elementenergy

Analysis of a Net Zero 2030 Target for Greater London

Final report

for

Greater London Authority

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Element Energy Limited
Suite 1, Bishop Bateman Court
Thompson's Lane
Cambridge
CB5 8AQ

Tel: 01223 852499

Executive Summary

Project Introduction

In 2018, the Mayor of London published the *London Environment Strategy* and *Zero Carbon London: A 1.5°C Compatible Plan*,[1] which presented a range of energy system scenarios for London consistent with a 2050 Net Zero target.[2]

Since their publication, the Mayor has committed to bring forward London's net zero target from 2050 to 2030. At the time of publication of the *1.5°C Plan*, the UK's ambition was to achieve an 80% reduction in emissions by 2050. Since then, both national and local climate ambition has increased. At a national level, the UK has committed to reach a 68% reduction in emissions by 2030 (relative to 1990 levels) and to reach net zero emissions by 2050.

A 2030 net zero target represents a substantial increase in ambition relative to a 2050 target and will require action at a London-level in a timeframe that goes beyond that which is supported or funded at national-level. The primary aim of this study is to help identify the possible pathways and the implications of the accelerated target relative to a 2050 target through:

- **Modelling a set of scenarios** to indicate how the net zero target could be achieved in London and to represent the range of uncertainty in the pathway to carbon neutrality.
- **Identifying the key challenges, implications, and opportunities** of delivering those scenarios within the 2030 timeline, including mitigation measures, infrastructure requirements, investment costs and opportunities for job creation.
- **Describing the likely policies to support delivery** the target, including the potential role of offsetting residual emissions. Moving the 2030 target forward will mean a higher level of offsetting is needed compared to the 2050 target, which will gradually reduce further after 2030.

The study does not aim to prescribe the precise approach for getting to net zero or the policies required or roles of key stakeholders in delivering the necessary levels of action. This will need to be further developed through the ongoing delivery planning and local area energy planning that is already taking place at multiple levels across London.

Overview of scenarios

Four scenarios, representing different levels of decarbonisation ambition, have been developed to explore the range of potential decarbonisation pathways for London. The scenarios illustrate a range of decarbonisation rates to 2030 but were modelled to 2050 to capture the full, long-term implications of each pathway.

The scenarios all represent a higher level of ambition than those of the UK government as well as those in the existing *1.5°C Plan,* and are differentiated by the level of residual emissions in 2030 (which would need to be offset) and by the technology mix in relation to energy supply, as summarised in Figure 1.

Two scenarios, High Electrification and High Hydrogen, are closest to current UK-wide targets (i.e. a 68% reduction in emissions by 2030 relative to 1990 levels) but still exceed this UK level commitment due to a more ambitious retrofit programme. These scenarios represent the maximum level of residual emissions considered to be still compatible with a 2030 Net Zero target[3] but are still equivalent to trajectories several years 'ahead' of those in the *1.5 'C Plan*. Reflecting that national-level decisions on the relative roles of electrification and hydrogen in the net zero transition strategy are not

[1] https://www.london.gov.uk/what-we-do/environment/climate-change/climate-action-plan

[2] Reaching net zero means that emissions are decreased to as low a level as is possible and any remaining emissions are then balanced by either removing an equivalent amount of carbon from the atmosphere (negative emissions measures) or offsetting through investment in carbon mitigation outside the region.

[3] On the basis that London should not aim to decarbonise more slowly than the national targeted average under a 2050 scenario.

expected until the mid-2020s, one scenario favours electrification of heat and transport (**High Electrification**) and one assumes that hydrogen is available at scale in the long-term (**High Hydrogen**).

The No Constraints scenario represents a significantly accelerated decarbonisation pathway that aims to deploy all possible policies and measures to reach the minimum achievable residual emissions by 2030; this includes more challenging policies to drive the transition such as early scrappage of boilers and vehicles. This scenario is not considered to be constrained by the costs or current local influence to implement such challenging policies and effect the necessary measures over the short timeframe. Due to the pace of decarbonisation required, technology options will necessarily be limited to those that are currently available or will certainly be available by the late 2020s, with a high reliance on widespread electrification.

The Accelerated Green scenario represents an intermediate scenario, in which London decarbonises as rapidly as possible ahead of the national targets while leaving long term technology options open as far as possible; in particular, allowing some heating systems to remain connected to a blended (hydrogen and biomethane) gas grid and a moderate share of pure hydrogen in selected applications. This scenario aims to reach the lowest possible residual emissions by 2030 without requiring the most difficult and costly approaches and measures to be undertaken, such as boiler and vehicle scrappage.

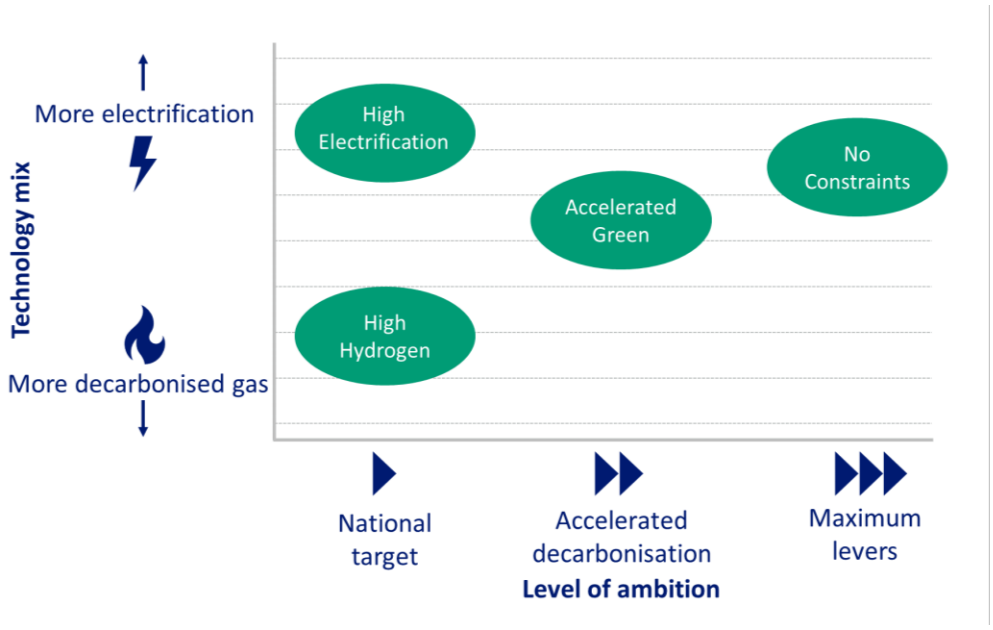

Figure 1 Overview of scenarios

Actions to reduce demand

All scenarios assume high degrees of both behaviour change and energy efficiency to support technology deployment in reducing emissions. This study assumes that these measures are prioritised in each scenario to reflect a ‘fabric-first’ demand-led approach to decarbonisation.

Energy efficiency retrofit in buildings is maximised to the same (very high) level across all scenarios to be consistent with existing ambition in London, requiring unprecedented levels of deployment over the next ten years. For travel behaviour change, a major shift to active, public, and shared transport is assumed in all scenarios. The High Hydrogen and High Electrification scenarios assume at least the levels required to meet the Mayor’s Transport Strategy (MTS) objectives, which target ambitious public and active travel mode shares by 2041 and already go significantly beyond national ambition. Accelerated Green and No Constraints require even higher levels of behaviour change than the MTS targets by 2030 to be able to achieve the high levels of emissions reductions targeted in these scenarios.

Emissions

The net zero 2050 scenarios developed for the *1.5°C Plan* all reached close to 10% residual emissions (relative to 1990 levels) by 2050, which would need to be offset.[4] All four scenarios in this study achieve greater levels of decarbonisation by 2030 than the scenarios in the *1.5°C Plan*, with the significant difference being the rate at which that decarbonisation happens (Figure 2 and Table 1), but all have more than 10% residual emissions (relative to 1990 levels) by 2030:

- The **No Constraints** scenario reaches 14% residual emissions (relative to 1990 levels) by 2030 but achieves 10% residual emissions shortly after, in 2033. This is considered the maximum level of emissions reduction possible by 2030 (minimum residual emissions) and relies on the deployment of very ambitious levels of behaviour change, modal shift in relation to transport and electrification of heat and transport, supported by significant supportive policy at the national and regional level.
- The **Accelerated Green** scenario reaches 22% residual emissions by 2030 and achieves 10% residual emissions in the late 2030s, 4 years later than No Constraints. It requires ambitious levels of behaviour change and as ambitious technology rollout as possible without requiring widescale scrappage;
- **High Electrification** and **High Hydrogen** slightly exceed national targets, with High Electrification decarbonising faster (27% residual emissions in 2030) due to the reliance of High Hydrogen (30% residual emissions in 2030) on conversion of the gas grid, which happens after 2030. The High Electrification and High Hydrogen scenarios only reach 10% emissions in the early 2040s.

For comparison, all four scenarios in the *1.5°C Plan* decarbonised less rapidly, such that around 40% emissions would remain in 2030.

The different rates of decarbonisation lead to significant differences in the cumulative emissions (Table 1), with close to 100 $MtCO_2e$ difference between the highest (High Hydrogen) and lowest (No Constraints) emissions scenarios by 2050. This saving in cumulative emissions demonstrates the importance of early action.

In all scenarios, the majority of remaining emissions in 2030 come from Buildings (40-50%, depending on scenario) and Transport (38-40%), with Agriculture, Forestry and Other Land Use (AFOLU), Waste and Industry each making up less than 10% of remaining emissions. For High Electrification, High Hydrogen, and Accelerated Green the majority of emissions come from remaining fossil fuel use (72%, 76%, and 70%, respectively), while in No Constraints, residual emissions from electricity use make up a larger share (38% of total residual emissions).

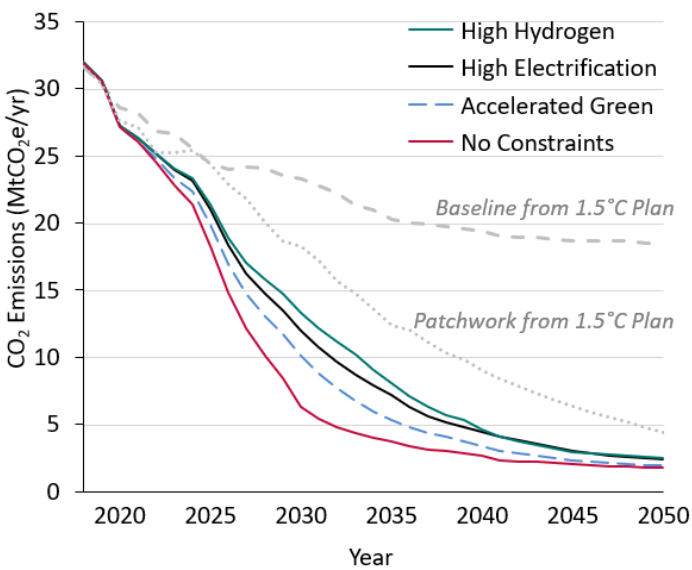

Figure 2 Annual emissions emissions over time for each scenario; Baseline and Patchwork scenarios from *1.5°C Plan* included for comparison

The level of residual emissions is highly dependent on the rate at which the electricity grid decarbonises and, if the national grid can decarbonise faster

[4] The residual emissions in 2050 reflect remaining emissions from hard-to-decarbonise sectors (such as aviation) and sources outside of the GLA's influence, including remaining electricity grid emissions.

Table 1: Summary of key decarbonisation metrics for the modelled scenarios in this study, compared to the Patchwork scenario developed in the *1.5°C Plan*.

	High Electrification	High Hydrogen	Accelerated Green	No Constraints	2050 Patchwork†
2030 emissions ($MtCO_2e$)	12.0	13.3	10.1	6.4	17.7
2030 emissions (% relative to 1990)	27%	30%	22%	14%	40%
Year reaches 10% residual emissions (level of emissions in 2050 in existing *1.5°C plan*)	2040	2041	2037	2033	2050
Cumulative emissions 2020 to 2030 / 2050 ($MtCO_2e$)	222 / 323	227 / 338	210 / 289	192 / 250	240 / 440

† Note that the Patchwork Scenario from the *1.5°C Plan* had a slightly narrower scope, as it did not include Agriculture, Forestry and Other Land Use (AFOLU) and only included landfill emissions from Waste.

than current projections, then higher emission reductions can be achieved. For example, if the grid decarbonises in line with the recently stated Government ambition to achieve a net zero carbon grid by 2035, emissions could reduce by over 1 $MtCO_2e$ in all scenarios, bringing residual emissions close to 10% relative to 1990 levels by 2030 in No Constraints, 19% for Accelerated Green, 24% for High Electrification and 27% for High Hydrogen. Similarly, if it was possible to achieve a fully renewable electricity supply for London by 2030, emissions could be reduced by close to 2 $MtCO_2e$ in all scenarios.

Policy to deliver the pathways

Reaching net zero by 2030 represents a significantly accelerated target compared to 2050. While the *1.5°C Plan* identified a series of "low regrets" actions to ensure delivery of a minimum level of mitigation while the long-term decarbonisation pathway was made, the urgency of a net zero 2030 target means that much more substantial action must be taken now. Waiting to make a decision on which pathway to follow risks either under-delivery by 2030 or more challenging action and investment in the mid-to-late 2020s to compensate for earlier under-delivery. As such, it will be necessary to take action in the next 5 years that goes beyond what might be considered "low-regrets" actions required for a 2050 pathway. High ambition in this period is essential to ensure the greatest chance of success.

The GLA, TfL, London boroughs, and other private sector and public bodies all must play a role in driving the net zero transition and will need to take be proactive in both leading local change and in working to put London in a strong position to take advantage of national opportunities as they arise. It is important to note that:

- **The Mayor can't deliver net zero emissions in London on his own, and many measures will rely on national-level decisions and coordinated action with relevant partner stakeholders, as well as engagement and behaviour change by the public and local businesses.**
- **All actors will need significant additional resource in the form of designated staff, funding streams and financing to deploy these policies and take crucial action.**

Examples of the likely additional policy and actions required to meet a 2030 net zero target compared to a 2050 target for the highest emitting sectors are summarised in Table 2.

Table 2 Summary of key outcomes and headline examples of policies required across scenarios modelled in this study (non-exhaustive), compared to the Patchwork scenario developed in the *1.5°C Plan*

Scenario (residual emissions in 2030):	No Constraints (14%)	Accelerated Green (22%)	High Electrification (27%)	High Hydrogen (30%)	2050 patchwork (40%)
Retrofit	37% reduction in total heat demand of domestic buildings and 39% reduction in total heat demand of non-domestic buildings by 2030. Heat demand of non-domestic buildings halved by 2034. 210,000 homes retrofitted each year between now and 2030 (approximately 420,000 at peak). 26,500 commercial and public buildings retrofitted each year between now and 2030 (approximately 45,000 at peak). Key policies: Retrofit programmes. Financial incentives (Grants, low interest loans), fiscal incentives (stamp duty, council tax rates, business rates that favour high energy efficiency), supportive planning policy to enforce retrofit at key trigger points (consequential improvement), development of retrofit skills. Acceleration of standards. Greater government funding.				Peak of 160,000 homes retrofitted in mid 2020s
Mandate for no replacement boilers	Yes – 2024 3.3 m heat pumps by 2030	Yes – 2026 (with exception for specific zones) 2.2 m heat pumps by 2030	Yes – 2035 1.8 m heat pumps by 2030	No – but H_2 ready boiler mandate by 2025-2030 0.9 m heat pumps by 2030 (including hybrids)	No 0.9m heat pumps by 2030
Scrappage for boilers	Boilers more than ten years old from 2024	Not needed		Not widely needed (some early H_2 areas only)	Not needed
Scrappage for cars	Yes, for cars more than 10 years old from 2022	Not needed			Not needed
Scrappage for HGVs	Widespread scrappage of rigid diesels more than 15 years old from 2022	Not needed			Not needed

Scenario (residual emissions in 2030):	No Constraints (14%)	Accelerated Green (22%)	High Electrification (27%)	High Hydrogen (30%)	2050 patchwork (40%)
Policies to support modal shift - including road space reallocation, improved transport offering, traffic and parking policies	40% reduction in car vkm Go beyond the MTS by 2030	27% reduction in car vkm Bring forward MTS outcomes by 10 years	12% reduction in car vkm In line with MTS		12% reduction in car vkm In line with MTS
London-wide road user charging	Yes – from early/mid 2020s	Yes – from mid-late 2020s[5]	Yes – post-2030[5]		Yes – post-2030[5]
End of sales of ICE cars and vans	2025	2030			2030s
Solar PV on roofs	3.9GW by 2050 Policies above current ambition, including funding and financing, increased ambition for public buildings, supporting community energy projects.		2GW by 2050 Policies in line with current ambition, including funding and financing, leading by example by deployment on public buildings, supporting community energy projects.		2GW by 2050
Support heat networks	610,000 connections by 2030	460,000 connections by 2030	380,000 connections by 2030		340,000 connections by 2030
	Policies: Implement Heat Network Zoning across London, designate zones and tailor policy and funding to support delivery, e.g. existing and new domestic and non-domestic buildings mandated to connect where HN operator is willing and able to connect and offer market competitive cost of heat. Design, develop, build and/or expand district energy networks in designated 'Heat Network Zones'.				

