible. Any of these interventions will reduce the energy demands of the building.

Increase renewable energy supply

Once the building is functioning as leanly as possible carbon emissions can be further reduced through:

- Removing systems that directly utilise fossil fuels as a heat or DHW source (gas boilers, gas fired calorifiers) and replace with electrical or hydrogen powered systems.
- Connection to low carbon heat network (if available).
- On-site renewable technologies that directly feed the building thereby reducing the buildings metered consumption. Note PV generation could be implemented independently of "reduce" measures, but it is recommended to prioritise "reduce" measures where possible.
- Off-site renewable installations on other SMG sites with a portion of their electricity generated 'delivered' to site via a PPA and offset emissions associated with the building.

Naturally all these options have spatial impact and as such renewable technology implementation should be carefully coordinated.

4.2 Achieve

To report on building performance and ensure a building is operating as efficiently as it should be, it is important to ensure that the energy consumption and generation of a building is monitored. This requires sufficient metering within the building services systems to allow monitoring of, as a minimum, the following performance criteria

Type of data	Description
Contextual data	• Update of GIA (m^2), if necessary
Building energy use	• Grid electricity consumption (kWh) • Gas consumption (kWh) • Other fuels consumption (kWh) • District heating/cooling consumption(kWh) (if applicable)
Renewable energy	• Renewable electricity generation (gross) (kWh) • Solar thermal heat generation (kWh) • Renewable electricity exported (kWh) • Renewable electricity used on site (kWh)
Energy storage equipment	• Battery storage capacity (kWh) • Net electricity flow to EVs (kWh)
Plant parameters (Energy exported)	• District heating energy exported (kWh) • District cooling energy exported (kWh)

4.3 Decarbonisation measures

For the purposes of this decarbonisation plan, the decarbonisation measures have been categorised as shown in the table below.

Categorisation of measures		Example of measures	Challenges and constraints
Reduce **(Energy Efficiency Measures)**	**Fabric**	Improving fabric and air tightness within a building improves energy efficiency reducing energy requirement. Interventions required can include: • Wall insulation applied externally as either a render or cladding system, or internally behind dry lining • Insulation under timber suspended ground floors • Roof insulation between and above rafters on traditional tiled roofs during roof renewal, adding insulation on top of concrete roofs before refurbishment of waterproofing • Replacing single glazing with double or secondary glazing Draught stripping of existing windows and doors. A building air leakage test can identify air leakage paths	Listed buildings prove a particular challenge, as any significant aesthetic change to the building (i.e. external cladding) will be rejected at planning. Older buildings typically benefit greatly from draught proofing and adding additional insulation where possible. When reducing air infiltration in buildings it is important to consider the ventilation requirements for occupants that may require the introduction of mechanical ventilation with heat recovery, see Building Services and Controls.
	Building services and controls	Heating: • Improving pipework insulation on LTHW and DHW systems • Providing variable speed pumping and replace 3 port with 2 port valve control to reduce water circulated around the building • Increase the size of all heat emitters including radiators, AHU coils, unit heaters and door heaters to accommodate lower flow temperature • Adding zone valves and electronic thermostatic radiator valves to improve control of space temperatures and allow heating to be turned off in rooms that are not being used Ventilation: • CO_2 controlled ventilation systems so that they respond to varied levels of occupancy minimising heat demand in winter and fan energy consumption all year Utilising exhaust air heat pump AHUs to reduce loads on central heating systems recovering additional heat that would otherwise be wasted	
	Controls and BMS	It is common for a building to either not have a central Building Management System, or for that system to be poorly commissioned. It important that, prior to installation of new HVAC equipment, the systems operate at their maximum efficiency. This could be achieved by installation of BMS for more complex buildings or utilising smart controls systems for smaller buildings with simple systems.	Constraints can be upgrading or interfacing with an old or obsolete BMS system. Specification of a new or upgraded BMS system therefore important and must be carried out by a controls specialist.
	Lighting	LED lighting is commonly installed as a quick and effective means of improving lighting efficiency when compared to traditional incandescent or compact fluorescent light bulbs. Lighting control should be considered at the same time as lighting upgrades. These typically include: • Daylight control to lights adjacent to glazing and under rooflights. Where it is important that lights are seen to be on, dimming to a minimum level rather than switching off would be appropriate • Presence detection in public circulation and toilets as well as for cleaning lights in exhibition spaces Consider absence detection in small offices and meeting rooms	LED drivers will be required to achieve required voltage, and lighting redesign may be required to ensure consistent and uniform light levels.
	Energy monitoring	Monitoring and targeting systems for buildings allow the user to operate their buildings efficiently by interrogating how energy is used in a building. This is successfully done using systems independent of a BMS.	Meters need to be calibrated and verified so that they can be relied on. Data must be stored so that it is not lost. It also requires responsibility to be assigned.
Renewable **(Heat decarbonisation plan)**	**Decarbonisation of heat**	Typically, this will involve the replacement of exiting gas fired boilers with heat pumps. This enables the shift away from direct combustion of fossil fuels in lieu of a decarbonising electrical grid. Heat pump systems are typically defined by the heat source, such as air source, ground source or water source. Heat pumps fed from ground and water sources are more efficient than those utilising outside air because water temperatures are higher than air temperatures in winter when heat demand is greatest Domestic hot water decarbonisation will involve the replacement of LTHW and direct gas fired water cylinders with either point of use electric water heaters when hot water demands are low, or Air or water source heat pumps feeding hot water cylinders.	Delivery temperature on conventional heat pumps is limited to around 60°C, although high temperature heat pumps are available, they are less efficient. I Existing radiators and heating coils are usually sized on water temperatures to 80oC. Significant building fabric insulation improvements and/or replacement of heat emitters sized for a maximum water temperature of no more than 50ºC are necessary. Space for heat extraction will be required, be it air, ground or water source. Constraints of existing electrical infrastructure capacity is also a typical constraint
	Photovoltaics	PV provides a scalable and cost-effective means of generating renewable electricity on site which would displace consumption of grid electricity. It can be implemented independently of other measures. On some buildings it is possible to install PV that can generate excess electricity in excess of the building demand and an export agreement would be required to benefit from this. There would also be the potential to arrange an SMG Group PPA agreement enabling the excess electricity generated to benefit other SMG sites	Photovoltaics provide a mature and scalable technology option to generate renewable energy on site. Key constraints include the condition of the roof (if roof mounted) which must be assessed by a structural engineer during feasibility. Any installation should be completed after any viable roof insulation works. The integration with the existing electrical LV system and an export contract with the electricity supplier is also important
	Infrastructure	An upgrade in electrical infrastructure may be required when heat supply is electrified. This is due to the increased demand on the building electrical supply when, for example, a gas boiler is switched out for a heat pump.	Infrastructure upgrades can be costly and take time. Early engagement with the DNO is recommended

5 Site Portfolio Summary

5.1 Overview of the Portfolio

The Science Museum Group consists of six sites in the UK containing around 56 buildings.

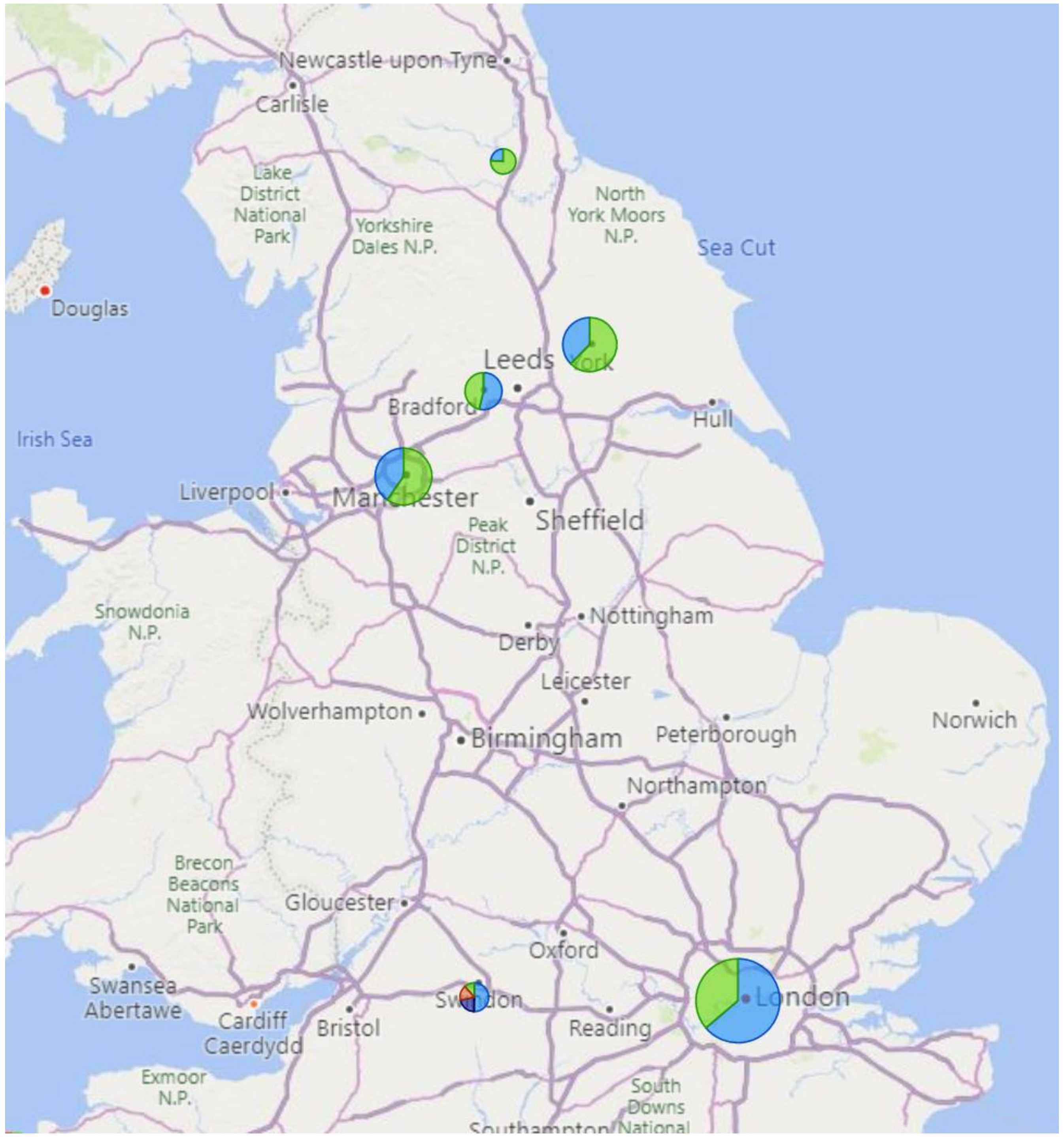


Figure 5—1 Energy consumption by location

In 2019/20 the SMG consumed 13GWh of electricity, 12.6GWh of gas, 0.32 GWh of oil and 0.25GWh of wood pellets. Nearly 40% was from the Science Museum, and around 20% for the Science and Industry Museum and the National Railway Museum.

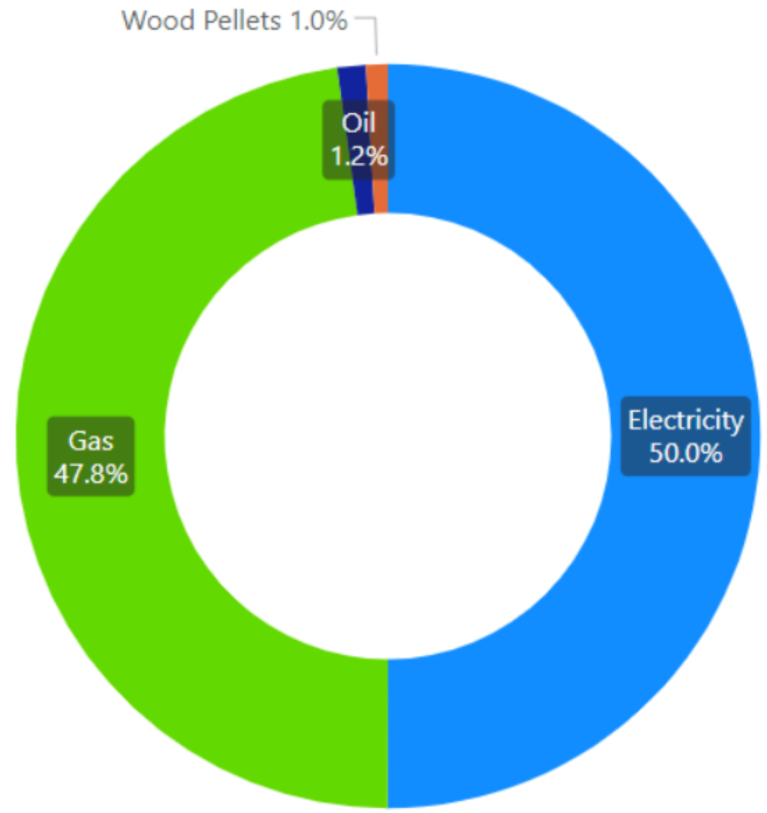


Figure 5—2 Fuel type breakdown for Science Museum Group

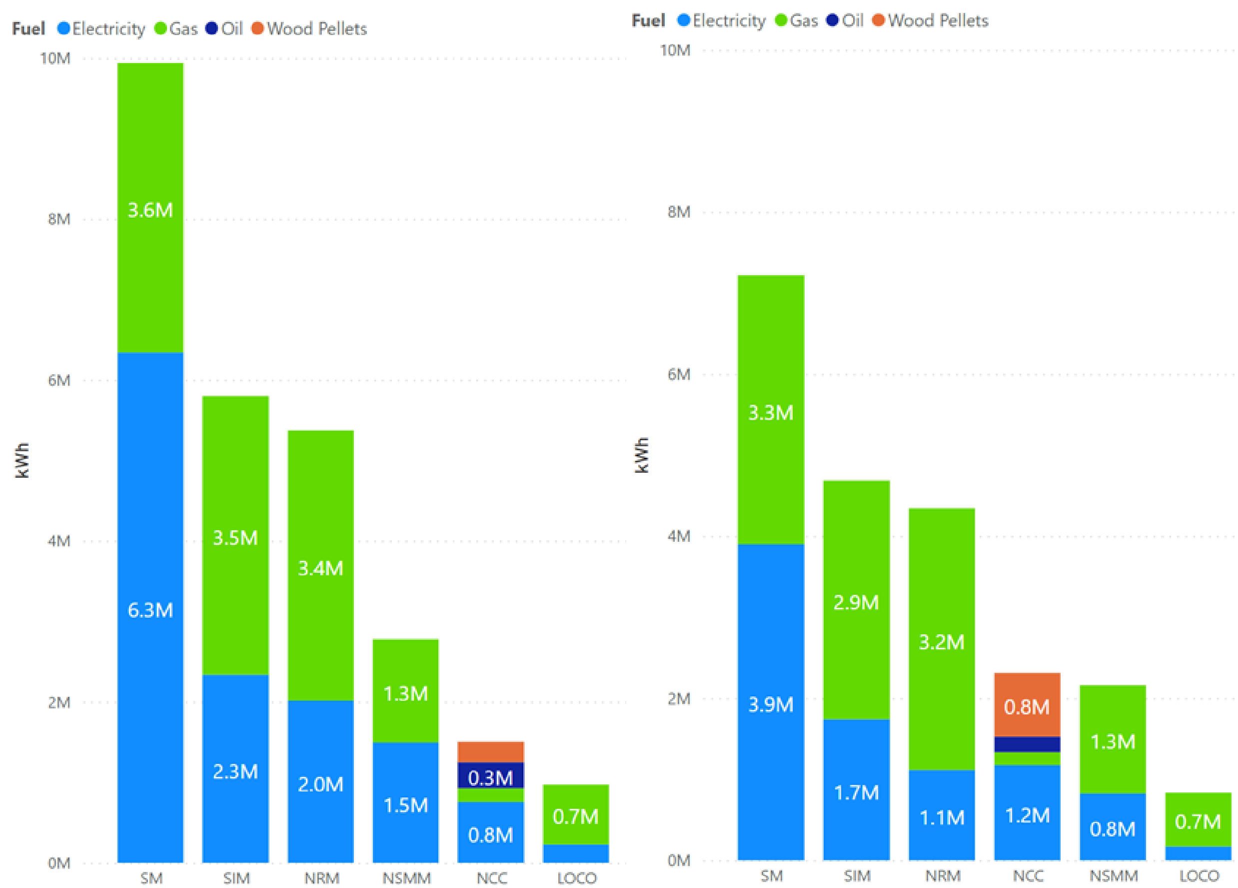


Figure 5—3 A comparison of fuel breakdowns for 2019/2020 to 2020/2021

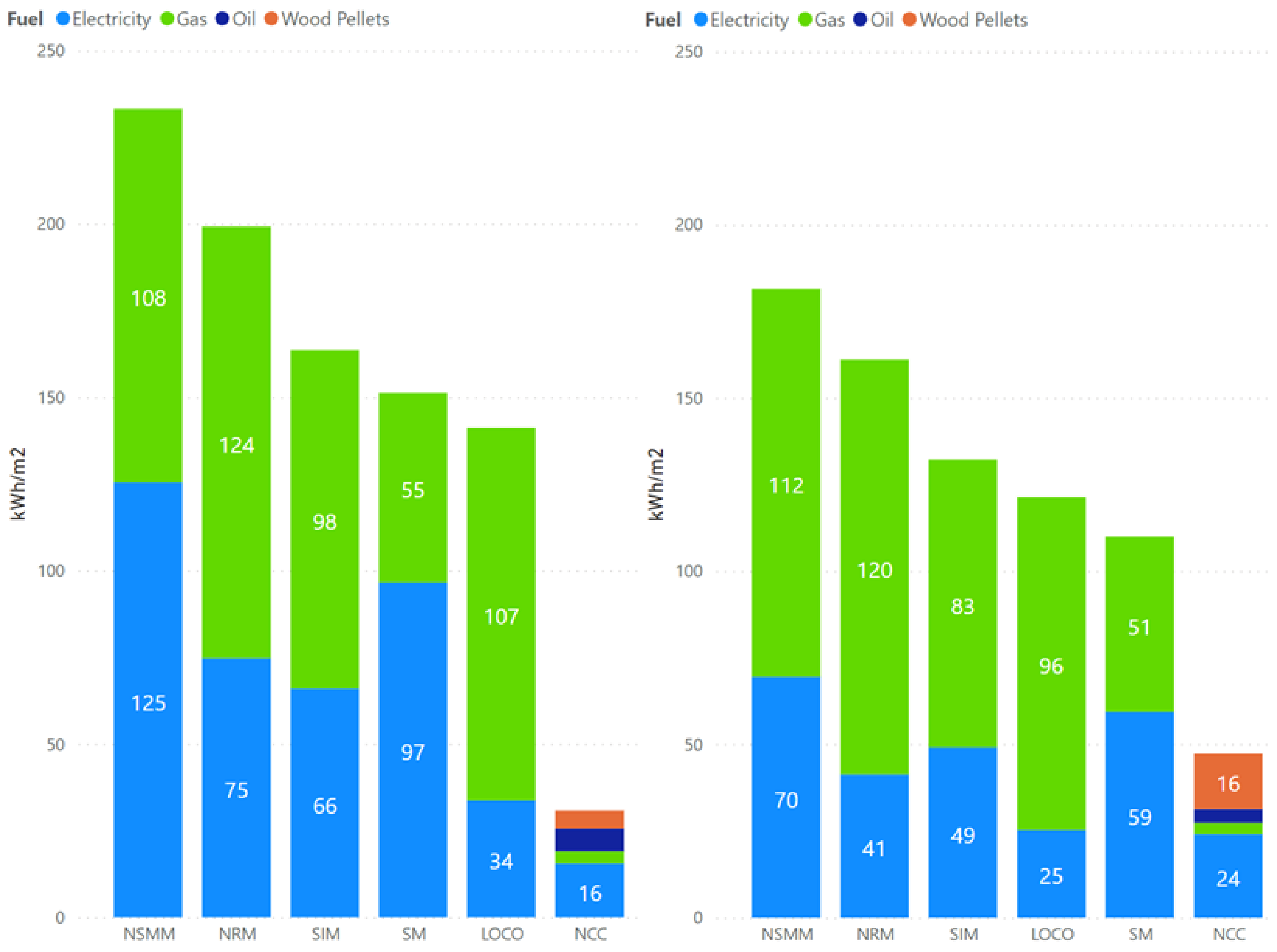


Figure 5—4 A energy use site comparison for kWh/m2 from 2019/2020 to 2020/2021

The energy consumption intensity was greatest at the National Science and Media Museum closely followed by the National Railway Museum. The lowest and increasing due to the recent addition of the conditioned Building One was the National Collections Centre.

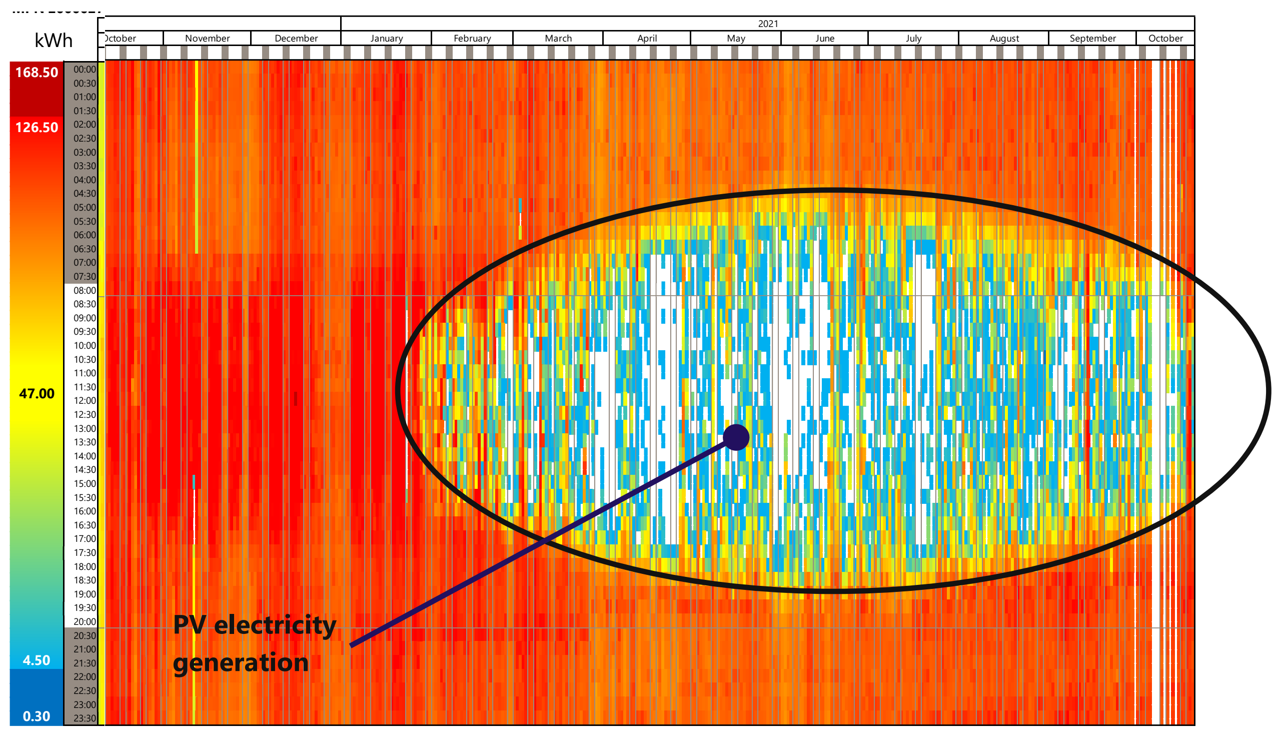
All buildings perform better than the average 270kWh/m^2 for Cultural Activities buildings in the UK. This is not unexpected particularly for the large volume buildings with heating only requirements.

5.2 Renewable energy generation

Currently roof mounted PV and a wind turbine generate about 1% of the estate electricity consumption.

Table 5—1 Schedule of renewable energy generators

Site	Generator	Notes
Shildon	Collections Building PV	Old PV array with several failed panels. Electricity generated unknown. Electricity generation evident on HH utility meter data.
	Free standing wind turbine	Old wind turbine that required maintenance and is likely to be beyond its economic life
Science Museum, London	PV integrated into atrium rooflights	Unknown electricity generation
	Roof mounted PV	Unknown electricity generation
National Collections Centre	Building One	1048kWp array generating significant electricity with regular export of electricity in summer during the day.
	Red Gate Security Building	Small PV array. Unknown electricity generation



Quality of data provided

For the heat decarbonisation plan to be reflective of the energy consumption of the portfolio, it is important that the data used is accurate and representative. As only site total energy consumption was provided the buildings and consumption data on individual buildings was varied assumption have been made generally on an area weighted basis.

The key to the success of operating energy efficient buildings is with recording and analysing the utility energy consumption of each building as well as the breakdown of energy use of HVAC systems, lighting, and exhibit power within each building. It is recognised that some data is available, particularly on the newer buildings and there was a lack of data on the older buildings. This is not uncommon for buildings in the UK.

In support of Pillar 4 Metering and Monitoring, it is recommended that a common outline specification is developed for all new developments and refurbishments that identifies what is metered and how the data must be collated and reported to support the Estates and Sustainability Managers.

5.3 Recent Development

The following major projects have been recently implemented or are underway across the group:

- National Collections Centre Building One completed in September 2020
- Museum of Science & Industry Power Hall refurbishment and heat decarbonisation due to be completed in 2022
- Vision 2025 second collections building at Shildon due for completion in 2023, and Central Hall and Wonderlab at the National Railway Museum due for completion by 2025

5.4 Future Development

The buildings listed below show the current planned decarbonisation projects. These are projects for which a funding application is already underway, or design/enabling works has begun.

- BMS, and metering and energy management performance specification

6 Opportunity and strategy evaluation

6.1 Building retrofit options list

Each building on each site has been audited to identify energy saving opportunities and routes to heat decarbonisation. The details are contained within each site's Local Energy Action Plan. The following opportunities common across the portfolio have been identified.

6.1.1 Pillar 1 – Fabric Performance

The main opportunities around improving fabric performance were to reduce unwanted infiltration and to upgrade roof insulation associated with the large volume spaces housing exhibits. Consideration to adopting Passivhaus and Enerphit principles on all new and existing developments for a fabric first approach is recommended.

It has been recognised that a Passivhaus approach has been adopted on the design of the new Central Hall at the National Railway Museum.

6.1.2 Pillar 2 – Heat (and cooling) sources

The key to Pillar 2 is to reduce demand on central heating and cooling systems and minimise the size and cost of installing heat pumps. This requires the increase in size of radiators, convectors, unit heaters, and AHU heating coils. Where extensive fabric insulation improvements and unwanted infiltration can be reduced, increase in heat emitters may not be necessary.

Heating

Reducing system LTHW temperatures is the one most important energy saving measure that can be implemented. If LTHW return temperatures to gas fired condensing boilers can be reduced to less than 55ºC at least a 10% reduction in gas consumption can be realised.

DHW

Building commonly have central direct gas fired domestic hot water cylinders or fed with LTHW from gas fired boilers generating the building heating. These have large storage volumes and long secondary circulation pipework that are often operated 24/7 and attract large heat losses.

It is recommended that all DHW cylinder cold water feeds are metered so that the volume and usage pattern can be established. This will enable the most energy efficient system to be adopted.

Electric water heaters generating hot water at the point of use removes most of the system losses associated with central systems and are cheaper to run when DHW demand is low. It is recommended that this approach is adopted

If DHW usage is large the use of a standalone CO_2 air source heat pump with storage cylinder is recommended.

Exhaust air heat pump air handling units providing mechanical fresh air ventilation

Where fresh air for occupants is provided mechanically by AHUs the air is heated by either direct gas fired within the AHU or indirectly via LTHW heating coils generated by gas fired boilers. Cooling is sometimes provided by chilled water or DX cooling. Heat recovery can be provided by plate heat exchangers or thermal wheels.

An alternative approach would be to extract heat from the exhaust air to heat the incoming air using a heat pump. This can also be reversed in summer to cool the warmer outside fresh air. This would remove the need for gas, LTHW, or CHW connections to the air handling units. Figure 6—1 shows the typical operating temperatures delivered by the AHUs in summer and winter. Working in conjunction with thermal wheel or plate heat exchanger heat recovery seasonal efficiencies for heating can exceed 800% and 600% for cooling and reduce energy costs. This system can be used where central ventilation systems are not providing individual room temperature control, for instance where there are room radiators, fan coil units, VRF heating and cooling.

If this unit was to be used to serve spaces that have local room-based heating and /or cooling, or close control this would remove demand from the central building heating and cooling systems and minimise the cost of decarbonising the central plant.

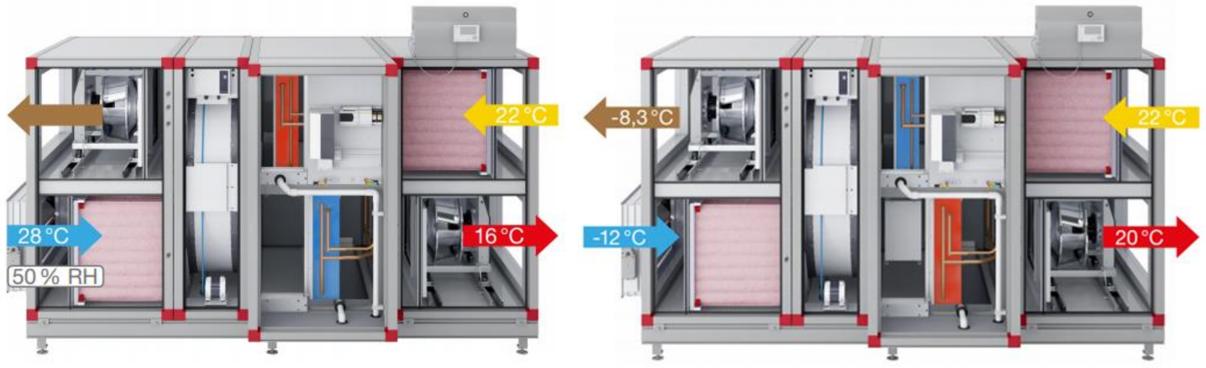


Figure 6—1 Exhaust air heat pump AHU operating in summer (left) and winter (right)

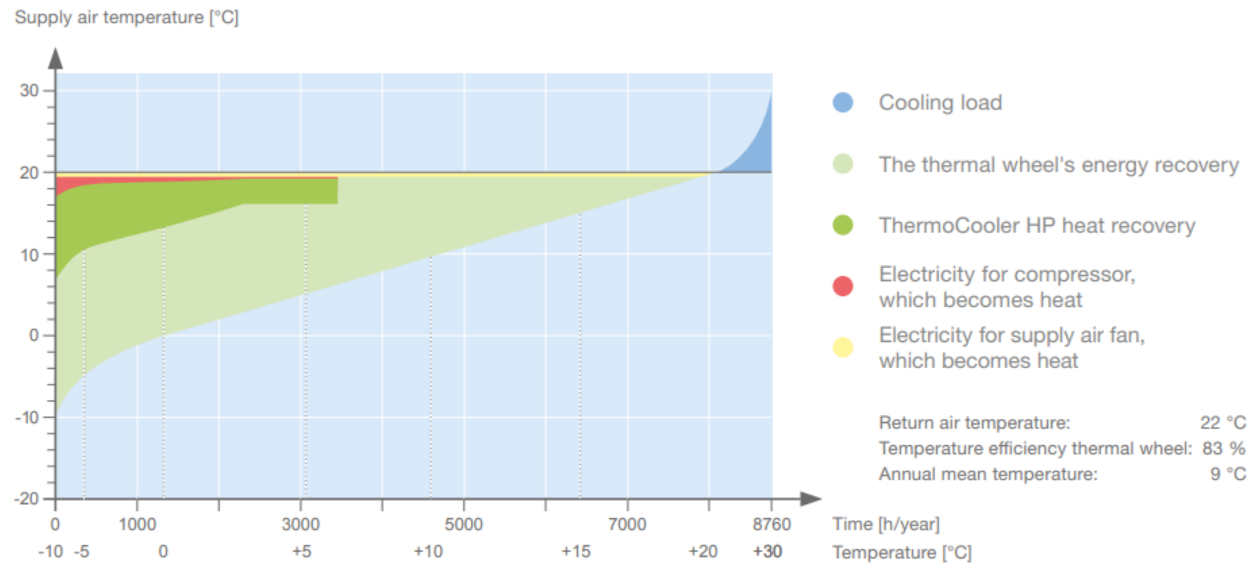


Figure 6—2 Exhaust air heat pump AHU typical performance

6.1.3 Pillar 3 – Systems Controls

BMS

There are a number of different BMS systems applied across the six sites, some being very old ad no longer supported and others up to date. There is an opportunity to upgrade existing BMS systems with an up-to-date system one with integral fault diagnostics. It is recommended that a new SMG controls and BMS standard is developed to enable the remote monitoring and operation of the building mechanical systems.

Small building with heaving only systems generally have simple standalone controls. It is recommended they are upgraded to a smart system similar to Nest or Hive that allows remote monitoring and control of the building mechanical systems and where necessary linking in with the BMS systems on larger buildings.

Lighting

The following lighting and controls strategy is recommended. Upgrade all remaining fluorescent display and general lighting to LED and introduce the following lighting controls strategy:

- Daylight control throughout to benefit from rooflights and perimeter glazing
- Install presence detection for maintenance lighting out of usual operation hours in any exhibit spaces
- Install presence detection in all toilets and circulation and absence detection in small offices, meeting rooms, and where individuals can take responsibility for their lighting.

6.1.4 Pillar 4 - Metering & Monitoring

To identify how energy is used across the estate it is important to establish the current gas and electricity consumption of each building. On sites with only a single metered utility supply that is connected to a number of individual buildings sub meters for each building is recommended.