[5] All scenarios would benefit from London-wide road user charging being introduced as early as possible. Given that transport is one of the areas where the Mayor has the strongest powers and the ability to make the quickest, guaranteed progress, road user charging has the potential to be a powerful lever to reduce emissions quickly and effectively. A gradual introduction could help strike an appropriate balance to ensure a fair transition.

Implications of the Scenarios

Electricity network

The electrification of heat and transport will require electricity grid reinforcement across all scenarios. The extent of reinforcement and the rate at which they will be required will primarily depend on the rate of deployment of electric heating as well as the technology mix (for example, direct electric heating has a higher impact on peak demand than heat pumps). The extent of flexibility measures deployed, such as demand side response (DSR) and energy storage, will also have a significant impact on how the peak demand is managed and the extent of grid upgrades required. Without flexibility measures, around 3-50 of London's 235 primary substations will need to be reinforced by 2030, reaching up to 125 by 2050. In the Accelerated Green and No Constraints scenarios, DSR reduces the number of primary substation upgrades required by 6-8 in 2030, however, by 2050 approximately 25 fewer substations could need reinforcement as the demand increases and DSR is rolled out more widely.

Analysis carried out by Imperial College London,[6] considered how cost savings from generation, transmission and distribution of energy compare with the cost of implementing flexibility through storage and DSR. Adapting these high-level estimates for London alone, indicates potential savings of between £1.3 to £1.6 billion across the scenarios by making use of flexibility measures, even when accounting for the cost of implementing such measures.

Hydrogen in London

The scenarios assume varying degrees of hydrogen use in London, although in all scenarios it only plays a small but strategic role in meeting the net zero by 2030 target. The High Hydrogen scenario is the most optimistic on the role that hydrogen will play in that it assumes there will be conversion of the existing gas grid to hydrogen in the post-2030 period. Conversion in that scenario begins in the early- to mid-2030s, with completion by 2045, and total demand reaching 26 TWh/year in 2050 (compared to current demand of close to 60 TWh/year natural gas). The current technological immaturity of hydrogen production and the need to deploy the Hydrogen that is available to strategically important sectors represents a significant risk factor in the High Hydrogen scenario, both in terms of uncertainty of availability, emissions intensity, and future costs.

Costs

The investment costs to deliver the scenarios have been estimated, covering building costs (energy efficiency and low carbon technology), fuel costs, infrastructure costs (electricity network upgrades, refuelling infrastructure, and hydrogen pipeline costs), and carbon costs.[7] Carbon costs were based on those in the HMT Green Book, ranging from £140-420/tonne CO_2 in 2030 to £189-568/tonne CO_2 in 2050 (low to high carbon price). The additional cost of upgrading public and active travel infrastructure was not included in the scope of the analysis since precise shifts of travel to public and active modes was not explicitly modelled. However, based on analysis of policies to support delivery the MTS, these measures could add at least £2.9-6.4bn per year to the total required investment.

All scenarios experience a significant peak in investment in the 2020s due to the ambitious energy efficiency deployment across all scenarios. The more ambitious scenarios have a higher spending peak in the 2020s due to more rapid deployment of low carbon heating technology, with No Constraints

[6] Carbon Trust and Imperial College London "*An analysis of electricity system flexibility for Great Britain"* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/568982/An_analysis_of_electricity_flexibility_for_Great_Britain.pdf *published November 2016*
[7] The carbon value is a metric used to estimate the economic damage of releasing CO_2 into the atmosphere. This carbon value provides a quantitative measure of the benefits of preventing CO_2 emissions.

requiring over £21bn in investment at its peak as energy efficiency measures and low-carbon heating are rolled out across the building stock.

The total cost across scenarios is very similar by 2050, with a range of £7.6bn (discounted) cost between the highest (No Constraints) and lowest cost (High Hydrogen) scenarios (Table 3). Without carbon costs, High Hydrogen is the lowest cost scenario, largely due to lower technology costs associated with gas boilers (H_2 or biomethane) compared to heat pumps. Despite the lower CAPEX costs in the High Hydrogen scenario, the higher fuel costs expected to heat a home using a hydrogen boiler over a heat pump, mean that the cumulative costs for High Hydrogen eventually increase above the other scenarios.

The point at which No Constraints becomes the scenario with the lowest cumulative costs varies with the carbon price used.

- No carbon value included – 2060
- Low carbon value – 2050
- Medium carbon value – 2036
- High carbon value – 2034.

With a carbon price included, the No Constraints scenario therefore becomes the most economically favourable within the timeframe of the UK net zero target, and achieves this shortly after 2030 with medium and high carbon values. This result highlights the benefits of early action on decarbonisation. Even without accounting for carbon, No Constraints offers the lowest cost pathway by 2060 with the added benefit of lower ongoing fuel costs than in other scenarios.

While the Accelerated Green scenario does not become the lowest cost scenario of those modelled at any timepoint, the main advantage of Accelerated Green compared to No Constraints is in its smoother rollout of low-carbon heat, leading to a marginally more consistent spread of the costs.

Job creation

The transition to net zero more quickly in London will not only offer job opportunities for Londoners but also those outside the region, through supporting the supply chain of goods and services. The potential for direct job creation through mitigation measures deployed in London[8] was estimated at a high-level for selected sectors (primarily energy efficiency retrofit and low carbon heating).

Job numbers peak in the mid-2020s driven by demand for skilled retrofit workers to install energy efficiency measures in buildings. The greater the rate of decarbonisation (as in Accelerated Green and No Constraints), the shorter the timescales on which skills are required and the greater the demand for people with the correct skills, which is inherently more difficult to manage. Mechanisms to smooth the required FTE over longer timeframes are beneficial as, although they lead to fewer jobs at the peak, the jobs generated are more long-term.

For energy efficiency, at the peak, the direct workforce for retrofits reaches 32,000 jobs, which additionally means that close to 900 retrofit coordinator roles will be required across London by the mid-2020s. For heat pumps and district heating deployment, up to 35,000 full-time equivalents will be required at the peak (23,000 average 2020-2030).

[8] The analysis does not define where the jobs will occur; however, retaining local value of the transition is an important principle of green recovery.

Table 3: Costs associated with each decarbonisation pathway. Costs are discounted unless specified otherwise.

Metric	High Electrification	High Hydrogen	Accelerated Green	No Constraints	Patchwork (2050)
Peak annual investment costs (without fuel) (£ bn)	10.2	9.4	10.7	12.0	N/A
Total cumulative building-level and infrastructure costs to 2050	106	95	110	113	61
Total cumulative fuel costs to 2050	184	190	184	180	226
Total cumulative investment costs to 2050	291	285	294	293	287
Total cumulative investment costs to 2050, including a "social" cost of carbon (£bn)	357	355	355	346	N/A
Annual fuel costs in 2050 (£ bn) (undiscounted)	8.5	9.5	9.0	8.3	N/A
Jobs supported in peak delivery year (selected sectors only)	47k	57k	61k	73k	N/A

The role of offsetting

Despite ambitious action, all scenarios fall short of zero residual emissions by 2030 and the remaining emissions will need to be offset to meet net zero.

A truly 'additional' offset – that is, one which would not have occurred otherwise – has the same physical impact on climate change as the equivalent direct emissions reduction, since the state of the atmosphere is the same whether carbon dioxide is emitted in one location or another. However, **offsetting in this way is only available as an option in the near and medium term**, as ultimately carbon neutrality will need to be achieved globally, meaning that emissions will need to be reduced to very low levels across all jurisdictions, with negative emissions measures required to balance any remaining emissions. As such, London will need to continue to reduce its emissions even further beyond 2030 and reduce its residual emissions to the absolute minimum as soon as possible after 2030.

Various kinds of negative emissions approaches and offsets are possible. It is estimated that the annual cost of offsetting residual emissions to achieve net zero in 2030 could range from £317m up to a maximum of £5.6 bn.

Next Steps

This analysis will be used by the Mayor to select a preferred pathway for meeting net zero emissions by 2030. The GLA will then use this analysis to engage key stakeholders across London, the UK and national government on how they can together achieve net zero emissions by 2030, and to build public consensus around the urgent changes needed to tackle climate change and achieve a green economy.

Contents

Authors

Heather Goodwin, Senior Consultant

Maciek Peplinski, Consultant

Katherine Orchard, Principal Consultant katherine.orchard@element-energy.co.uk

Reviewers

Sam Foster, Partner sam.foster@element-energy.co.uk

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Organisation	**Topic**
Cadent	Gas network scenarios and hydrogen assumptions
SGN	Gas network scenarios and hydrogen assumptions
UK Power Networks	Electricity distribution infrastructure impacts and planning
SSE	Electricity distribution infrastructure impacts and planning
Association for Decentralised Energy	District heating assumptions and policy
Heat Pump Federation	Heat pump assumptions and policy
Statera Energy	Hydrogen production assumptions
Ryse	Hydrogen production assumptions
Transport for London	Transport scenario assumptions
Port of London Authority	Transport scenario assumptions

This work also benefitted from input from wider groups within GLA and Transport for London, which we gratefully acknowledge.

Disclaimer

This report does not necessarily reflect the views of the GLA. No endorsement by the GLA of specific policies, regulations or programmes discussed in the report is claimed or implied.

While the authors consider that the data and opinions contained in this report are sound, all parties must rely upon their own skill and judgement when using it. The authors assume no liability for any loss or damage arising from decisions made based on this report.

Acronyms

AD	Anaerobic Digestion
AFOLU	agriculture, forestry and land use
ASHP	air-source heat pump
ATR	autothermal reformation
BEIS	Department of Business, Energy and Industrial Strategy
BEV	battery electric vehicle
CCC	Climate Change Committee
CCS	carbon capture and storage
CCUS	carbon capture, use and storage
CHP	combined heat and power
CITB	Construction Industry Training Board
DH	district heating
DNO	distribution network operator
DSR	demand side response
EU ETS	European Union Emissions Trading Scheme
EV	electric vehicle
EVCP	electric vehicle charge point
FC CHP	fuel cell combined heat and power
FCEV	fuel-cell electric vehicle
FES	Future Energy Scenarios
FTE	full time equivalent
GHG	greenhouse gases
GLA	Greater London Authority
GSHP	ground-source heat pump
HFC	hydrofluorocarbon
HGV	heavy goods vehicle
HHP	hybrid heat pump
HMT	Her Majesty's Treasury
HPA	Heat Pump Association
ICE	internal combustion engine
IPPU	industrial processes and product use
LEGGI	London Energy and Greenhouse Gas Inventory
MTS	The Mayor's Transport Strategy
PHEV	plug-in hybrid electric vehicle
PLA	Port of London Authority
PPA	power purchase agreement
PV	photovoltaics
SAF	sustainable aviation fuel
SNG	Synthetic natural gas
STR	steam methane reformation
TfL	Transport for London
UKPN	United Kingdom Power Networks
ULEV	ultra-low emission vehicle
vkm	vehicle kilometres
ZEV	zero emission vehicle

1 Introduction

1.1 Context

In 2018, the Greater London Authority (GLA) published the *London Environment Strategy*[9] and *Zero Carbon London: A 1.5°C Compatible Plan*,[10] which presented a range of energy system scenarios for London consistent with a 2050 Net Zero target. This study was underpinned by scenario modelling undertaken by Element Energy for the GLA and C40 Cities.[11]

At the time of publication of the *1.5°C Plan*, the UK ambition was to achieve an 80% reduction in emissions by 2050. Since then, national climate ambition has increased; in June 2019, parliament passed legislation requiring the UK Government to achieve 'Net Zero' greenhouse gas emissions by 2050 at the latest and, in 2020, set our 'Nationally Determined Contribution' (NDC) under the Paris Climate Agreement to a 68% reduction by 2030 versus 1990 levels. In parallel, supportive policy and funding has been announced to begin to support this transition (see Appendix section 5.1, for a summary of relevant policy development).

However, in recognition of the imperative of early action in limiting global temperature rise to well below 2°C, a number of regions – including London – have committed to, or are considering, an accelerated Net Zero target. In 2020, the Mayor of London committed to set a target for carbon neutrality across Greater London by 2030 which was reconfirmed in the Mayor's 2021 election manifesto. A 2030 target for carbon neutrality, or Net Zero, represents a substantial increase in the level of ambition relative to a 2050 target.

In light of the increased level of policy ambition at both national and London-level since the publication of the *1.5°C Plan*, the GLA commissioned Element Energy to update the previous energy system scenario analysis to give insight into the implications of a Net Zero 2030 target for London.

Definition of net zero

Reaching net zero means that any remaining emissions of GHGs are balanced by removal of an equivalent amount of CO_2 from the atmosphere (sequestration) or by preventing emissions which otherwise would have occurred elsewhere (offsetting). For local and regional authorities, in practice this means reducing Scope 1 and 2 emissions (see Section 1.3) that arise within the local area as far as possible and to very low levels, and either balancing the remaining emissions with sequestration within the region or offsetting through action or investment in carbon mitigation outside the region.

1.2 Objectives

The objective of this work is to update the analysis underpinning the *1.5°C Plan* on achieving net zero in London in order to identify the key challenges, risks and implications of a 2030 Net Zero target relative to a 2050 target through:

- **Developing a set of scenarios that meet net zero by 2030**, differentiated by the level of local political ambition, the resulting residual emissions (which would need to be offset), and the associated technology mix. The range of pathways was developed to indicate how the net zero target could be achieved and to represent the range of uncertainty in the pathway to carbon neutrality.

[9] https://www.london.gov.uk/what-we-do/environment/london-environment-strategy
[10] https://www.london.gov.uk/what-we-do/environment/climate-change/climate-action-plan
[11] https://www.london.gov.uk/sites/default/files/element_zero_carbon_energy_systems_report.pdf

- **Identifying the key challenges, risks, and implications** of delivering those scenarios within the 2030 timeline, including the system, infrastructure, technology and behaviour change required.
- **Describing the policies required at national and London-level to stimulate activity and deliver the target**, including the potential role of carbon offsetting.

This report does not aim to define the roles of key stakeholders that will be critical to delivering the pathways, or to provide a delivery plan for action going forward; these will be important areas for subsequent work that will follow this report as London continues to develop its climate ambitions.

As an outcome of this work, a key objective is to update the GLA's existing Zero Carbon Pathway Tool (ZCPT) to reflect the increased policy ambition. The modelling in this study is therefore built around the existing functionality within the ZCPT, with the calculation methodology and underlying analysis updated as required.

1.3 Approach and Scope

Modelling and emissions scope

This study aims to assess the potential pathways and actions needed to drive reduction in Scope 1 and 2 emissions across London, as defined in Table 1.1. Scope 3 emissions associated with embodied emissions in goods, services, or construction projects (e.g. road building, housing developments etc.) are not included in the analysis but it is recognised that actions to address these emissions must be considered as part of wider climate change mitigation strategies.

The scenarios developed for this work cover all end-use sectors included in the *1.5°C Plan*, including Buildings (domestic and non-domestic), Transport (road transport, rail, river, and aviation), and Industry. Industrial Processes and Product Use (IPPU), Agriculture, Forestry and Other Land Use (AFOLU) and Waste have been added to the scope, in line with latest emissions data from the London Energy and Greenhouse Gas Inventory (LEGGI).