For the larger building further sub metering of heating, cooling, humidification, DHW, HVAC, lighting, exhibit power, data, and lifts is advised. These categories may consist of several individual meters that can be summed virtually to establish the energy consumption associated with each category. Energy meters measuring heating and cooling demand together with fuel input will allow the seasonal efficiency of each system to be calculated.

When consumption of a particular category exceeds the expected consumption, it is then possible to drill down to individual meters to identify necessary operational changes. With an intelligent system these processes can be automated, and reporting can highlight specific plant to be investigated allowing responsive building management.

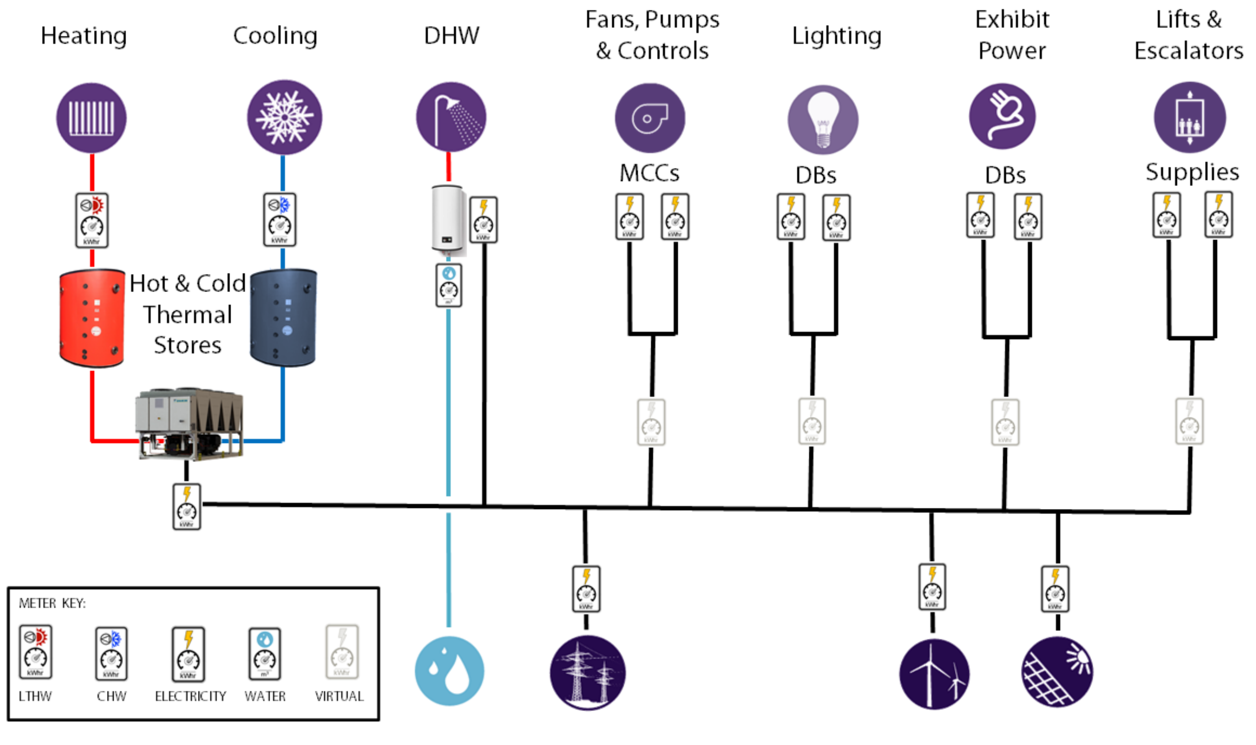


Figure 6—3 Example metering strategy

6.2 Heat Decarbonisation strategy

Geothermal Heating

There is potential for geothermal heating in limited parts of the UK, most notably in Cornwall. As they do not coincide with any of the SMG sites it is not considered further.

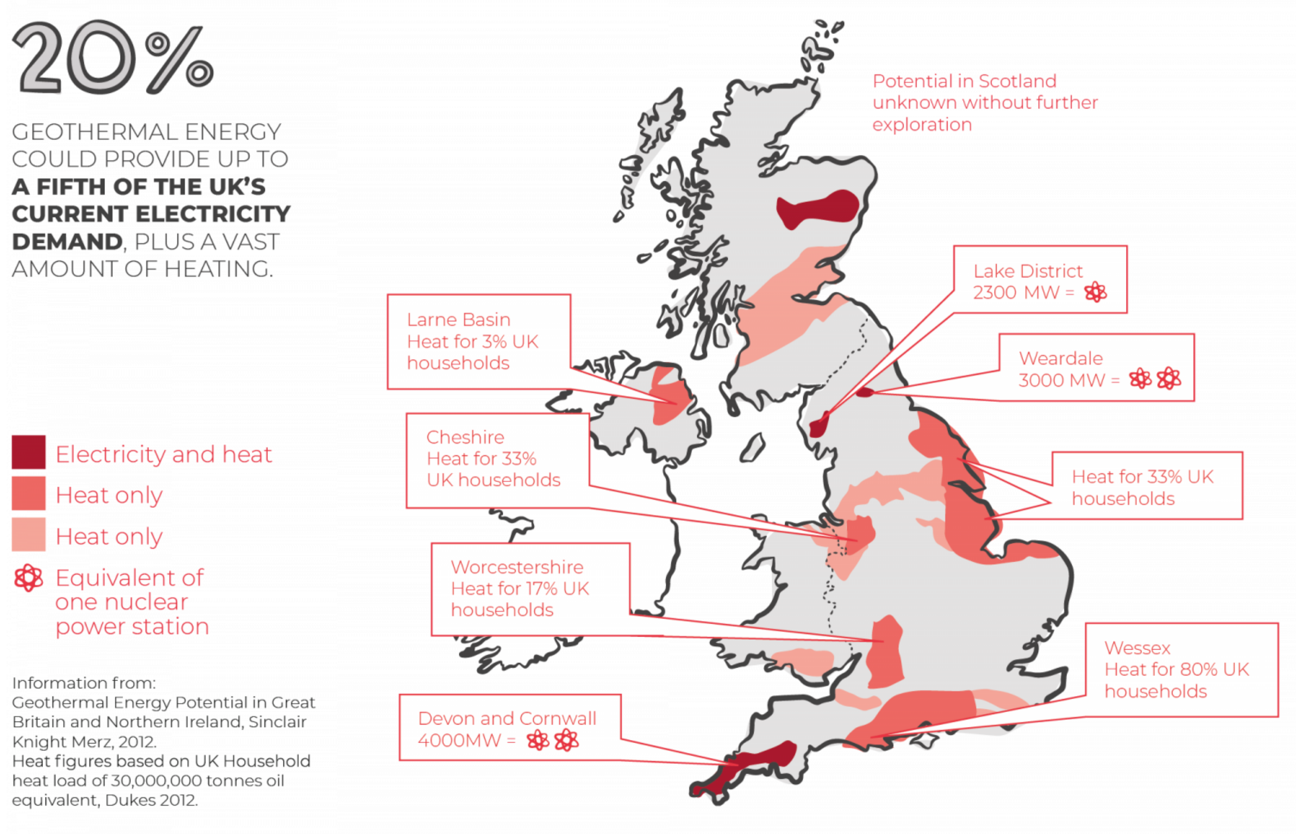


Figure 6—4 UKs geothermal resource

Heat Pumps

The key to a successful heat decarbonisation strategy utilising heat pumps is to establish the annual demand profile for both heating and cooling and design a system that incorporates appropriately sizes plant including:

- Hot and cold thermal stores to decouple demand from generation
- Heat Pumps that satisfy simultaneous heating and cooling demands
- Reverse cycle heat pumps to deliver peak heating and cooling demands in winter and summer respectively
- Utilise open loop boreholes (SIM) and cooling towers (SM) for free cooling
- Utilise vertical ground arrays as a source of heat for heat pumps in preference to air as a source because they are more efficient because of the higher source temperature although they do attract a higher capital cost.

For each location a desktop study has been undertaken to identify the potential for open and closed loop vertical boreholes as a source for heat pumps. All sites were favourable, some with limitations and can be compared with the Science and Industry Museum where open loop boreholes are currently being installed. The remaining sites and would benefit a more detailed study to identify their potential.

Table 6—1 Potential for ground source heat pump installations

Location	Bedrock Aquifer Potential	Depth to source (m)	Protected areas	GSHP Viability
Science Museum	Concealed aquifer at depth	50-100	No designations	Favourable
National Collections Centre	Good aquifer (>6l/s) at outcrop, concealed aquifer at depth	<=50	Site contains a Source Protection Zone	Favourable for closed loop boreholes Open loop boreholes may be limited by adjacency to a SPZ Archaeology may limit extent of vertical boreholes and would preclude horizontal arrays
Locomotion	Moderate aquifer (1-6l/s) at outcrop	<=50	Close to a Source Protection Zone	Favourable for closed loop vertical boreholes Open loop boreholes may be limited by abstraction capacity and adjacency to a SPZ
National Science & Media Museum	Good aquifer (>6l/s) at outcrop	<=50	No designations	Favourable for open and closed loop vertical boreholes
National Railway Museum	Good aquifer (>6l/s) at outcrop	<=50	No designations	Favourable for open and closed loop vertical boreholes
Science & Industry Museum	Good aquifer (>6l/s) at outcrop	<=50	No designations	Favourable Open loop boreholes currently being installed. Low flow rates require additional boreholes

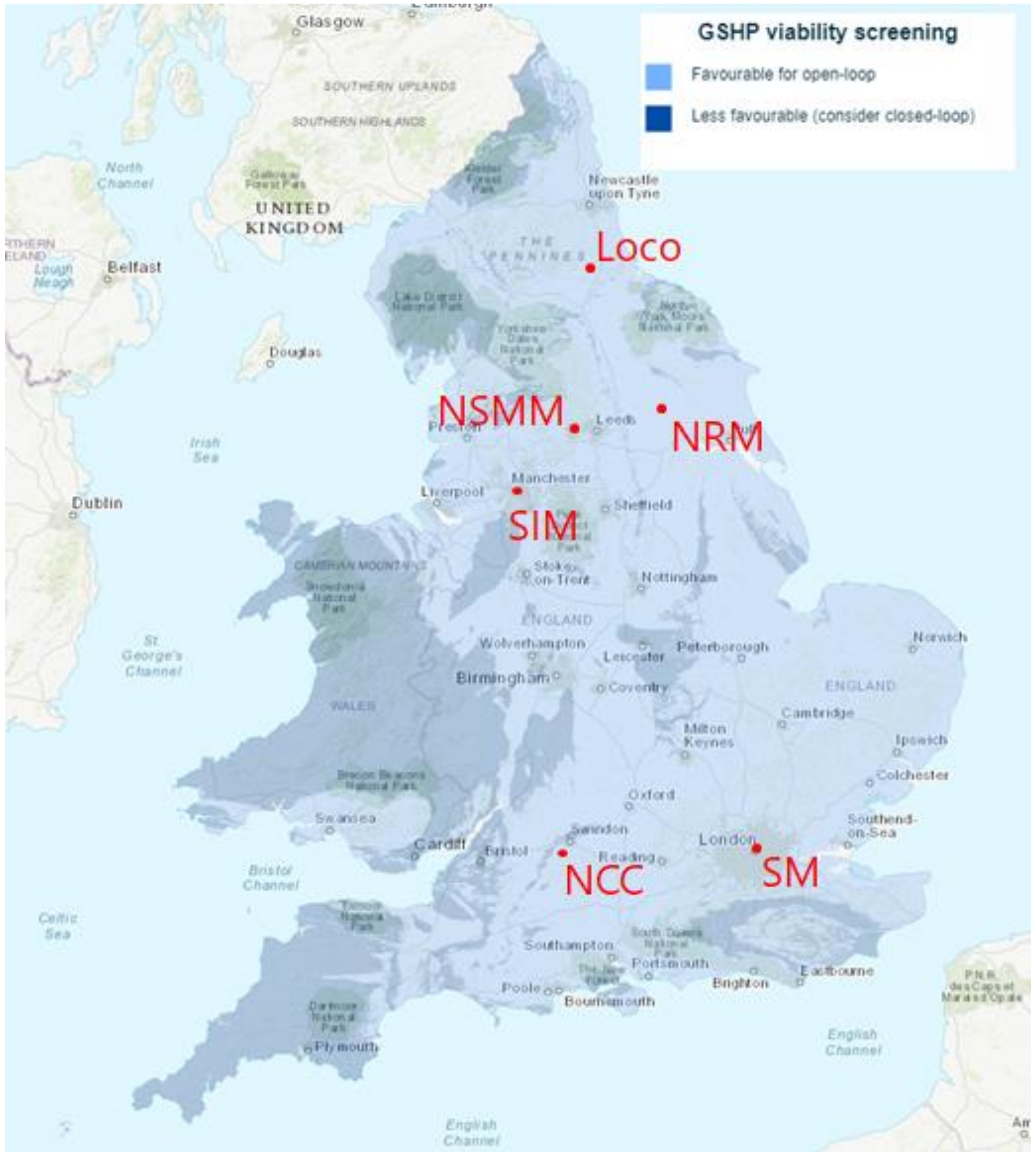


Figure 6—5 Potential for ground source heat pump installations

District Heating

The potential to serve buildings from district heating networks are being investigated in many city centre locations in the UK and can come in a range of forms. 2nd and 3rd Generation systems are based on the use of gas fired CHP with backup from gas fired boilers which can have very high carbon emission factors. Others utilise waste heat from waste incineration again with backup from gas fired boilers. These systems do have very high carbon emission factors so would not address the goal of decarbonisation even if they stack up financially.

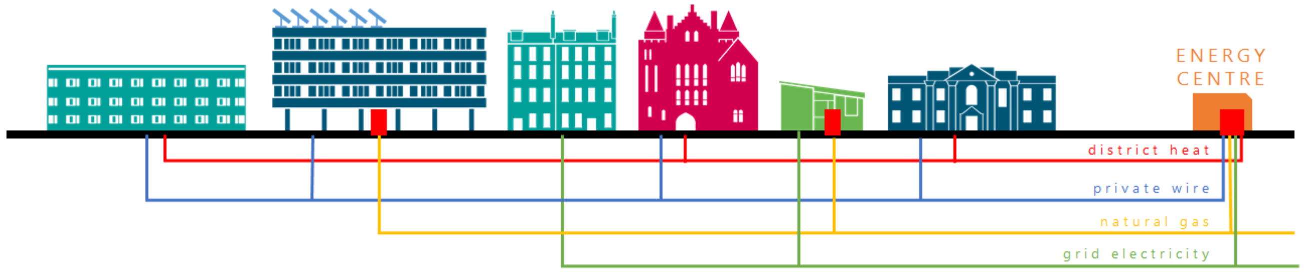


Figure 6—6 Typical district heating network

More recent 4th Generation systems being designed do use air or water source heat pumps; however, they do incur a penalty on efficiency with the relatively high network water temperatures and higher operating costs. They are also usually backed up by gas fired boilers.

The idea 5th Generation system would be an ambient loop with building-based heat pumps to boost water temperatures allows heat recovery between buildings.

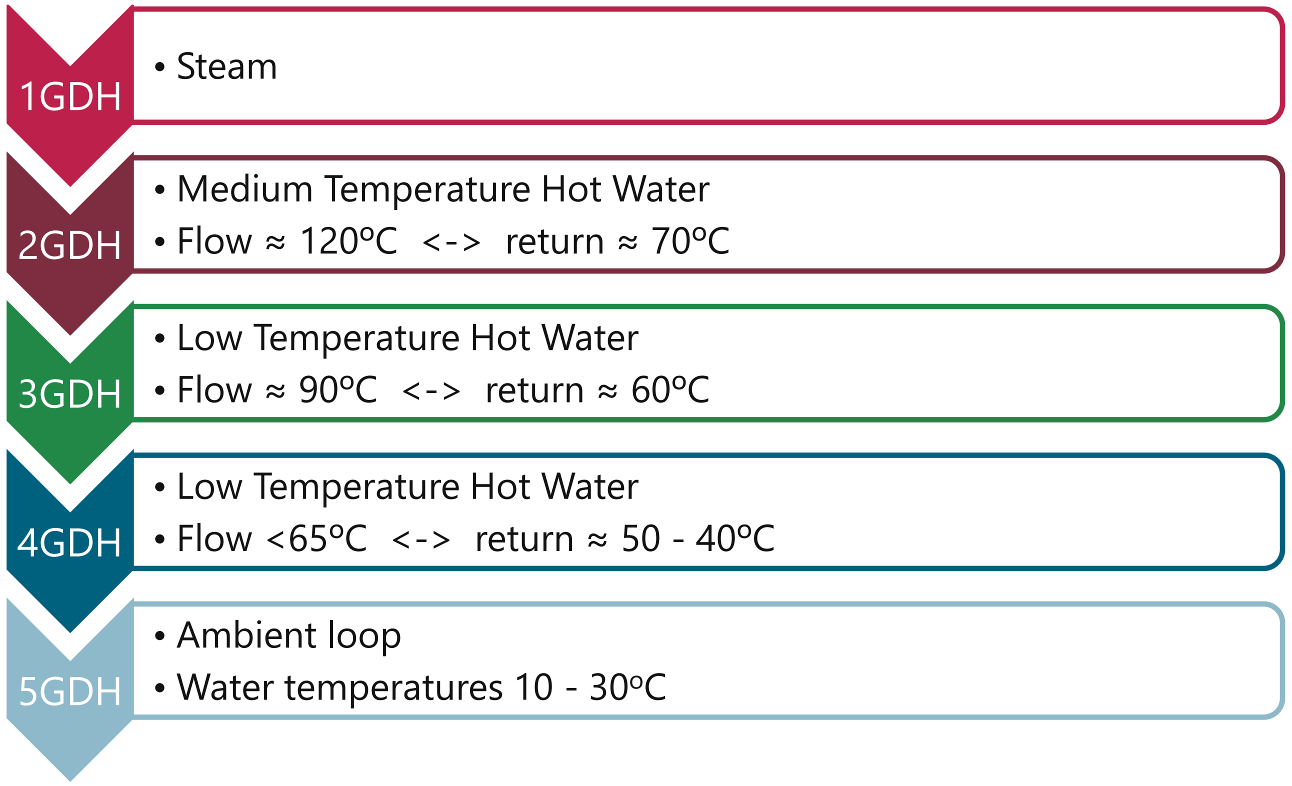


Figure 6—7 District heating classification

There are plans for major investment in a district heating network in Bradford with a plan to bring some initial buildings online in 2023 and being available to most buildings around Jacobs Well from 2024. Provided the CO2 emission factor for the heat generation is low and there is strategy in place for it to fully decarbonise by 2033 it should be considered as a heat source when heat recovery from cooling heat rejection is not sufficient. Future district heating connection opportunities could also be possible in York and London.

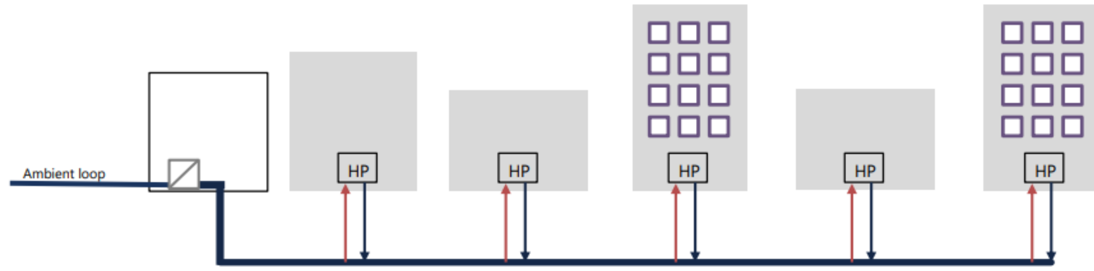


Figure 6—8 Typical 5th Generation Ambient Loop network

Hydrogen

Currently the potential to use hydrogen as a direct replacement for natural gas is in its infancy and is currently considered as the best approach for large industrial consumers of natural gas and has not been considered further. An analysis of the potential for using hydrogen can be found in Appendix E.

6.3 Renewable energy

6.3.1 PV

PV technology has matured as a technology and given accessible and unshaded roof space with sufficient structural capacity can provide significant benefits.

The available roofs within the science Museum estate that are suitable for PV installation have been identified that has the potential to generate between 20 and 37% of the likely projected future electricity demand of the estate.

Risks associated with roof PV installations include assessment of the structural capacity of roofs, provision of safe access for maintenance, and in some cases planning permission. These issues can be overcome by installing a ground-based PV array at the National Collections Centre to generate electricity for the whole estate.

Estate	Annual Generation (MWh)		Notes
	Minimum	Maximum	
Locomotion, Shildon	153	161	Additional capacity may be difficult to install on the Welcome Building roof
Science & Industry Museum, Manchester	307	331	Permission to install and provide safe access on some roofs may limit potential installed capacity
National Science & Media Museum, Bradford	200	350	Roof space is at a premium for heat pumps which would need to take precedence on this site
Science Museum, London	82	134	Providing safe access may limit potential installed capacity
National Railway Museum, York	390	430	Providing safe access may limit potential installed capacity
National Collection Centre, Swindon	2,600	4,300	On buildings roofs. Significant additional area available as a ground array as a cheaper alternative to roof mounted arrays
Total	**3,732**	**5,706**	

6.3.2 Wind

Figure 6—9 Wind farm installation near Swindon

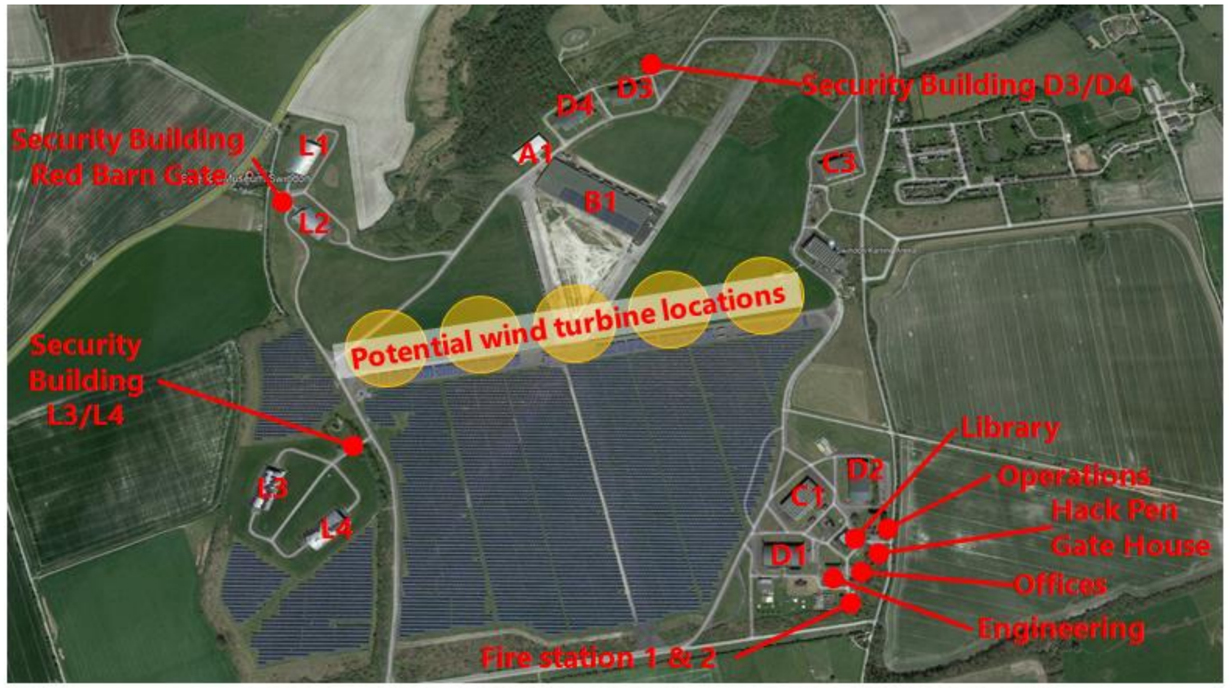


Figure 6—10 Site plan showing electricity generation potential

As PV electricity is only generated during the day and there is considerable electricity demand during the night, other technology such as large-scale wind turbines could be utilised to offset nighttime electricity demand.

The National Collections Centre is the only site that has been considered suitable for large scale wind turbines and there is an existing wind farm approximately 16km Northeast of NCC. The wind farm consists of five 1.3MW turbines that on average has generated 9,800MWh of electricity annually. There is the potential to install up to 5 wind turbines at NCC and generate electricity for the whole estate.

The potential of wind turbines at the NCC site in Swindon has been analysed. Figure 6—11 shows a wind rose for the location indicating speed, direction, and occurrence.

Figure 6—11 Swindon Wind Rose

The site has potential for 5no. 1.3MW turbines approximately 200m apart which have the potential to generate around 9.8GWh of electricity annually.

6.3.3 Energy storage and Power Purchase Agreements

There is potential to generate excess electricity providing an opportunity to export the excess electricity and supply the other sites in the SMG portfolio via a Power Purchase Agreement. These agreements are usually around guaranteed volumes of energy and are often considered in conjunction with REGOs. Further details of renewable energy procurement and PPAs can be found in Appendix C.

Depending on what deals can be made, there may be some benefit in considering electricity storage utilising batteries to have more control over balancing import and export of electricity.

7 Buildings Portfolio to Net Zero Carbon

7.1 Decarbonisation Action Plan

Short term: 2022-2025

- **Review building specification – electric only buildings**
- **Establish a common BMS/controls specification**
- **Establish a common sub-metering and energy consumption monitoring**
- **Assess potential PPA agreement**
- **Support site heating/cooling demand assessments**
- **Technology Trials**

Medium term: 2025-2027

- **Design PV arrays and wind turbines for estate**
- **Negotiate PPA agreement for electrical supply and export**

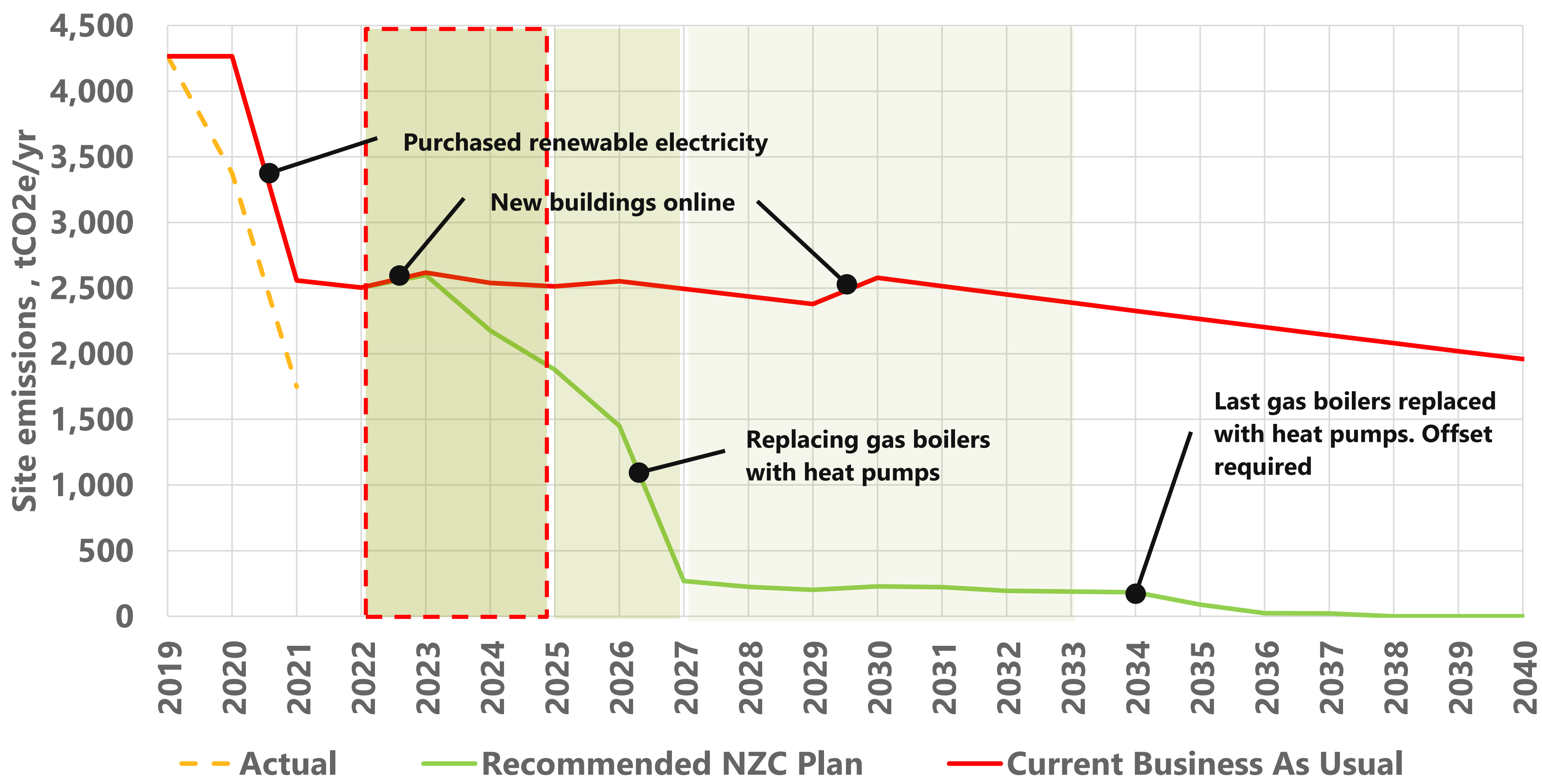
Long term: 2027-2033

- **Install PV arrays on all buildings and implement PPA agreement**
- **Purchase carbon offsets between 2033 and 2036 prior to final removal of gas and biomass-fired boilers.**

Detailed Short Term Action Plan

- Review and amend performance specification for building projects to incorporate the heat decarbonisation approach
- Create a common performance specification for BMS and controls to support energy efficient building operation
- Create a common submetering and energy consumption monitoring specification and establish building by building energy consumption
- Start the process for negotiation of an SMG Power Purchase Agreement to establish the potential for NCC to generate renewable electricity for the entire estate
- Support site heating/cooling demand assessment to establish best approach for delivering heat pump installations
- Establish trials for evaluating the potential of new technology, including exhaust air heat pumps

Locomotion Decarbonisation Pathway



7.2 Energy consumption projection

The heat decarbonisation plan shows two scenarios:

- The RED line indicates the current business as usual which includes the energy consumption of the existing buildings and those currently being planned on the site.
- The GREEN line indicates the recommended Net Zero Carbon Plan scenario includes proposed fabric, lighting and building control improvements were made to the buildings as stipulated building by building in section 14. It also includes the decarbonisation of heat through removal of fossil fuel generators and inclusion of heat pumps and on-site PV generation.

Emissions projections take account of the purchase of zero carbon electricity in the form of REGOs from 2021.

The energy consumption projections are from a baseline of the 2019/20 financial year. The actual energy consumption on site is indicated by the dashed ORANGE line are shown to reduce indicating the impact of covid.

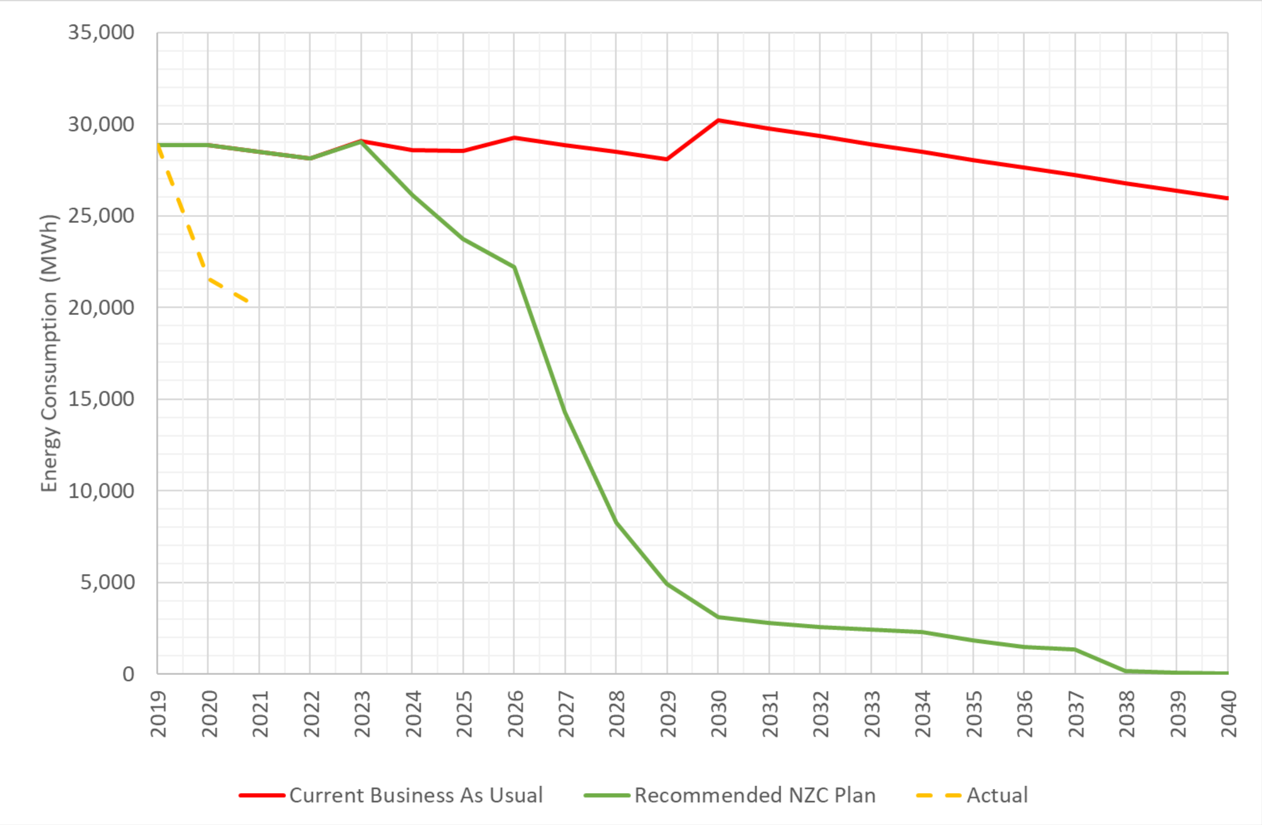


Figure 7—1 Energy Consumption

The energy consumption projection by source is shown in Figure 7—2. The reduction in gas consumption is part dependent on investing in energy efficiency measures as well as the replacement of gas boilers with heat pumps. The energy consumption projection indicates a reduction of up to 45% by 2033 if all measures are implemented. This is more than the targeted 20% reduction.