Within these sectors, buildings and road transport trajectories are modelled in greatest detail as these are the largest emitting sectors within London. For the purposes of this study, smaller sources of emissions such as rail, river, aviation, industry (including IPPU), AFOLU and waste emissions are all modelled at a comparatively high-level to understand their role in achieving the carbon reduction targets. However, these sources have an important role to play in helping London to reach net zero and further work to define more detailed pathways for these sectors is recommended.

While the study focuses primarily on the path to 2030, the scenarios are modelled to 2050 to assess the longer-term carbon, cost and employment impact of each trajectory.

For the purposes of this study, the analysis considered emissions reduction and action across London as a whole and does not aim to explicitly define action at more granular geographic level (e.g. Inner vs Outer London, or borough-level). However, the modelling underpinning the *1.5°C Plan* did consider some aspects of the energy transition at more localised level (for example, potential for heat network deployment and distribution of energy demand at borough-level); therefore, where this study builds on the existing modelling, some more local aspects will be inherently captured.

The approach taken does not explicitly model individual infrastructure projects, but such projects may indirectly feed into the assumptions. For example, for transport, only the km travelled as a result of implementing the Mayor's Transport Strategy (MTS) has been used as an input to the analysis. However, the km travelled in the MTS is a function of the transport related projects in the MTS.

Costs and benefits

Indicative estimates of investment costs and job creation potential have been developed for selected sectors and technologies to highlight the relative implications and benefits of each scenario. These estimates cover key investment and skills needs to support the transition to net zero, including building-level, infrastructure and fuel investments and direct job creation (installers, design engineers etc.). It does not include indirect or supply chain jobs estimates.

Table 1.1 Overview of emissions sources within scope of this study

Scope	Type	Definition	Examples	In study Scope?
Scope 1	Direct	GHG emissions from sources located within the city boundary.	• Emissions from fossil fuels used to **heat** homes and non-domestic buildings, **road travel** occurring within the city boundary, and **industrial processes** • **Refrigerant emissions** from industrial processes • Use of fossil fuels to power non-road transport occurring within the city boundary, including **aviation, shipping, rail, and non-road mobile machinery** • **Landfill and waste** disposal • Direct emissions from **livestock, land, and agricultural machinery**	✓
Scope 2	Indirect	GHG emissions occurring as a consequence of energy used within the city boundary but generated outside the city.	• Electricity used within the city for heating and cooling buildings, appliances, electric vehicles, and industrial uses • Heat supplied to district heating networks (if generated outside the city)	✓
Scope 3		All other GHG emissions that occur outside the city boundary as a result of activities taking place within the city boundary.	• Embedded emissions of products and services • Travel outside the city by residents and visitors • Emissions from waste arising within the city boundary but treated outside the city • Upstream emissions from energy production	✗

Policy recommendations

In assessing the level of policy support and action to support the pathways, the analysis assumes that policy is in place at national and London level to achieve, as a minimum, the UK's 2050 net zero commitments since a net zero 2030 target must necessarily go beyond action needed to be compliant with national targets. The recommendations in this report therefore focus on the increased level of policy required to meet a 2030 net zero target in London, compared to a 2050 target. In developing the policy recommendations, this study indicates the type of policy and level of ambition that may be required to meet key outcomes but does not aim to specify the exact form of any policy required.

Wider input

As part of this study, selected relevant external stakeholders and internal GLA policy teams were consulted to understand the current and potential limiting factors in delivering the scenarios and to help in refining the analysis. This was the first stage in the GLA's engagement plan and, following publication of this study, the GLA will be exploring the options with stakeholders to secure buy-in for London's approach.

2 Pathways to Net Zero

2.1 Scenario overview and rationale

Four scenarios across three levels of decarbonisation ambition have been developed for this study to explore the range of potential pathways for London to 2030 and beyond. The scenarios are differentiated by varying levels of target residual emissions in 2030 (which would need to be offset) and by technology mix, as summarised in Figure 2.1. The scenarios have been developed to explore the implications of different levels of ambition to 2030, and what that means in terms of required policy, technology choice, and deployment rates.

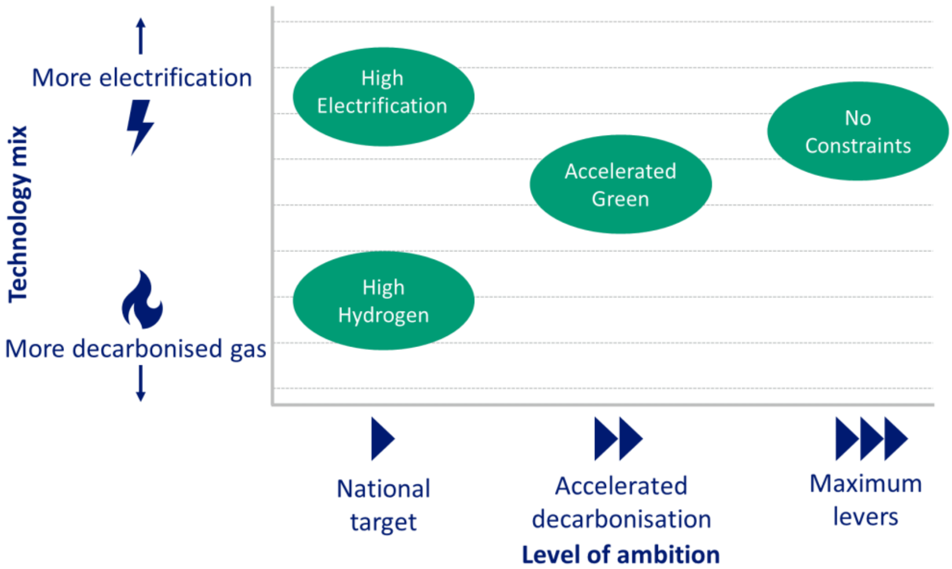

Figure 2.1 Overview of scenarios

Two scenarios have been developed that are broadly in line with UK-wide targets for a 68% reduction in emissions by 2030 relative to 1990 levels (approximately 14 $MtCO_2e$ for London). These represent the maximum level of residual emissions that need to be targeted to be compatible with a 2030 Net Zero scenario[12] and are equivalent to trajectories that would be several years 'ahead' of those in the *1.5 'C Plan*, which reached a residual 14 $MtCO_2e$ by approximately 2034-35.

To accommodate the uncertainty in which technology options will be supported or favoured under a national target-compliant scenario, one scenario that favours electrification of heat and transport (High Electrification) and one that assumes that hydrogen will be available at scale in the longer term (High Hydrogen) have been developed. The UK Government recently confirmed its intention to take a decision on the role of hydrogen for heating in 2026 and to take a decision on technology for HGVs in the mid-2020s.[13] As such, it is appropriate at this stage to explore both approaches.

The No Constraints scenario represents a significantly accelerated decarbonisation pathway that aims to deploy all available policy levers and measures to reach minimum achievable residual emissions by 2030; this includes more challenging policies such as early scrappage of boilers and vehicles. This scenario is not considered to be constrained by the costs or level of current local influence to implement such challenging policies and effect the necessary measures over the short timeframe. Due to the pace of decarbonisation required, technology options will necessarily be limited to those

[12] On the basis that London would need to decarbonise quicker than the national targeted average under a 2050 scenario.
[13] BEIS Net Zero Strategy: Build Back Greener (October 2021)

available by 2030. While technology solutions primarily focus on electrification, a key consideration of this study was to define the feasible level of hydrogen that could be available in London by 2030 to support decarbonisation efforts. This scenario includes the maximum feasible deployment of hydrogen, based on consultation with industry representatives (see also Section 2.2.1). Due to limitations in stock turnover and supply chains, technology deployment needs to be supported by very high levels of behaviour change in society to minimise emissions.[14]

The Accelerated Green scenario represents an intermediate scenario, in which London decarbonises as rapidly as possible ahead of the national targets while leaving long-term technology options open as far as possible; in particular, this allows for some heating systems to remain connected to an increasingly decarbonised (but reduced capacity) gas grid through blending with biomethane, with a moderate share of hydrogen to be used in selected applications that lie along a dedicated supply route (see next section). This scenario aims to reach as low residual emissions as is possible by 2030 without requiring the most difficult and expensive measures, such as scrappage, to be implemented and combines accelerated technology shift and increased levels of behaviour change compared to the national target-compliant scenarios.

2.2 Key Sectoral Assumptions

2.2.1 Low-Carbon Gases

Hydrogen

There is a great deal of uncertainty around the precise future role of hydrogen, both at national and local level, with decisions at national level expected to be taken in 2026 at the earliest. Given that London does not lie in direct proximity of areas currently supported for early large-scale hydrogen deployment,[15] understanding the potential role of hydrogen in London by 2030, or soon after, was a key consideration for this study. The assumptions regarding the role of hydrogen in the scenarios have been informed by consideration of both the likely supply and demand from targeted applications.

Demand-side assumptions - Widespread deployment of hydrogen for heating in buildings (either hydrogen boilers or hybrid heat pumps) is not considered viable before conversion of the gas grid. While some areas of the gas grid may be able to begin conversion in the early 2030s,[16] full conversion of the grid is not likely to be complete until the 2040s, in line with expectations around national hydrogen supply chain development.[17] The likely applications for hydrogen by 2030 include large anchor demands that can stimulate local production, as summarised in Table 2.1.

Ahead of 2030, hydrogen is expected to be supplied either by carrier (either road trailer or river barge) or by dedicated pipeline (where the level of demand justifies construction of a pipeline, such as for large industrial sites). Full conversion of the existing gas grid is only assumed in the High Hydrogen scenario. In line with the Patchwork scenario developed in the *1.5°C Plan* (see Appendix, Section 5.2), the Accelerated Green scenario assumes that a new, dedicated and strategic ‘backbone’ or pipeline is constructed to supply a larger number of industrial sites, transport refuelling sites and energy centres for district energy networks across London from the late 2030s.

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[14] While all scenarios require a degree of behaviour change, No Constraints requires the most to achieve the very high levels of emissions reductions targeted in this scenario

[15] Track 1 clusters for development in the mid-2020s under the UK’s CCUS Cluster Sequencing Process include Hynet (a H_2 project in the North West) and East Coast clusters. [Climate Change Update statement, October 2021]

[16] Based on consultation with SGN and Cadent

[17] Gas grid conversion is expected to occur in phases, with defined sections of the gas grid transitioning earlier than others. Within converted areas, all appliances connected to the gas grid, such as boilers and industrial equipment, would need to be converted to run on hydrogen at or before the time of local grid conversion (cooking appliances are expected to be converted to electrical appliances, in line with assumptions underpinning the CCC’s net zero modelling) .

Table 2.1 Summary of key target applications for hydrogen in 2030 assumed in the emissions reduction scenarios

Target application	Details
Transport	Hydrogen use in transport does not rely on conversion of the gas grid, since refuelling stations can be supplied in the interim through either on-site electrolysis or trailer delivery.[18] The car market is largely expected to electrify, with the main early application of hydrogen in transport expected to be in **heavy duty transport** (buses and heavy goods vehicles, HGVs), although vans are also expected to become a significant source of hydrogen demand by 2050, particularly in the High Hydrogen scenario. Some deployment of hydrogen across all road transport modes by 2050 is assumed in all scenarios.
Grid blending	Blending of hydrogen into the gas grid is limited to approximately 20% by volume, and 7% by energy. Blending is assumed in all scenarios, beginning in 2026 ramping up to **20% by volume by 2030**, in line with expected ramp up of local production projects (see “Supply-side assumptions” below).
District heating	Heat supply to heat networks is expected to be a suitable early application for hydrogen deployment. Due to the low availability and high cost of early hydrogen, it is assumed that hydrogen is primarily deployed for **peaking heat demand.** The modelling assumes that 30% of boilers[19] supplying **peaking heat demand** in all (current and forecast) heat networks are **hydrogen boilers** in the High Hydrogen, Accelerated Green, and No Constraints scenarios at maximum deployment level; for No Constraints, this is reached in 2030 and in Accelerated Green this is reached by 2035 (representing 8% of total heat supply to networks). However, supply to networks where heat is generated in larger energy centres through the use of CHP is also considered a suitable potential application, so that zero carbon electricity can be supplied into the local electricity network to support flexibility, resilience and to accelerate decarbonisation beyond the trajectory of the national grid. A small share of **fuel cell combined heat and power (FC CHP)** units are assumed in these scenarios to reflect possible non-peaking heat supply in strategic energy centres (for example, where electricity grid constraints may favour use of heat supply other than heat pumps, and/or benefit from co-generation of electricity).
Selected industry	**Selected large industrial sites**, predominantly in the food & drink sector for London, are assumed to be able to act as anchor demands for a dedicated hydrogen supply for use in industrial processes.
Power generation	Power generation is a target sector for initial production (see “Supply-side assumptions”), through blended supply (up to 20%) and, later, through full conversion to hydrogen turbines. The power sector is not included in the emissions trajectories but is discussed at a high-level in Section 2.2.6 and **investing in** further decarbonising power generation **outside London** could be considered an option for further minimising residual emissions in 2030 (see also Section 2.2.6).

[18] The majority of current (small-scale) hydrogen refuelling stations in the UK are supplied by on-site electrolysis
[19] Based on the share of projected heat networks in East London with access to expected routes for imported hydrogen along the Thames

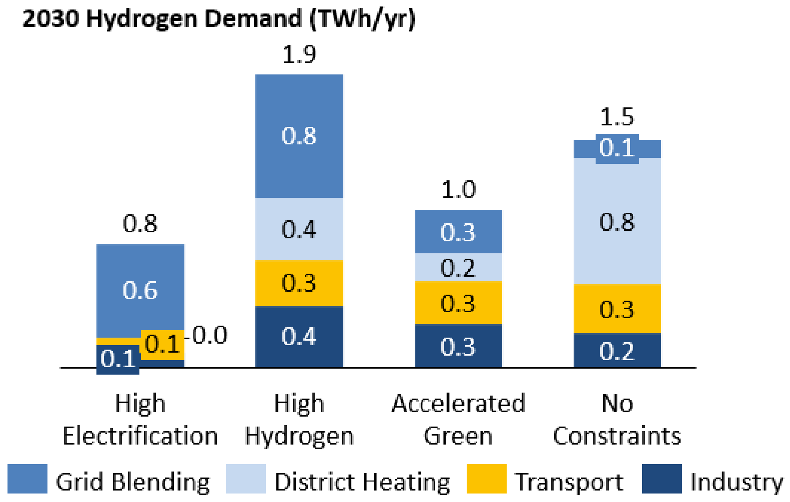

Figure 2.2 Estimated hydrogen demand from key target applications in London in 2030

The total demand expected from these applications in 2030 ranges from 0.8 to 1.9 TWh/year (Figure 2.2).

Supply-side assumptions: Large-scale low carbon hydrogen production is expected to rely in large part on the development of Carbon Capture Usage and Storage (CCUS). The Government's focus for CCUS development up to 2030 is on four industrial clusters in the North East, North West, Scotland, and Wales (with North East and North West clusters confirmed as "track 1" clusters).[20,21,22] While there are limited options for local large-scale production to supply London ahead of 2030, there are a number of projects that have the potential to supply hydrogen to small-scale, targeted applications, summarised in Table 2.2.

All projects in Table 2.2 are located outside of the GLA boundary, with Project Cavendish (at the Isle of Grain) and the Statera Energy site (in Thurrock) closest to London, both with supply routes from the East along the Thames. If successfully developed, one or more of these projects would be capable of supplying the demand estimated for London in 2030 in all scenarios. Supply beyond 2030 is highly uncertain; however, all projects listed have the potential to scale up significantly and London is expected to have access to a wider supply than the projects listed as national production increases.

Supply mix: Up to the early 2030s, the hydrogen supply is expected to be largely met by a combination of the sources detailed in Table 2.2. The mix is expected to be primarily blue hydrogen (ATR+CCUS) for industry and injection into the grid, with transport predominantly supplied by hydrogen from electrolysis, in line with current supply to hydrogen refuelling stations as well as agreed future short-term supply to transport projects. Between 2030 and 2040, the hydrogen mix is assumed to incorporate a greater share from electrolysis and, ultimately, to align with the expected wider UK supply (Figure 2.3).[23] Production energy and emissions assumptions are provided in the Appendix, Section 5.3.1.