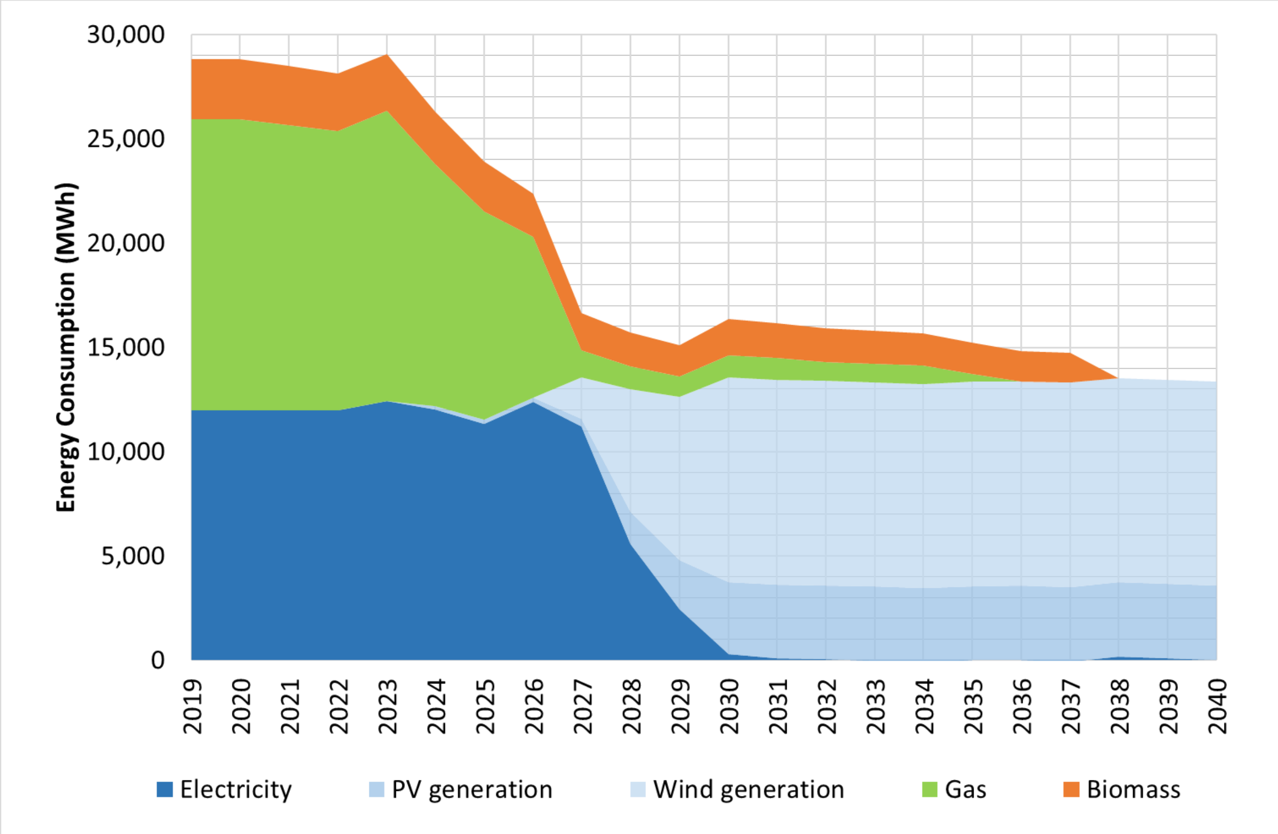


Figure 7—2 Energy consumption by source

Electricity consumption does however rise from around 12GWh to 14.5GWh at the end of decarbonisation. Should not all energy savings be realised this could increase to around 19.5GWh.

7.3 Capital and operational costs

An estimation of the likely capital investment required to deliver the Heat Decarbonisation Plan has been identified in Figure 7—3. The costs total just over £78M and include an allowance for design, prelims, and contingency. There has been no allowance for future plant replacement at its end of life. VAT is excluded.

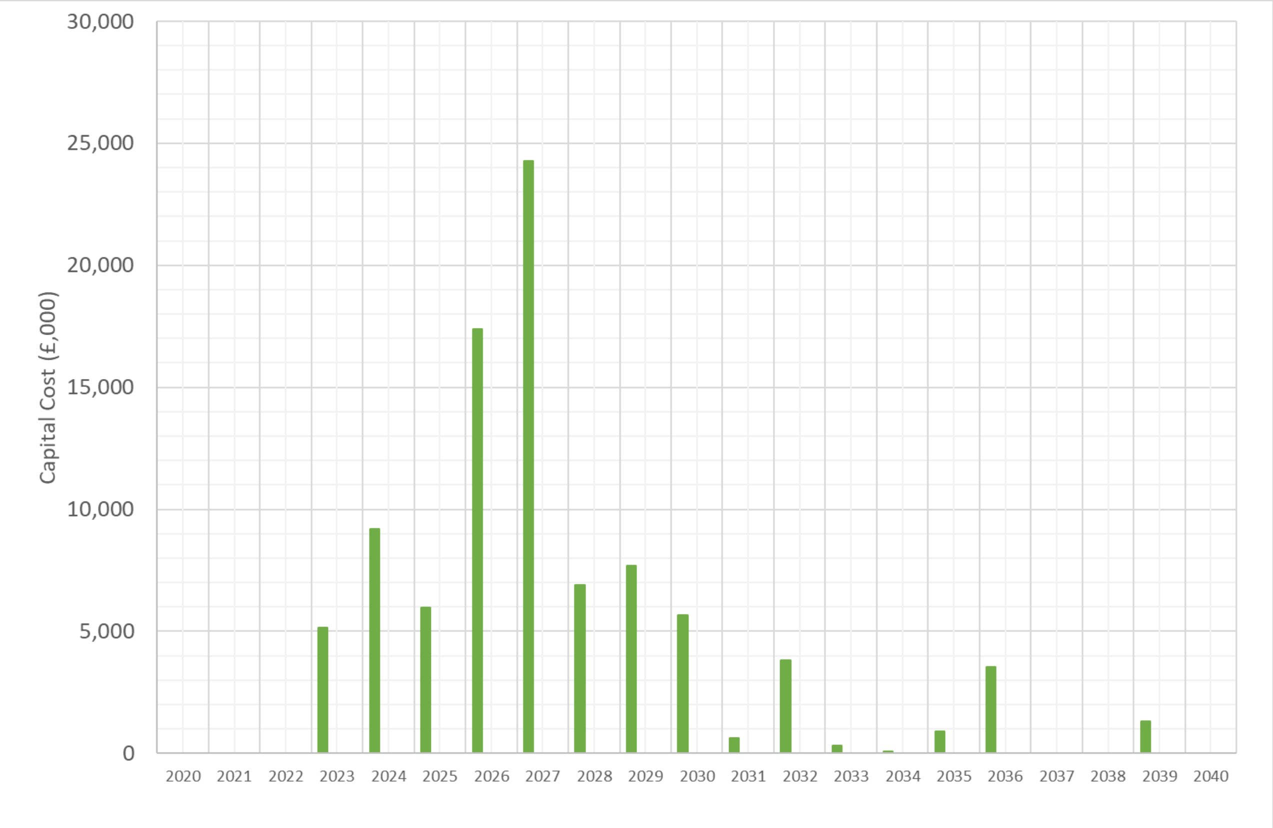


Figure 7—3 Projected capital expenditure

The projected operational costs are shown in Figure 7—4. These costs include an allowance for the maintenance of heating, cooling plant, as well as the utility energy and carbon offset costs for any remaining emissions beyond 2033.

The operational costs will be subject to a PPA where excess electricity generated at NCC can be utilised at other sites. The operational cost projections have therefore assumed a cost ranging from 2.5p/kWh up to 9p/kWh based on the current cost of grid electricity less 5p/kWh income for exported electricity.

The increase in operating costs from 2033 that occurs for the business-as-usual scenario is from the purchase of carbon offsets.

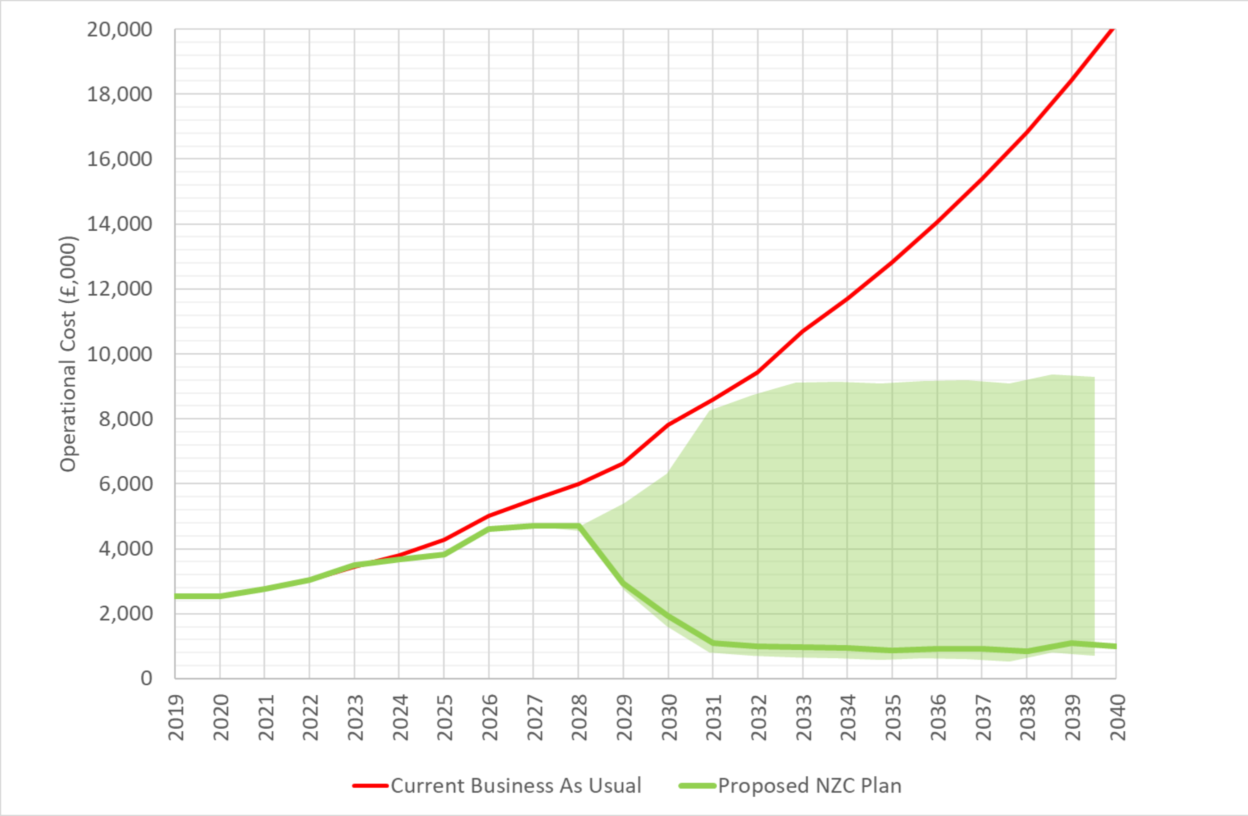


Figure 7—4 Projected operational costs

8 Conclusions

This heat decarbonisation plan has identified the work that SMG is doing and the actions that are recommended to achieve their Net Zero Carbon Strategy and the following key objectives:

- Targeting a 20% reduction in energy consumption against a 2019 benchmark on a kWh/m2 basis by 2033
- Targeting 20% of the electrical energy consumption of the estate being generated from on-site renewable technology.

Each site location has advantages and disadvantages associated with these objectives and the combined strengths of each site will contribute to achieving them. Table 8—1 summarised the strengths and contribution towards the estate objectives.

Table 8—1 Location based contribution to the decarbonisation objectives

Location	Strengths	Projected energy reduction (%)	Renewable contribution
Science Museum	Climate favourable for cooling towers delivering free cooling and water-cooled heat recovery chillers Refurbishment of the Welcome Wing roof gives opportunity to install extensive PV Potential to connect to an Ambient Loop system in conjunction with the adjacent Natural History Museum and other buildings should it be progressed	41%	5%
National Science &Media Museum	Benefits from the potential of simultaneous heating and cooling demands for increased efficiency of air source heat pumps Climate favourable for cooling towers delivering free cooling and water-cooled heat recovery chillers Potential to connect to an Ambient Loop system should it be developed as part of Bradford's district heating ambitions.	33%	4%
Science & Industry Museum	Ground water resource to provide free cooling and heating with water source heat pumps to support air source heat pumps	56%	8%
National Railway Museum	Space to install ground source heat pumps	48%	12%
Locomotion	Roof space to install PV to generate enough electricity to satisfy all the demands on site Space for ground arrays as a source for heat pumps with the potential to link with the local community	50%	34%
National Collections Centre	The SMG Energy Generation Centre - Space to install wind and PV to generate enough electricity to satisfy the projected electricity demands of the whole estate	34%	31-100%
SMG Estate		47%	Up to 100%

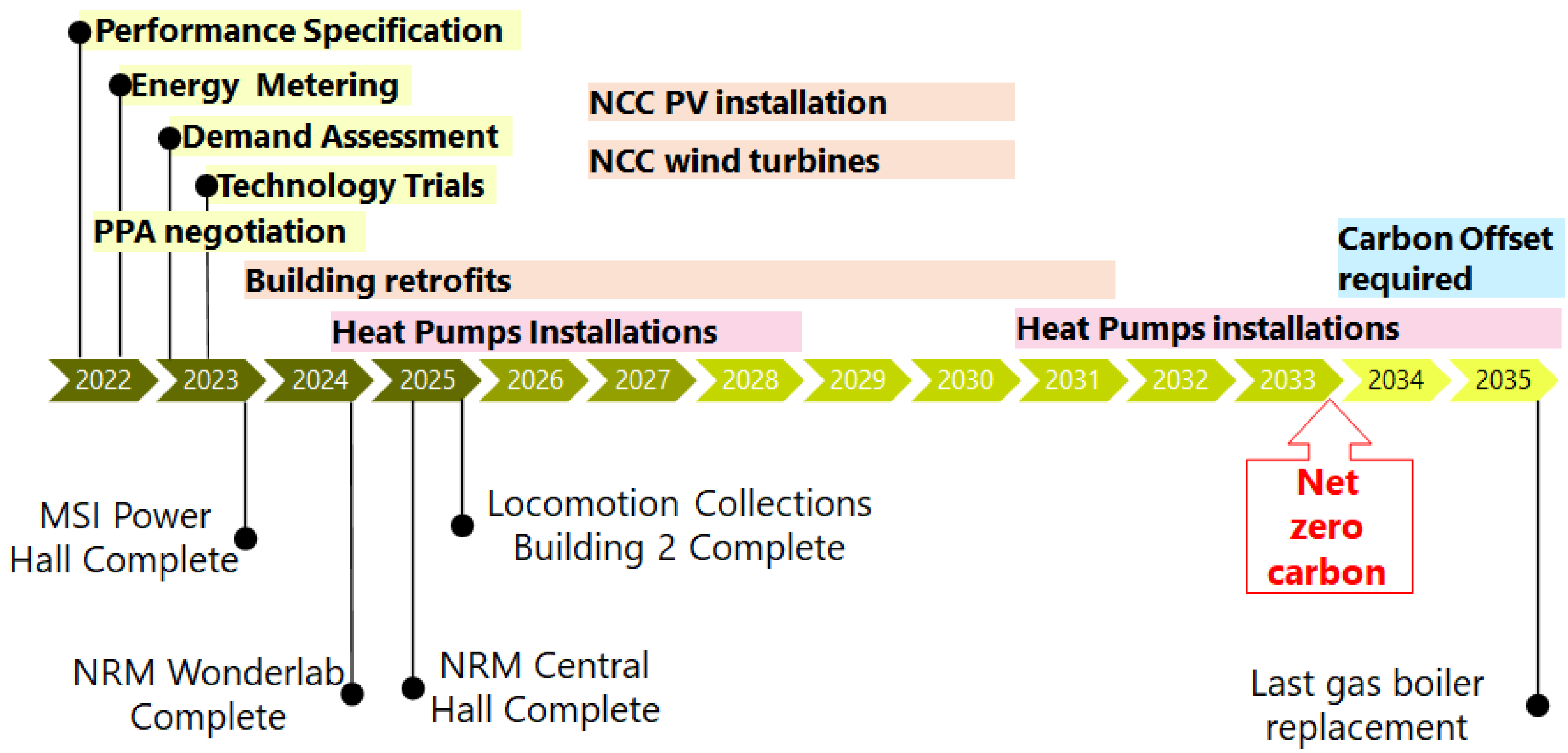


Figure 8—1 Implementation programme

Appendix A Key assumptions and data sources

A.1 Assumptions

A.1.1 UK carbon emission factors

Grid electricity and gas carbon factor projections for the UK are available from the Green Book, Table 1: Electricity emission factors to 2100, consumption based for commercial/public sector