[20] Carbon Capture Usage and Storage: Market Engagement on Cluster Sequencing – Consultation 2021
[21] *The Ten Point Plan for a Green Industrial Revolution* (2020) BEIS
[22] https://questions-statements.parliament.uk/written-statements/detail/2021-10-19/hcws325 Accessed 19th October 2021
[23] Based on the CCC 6th Carbon Budget Balanced Pathway

Table 2.2 Selected projects with potential to supply hydrogen to London in 2030

Project	Production method†	Capacity in 2030 (GW)	Target sector(s)*	Likelihood††
Project Cavendish	● ATR + CCUS	1.75		Likely
Statera Energy	● Electrolysis (grid or renewables)	0.02-0.2		Likely
Ryze Hydrogen	● Electrolysis (grid or renewables)	1		Very likely
Bacton Energy Park	● ATR + CCUS ● Electrolysis (renewables)	*Unknown*		Likely
Southampton Water	● ATR + CCUS	*Unknown*		Likely

† ● = "blue" hydrogen, where ATR = Autothermal reforming (of methane) and CCUS = Carbon Capture and Storage; ● = "green" hydrogen produced by electrolysis; note that truly green hydrogen requires electrolysis direct from renewables or the renewables share of grid electricity

*  = grid blending,  = power generation,  = transport,  = industry

†† High-level (in-house) assessment of likelihood of project going ahead, based on stage of project development, funding allocated or applied for, and confirmed customer base (e.g. Ryze has confirmed supply to bus fleets across the country, including London, using supply from sites in the East of England, and has recently agreed a collaboration with HyNet as a further hydrogen supplier).

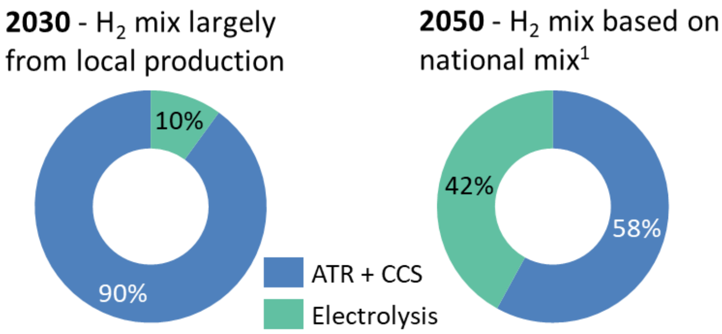

Figure 2.3 Hydrogen supply mix assumed in the scenarios

Green gases

The gas grid is further decarbonised in all scenarios through blending of biomethane (from anaerobic digestion, AD) and bio-synthetic natural gas (bioSNG). The trajectories for biomethane and bioSNG deployment are based on those assumed in the *1.5°C Plan* and adjusted to reflect the assumed deployment of green gas in the latest National Grid Future Energy Scenarios.[24] Biomethane production is assumed to reach its peak in 2030-2035 (depending on the scenario) then remain constant. BioSNG production is expected to begin in the mid 2020s but only become significant in the later 2030s (see Appendix, Figure 5.2 for uptake trajectories).

Allocating a fair share of the UK's biomethane and bioSNG to London results in between 1.3 TWh (Low scenario) and 7 TWh (High scenario) of green gas is assumed to be available for injection into London's grid by 2050. The High Electrification scenario assumes supply in line with the Low scenario (reflecting a future that does not rely on widespread green gas deployment), whereas High Hydrogen, Accelerated Green and No Constraints assume supply in line with the High scenario.

[24] FES 2021 https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2021

There is currently only one AD plant injecting biomethane into London's gas grid. Current enquiries submitted for connection in North London could potentially generate around 0.8 TWh/yr of biomethane if all are taken forward, representing 40%-60% of the required demand across the scenarios in 2030. However, it is unlikely that all projects will reach completion and therefore further capacity will be required to meet the assumed supply that London needs in the scenarios modelled here.

2.2.2 Buildings

For the purpose of this study, the modelling did not explicitly deploy energy efficiency or heating technologies according to building type (detached, semi-detached, age of property etc) or tenure (owner-occupier, private rented, social rented), and instead deployed these measures as a share of the domestic and non-domestic building-stock at a London-wide level. However, some of these aspects are captured at a high-level where this level of disaggregation was already present in the underlying analysis underpinning the *1.5°C Plan.* In practice, there are different challenges associated with decarbonising different building stock characteristics and tenure types, which must be considered in policy development and delivery models.

Energy efficiency

Energy efficiency measures, such as cavity wall insulation, loft insulation, and low energy lighting reduce the energy demand in a building. Reducing the overall energy demand of buildings is crucial both to reduce overall fuel use, and therefore emissions, and to ensure that low carbon heating systems are both cost-effective and deliver suitable levels of comfort for consumers.

The domestic energy efficiency trajectory targets an average space heating demand of 65 kWh per m^2 by 2030 in all scenarios, in-line with modelling by Parity Projects for London Councils.[25,26] This level of space heating demand is in line with the London Councils' ambition for all homes to reach an average of EPC B after fabric and low carbon heating measures. This trajectory goes beyond national ambition and therefore means that the High Electrification and High Hydrogen scenarios are more ambitious than national targets in this respect. Overall, the total heating demand of existing domestic buildings reduces by 37% by 2030 (Figure 2.4), with space heating reducing by 42% by 2030; this is equivalent to 210,000 homes on average receiving significant insulation improvements each year between now and 2030. With a slower ramp-up in rate of deployment than that shown in Figure 2.4, resulting in less linear deployment, the peak rate would need to be much higher in the late 2020s (in the region of 500,000 homes per year) to achieve the same level of overall deployment (see Appendix, Section 5.3.2 for further detail).

The non-domestic modelling uses existing trajectories developed by Arup for the analysis underpinning the *1.5 'C Plan*.[27] The trajectory used, Arup's "More Effective" scenario, achieves a reduction in total heating demand of close to 50% by 2034 (39% by 2030; Figure 2.4), with space heating reducing by 43% by 2030. This trajectory is more ambitious than was used in the scenarios detailed in the *1.5°C Plan*, which

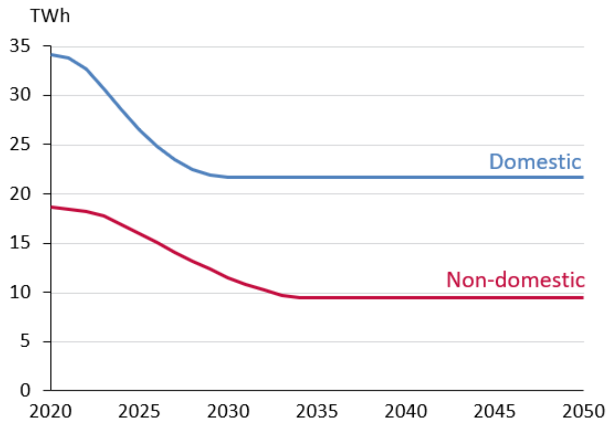

Figure 2.4 Total heat demand of existing buildings after energy efficiency improvements

[25] *London Councils: Pathways Report*, Parity Projects, 2021
[26] This target represents an average space heating demand, but recognizes that there will be a distribution around this point whereby some buildings will be able to reduce their energy demand further but others will be more challenging to retrofit.
[27] *London's Climate Action Plan*, Work Package 2: Building Retrofit Programme Assessment, Arup, 2018

used Arup's "Central" scenario, and is broadly equivalent to the level of efficiency achieved in the Domestic sector scenarios.[28]

Behaviour change was not explicitly modelled for either buildings sectors; however, Parity Projects modelling for the domestic sector states that a degree of behaviour change (such as lowering thermostat temperatures) will be required to achieve maximum energy savings.

This study assumes that energy efficiency is prioritised and maximised to the same level across all scenarios for both domestic and non-domestic sectors, to be consistent with existing ambition in London and to reflect a 'fabric-first' or energy demand reduction-led approach.

Low carbon heating

To achieve the levels of emissions reduction required, all scenarios require significantly increased deployment rates of low carbon heating.

Heat pumps are deployed widely in all scenarios to decarbonise heating in the 2020s and early 2030s, but the maximum rate of deployment and the date by which this rate is achieved vary by scenario (Figure 2.5). In all scenarios, heat pump connections refer to individual heat pumps installed in homes or connections to larger communal systems (such as one heat pump serving a block of flats).

The No Constraints scenario requires early scrappage of existing heating systems, with 330,000 heat pump connections per year in existing buildings from 2025, with a further 50,000 heating systems installed (mainly district heating connections, or like-for-like replacements of existing counterfactual systems).[29] This number of heat pump installations per year is 53% higher than the natural replacement rate (115,000 more installations per year than would otherwise be replaced at end of life),[30] meaning that, on average, existing heating systems will be replaced 5 years earlier than in the other scenarios. This deployment rate represents more than half of the Government target for UK annual installations by 2028 (600,000 per year).[31] In contrast, the Accelerated Green scenario requires 215,000 heat pump connections per year in existing buildings from 2026, representing 73% of all replacement heating systems, with no early scrappage of existing heating systems. Since the majority of lifetime emissions of heating systems arise during operation,[32] the embedded emissions associated with retiring heating systems 5 years early are expected to be more than offset by savings from avoided natural gas use; however, further work would be required to fully understand the implications of scrappage.

By 2030, 3m homes are served by heat pumps in No Constraints, compared to 2m in Accelerated Green, 1.7m in High Electrification, and 0.8m in High Hydrogen. In No Constraints, Accelerated Green and High Electrification, these heat pumps are all standalone heat pumps, whereas in High Hydrogen, 6% are hybrid heat pumps (i.e. work alongside a (Hyready) boiler).

Energy efficiency retrofit is necessary for low carbon heating to be cost-effective and to deliver suitable levels of comfort for consumers. For the purposes of the modelling, installation of heat pumps is assumed to occur after any energy efficiency improvements in each property; however, in practice, this will not necessarily be the case as joint retrofit of energy efficiency and low carbon heating will be beneficial in many cases to minimise disruption to households. In No Constraints, the rate of heat pump

[28] The Arup modelling targeted an average of EPC C for all buildings, with the More Effective scenario reaching a higher level of uptake (typically 40% higher) of supportive policies among target subsectors; overall, the More Effective scenario achieved 100% of heat demand from buildings EPC C or above, whereas the Central scenario achieved 65% of heat demand at EPC C or above (see also the underlying report)
[29] The majority of the remaining replacements are district heating connections, with some direct electric heating where other low carbon systems are unsuitable
[30] Assuming an average lifetime for counterfactual heating systems (such as gas boilers) of 15 years.
[31] *The Ten Point Plan for a Green Industrial Revolution* (2020) BEIS
[32] Space & Combination heaters, EEL, Task 5, Environmental & Economics (base cases, LCA & LCC), VHK for the European Commission (2019)

installation in the 2020s means that the majority of installations will likely occur alongside energy efficiency retrofits and this is also likely to be common after 2025 in Accelerated Green, due to the high deployment rate of both heat pumps and energy efficiency in this timeframe.

The modelled heat pump installation trajectories (Figure 2.5) assume rapid ramp up of deployment rates to minimise the peak number of systems installed per year. If a slower ramp rate is followed (see Appendix Section 5.3.2 for further details), then higher deployment rates will be required in the late 2020s to achieve the same total number of installations, and could reach in the region of 600,000 per year (close to double the modelled rate) at the peak. This increase comes with associated challenges of further cost, disruption, and skill requirement.

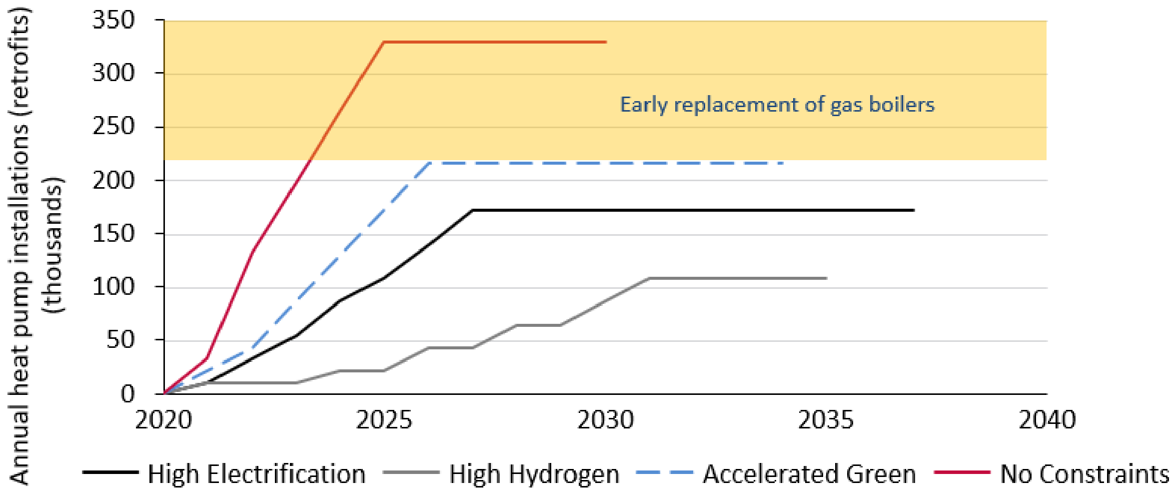

Figure 2.5 Deployment of heat pumps in existing domestic buildings in each scenario (including hybrid heat pumps). The highlighted area indicates where installation rate exceeds natural replacement rate of heating systems and therefore requires scrappage.

District heating is deployed in all scenarios to further decarbonise heating. Three deployment trajectories have been considered, with differing deployment rates from the early 2020s to reflect the different level of ambition of the scenarios (Figure 2.6).

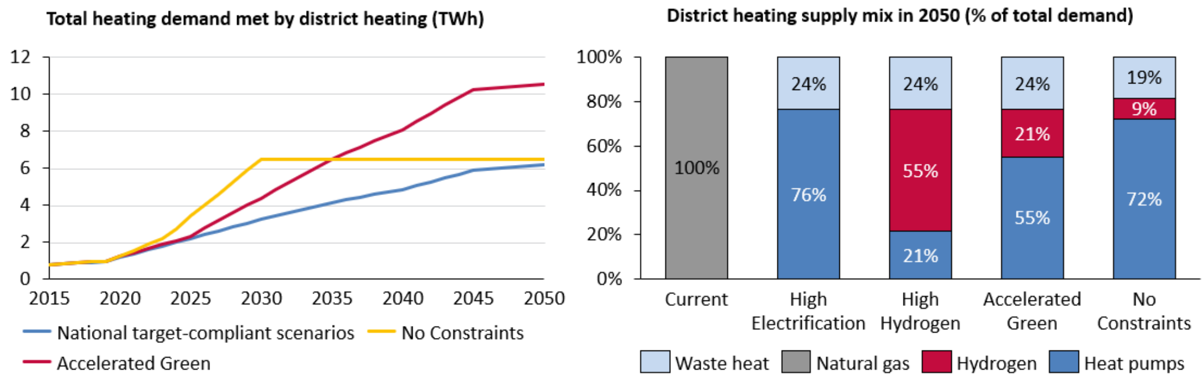

Figure 2.6 Total heating demand met by district heating in each scenario (left) and district heating supply mix in 2050 (right).

The uptake trajectories used in the two National target-compliant scenarios and Accelerated Green are based on the existing scenarios in the ZCPT (medium and high, respectively). The trajectory used in the No Constraints scenario represents significantly accelerated deployment, reaching the same level of deployment in 2030 as is achieved in the Accelerated Green trajectory in 2035.[33] In No Constraints, 640k homes are connected to district heating networks by 2030 (with no further uptake to 2050), whereas 420k are connected by 2030 and 1.1m connected by 2050 in Accelerated Green. The High Electrification and High Hydrogen scenarios reach 380k connections by 2030.

District heating is predominantly installed in existing non-domestic buildings (compared to new builds) with approximately 75% of all non-domestic connections in existing buildings across all scenarios. Connections in domestic properties are more evenly split between existing and new buildings, with approximately half of connections in each across all scenarios.

The heating supply mix differs between scenarios, based on detailed spatial modelling underpinning the *1.5°C Plan*,[34] but altered to replace a share of gas boilers with H_2 boilers for peaking in all but the High Electrification scenario and the deployment of a small share of hydrogen fuel cell combined heat and power (FC CHP) in both Accelerated Green and No Constraints by 2030 (Figure 2.6, right). No Constraints again uses an accelerated trajectory.

Phase out of fossil fuel heating

To ensure the high deployment of both heat pumps and district heating in the No Constraints scenario, a low carbon heat mandate has been modelled for all domestic and non-domestic buildings from 2024, preventing gas boiler replacements after this date in existing buildings. For High Electrification, a mandate for replacement heating systems is required much later, in 2035. For Accelerated Green, a mandate is required in 2026; however, some heating systems remain connected to a fully biomethane grid in 2050 (either boilers or hybrids) and therefore some properties are assumed to be exempt from the mandate where they are in suitable locations.[35] In the High Hydrogen scenario, more than 60% of heat demand is met by heating systems connected to a converted gas grid (hydrogen boilers or hybrid heat pumps) and therefore a London-wide mandate is not required. However, a mandate for Hy-ready boilers may be required in areas due to convert early to minimise the need for scrappage as the grid converts.

For new properties, this low carbon heat mandate has been modelled from 2023 in the No Constraints scenario, and from 2025 in all other scenarios, in both domestic and non-domestic properties.

Building-level solar

Solar thermal and solar PV are deployed in all scenarios to reduce the energy demand of the buildings; in all cases, heat and electricity generated by rooftop technologies are assumed to be used directly in the buildings themselves and to reduce overall demand for external sources of energy (primarily demand for electricity on the grid). In the High Electrification and High Hydrogen scenarios, a total of 2 GW of rooftop solar PV capacity across non-domestic and domestic buildings is assumed to be installed by 2050, in line with the most ambitious solar PV scenario from the *1.5°C Plan* modelling. In Accelerated Green and No Constraints, a total of 3.9 GW of rooftop solar PV capacity is assumed to be installed by 2050 across London.[36] This level of deployment represents approximately 25% of the total potential identified in London.[37]

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[33] After 2030, district heating deployment ceases in No Constraints as the majority of homes have already switched to low carbon heating.
[34] Which considered proximity to waste, river and other heat sources.
[35] The modelling does not define where these areas are – this would instead be in the scope of Local Area Energy Plans.
[36] Element Energy analysis, assuming 25% of roof area is available and 50% of available area is useful (26 km2 final useful area available), and panel efficiency of 15%.
[37] London Solar Opportunity Map, based on polycrystalline panels (efficiency 11.9%).

Final technology mix

The final domestic heat demand technology supply mixes are shown in Figure 2.7. The equivalent graph for non-domestic heat demand is shown in Figure 5.4 in the Appendix.

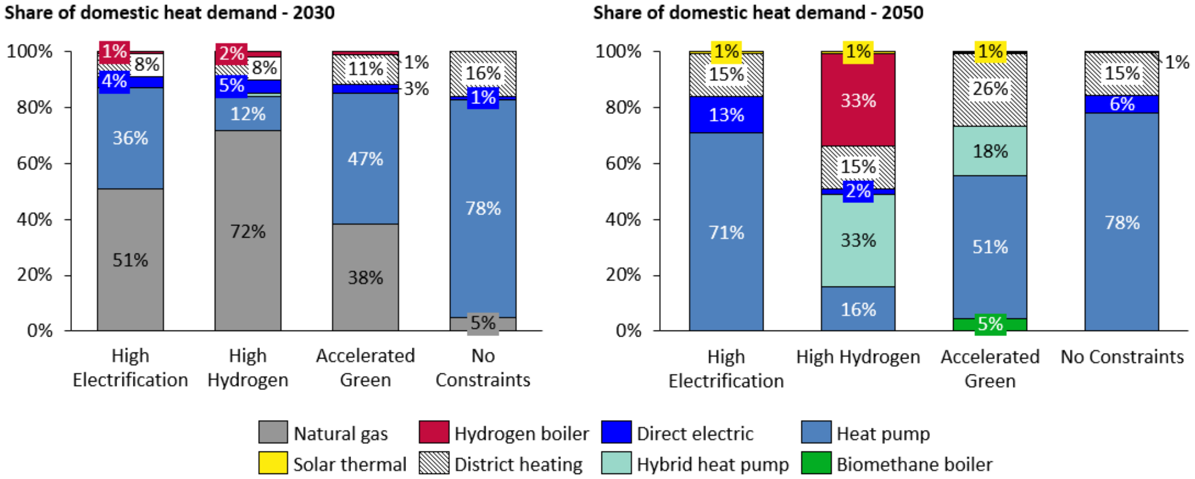

Figure 2.7 Domestic heating technology mix in 2030 and 2050 across the scenarios.

In all scenarios there is a portion of heating demand not met by heat pumps (both standalone and hybrid systems), district heating or solar thermal by 2050. The technologies used to meet this heating demand vary by scenario. In the No Constraints and High Electrificaton scenarios, the residual heat is supplied by direct electric heating technologies (both electric resistive and electric storage heating). In the High Hydrogen scenario, hydrogen gas burnt in in-property boilers meets this residual heat demand. In the Accelerated Green scenario, any remaining heat is a mix of direct electric heating technologies and biomethane boilers, assumed to be connected to selected areas of the gas grid remaining in 2050.

2.2.3 Transport

Behaviour change

Due to limited supply chains, slow turnover of vehicle stock, and reliance on grid decarbonisation, reaching net zero early cannot be achieved by technology alone. The earlier the net zero target date, the greater the importance of behaviour change to reduce demand for travel in high carbon modes (primarily private vehicles).

Passenger travel: In all scenarios, car travel demand (represented as vehicle kilometres travelled, vkm) is assumed to reduce through a combination of absolute demand reduction (avoidance of the need for travel, for example through relocation of services or greater teleconferencing) and shift of remaining travel to shared (car clubs and other forms of car sharing, including on-demand services), active (cycling and walking), and public transport, with active and public transport prioritised: [38]

- The High Electrification and High Hydrogen scenarios follow the level of behaviour change assumed in the Mayor's Transport Strategy (MTS) modelling,[39] reaching **12% reduction** in car

[38] Note that modelled reductions in car vkm were not explicitly associated with defined levels of each interventions; for example, the levels of teleconferencing and home working, and the distribution of shifted car travel to alternative modes, were not determined; the impact of home working on buildings emissions are not reflected in the buildings modelling, as the impact is complex and can vary depending on house type and precise behaviour change. For example, see: https://www.climatexchange.org.uk/media/4941/emissions-impact-of-home-working-in-scotland-cxc-june-2021.pdf
[39] TfL, *Mayor's Transport Strategy: Supporting Evidence, Outcomes Summary Report* (2017)

vkm relative to 2018 by 2030. This level of behaviour change is in line with the MTS target of 80% share of trips by sustainable modes by 2041. This change in travel already represents much greater ambition than national targets or projections[40] and will require a range of local supporting measures to achieve.

- The Accelerated Green scenario assumes an acceleration of the MTS pathway by 10 years, reaching **27% reduction** in car vkm relative to 2018. This pathway is likely to require the same mix of policy action as the MTS pathway but delivered at an accelerated timescale.
- No Constraints goes significantly beyond the MTS, reaching **40% reduction** in car vkm compared to 2018 by 2030. This represents a highly ambitious scenario that will require additional measures above the MTS with a greatly accelerated timeframe.

These levels of behaviour change represent an average across London, with greater capacity for active and public modes expected to be achievable in Central London than in Outer London; however, a higher share of current car travel occurs in Outer London (43% mode share compared to 19% for Inner London),[41] meaning that measures to address car travel in these areas is a priority.

A shift to public, active and shared transport will require increases in capacity of these alternative transport modes. The exact distribution of final travel demand across alternative modes was not explicitly modelled; however, an indicative estimate of the impact of behaviour change on public transport emissions has been represented at a high-level through illustrative increases in bus vkm:

- The High Electrification and High Hydrogen scenarios are modelled in line with the MTS scenario, with an overall increase in vkm of less than 1% by 2030 and 1% by 2050, relative to 2018.
- Accelerated Green assumes a slightly higher level of increase, reaching 2% above 2018 levels by 2030 and maintaining this increase by 2050.
- No Constraints assumes a 5% increase in vkm by 2050, reaching 4% by 2030.

In practice, a decrease in car vkm of 40% could require a greater increase in bus vkm than the increases modelled in this study, depending on the share of travel shifted to each mode (for example, up to 25-50%).[42] If the bus fleet is largely zero emission by 2030 (see next section), the emissions impact of a larger increase in bus vkm is relatively small (<0.1 $MtCO_2e$ in 2030) but the energy demand required to fuel this additional travel is likely to increase significantly. Defining the likely distribution of shifted travel is an important area for future work to further understand the precise actions to support delivery the pathways.

Freight: Measures to reduce road freight demand are assumed in all scenarios, such as increased consolidation and a shift to cycle freight and non-road modes (such as river or rail):[43]

- The High Electrification and High Hydrogen scenarios assume total van vkm grow in line with the CCC's 6th Carbon Budget Balanced Pathway (representing overall 3% reduction compared to Baseline growth,[44] but absolute growth of 2% relative to 2020 levels) and HGV vkm grow by 5% relative to 2018, in line with the MTS scenario

[40] For example, the CCC's 6th Carbon Budget Balanced Pathway assumes approximately 1% reduction by 2030 and 5% reduction by 2050, relative to 2020 levels.
[41] TfL *Travel in London Report 13* (2020)
[42] Based on Element Energy analysis for other regional authorities, using detailed travel survey data
[43] Note that shift to other modes was not explicitly modelled and therefore representative increases in emissions from rail or river travel are not reflected in the trajectories; however, the impact is expected to be relatively low since these modes are much less emissions-intensive than road freight transport.
[44] Assumed to be 27% growth in the MTS scenario used in the *1.5°C Plan*

- The Accelerated Green and No Constraints scenarios assume double the reduction in van km compared to the national target-compliant scenarios[45] and measures to result in no growth in HGV vkm beyond 2018, in line with MTS scenario modelling.[46]

Low emission vehicle uptake

Light duty vehicles: All scenarios follow rapid electric vehicle uptake, with the High Electrification, High Hydrogen, and Accelerated Green scenarios following uptake in line with consumer-choice modelling under varying policy environments:[47]

- High Electrification, High Hydrogen and Accelerated Green all assume that the government's ban on the sales of new petrol and diesel cars and vans is enforced, with sales of ultra low emission vehicles (ULEVs)[48] reaching 100% in 2030 and sales of zero emission vehicles (ZEVs) reaching 100% in 2035
- High Hydrogen assumes that low-cost hydrogen becomes available at scale across the economy in the long-term, allowing for fuel cost reductions that make fuel cell electric vehicles (FCEVs) cost competitive with battery electric vehicles (BEVs). As such, this scenario has higher fuel cell vehicle uptake than the other scenarios

The No Constraints scenario assumes that London is able to take the lead and significantly deter the local sale of petrol and diesel cars and vans in the mid 2020s; this is predominantly expected to be through measures such as emission zones with charging schemes that encourage newly registered vehicles to be ULEVs. To ensure rapid electrification of the fleet, widespread scrappage (or age limit restrictions on vehicles travelling in London) of all petrol and diesel cars and vans over 10 years old is required. Further work would be required to understand the implications in terms of embodied carbon (Scope 3 emissions) associated with widespread early retirement of vehicles.

Although this level of uptake requires rapid increases in sales share of battery electric vehicles (close to 200,000 ULEV cars and 40,000 ULEV vans per year between 2024 and 2030, compared to approximately 8,000 per year currently)[49], the decrease in car vkm – and associated reduction in total stock size – means that the overall number of ULEVs sold in 2030 is very similar between No Constraints and High Electrification.

The final fleet mix for cars is shown in Figure 2.8 (see Figure 5.5 in the Appendix for the equivalent graphs for vans). Despite very ambitious measures, stock turnover rates mean that some fossil fuel vehicles remain in the fleet in 2030 under all scenarios. By 2050, all scenarios are almost exclusively ULEVs, with the majority battery electric.

All scenarios assume that sufficient charging infrastructure is in place to support the transition, including the accelerated deployment required to meet demand through accelerated electric vehicle deployment in No Constraints. It is estimated that 34-40,000 public chargers will be required to meet demand in 2030 across scenarios, of which, 4,000-5,000 could be rapid (50 kW and above) chargers.[50] This

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[45] Based on Element Energy analysis for TfL of potential for cycle freight in London
[46] TfL, *Mayor's Transport Strategy: Supporting Evidence, Outcomes Summary Report* (2017) Package E.
[47] Trajectories from Element Energy's ECCo modelling, used by DfT
[48] Ultra-low emission vehicle includes plug-in hybrid electric vehicles, battery electric vehicles and fuel cell electric vehicles
[49] DfT licensing statistics, Table VEH0172
[50] Number and distribution of chargepoints estimated based on methodology set out by the ICCT, for example in *Fulfilling electric vehicle charging infrastructure needs in Greater London and its boroughs*

deployment level is comparable to projections in TfL's recent EV Charging Infrastructure Strategy (40,000-60,000 charge points by 2030, of which up to 3,900 could be rapid, not assuming modal shift).[51]

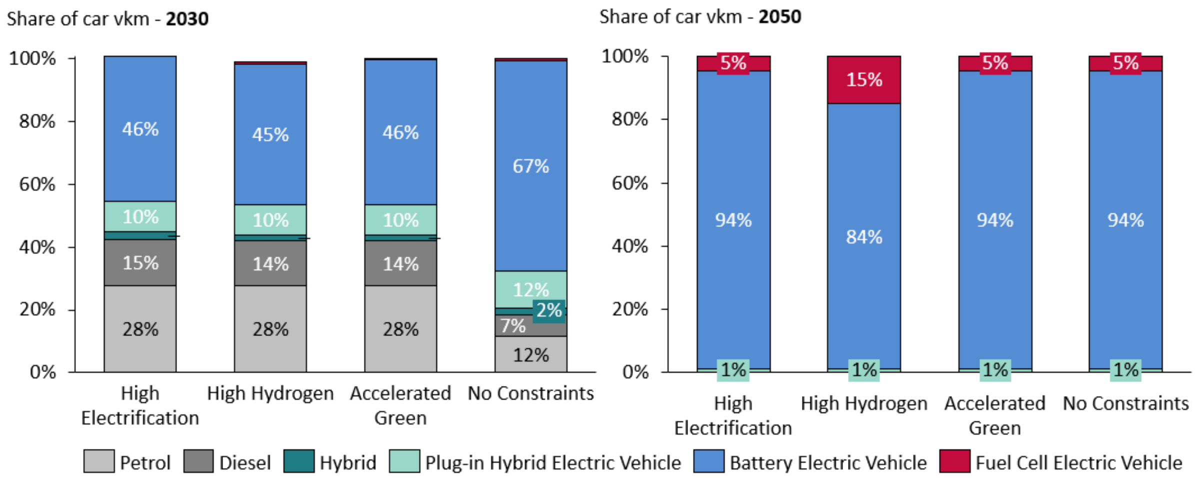

Figure 2.8 Car fleet mix by powertrain across scenarios in 2030 and 2050

Heavy goods vehicles: HGVs are the hardest road transport sector to decarbonise due to their duty cycle and capacity requirements. The High Electrification, High Hydrogen, and Accelerated Green scenarios are all assumed to follow consumer-led national uptake projections under varying policy environments:[52]

- All assume that diesel sales end by 2035 for rigid HGVs and 2040 for artic HGVs
- High Electrification and High Hydrogen assume supportive policy to rollout a comprehensive national refuelling infrastructure by 2045[53]
- Accelerated Green assumes accelerated national refuelling infrastructure rollout, with full deployment by 2040, and supportive policy to bring down vehicle costs

The No Constraints scenario assumes a significant increase in ambition for decarbonisation of rigid HGVs, primarily driven by local policy incentives such as emission zones to accelerate uptake of EVs and either local or national funding. Close to 60% of the rigid HGV fleet is either battery electric or hydrogen fuel cell by 2030 (compared to 13% in Accelerated Green). Reaching this fleet share requires sales of close to 2,000 battery electric HGVs per year by 2030, representing close to 30% of likely UK supply.[52] To ensure rapid electrification of the fleet, widespread scrappage of diesel HGVs over 15 years old is required.