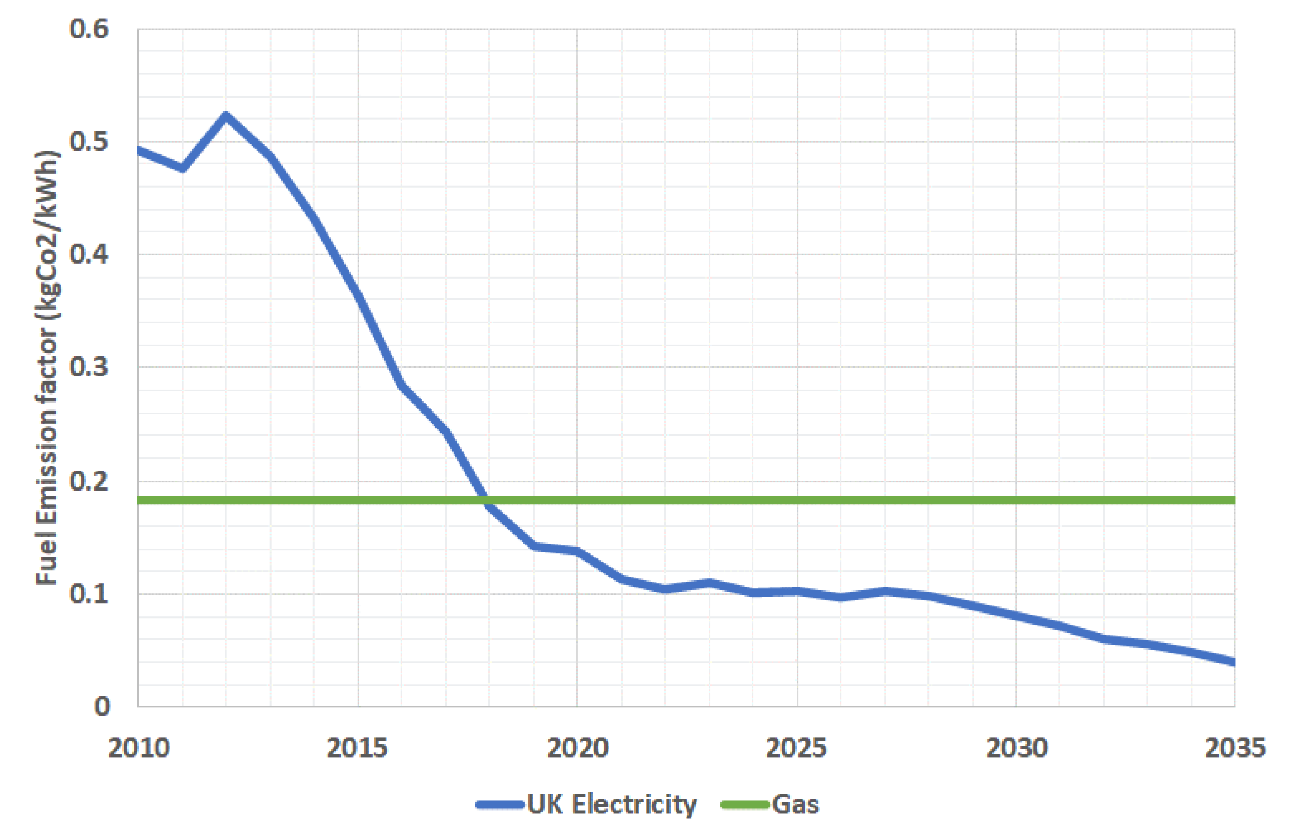


Figure 8—2 UK carbon emission factors

A.1.2 Fuel costs

Fuel	Cost (p/kWh)	Source
Grid electricity	13.0	BEIS Q4 2021
Grid Electricity (REGO)	13.8	SMG 2021 REGO price
Electricity export	5.0	SMG current export from NCC
Renewable PPA	Not available	
Natural gas	3.59	SMG 2021 price
Hydrogen	5.1	Long term price estimation

Fuel costs are indexed based on the Green Book, Table 4 Retail Electricity Prices and Table 5 Retail Gas Prices

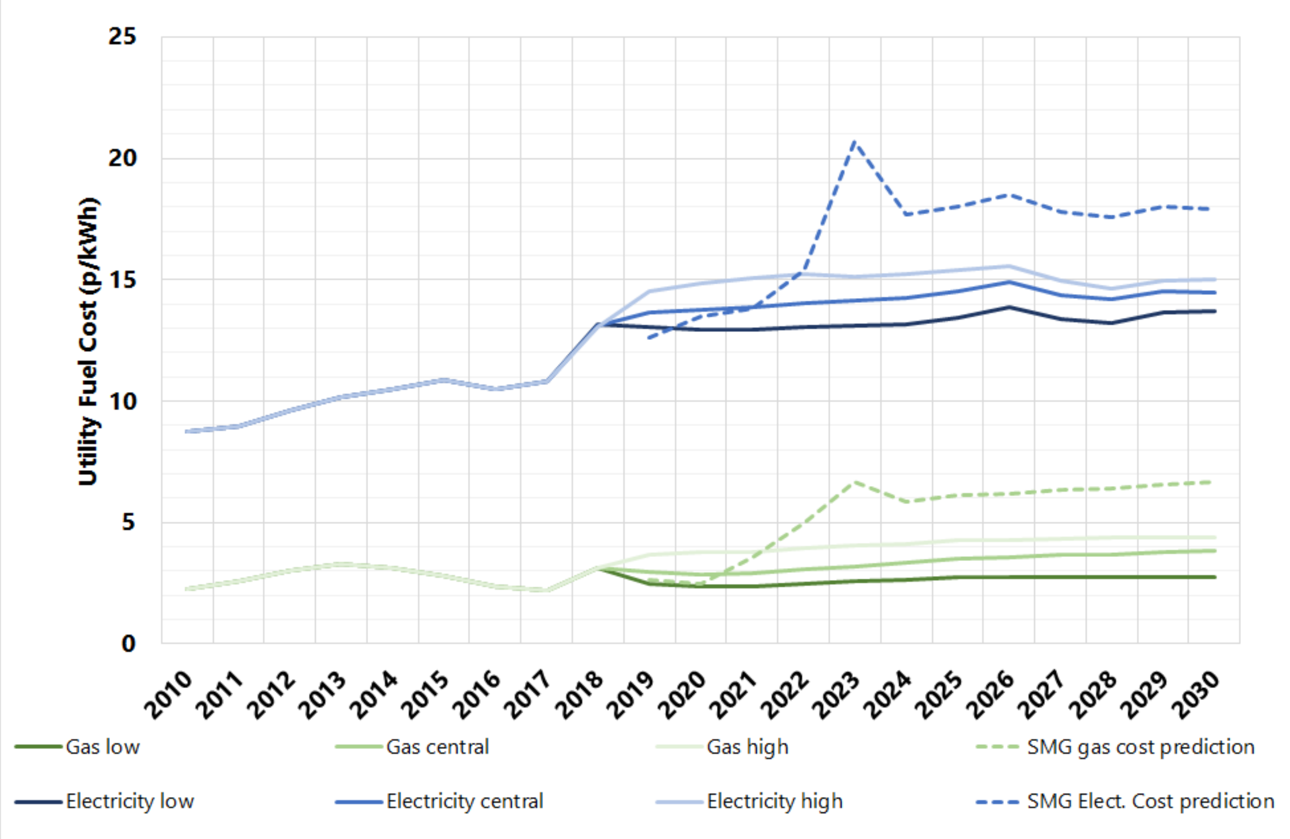


Figure 8—3 BEIS and SMG fuel cost projection

A.1.3 Maintenance expenditure

Technology	Maintenance cost	Units	Source
Gas boilers	0.3	p/kWh	DECC 2050 Pathways model
Air source heat pumps	0.2	p/kWh	DECC 2050 Pathways model
Ground source heat pump	0.1	p/kWh	DECC 2050 Pathways model
Water source heat pump	0.1	p/kWh	DECC 2050 Pathways model
Chiller	0.4	p/kWh	DECC 2050 Pathways model
Wind Turbine	28.7	p/kWp	Westmill Wind Farm

A.1.4 Carbon Offset Cost

Carbon offset cost has been based on the Green Book, Non-traded, Central Table 3: Carbon Prices and sensitivities 2010-2100 for appraisal, 2018. The cost of carbon offset has been applied from 2033.

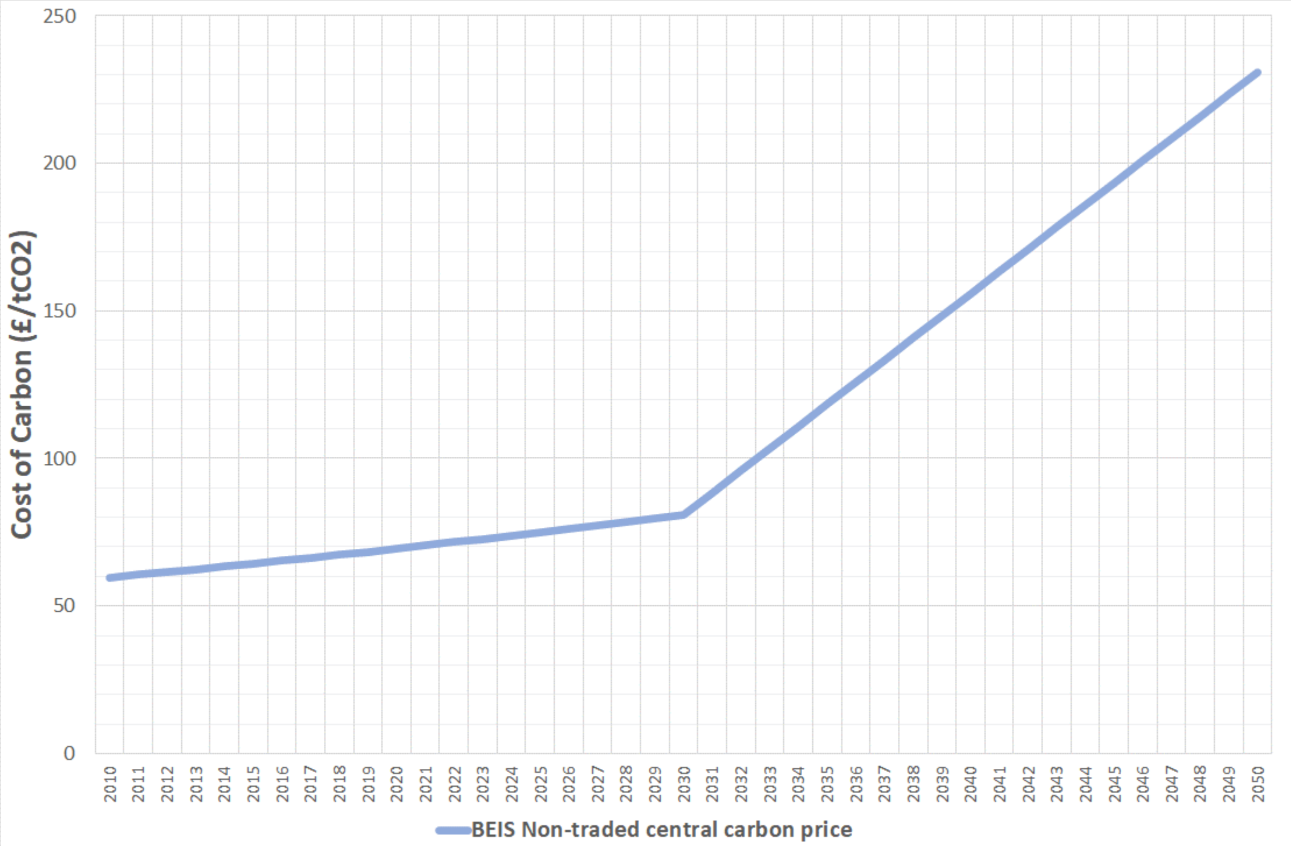


Figure 8—4 Carbon offset cost predictions

A.1.5 Photovoltaic cells

The performance ratio for prediction of PV output was 11.59%. This value is a combination of panel losses and overall efficiency detailed below.

PV losses	Standard value	Estimated value
Inverter	6% - 15%	8%
Temperature	5% - 15%	8%
DC cables	1% – 3%	2%
AC cables	1% - 3%	2%
Shading	0% - 40%	0%
Losses weak irradiation	3% - 7%	3%
Losses due to dust, snow	2%	2%
Other losses		0%
Panel efficiency		20%

A.2 Data sources

Efficiency assumptions are listed below.

Renewable/low carbon technology	Heating Efficiency	DHW efficiency	Fuel source
Air source heat pump	300%	200%	Electricity
Biomass boiler	80%	80%	Biomass
Electric boiler / direct electric	100%	100%	Electricity
District heating	100%	100%	District Heating network
Gas boiler	85%	85%	Gas
Ground source heat pump	350%	300%	Electricity
Oil boiler	85%	85%	Oil

A.3 Reference documents

Science Museum Group Estate Decarbonisation Strategy Version 1.0 June 2021

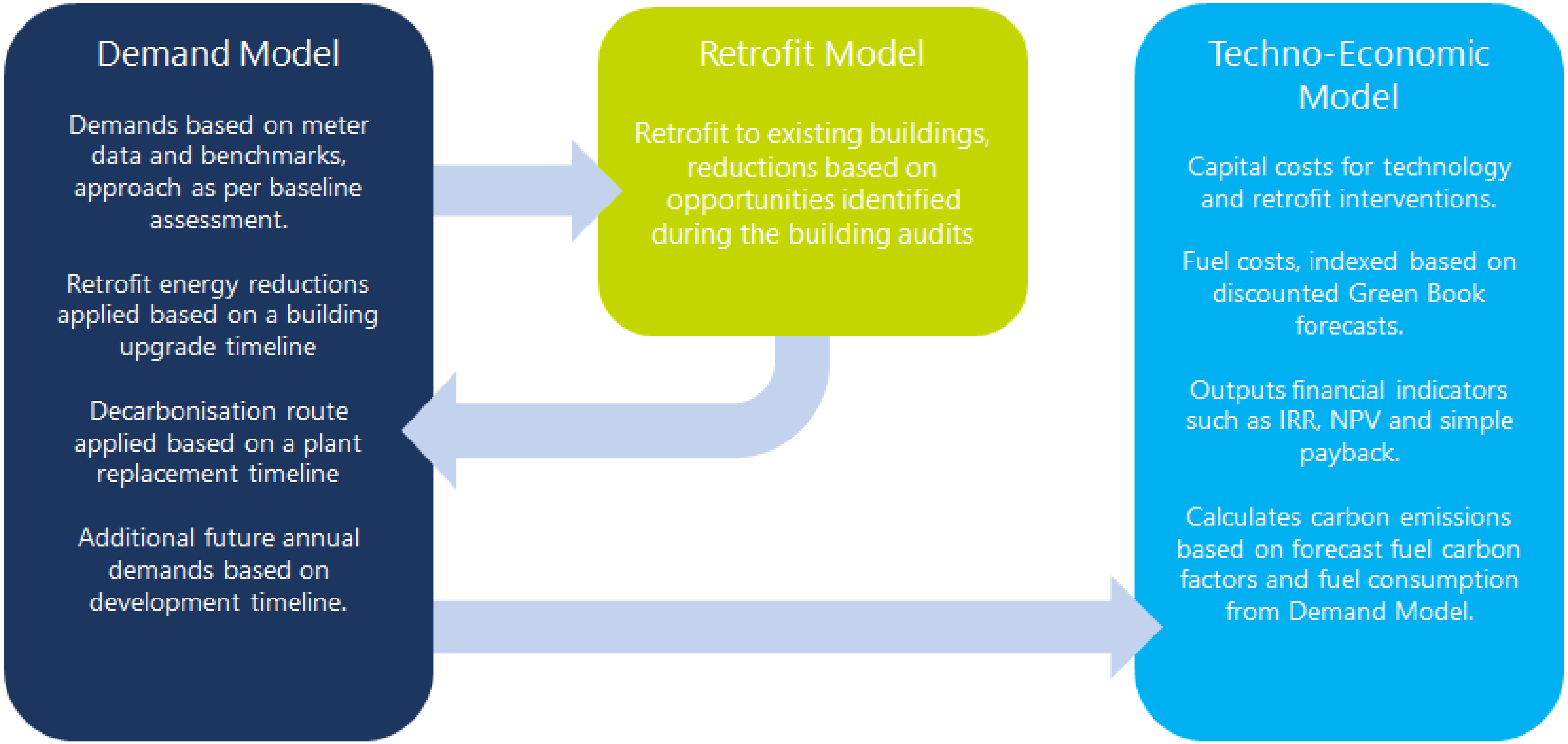
Estates Priority List

Assets at Risk

Asset condition data

Ground source heat pump screening tool
http://mapapps2.bgs.ac.uk/gshpnational2/app/index.html?_ga=2.166917822.1851296184.1636564392-714774782.1636564392

Appendix B Model Methodology



Appendix C Renewable energy procurement

Outlined within the UKGBC Net Zero Carbon Buildings: A Framework Designation the following steps can be taken to increase renewable energy supply use:

- On-site renewable energy source should be prioritised.
- Off-site renewables should demonstrate additionally. Supply should be direct to the development to avoid double counting of off-site renewables.