Decarbonisation of the artic fleet is not assumed to accelerate beyond national trajectories since duty cycles of this sector are more likely to extend beyond London and therefore rely more heavily on national developments.

[51] https://lruc.content.tfl.gov.uk/londons-2030-electric-vehicle-ev-infrastructure-strategy-exec-summary.pdf; note that the TfL EV charging strategy assumes a higher average power rating for rapid chargers than the ICCT methodology, requiring fewer chargers (see also Appendix Section 5.5.2)
[52] *Analysis to provide costs, efficiencies and roll-out trajectories for zero-emission HGVs, buses and coaches* (2020) Element Energy for the CCC
[53] Requiring in the region of 1,600-2,300 public refuelling connections nationally to meet operator's needs (see reference 52 for details)

The final fleet share for all HGVs (rigids and artics) is shown in Figure 2.9. The less developed supply chain for zero emission HGVs compared to light duty vehicles means that more than half of the fleet is still diesel in 2030 even in the most ambitious scenario; however, by 2050, the fleet is close to fully zero emission, with a mix of fuel cell and electric vehicles.

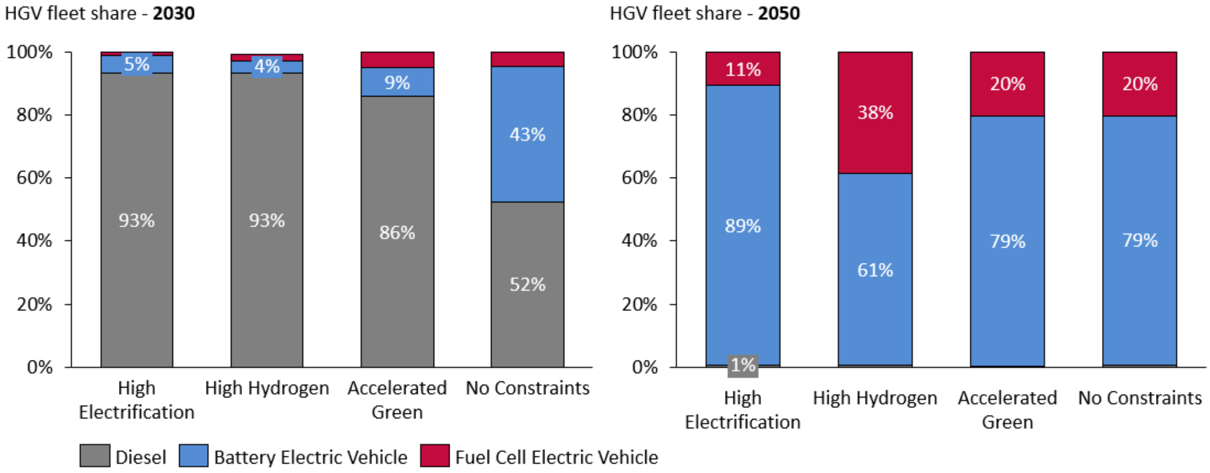

Figure 2.9 Fleet share by powertrain across scenarios for HGVs (showing average across rigids and artics) in 2030 and 2050.

Buses: Non-TfL buses represent a relatively small share of bus vkm travelled and technology uptake was modelled in line with national scenarios.[54]

All scenarios assume that the TfL bus fleet reaches fully zero emission at tailpipe by 2030, in line with TfL's ambition, but subject to Government funding (TfL has committed to a zero emission bus fleet by 2034 with the current funding options available). This is primarily achieved through a shift to battery electric vehicles, with a small share of fuel cell electric vehicles (increased from the current fleet of 20 buses) in the High Hydrogen and Accelerated Green scenarios.

The fleet shares are shown in Figure 2.10. In the High Electrification and No Constraints scenarios, the fleet is assumed to remain fully battery electric to reflect the lack of widespread, low cost hydrogen in these scenarios. In the High Hydrogen and Accelerated Green scenarios, a share of the fleet is assumed to transition to fuel cell electric vehicles as hydrogen becomes more widely available. In these scenarios, a proportion of bus routes shift to fuel cell buses after the electric buses have been in operation for 15 years, to allow investments in depot upgrade to pay back. In practice, other considerations such as depot footprint (and ability to incorporate hydrogen refuelling infrastructure) may be a greater factor in the suitability for transition.

[54] Analysis to provide costs, efficiencies and roll-out trajectories for zero-emission HGVs, buses and coaches (2020) Element Energy for the CCC

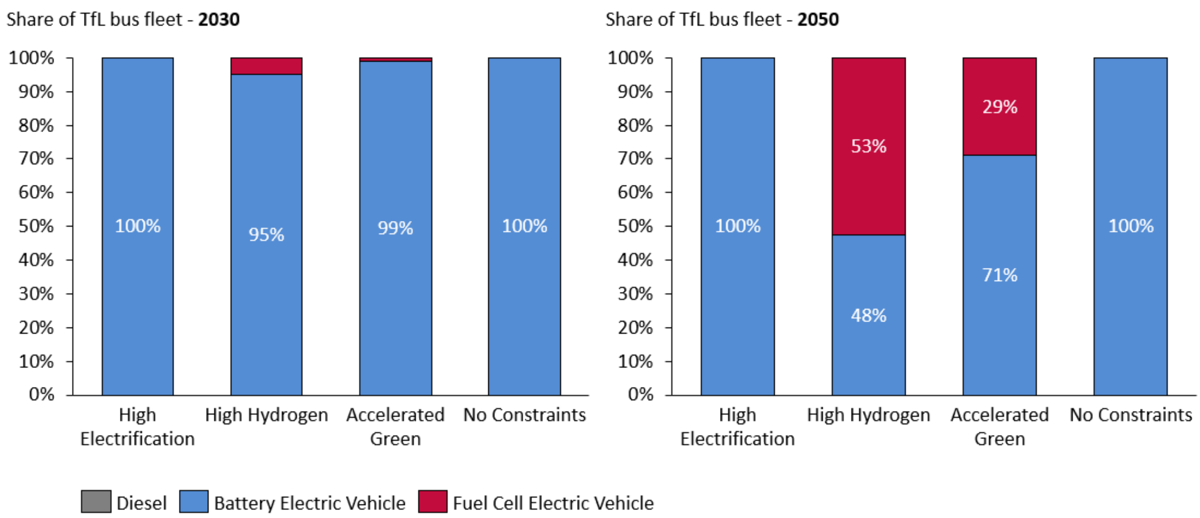

Figure 2.10 TfL bus fleet share by powertrain in 2030 and 2050.

Other road transport assumptions

Taxis: Taxis represented 2% of transport emissions in 2018 (note that Private Hire vehicles were not modelled separately and were incorporated into car fleet emissions, in line with modelling underpinning the *1.5°C Plan*). The taxi fleet is assumed to decarbonise to reach 100% zero emission capable by 2033, in line with age limits and licencing requirements (modelled as 41% PHEV, 57% BEV, and 1% FCEV). The No Constraints scenario goes further than the other scenarios by shifting to predominantly zero emission vehicles by 2033 (8% PHEV, 90% BEV, 2% FCEV). Taxi vkm are assumed to increase by 6% in the High Electrification and High Hydrogen scenarios, in line with the MTS scenario. This is reduced by 50% (to a 3% increase) in Accelerated Green, and vkm remain approximately constant in No Constraints.

Motorcycles: Motorcycles represented 1% of transport emissions in 2018. The High Electrification, High Hydrogen and Accelerated Green scenarios assume decarbonisation in line with the MTS scenario, reaching 100% BEV fleet share in 2050 (50% sales share in 2030). The No Constraints accelerates this target to reach 100% BEV fleet share in 2046 (76% sales share in 2030).

Aviation

A significant reduction in air travel has been experienced due to the COVID-19 pandemic and recovery of the industry is highly uncertain. The scenarios each see a different level of recovery by 2030, and a different level of ambition for growth out to 2050:

- High Electrification and High Hydrogen assume passenger numbers recover to 2018 levels by 2030, and grow to 25% above 2018 levels by 2050, in line with the CCC's 6th Carbon Budget Balanced Pathway
- No Constraints assumes no recovery in passenger numbers between 2020 and 2030 (aviation activity maintained at 40% of 2018 levels),[55] while Accelerated Green assumes recovery to 50% of 2018 levels by 2030
- No Constraints and Accelerated Green assume that passenger numbers recover to 85% of 2018 levels between 2030 and 2050, in line with the CCC's 6th Carbon Budget Widespread Engagement Pathway

[55] Based on UK Civil Aviation Authority data for London airports within the GLA boundary

In addition to limits to growth, the introduction of Sustainable Aviation Fuel (SAF) is assumed to reduce emissions from aviation (5% blending of SAF by 2030, 50% by 2050), in line with proposed UK target ranges.[56]

Other non-road transport assumptions

Rail emissions represented 6% of transport emissions in 2018.[57] Rail decarbonisation is assumed to follow the MTS scenario trajectory for all scenarios, which is largely electrified by 2030. Remaining diesel emissions are assumed to be primarily related to freight movements which are largely determined by non-electrified destinations outside of London.

River emissions represented 0.5% of transport emissions in 2018.[57] Decarbonisation of shipping activity in London is represented by two trajectories:

- The High Electrification and High Hydrogen scenarios assume decarbonisation in line with Port of London Authority's (PLA's) Air Quality Strategy,[58] targeting 25% reduction for inland vessel emissions (but no reduction for shipping) by 2031, increasing to 95% for inland vessels and 60% for shipping by 2051, relative to 2016 levels (resulting in overall decrease of 16% by 2030 and 88% by 2050).
- The Accelerated Green and No Constraints scenarios accelerate the decarbonisation of inland vessels in line with the PLA's Technology Roadmap for Inland Shipping,[59] reaching 60% reduction by 2031 and close to 100% reduction by 2050 (overall decrease of 38% by 2030 and 89% by 2050), relative to 2016 levels.

Non-road mobile machinery (NRMM): NRMM emissions represented 3% of transport emissions in 2018.[57] All scenarios assume a decarbonisation trajectory in line with the modelling underpinning the *1.5°C Plan*, and reach 80% of 2018 levels by 2050.

2.2.4 Industrial emissions

Energy Use in Industry

Energy use represents 17% of industrial emissions (11% due to natural gas use and 6% due to electricity use). Emissions trajectories for industrial energy use were modelled at a high-level based on improvements in energy efficiency through measures such as heat recovery, and fuel switching to electrification or hydrogen.

Within London, the sector with the highest direct CO_2 emissions is the food & drink sector. Within the food and drink sector, there are two main emitting sites: Tate & Lyle (sugar refinery) and Arthur Daniels Midland Erith (oil refinery – edible oils). These sites are located close to the Thames (see map, Figure 5.6 Appendix) and are key opportunities for hydrogen supply from projects to the East of London. Assumptions for uptake of hydrogen were based on early conversion of these two sites through dedicated supply, with later conversion of wider industrial sites in High Hydrogen and Accelerated Green via supply from the converted gas grid or backbone pipeline, respectively.

The final energy mix in 2030 across scenarios for industry is shown in Figure 2.11.

[56] Based on Scenario C in the current Government consultation regarding a Sustainable Aviation Fuel mandate
[57] LEGGI 2018
[58] Air Quality Strategy for the Tidal Thames (2020 update)
[59] Emission reduction roadmap for inland shipping on the Tidal Thames (2020)

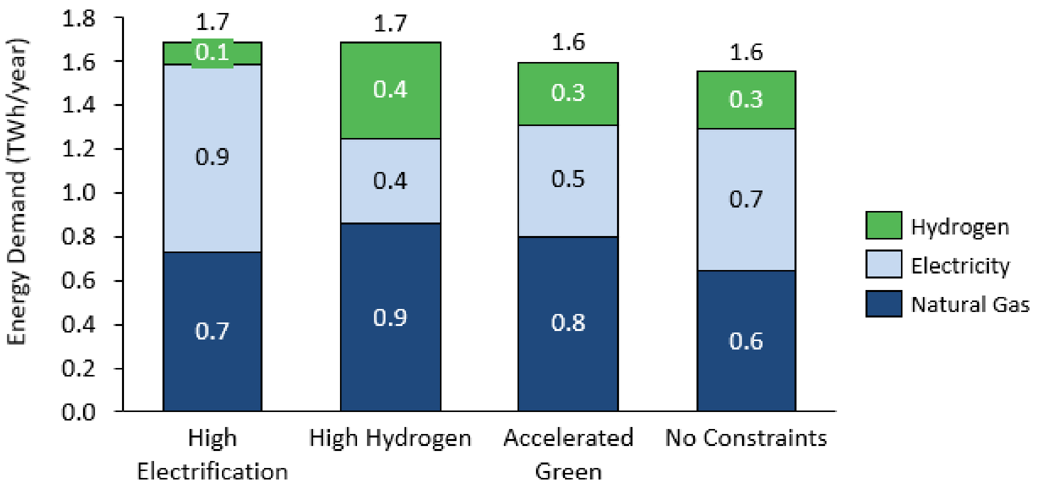

Figure 2.11 Energy use by fuel for industry in London in 2030

Industrial Processes and Product Use

Industrial processes and product use (IPPU) represent 84% of industrial emissions, the majority of which are due to hydrofluorocarbons (HFCs, or F-gases). In London, close to 80% of HFC emissions come from refrigeration and air conditioning appliances (35% and 44% respectively).[60] EU regulation placed a cap on the production and importation of F-gases that required a 79% cut in hydrofluorocarbons (HFCs) by 2030 compared to 2015 levels. The UK has declared an intention to use the same schedule to phase down HFC emissions.[61]

Within the regulation on F-gases, certain uses are exempt from the reductions, including medical and military applications, as well as some semiconductor fabrication processes; together, these applications account for 8% of F-gas emissions in London. The regulation will also ban the use of F-gases in new types of equipment "where less harmful alternatives are widely available, such as fridges in homes or supermarkets, air conditioning and foams and aerosols". These applications, in which F-gases will be banned by 2030, accounted for 87% of London's 2018 F-gas emissions.[62]

Without a more detailed study, it is not known what the warming potential of their replacements will be, although it is expected that they will have lower warming potential than currently. For the purposes of the scenarios studied here, two scenarios have been assumed:

- A 79% reduction in overall HFC emissions, used for national ambition scenarios High Electrification and High Hydrogen.
- A ban on F-gas emission in relevant sectors (refrigeration, air conditioning, foam blowing), no change for exempt sectors (military, medical and semiconductor fabrication), 79% reduction in other areas. This leads to an 89% emission reduction in F-gases used in the Accelerated Green and Maximum Ambition scenarios.

[60] London Energy and Greenhouse Gas Inventory (LEGGI) (2018) https://data.london.gov.uk/dataset/leggi
[61] UK Government *"Fluorinated gas (F gas): guidance for users, producers and traders" https://www.gov.uk/government/collections/fluorinated-gas-f-gas-guidance-for-users-producers-and-traders accessed September 2021*
[62] Note that the global warming potential of F-gas replacements will need to be accounted for in future, however, with F-gases having warming potentials tens of thousands of times higher than CO_2, and likely replacements on the order of hundreds of times higher, the GHG emission reduction in terms of CO_2 equivalents would reduce by two orders of magnitude.

2.2.5 Agriculture, Forestry, Other Land Use (AFOLU) and Waste

AFOLU: AFOLU emissions contributed 0.2% of London's emissions in 2018. Emissions in 2018 from settlements, cropland, and livestock agriculture were taken from the LEGGI,[63] and were projected to change (either increase or decrease) in line with historical trends.[64] Overall, emissions reduce by 15% and 30% by 2030 and 2050, respectively. Note that only emissions from AFOLU were included in the trajectories, in line with LEGGI reporting; however, London has some negative emissions from grasslands and forestry that partially offset positive emissions.