The benefits of installing on-site renewable technologies can reduce a site demand on the grid and can increase development value.

Procurement of renewable electricity can be achieved through a variety of methods. The methods, and order in which they should be considered are outlined in Figure 8—5 Renewable Energy Procurement Options Hierarchy

.

Figure 8—5 Renewable Energy Procurement Options Hierarchy

C.1 Generate Own Renewable Energy On-site

This could include rooftop solar PV. Although on-site solar PV would likely only contribute a fraction of the required electricity there is considerable potential. Rather than direct investment, an on-site renewable energy purchase agreement would be the considered option.

C.2 Set up a Power Purchase Agreement (PPA) or Gas Purchase Agreement (GPA)

This option allows purchase of renewable energy directly from a renewable energy generator. This ensures that additional renewable energy capacity is installed on the UK power grid, leading to long-term greening of the electricity and gas supply. This option is accessible for very large customers (for electricity usually minimum ~15MW).

There are options to set up joint PPAs with other interested smaller consumers to reach the minimum required minimum capacity if necessary.

C.3 Set up a Power Supply Agreement (PSA) or a Green Gas Supply Agreement (GSA)

A PSA or GSA would be an agreement set up directly with trusted energy companies that only supply energy from renewable energy sources. These companies own part of the renewable energy generation capacity and cover the remaining demand by purchasing electricity certified by REGO (Renewable Electricity Guarantee of Origin) or by purchasing gas certified by RGGO (Renewable Gas Guarantee of Origin).

C.4 Switch to a Green Tariff

Apply to switch to a green tariff. There is on-going discussion on the credibility and long-term impact of some green tariffs, including the method adopted to certify the renewable origin and its role in supporting the development of additional renewable energy capacity. This would still present as a short-term option as it is easy and fast to roll-out and can have immediate effect on the carbon footprint.

These 4 options have their benefits and drawbacks which are weighed up in **Error! Reference source not found.**.

Table 8—2 Pros and Cons of varying renewable energy supply options

Option	Pros	Cons
On-site renewable	On-site generation can all be used behind the meter leading to long-term operational savings Good image and shows commitment Could be financed with a RE purchase agreement	Limited capacity available due to site constraints Require on-site space Requires initial investment Dependant on available renewable sources on-site
PPA or GPA	Enable full decarbonisation Lock-in price for next 10 – 15 years – safeguard against rising and variable market energy prices Shows long-term commitment Ensures development of additional renewable energy capacity	Requires longer time to implement and long-term contract (e.g. 10 – 15 years) Usually for large consumers (min. ~15 MW) but can set up joint PPAs with other consumers to reach required scale Risk of higher power price than the market power price in the future
PSA or GSA	Ensures energy comes from renewable energy sources Good image and reputation as it requires setting up PSA with trusted renewable energy provider Quicker than PPA Available for smaller consumers	Requires switching to a new energy provider Mostly relies on REGOs and RGGOs and not on renewable energy capacity Future prices unknown
Green tariffs for Electricity or Gas	Quick roll-out Does not require to switch to new energy provider Good short-term option to immediately decrease carbon footprint	Future prices unknown Guarantee of origin not always certain Does not lead to long-term additional renewable energy capacity Does not demonstrate long-term commitment

Appendix D Offsetting

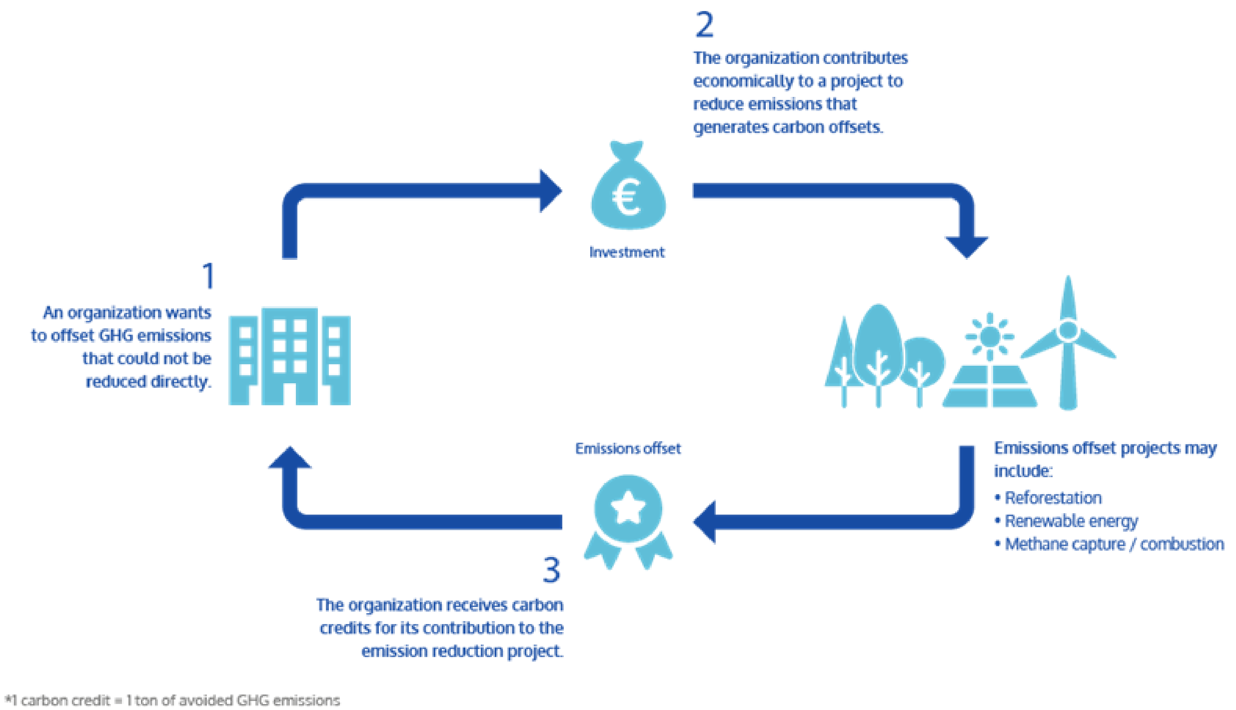


Figure 8—6 Offsetting

Outlined within the UKGBC Net Zero Carbon Buildings: A Framework Designation the following steps can be taken to offset remaining carbon:

- Offset any remaining carbon using a recognised offsetting framework
- Publicly disclose the amount of offsets

D.1 Introduction

Carbon offsetting is the action of compensating carbon emissions by participating in schemes designed to make equivalent carbon emission reductions off site. The built environment contributes to 40% of all UK carbon emissions and this could be drastically reduced by fulfilling a net zero approach to construction. However, it will not be physically or economically possible for M&S to be net zero through energy efficiency and on or offsite renewables; therefore, carbon offsetting will be an essential part of decarbonising.

After all measures for reducing carbon impacts have been reasonably exhausted on site, the final step in the UKGBC Net Zero Carbon Framework is to offset any remaining carbon using a recognised offsetting framework, with the amount of offsets used being publicly disclosed.

As part of the technical requirements of this, UKGBC specify that offsets should be procured directly or via a recognised existing offsetting framework, either way the chosen route should seek to demonstrate additionality, avoid double counting, and provide a clear process for verification of carbon savings.

UKGBC site the following offsetting frameworks that should be considered:

- Clean Development Mechanism
- Gold Standard

D.2 UN Clean Development Mechanism

The UN Clean Development Mechanism (CDM) allows a country with an emission-reduction or emission-limitation commitment under the Kyoto Protocol to implement an emission-reduction project in developing countries. These projects can earn saleable Certified Emission Reduction (CER) credits, each equivalent to one tonne of CO_2. It is a global, environmental investment and credit scheme which provides a standardised emission offset instrument.

D.3 Gold Standard

"Gold Standard was established in 2003 by WWF and other international NGOs to ensure projects that reduced carbon emissions featured the highest levels of environmental integrity and also contributed to sustainable development." (Source *goldstandard.org*).

It acts as a best practice standard for climate and sustainable development interventions. Through the Gold Standard, one is able to purchase carbon credits for different approved projects at varying prices.

D.4 Traded and Non-traded Carbon Credits

Through the purchase of carbon credits, it is possible to compensate for every tonne of CO_2 emitted by investing in a carbon reduction project.

Two types of carbon credit are available:

- Traded / Certified Emission reductions (CER)
- Non-traded / Voluntary Emission reductions (VER)

D.5 Traded Carbon Credits

Otherwise known as Certified Emission reductions (CER), these carbon credits are emission units created through a regulatory framework with a purpose of offsetting a projects emission. CER projects are expensive to establish (relative to Voluntary Emission Reductions) and as such will likely be larger scale projects. As CERs are on compliance markets, the price of CERs fluctuate with the market.

D.6 Non-traded Carbon Credits

Non-traded, or Voluntary Emission Reductions (VER) are voluntary offset markets that function outside the compliance markets and enable companies and individuals to purchase carbon offsets on a voluntary basis. A greater range of smaller, specific VER offset projects are available. Typically, however, the impact of such projects is harder to quantify and monitor, although they can demonstrate wider sustainable development benefits relative to CERs.

D.7 Cost of Carbon offsets

The cost of carbon offsets is variable and differ depending on what offsetting strategies are used. There are a growing number of companies who sell and manage offsets. BEIS is the UK government's Department for Business, Energy and Industrial Strategy. BEIS publish anticipated carbon prices between 2005-2100. Figure 12 maps these projections. Given the context of the project and BEIS UK Government projections, for the purpose of this study BEIS figures have been adopted to represent offsetting costs.

The prices published by BEIS give an upper and lower bound, which reflects the potential variation in price. Both 'Traded' (CER) and 'Non-traded' (VER) figures up to 2030 are also presented.

The traded figures represent the value of carbon in the EU ETS (Emission trading Scheme). This would involve the purchase of offsetting credits through a CER, which are expected to be the cheaper option, however, do not tend to have the same no-carbon impact as VERs. The non-traded figure represents the expected cost of offsetting carbon within the

UK, or outside the EU ETS scheme. Therefore, depending on where the offsetting scheme is and how it is funded, will substantially vary the price of offsetting the expected carbon emissions.

Figure 8—7 BEIS Traded Vs. Non-Traded Central Carbon Price

shows that come 2030, the cost of traded and non-traded carbon will match and continue along the projection of the traded carbon. Beyond 2030, a fully working global carbon market is assumed. This will result in a single carbon value for economic appraisal from 2031-2050. This value will reflect the cost required to achieve the EU long term target of limiting dangerous climate change to the 2-degree limit. This approach is outlined in BEIS Guidance on Estimation Carbon Values Beyond 2050.

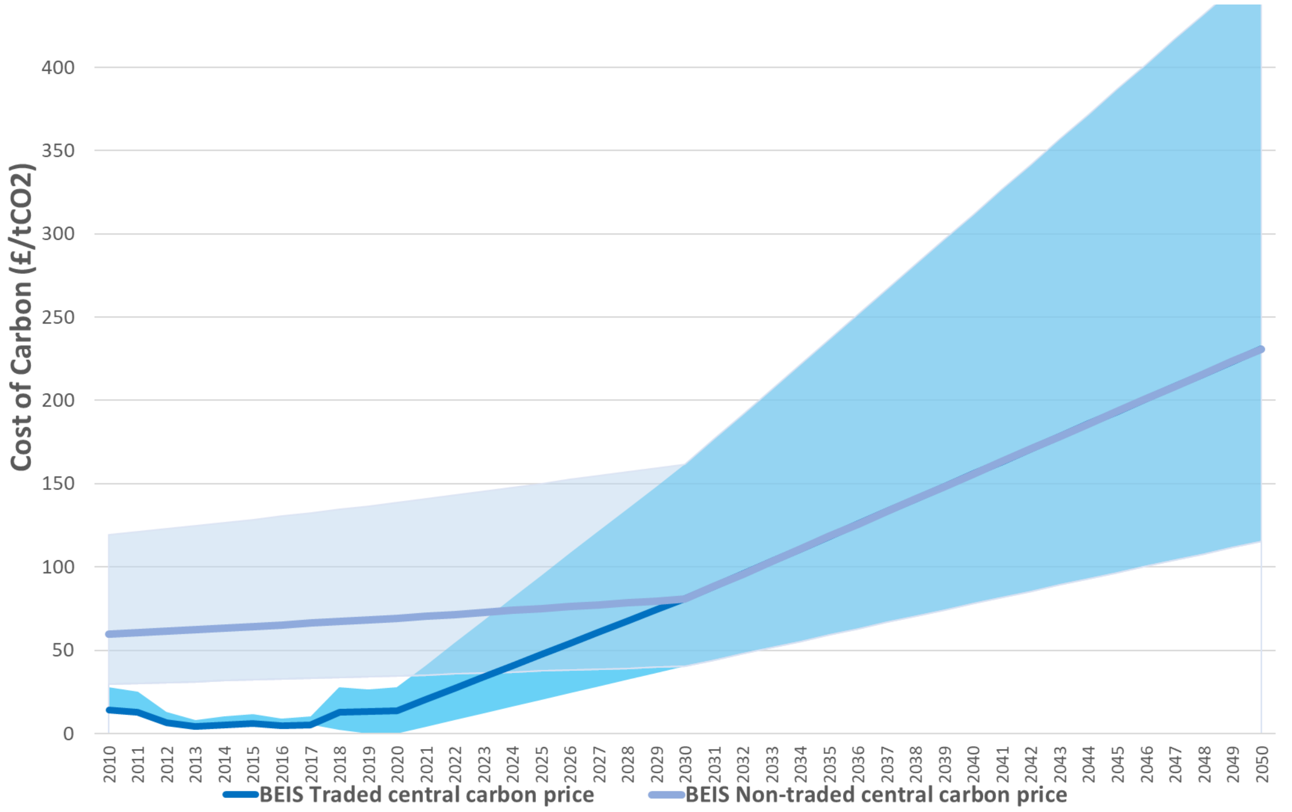


Figure 8—7 BEIS Traded Vs. Non-Traded Central Carbon Price

D.8 Traded/ Certified Emissions schemes

Frequently the schemes that are certified, through Gold Standard for example, provide funding to projects around the globe. Whilst the benefit of certification brings added rigour and accountability, there would be substantial benefits of using the funding more locally. The drawback though is that local initiatives tend not to be formally certified due to the scale of the current certification processes and to avoid double counting under DEFRA's GHG inventory.

The offsetting options provided by the Gold Standard can be found on their website[1], and come with a range of costs depending on the project one invests in. The projects fall under a variety of themes including community-based projects, energy efficiency, forests, renewable energy, waste management, and water. Some examples are shown below.

Similarly, the UN CDM website lists its registered projects on its website. Projects cover areas such as energy, manufacturing, chemical industries, construction, transport, mining, metal production, fugitive emissions, solvent use, waste handling, afforestation and reforestation, and agriculture. Price of the CDM registered projects are negotiated directly between buyers and sellers, therefore information of price is not provided on the CDM website.