Waste: Waste emissions contributed 4% of London's emissions in 2018. Emissions in 2018 were taken from the LEGGI and disaggregated by emissions source, comprising Landfill, Anaerobic Digestion (AD), Composting, and Wastewater treatment.[63] Landfill emissions were projected to decrease to 2050 in line with the modelled trajectory underpinning the *1.5°C Plan* reaching 14% of 2018 levels by 2030. The change in London's emissions from AD, composting, and wastewater were modelled in line with national assumptions in the CCC's Net Zero report and 6th Carbon Budget.

2.2.6 Electricity generation

The Net Zero 2030 scenario modelling assumes that emissions from electricity consumed within other sectors are in line with national grid emissions intensities and use the carbon intensity projection from the HMT Green Book.[65] However, although local electricity generation emissions are not explicitly included in the emissions reduction trajectories, the power sector does offer a means to reduce London's overall emissions. To provide an indicative estimate of the role that local generation could play in London's climate targets, the potential for additional local generation from renewable sources and fuel-switching at existing power plants has been assessed at a high-level.

Current generation

London is a net importer of electricity, with 0.8 GWe currently installed generation capacity[66] (equivalent to ~4 TWh/year generation), compared to close to 40 TWh electricity consumption.[67] More than three-quarters of London's installed capacity is fossil-generated,[68] 20% is Energy from Waste (EfW), and 4% is solar PV. Overall, emissions from electricity generation in London are 1.5 $MtCO_2e$ per year.[69]

Potential decarbonisation options

Renewable generation: Power modelling undertaken as part of the *1.5°C Plan* estimated that local generation from renewable sources could reach 3.6 TWh/year in 2030 and 8.0 TWh/year in 2050. Of this generation, 1.0 and 4.0 TWh/year could be from wind and solar PV, respectively, with 1.7 TWh/year generated from EfW by 2030,[70] with no further increase to 2050.[71] The generation capacity for EfW is consistent with London's ambitions to become self-sufficient in treatment of waste (no waste generated within London to be sent outside London) without increasing the capacity of EfW plants (i.e. does not assume increase in overall installed capacity).

Decarbonising energy from waste: Use of waste heat from EfW plants to supply heat networks is an important option for using existing assets to decarbonise the buildings sector, and is already being

[63] London Energy and Greenhouse Gas Inventory 2018 https://data.london.gov.uk/dataset/leggi
[64] Based on emissions changes over the past 10 years as reported in the BEIS Local Authority CO_2 Dataset.
[65] *The Green Book*, HM Treasury, Data tables (2021 update)
[66] Digest of UK Energy Statistics (2021)
[67] LEGGI 2018
[68] Not including building-level CHP
[69] Modelled emissions based on estimated generation capacity and emissions factors for each site.
[70] This includes a slight increase in generation above current levels through replacement of London Energy Centre with North London Heat and Power Project.
[71] The remainder is expected to come from microCHP and hydroelectric power.

deployed in London under the North London Heat and Power Project.[72] Adding CCUS to EfW plants could be used to generate electricity with net negative GHG emissions, which offers the opportunity to offset some of the remaining emissions from other sectors.

The CCC's 6th Carbon Budget Balanced Pathway requires all EfW plants to be fitted with CCUS by 2050. Achieving this technology deployment relies on CCUS infrastructure being rolled out across the UK. In London, this transition relies on local projects developing CCUS transport chains[73] for London's EfW plants to join with and therefore the timing of when CCUS could be viable solution for EfW plants strongly depends on development of these projects. Project Cavendish is aiming to begin operation of hydrogen production with CCUS in the late 2020s, offering a potential opportunity for consolidation of CO_2 transport and storage supply chains if one or more of London's EfW plants were to convert in the early 2030s. Without this project (or other opportunities for lower cost CO_2 transport and storage), it may be more likely that conversion happens later, in the 2030s or early 2040s, as wider CCUS supply chains ramp up.

If CCUS could be in place at the largest EfW plants by 2030-2032, emissions from EfW could be net negative at -0.2 $MtCO_2e$.[74] Recent UK-wide analysis placed London's EfW plants within a second phase of conversion that could occur between 2031-2040, meaning that this transition is technically feasible if London's plants could convert at the beginning of this phase.[75]

Hydrogen for generation: Replacing fossil-based generation at London's largest CCGT plant (Enfield) with H_2GT (gas turbines running on pure H_2) is estimated to reduce local electricity generation emissions by over two-thirds (not including any negative emissions potential from EfW, above), to approximately 0.5 $MtCO_2e$/year.[76] While hydrogen-fuelled power generation is a demonstrated technology, converting existing plants is disruptive (requiring dedicated equipment for handling hydrogen) and highly dependent on securing sufficient low carbon hydrogen at a competitive cost. Retrofit of existing plants may also not be technically feasible at some sites.[77] As such, deployment up to the early 2030s is more likely to focus on using blended supply in suitable "Hyready" gas turbines (20% by volume in natural gas) rather than on deploying turbines that run on pure hydrogen (and require much larger volumes of hydrogen than would be expected to be available at a competitive cost).

2.3 Scenario Results

2.3.1 Energy Use and Carbon Emissions

Residual and cumulative emissions

The net zero 2050 scenarios developed for the *1.5°C Plan* all reached close to 10% residual emissions (relative to 1990 levels) by 2050, which would need to be offset. All four scenarios in this study achieve greater levels of decarbonisation by 2030 than the scenarios in the *1.5°C Plan*, with the significant difference being the rate at which that decarbonisation happens (as shown in Figure 2.12 and Table 2.3), but all have more than 10% residual emissions (relative to 1990 levels) by 2030:

72 http://northlondonheatandpower.london/
73 For example, Project Cavendish is planning to transport CO_2 captured from hydrogen production by ship to storage sites elsewhere in the UK.
74 Assuming emissions intensity of EfW with CCS of -328 gCO_2e/kWh, based on assumptions within the CCC's Net Zero report (54% biodegradable waste, 0.36 tCO_2/tonne waste for non-biodegradable waste, and 90% CCS capture rate)
75 Eunomia for Viridor "*CCUS Development Pathway for the EfW Sector*" (2021)
76 Based on emissions intensity of CCGT plant of 342 gCO_2e/kWh and H_2GT of 64 gCO_2e/kWh by 2030, assuming supply from ATR + CCS.
77 Note that this analysis has not assessed the technical feasibility at London's sites, and this would need to be explored in further work.

- The **No Constraints scenario** reaches 14% residual emissions (relative to 1990 levels) by 2030. This is considered the maximum level of emissions reduction by 2030 (minimum residual emissions) and relies on deployment of very ambitious levels of behaviour change and electrification of heat and transport, supported by significant supportive policy at the national and regional level.
- The **Accelerated Green** reaches 22% residual emissions by 2030 but achieves 10% residual emissions in the late 2030s, only 4 years later than No Constraints. It requires ambitious levels of behaviour change and as ambitious technology rollout as possible without requiring widescale scrappage;
- **High Electrification** and **High Hydrogen** slightly exceed national targets,[78] with High Electrification decarbonising faster (27% in 2030) due to the reliance of High Hydrogen (30% in 2030) on conversion of the gas grid. The High Electrification and High Hydrogen scenarios only reach 10% emissions in the early 2040s.
- For comparison, all four scenarios in the *1.5°C Plan* reached close to 10% emissions by 2050 but with a less rapid reduction such that around 40% emissions would remain in 2030.

The different rates of decarbonisation lead to significant differences in the cumulative emissions (Figure 2.12, right). Cumulative emissions for the scenarios begin to diverge from 2025 as deployment of low-carbon technologies and behaviour changes begin to affect London's emissions. No Constraints has the lowest cumulative emissions, reaching 192 $MtCO_2e$ in 2030 and 250 $MtCO_2e$ by 2050. High Hydrogen has the highest cumulative emissions, reaching 227 $MtCO_2e$ in 2030 and 338 $MtCO_2e$ in 2050. As a result, the variance in the cumulative emissions over the next 30 years between the scenarios is 88 $MtCO_2e$ emissions. All scenarios reach a lower level of cumulative emissions between 2020-2050 compared to the *1.5 Plan* scenarios (for example, Patchwork, as shown in Table 2.3), highlighting the importance of early action to reduce London's climate impact.

In all scenarios, the majority of remaining emissions in 2030 come from Buildings and Transport (Figure 2.13, left). For High Electrification, High Hydrogen, and Accelerated Green the majority of emissions come from remaining fossil fuel use, while in No Constraints emissions from electricity use make up a larger share (38% of total residual emissions).

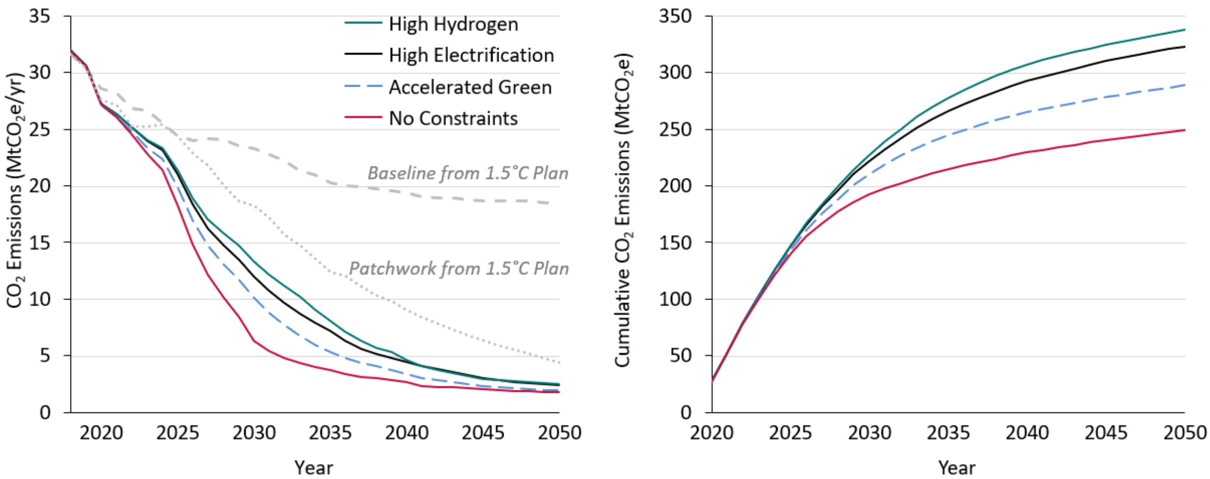

Figure 2.12: Annual (left) and cumulative (right) emissions over time for each scenario; Baseline and Patchwork scenarios from *1.5°C Plan* included in annual emissions graph for comparison.

78 National targets are for a 78% emission *reduction* by 2035, High Electrification reaches 84% reductions by 2035 while High Hydrogen reaches 81%.

Table 2.3 Summary of key decarbonisation metrics for the modelled scenarios in this study, compared to the Patchwork scenario developed in the *1.5°C Plan*.

	High Electrification	High Hydrogen	Accelerated Green	No Constraints	2050 Patchwork[ł]
2030 emissions ($MtCO_2e$)	12.0	13.3	10.1	6.4	17.7
2030 emissions (% relative to 1990)	27%	30%	22%	14%	40%
Year reaches 10% residual emissions (level of emissions in 2050 in existing *1.5°C plan*)	2040	2041	2037	2033	2050
Cumulative emissions 2020 to 2030 / 2050 ($MtCO_2e$)	222 / 323	227 / 338	210 / 289	192 / 250	240 / 440

ł Note that the Patchwork Scenario from the *1.5°C Plan* had a slightly narrower scope, as it did not include Agriculture, Forestry and Other Land Use (AFOLU) and only included landfill emissions from Waste.

Across the sectors modelled, very high levels of ambition are assumed, with high levels of decarbonisation assumed for those sectors where rapid decarbonisation could occur in the timeframe required through significant behaviour change and a shift to currently available technologies (e.g. car emissions, heating systems; see the Scale of the Challenge, Table 2.4). In most scenarios, but particularly in the No Constraints, these sectors are already compensating for lower emissions reduction in sectors where technology alternatives do not currently exist (e.g. aviation, heavy goods vehicles). Under-delivery in one sector or aspect (such as energy efficiency) is likely to result in higher residual emissions overall, particularly in the No Constraints scenario where policy levers are already at the highest level and compensating for under delivery would be very challenging.

Hydrogen contributes very little to residual emissions in 2030; however, by 2050 indirect emissions from hydrogen production make up over 40% of residual emissions from buildings in the High Hydrogen scenario due to the high share of heating systems connected to the (hydrogen) gas grid, and the non-zero emissions associated with production of hydrogen.[79]

The level of residual emissions in 2030 is highly dependent on the rate at which the electricity grid decarbonises. The scenarios assume decarbonisation in line with the latest HMT Green Book projections, which reach 0.05 gCO_2e/kWh in 2030. Previous HMT Green Book projections have been less ambitious, reaching 0.08 gCO_2e/kWh;[80] if the grid only decarbonises to this higher value, residual emissions in No Constraints would be 1.4 $MtCO_2e$ higher (7.4 $MtCO_2e$ total, 16% relative to 1990 levels). Conversely, if the grid can decarbonise faster than current projections then higher levels of emissions reduction will be possible (see also Section 4.1.5). Since this study began, the UK Government has stated its ambition for the grid to reach net zero by 2035 which could mean a grid emissions intensity close to half of that modelled here[81] and could reduce emissions by 1.1-1.4 $MtCO_2e$ across scenarios (with highest change in No Constraints). This would bring residual emissions to 11% relative to 1990 levels by 2030 under No Constraints, and 19% for Accelerated Green, 24% for High Electrification, and 27% for High Hydrogen.

[79] Both blue hydrogen and hydrogen from grid electrolysis.
[80] For example, see the 2019 HMT Green Book update.
[81] Based on scenarios within National Grid's latest Future Energy Scenarios, that reach net negative by 2035.

Table 2.4 The scale of the challenge – what needs to be achieved in each scenario by 2030, compared with the Patchwork scenario from the *1.5°C Plan*.

	High Electrification	High Hydrogen	Accelerated Green	No Constraints	*1.5°C Plan Patchwork*
Transport					
Reduction in car vkm relative to 2018 levels	12%	12%	27%	40%	12%
Share of car fleet zero emission in 2030	46%	46%	46%	68%	12%
End of fossil fuel vehicle sales	2030, with enforcement			2025	Mid-2030s
Buildings					
Retrofit	37% reduction in total heating demand (space heating plus hot water) of domestic buildings by 2030, and 39% reduction in heating demand of non-domestic buildings by 2030. 210,000 homes retrofitted each year between now and 2030 (average); approximately 420,000 at peak. 26,500 commercial and public buildings retrofitted each year between now and 2030 (average); approximately 45,000 at peak.				14% reduction in space heating demand 160,000 homes retrofitted at peak
Heat pumps installed by 2030 (domestic and non-domestic)	1.8 m 630 per day 2025-2030	0.9 m[ⱡ] 400 per day 2025-2030	2.2 m 750 per day 2025-2030	3.3 m 1,100 per day 2025-2030	0.9 m
Total district heat domestic connections by 2030	380,000	380,000	460,000	610,000	340,000
Rooftop solar PV	0.8 GW (2030); 2 GW (2050)		1.5 GW (2030); 3.9 GW (2050)		0.8 GW (2030); 2 GW (2050)
Hydrogen					
Supply by 2030	0.8 TWh	1.9 TWh	1.0 TWh	1.5 TWh	0.3 TWh

[ⱡ]Includes both standalone heat pumps and hybrid heat pumps

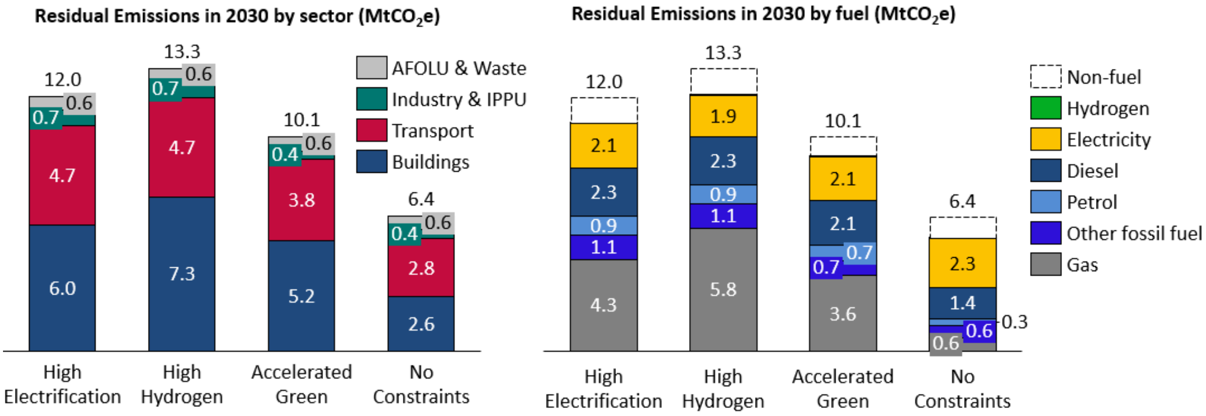

Figure 2.13: Sources of residual emissions for each scenario in 2030 by sector (left) and fuel (right). Note that emissions from gas include both natural gas and biomethane/bioSNG.