[1] https://www.goldstandard.org/

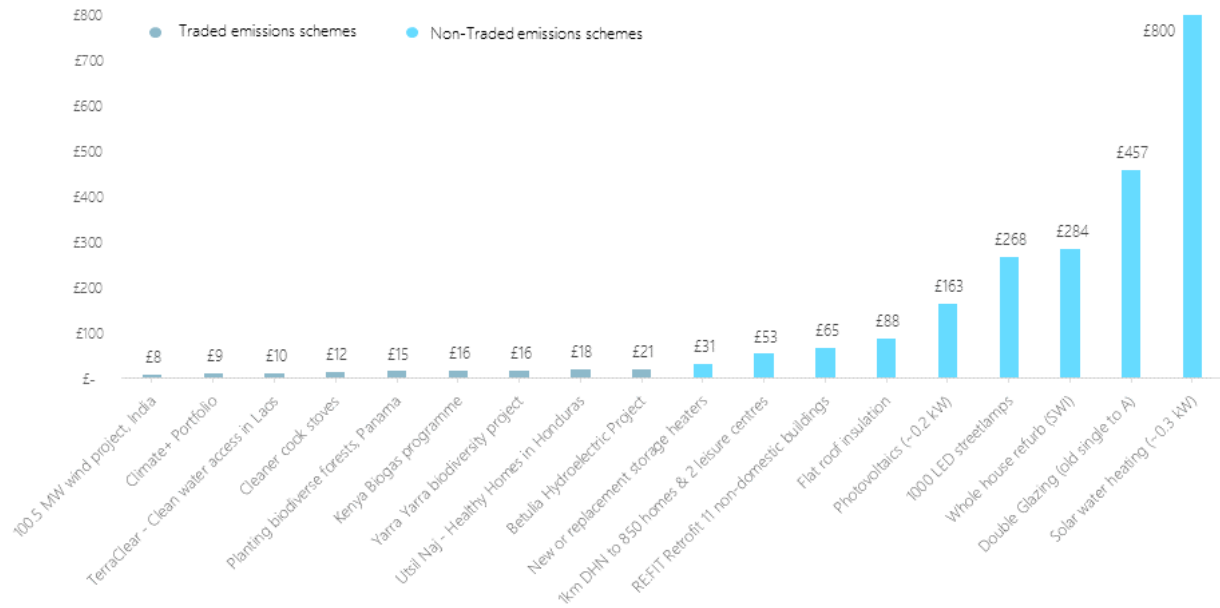


Figure 8—8 Traded Emissions vs Non-Traded Emissions

Table 8—3 Examples of Gold Standard Offsetting Options

Project	About	Cost
Cleaner cook stoves in Rwanda	Supplies locally made, improved cook stove to families so that they can cook with less fuel, effort and smoke in their homes	£12 /tonne
Planting biodiverse forests in Panama	Re-transforming degraded pastureland into ecological sound forests that offer a safe haven for native animals	£15 /tonne
100.5 MW Wind Project in India by Orange Renewable	Wind project in India focussing on sustainable development of the local community	£8 /tonne
Utsil Naj – Healthy Homes for All in Honduras	Addressing climate change in the "Dry Corridor" of Honduras by promoting community-based solutions	£18 /tonne
Terraclear – Clean Water Access for families in Laos	Enhancing clean water access for rural communities in Laos	£10 /tonne
Cambodia National Biodigester Programme	Using biogas to create an indigenous, sustainable source of energy in Cambodia – reducing emissions and improving agricultural yields	£16 /tonne
20MW Solar Project in Rajasthan, India	Utilising the sun for clean energy, reducing emissions and providing benefits to local communities	£10 /tonne
Ethiopian Forest Regeneration	The regeneration and new establishment of forests on Mount Damota contributes to a sustainable income for rural communities	£15 /tonne
Climate+ Portfolio: Variety of Projects	Purchase carbon credits from a range of Gold Standard certified projects all over the globe.	£9 /tonne

D.9 Conclusion

Offsetting should be a last resort, after exhausting all steps prior.

It is difficult to guarantee that a carbon offsetting scheme can deliver consistent carbon savings, indefinitely, and ensure that the carbon remains offset. As such offsetting through payments should not be relied upon as a primary method to achieve decarbonisation. It can still provide a method through which residual emissions can be tackled until such a time that the grid is decarbonised to an acceptable level.

As the context of this report is framed in line with the UKGBC Hierarchy it is recommend that all carbon credits purchased are credible and quality assured, through certifications such as UN CDM and the Gold Standard.

Appendix E Hydrogen

E.1 Introduction

The emissions reductions required by 2050 under the Climate change act points to a large role for electricity, for which several low-cost zero-carbon production technologies are already available. It could also mean a role for hydrogen, which can be produced in low-carbon ways from electricity or with carbon capture and storage (CCS). It seems unlikely that zero carbon hydrogen supplied via a re-purposed gas mains network will be available, for the vast majority of buildings, for the foreseeable future.

Hydrogen as an energy delivery carrier is relatively inefficient compared with using renewable electricity with heat pumps. Hydrogen could provide useful renewable energy storage until needed for winter peaks. However, this can be more efficiently implemented using re-purposed combined cycle gas turbine (CCGT) power-stations without needing wider gas grid conversion.

E.2 Production

Hydrogen is generally produced at industrial scale by either:

- Blue Hydrogen (gas reforming) - utilising natural gas a feedstock, Steam Methane Reformation (SMR) is the most commonly used process worldwide to produce hydrogen currently.
- Green Hydrogen (electrolysis) - utilises water as a feedstock, using electricity to split the water into hydrogen and oxygen. Renewable electricity can make this approach zero-carbon.
- Gasification - involves heating carbonaceous materials such as biomass or coal to a high temperature, to produce carbon monoxide, hydrogen and carbon dioxide. The carbon monoxide then reacts with water to form carbon dioxide and more hydrogen.

Blue Hydrogen
The gas supply industry is advocating 'Blue' hydrogen manufactured by massively scaling up the process of natural gas steam reformation. This process does however emit CO2 as well as having upstream methane greenhouse gas (GHG) leakages. Large-scale carbon capture and storage (CCS) technology is proposed to capture some 90% of these CO2 emissions. Additional bio-sequestration or similar would also be required to remove the remaining 10% of CO2 for 'Blue' hydrogen to become zero carbon. There are significant uncertainties in developing, up-scaling and deploying these technologies. In addition, large volume storage of hydrogen for the winter peak demands would be required. Long term storage of captured carbon dioxide would also need to be developed. It seems likely that for the period until CCS is proven and implemented at scale, significant GHGs would be emitted before blue hydrogen can be delivered.

Green Hydrogen
'Green' hydrogen is created using renewable electricity with an electrolysis process and hence without the consequential CO2 emissions. Interestingly, Germany's new hydrogen national strategy has decided not to consider 'Blue' hydrogen for either the short term or the long term, instead focusing on 'Green' hydrogen. It also acknowledges they expect to become dependent on hydrogen imports because of insufficient indigenous renewable energy sources. They have therefore concluded that hydrogen should be focused on uses where portability, storage and intensity of energy is critical and where there are therefore few alternatives.

It is not yet clear what the mixture of technologies for producing hydrogen for a future hydrogen-rich UK gas network will be. Should gas reforming processes continue to dominate hydrogen production, the implementation of carbon capture and storage (CCS) will be a key parameter in securing a low carbon factor for the gas. CCS is still not sufficiently developed in the UK to support large-scale low-carbon hydrogen production via gas reforming.

The anticipated carbon emissions intensity associated with each of these method is described in Figure 8—9 Estimated hydrogen production costs 2030

, from the Committee on Climate Change.

Table 8—4 Carbon emissions intensity associated with different methods of hydrogen production

	Method	Key inputs	CO_2 intensity, gCO_2/kWh	Other considerations
Blue Hydrogen (Gas reforming)	Steam methane reforming (SMR) + CCS	Natural gas	45-120	Exposure to natural gas price
	Advanced gas reforming + CCS	Natural gas, oxygen	29-99	Exposure to natural gas price
Green Hydrogen (Electrolysis)	Proton exchange membrane electrolysers	Low-carbon electricity, water	0-325	Water use/desalination
	Alkaline electrolysers	Low-carbon electricity, water	0-325	Water use/desalination
	Solid oxide electrolyser	Low-carbon electricity, water, low-carbon heat	0-288	Water use and availability of low-carbon waste heat
Gasification	Coal gasification + CCS	Coal	112-186	Land footprint
	Biomass gasification + CCS	Sustainable biomass	Potential to achieve negative emissions	Sustainable supply of biomass feedstock

E.3 Regional context

The H21 Leeds City Gate feasibility study, undertaken by Northern Gas Networks, concluded that it was technically and economically viable to decarbonise the UK's gas distribution networks by converting them from natural gas to 100% hydrogen. The study focused on the provision of heat through a 100% hydrogen gas network conversion for Leeds.

Leeds was chosen as a pilot site due to its size and location near to Teesside's existing hydrogen infrastructure and the salt beds north of Hull (an opportunity for interseasonal storage of hydrogen). The project proposes conversion of the existing gas network to hydrogen in 2028, with expansion across the North of England over the following seven years.

The HyDeploy project is investigating if blending up to 20% hydrogen by volume could also be an option to decarbonise the gas grid, without the need to change consumer gas appliances. A demonstrator project is currently underway at Keele University as part of the first phase of the programme.

The second phase of HyDeploy will use the same technology, but on a public gas network, serving a wider variety of customers in the Northeast. It is expected that Phase 2 will begin in December 2020.

For the hydrogen to be 100% zero carbon it would have to be produced by gas reforming or gasification with CCS, or by electrolysis with zero carbon electricity.

For this to be a credible approach to zero carbon heat, consideration must be given to the feasibility of different approaches, including:

- Self-generation, e.g. by electrolysis using renewable electricity
- Connection to a converted hydrogen gas network

- Purchase of hydrogen from a registered supplier

E.4 Local constraints

If low-carbon hydrogen technologies are to be implemented as a strategy for heating rather than natural gas, there are several constraints to consider.

There are spatial constraints to hydrogen generation on-site and is unlikely to be practical even in the very long term. When considering hydrogen delivered through a converted gas network, or purchased from a private supplier, connectivity will be key to ensure resilience of the strategy. On-site storage of hydrogen is also likely to be required, which will require space. This is unlikely to be achievable, however connection to and support of local initiatives could be considered with a dedicated pipeline from the storage site.

The cost of hydrogen may reduce its cost competitiveness in the near term. Figure 8—9 Estimated hydrogen production costs 2030

shows the anticipated cost of Hydrogen production in 2030[2]. The lower estimate of 2 USD/kgH_2 is approximately equivalent to 4.6 p/kWh. This figure does not account for the cost of storage, distribution and infrastructure upgrades.

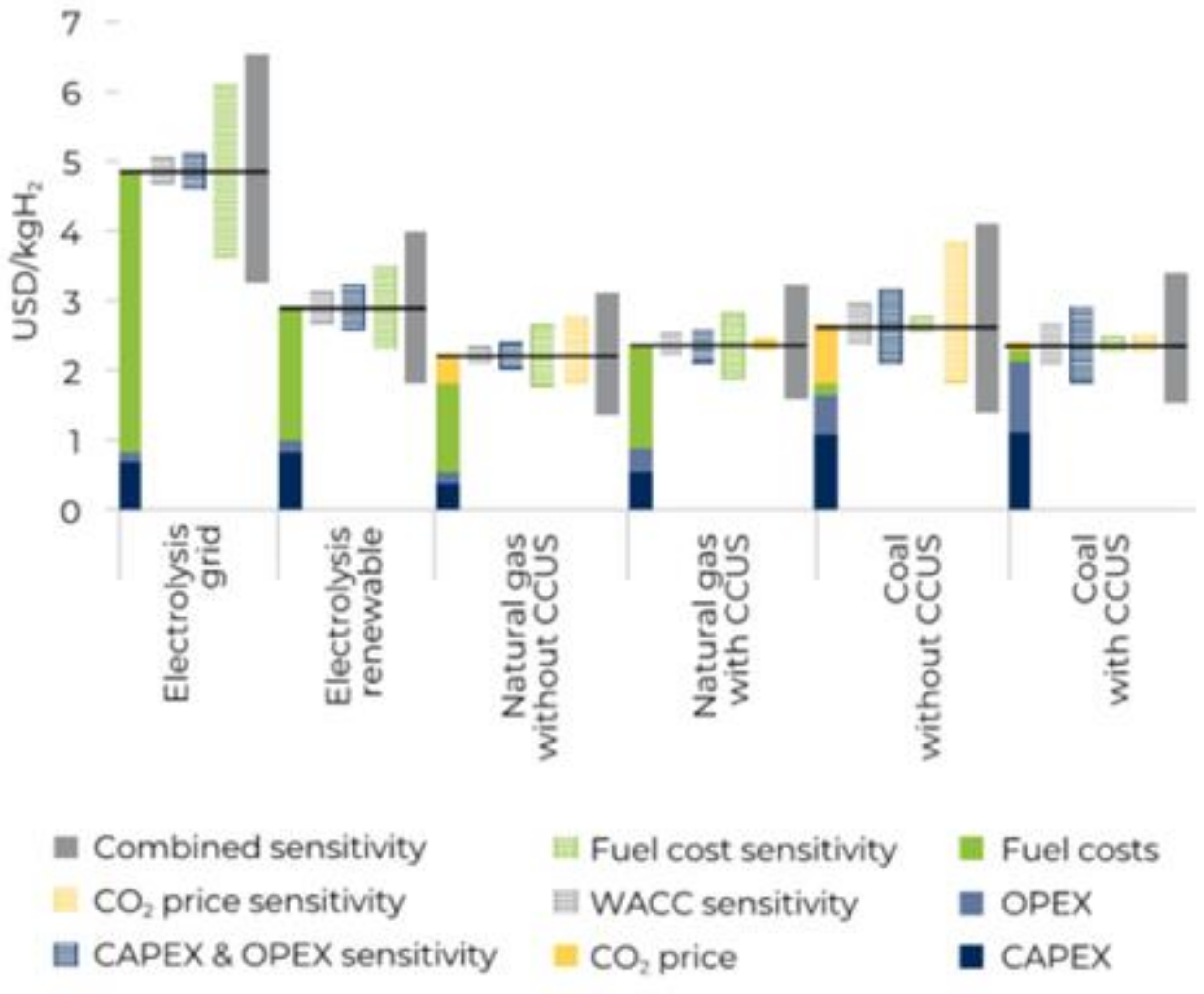


Figure 8—9 Estimated hydrogen production costs 2030

The ideal situation for hydrogen is for it to be transmitted through the existing gas network. As mentioned earlier, the H21 Leeds City Gate project considered the feasibility of converting the gas network to 100% hydrogen. For the city of Leeds, Hydrogen would be provided through 1 GW of steam methane reformers located at Teesside due to its access to carbon capture and storage. The total cost to convert Leeds including hydrogen production and storage, all associated infrastructure and appliance conversions would be in the region of £2bn.

The Institute of Engineering Technology has reported that initial investigations have shown that hydrogen boilers can deliver comparable levels of performance to natural gas for a similar cost. Boilers and appliances can be designed to be "hydrogen-ready". In the power and combined heat and power (CHP) sectors, work is ongoing to develop gas turbine combustion systems suitable for 100% hydrogen fuel. Hydrogen combustion also suffers from high NOx emissions. In a city centre environment with air quality constraints, NOx levels should be reduced where feasible.

There are further constraints associated with consumer premises for hydrogen. Gas pipework in existing premises might comprise different materials (steel, copper) and may not meet modern standards. Building ventilation requirements may also be different for hydrogen and other forms of detectors are needed for leakage.

Given the cost and technology readiness level of hydrogen, hydrogen boilers are not assumed to be a realistic technology for inclusion.

Conclusion

A 'full hydrogen' pathway would require large volumes of hydrogen. Depending on how this demand is met, this would lock-in to significant residual emissions and/or mean extremely challenging build rates for low-carbon energy infrastructure.

- Producing large volumes of hydrogen from natural gas with CCS could lock the UK into a path with insufficient emissions reductions by 2050 – this route offers a reduction in lifecycle emissions of 60-85% compared to natural gas boilers, so could leave residual emissions of 20-70 Mt. It also depends heavily on both deployment of CCS at very large scale and gas imports at around double today's levels.
- While production of hydrogen through electrolysis from 'surplus' renewables and/or nuclear could be a cost-effective niche, the size of this opportunity is small in comparison to potential demands for hydrogen. Producing hydrogen in bulk from electrolysis would be much more expensive and would entail extremely challenging build rates for electricity generation capacity.
- Although it may become possible to import hydrogen from low-cost production elsewhere in the world, in making strategic infrastructure decisions in the near term it would not be sensible to rely on an international market in low-carbon hydrogen emerging over the coming decades.

[2] Hydrogen Gas Turbines. (2019). [pdf] Brussels: ETN, p.4. Available at: https://etn.global/news-and-events/news/hydrogen-gas-turbines-report/ [Accessed 25 Feb. 2020]

Appendix F Cost Report

The detailed cost reports for each site can be found in the respective Local Energy Action Plan and the total estimated costs for each site are provided below.

Cost estimates are based on 2022 estimates and include the following allowances:

- 15% Preliminaries
- 10% Contingency
- 10% Design Fees

No account has been taken of inflation, costs of protecting and decanting of exhibits, or for plant replacement at the end of its useful life.

Building	Cost	Notes
Locomotion, Sheldon	£4,900,000	
National Collections Centre, Swindon	£12,800,000	Excludes costs associated with the Library AHU replacement, A1, and D2 boiler replacement works
National Railway Museum, York	£27,300,000	
National Science and Media Museum, Bradford	£5,000,000	
Science and Industry Museum, Manchester	£11,500,000	
Science Museum, London	£24,000,000	
Estate wide Renewable electricity generation – Wind Turbines at NCC	£9,400,000	
Total	**£94,900,000**	