Energy Mix

The pathways rely on differing fuel mixes to achieve the target emissions reduction, with the greatest switch to low carbon sources achieved by 2030 in No Constraints (Figure 2.14). On the route to net zero, all scenarios necessarily have a reduction in natural gas and other fossil fuel use, with almost none by 2050 (note that gas use in Accelerated Green is fully biomethane/bioSNG). Hydrogen use is similar between the scenarios in 2030 but diverges greatly after this point, with the highest reliance on hydrogen in the High Hydrogen scenario by 2050 and little growth in hydrogen applications in No Constraints or High Electrification. The High Hydrogen scenario assumes full conversion of the gas grid to hydrogen by 2045, with hydrogen making up nearly 40% of fuel use by 2050.

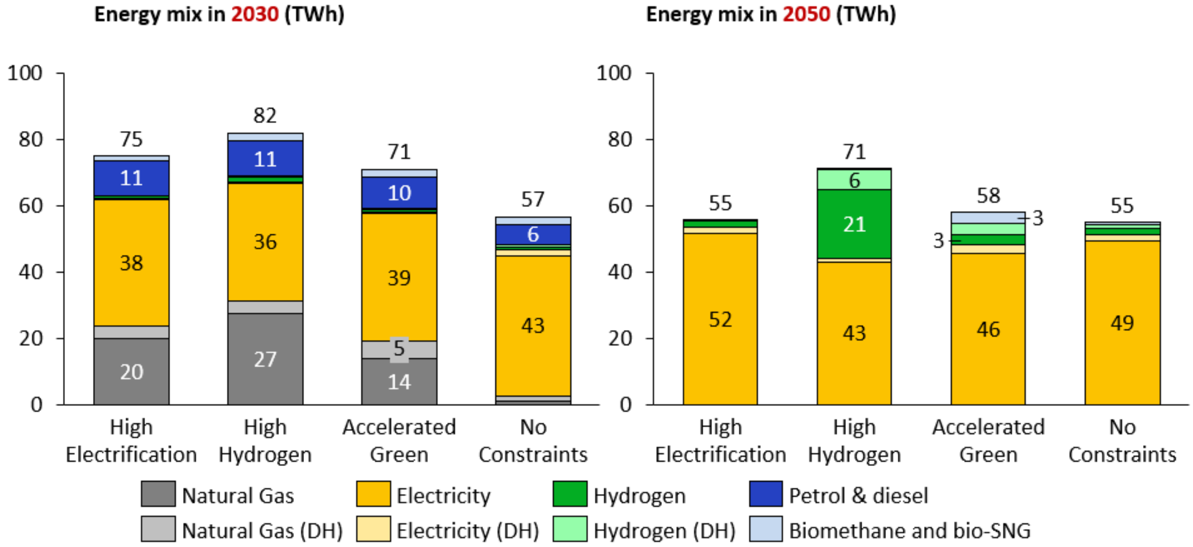

Figure 2.14: Energy mix in TWh across scenarios in 2030 (left) and 2050 (right). Note that gas use includes natural gas, biomethane and bioSNG; totals do not include aviation fuel or fuel in river transport or non-road mobile machinery.

2.3.2 Sectoral Contributions to Emission Reductions

In line with the size of their contribution to current emissions, the largest emissions savings between 2018 and 2030 come from Buildings (18 $MtCO_2e$ savings in No Constraints, 68% of total), followed by Transport (6 $MtCO_2e$ savings in No Constraints, 23% of total). Overall, by 2030, the buildings sector achieves an 88% reduction in emissions relative to 2018 levels in No Constraints (10% residual emissions relative to 1990) and Transport achieves a 71% reduction relative to 2018 (12% residual emissions relative to 1990 levels).

In the Buildings sector, the majority of emission reductions come from energy efficiency (34% to 51%, depending on scenario; highest in High Hydrogen; Figure 2.15). In line with the increased deployment of heat pumps and district heating in No Constraints, low carbon heating systems represent a larger share of emissions reduction in this scenario compared to the other scenarios (34% compared to 19% for High electrification, for example). Across all scenarios, decarbonising the electricity grid contributes a large share of emissions reduction by 2030. Increased deployment of solar PV contributes a relatively small proportion of emissions reductions by 2030 (for example, 1% in No Constraints); however, solar PV deployment is also expected to play an important role in reducing the impact of widespread electrification of heat on the electricity grid, The remaining emissions reductions are achieved through electrifying the remaining residual heat further, and through reducing emissions factors further through increasing the share of biomethane and bioSNG in the gas grid.

In the Transport sector, behaviour change accounts for 10% of emissions savings in High Electrification and High Hydrogen but 19-24% of savings in Accelerated Green and No Constraints (Figure 2.16). The shift to ultra low emission vehicles accounts for close to 50% of additional savings in No Constraints and Accelerated Green but, due to the relatively low contribution of behaviour change, contributes a much higher share of emissions savings in High Electrification and High Hydrogen (close to 70%). Air travel is also an important factor, accounting for an increase in emissions in the High Electrification, High Hydrogen and Accelerated Green scenarios but no change in emissions in the No Constraints scenario.

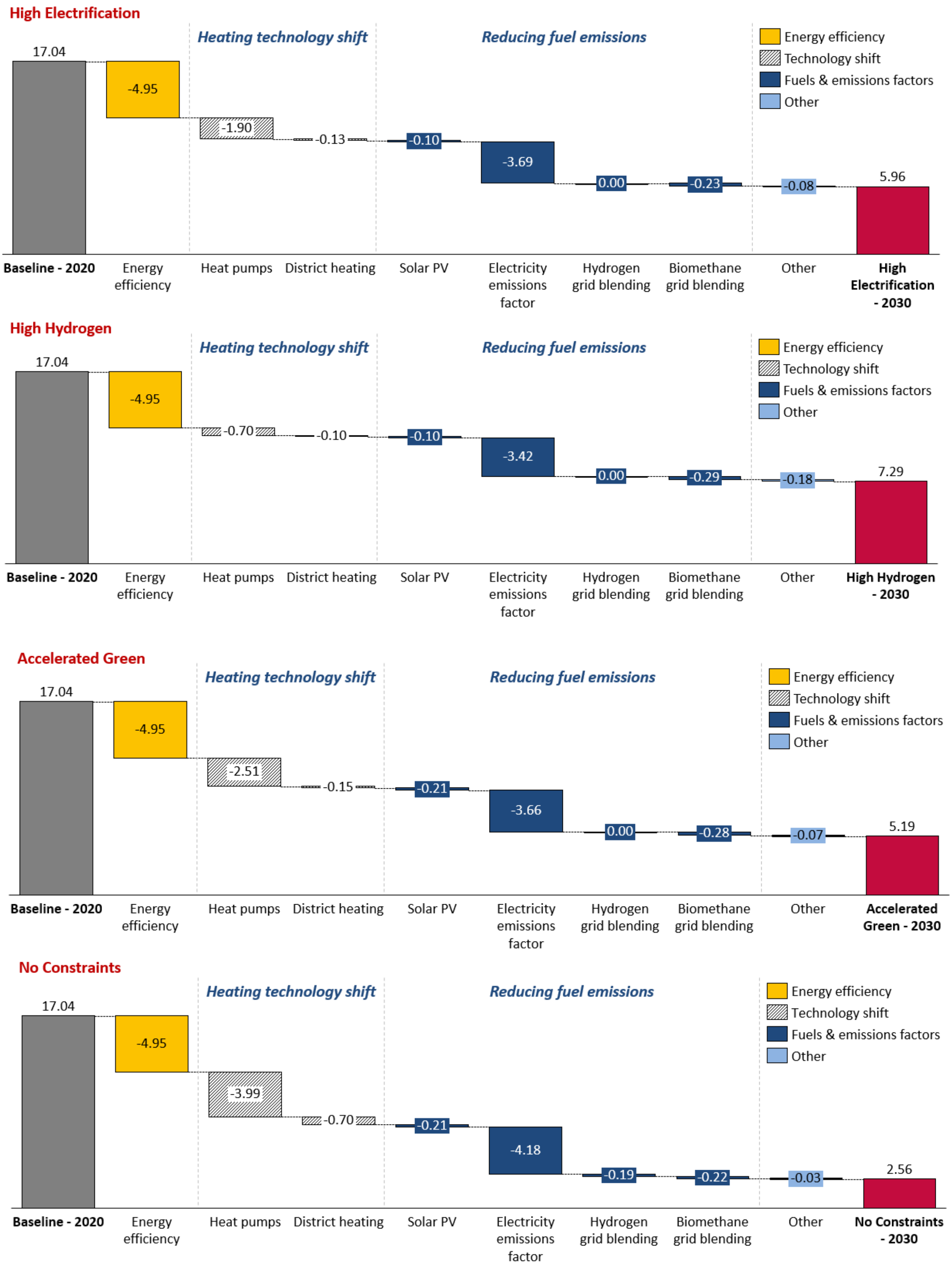

Figure 2.15 Relative contribution of emissions reduction measures to savings in the Buildings sector under each scenario

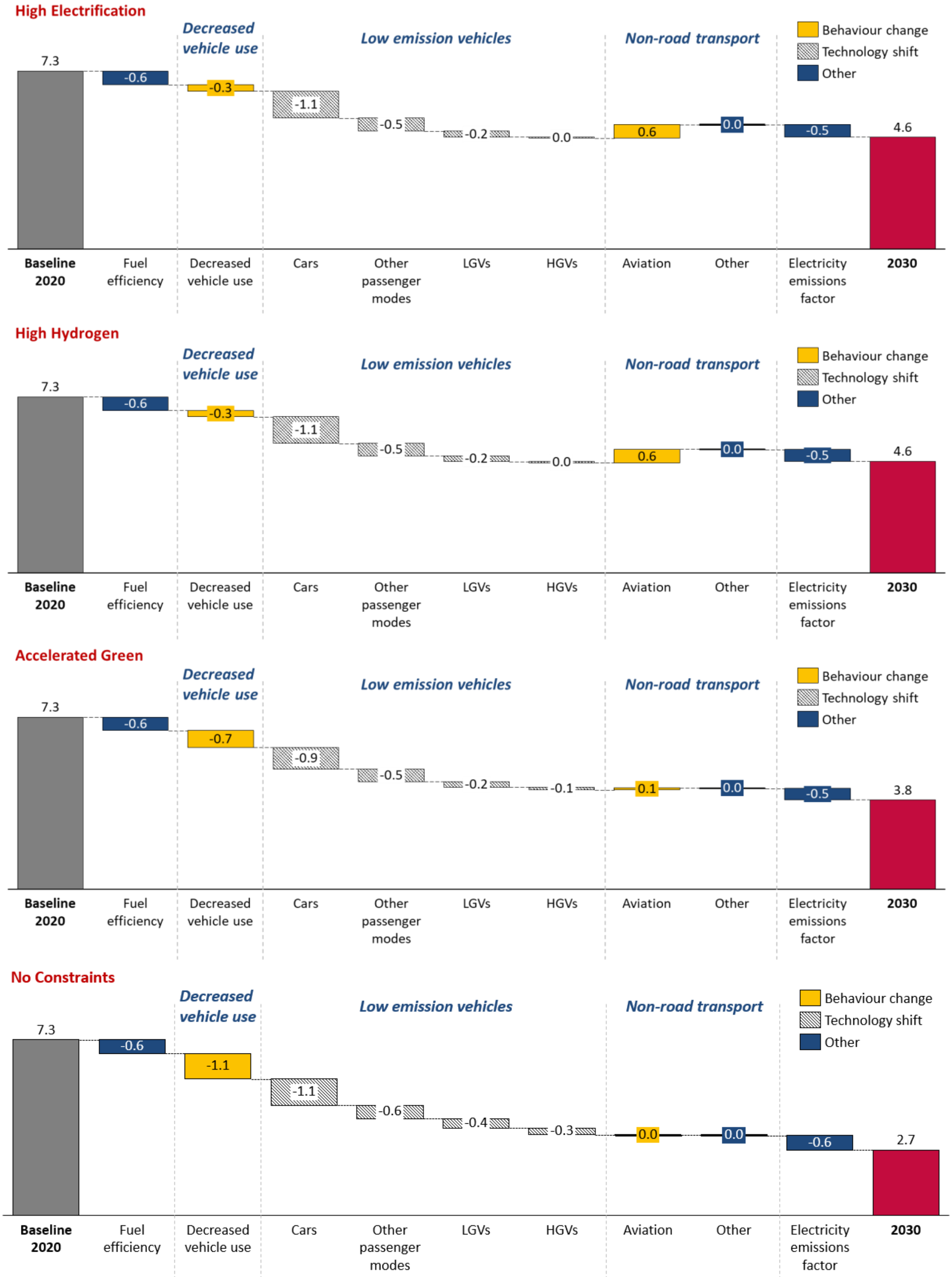

Figure 2.16 Relative contributions of measures to emissions reductions in the Transport sector across scenarios

2.3.3 Role of hydrogen

By 2030, between 0.8 and 1.8 TWh/year of hydrogen is needed in London to achieve the emissions reduction scenario trajectories. However, this is a relatively small proportion of fuel demand – making up approximately 2.5% of all fuel use in London (Figure 2.14).

The main barriers to achieving this level of hydrogen deployment are financial, with production dependent on funding and Government support for projects.[82] In addition to suitable production close to injection points, blending into the grid will require regulation to be in place to allow the maximum volume to be deployed.

Finally, although there is potential for low carbon hydrogen production using electrolysis (either using grid electricity or renewables such as offshore wind), the majority of current projects with potential to supply London will use methane reforming with CCUS which relies on deployment of CCUS within the UK by the mid-2020s.

In the worst case, if hydrogen is not delivered in the required volumes by 2030 and all hydrogen appliances projected to be installed by 2030 instead run on natural gas, emissions would increase by 0.1-0.3 $MtCO_2e$, with No Constraints reaching a total of 6.1 $MtCO_2e$ residual emissions (14% relative to 1990 levels). This means that the risk to London's climate ambitions of non-delivery of hydrogen in the short-term is very low.

The blue hydrogen production emissions modelled in this study assume that all blue hydrogen is produced by ATR with CCUS, since this is in line with the majority of UK blue hydrogen projects currently planned or under development and, in particular, those with potential to supply London in the short-term. ATR with CCUS plants are assumed to have high efficiency (kWh_{gas}/kWh_{H2} of 79% on a lower heating value basis) and a high CO_2 capture rate (95%).[83]

A worst-case scenario for UK production is considered for the case of blue hydrogen produced by steam methane reforming, retrofitted with CCUS. Such plants are assumed to have a lower efficiency than new ATR plants (70% on a lower heating value basis) and a lower CO_2 capture rate (60%). If all hydrogen is assumed to be produced this way (compared to the core scenarios which assume a mix of blue hydrogen and electrolysis), this would result in the emission factor of hydrogen approximately doubling. In this case, the impact is highest for the High Hydrogen scenario where the residual emissions in 2050 increase by around 15% (residual emissions increased by ~1.2 absolute percentage points); emissions in the other scenarios increase by around 5%.

The hydrogen emissions factors in this study only consider the emissions from production and distribution of hydrogen; however, upstream (Scope 3) emissions from natural gas production contribute a large proportion of whole-chain emissions for blue hydrogen, and are heavily influenced by the share of gas supplied as liquified natural gas (LNG) compared to pipeline gas.[83] Upstream emissions are typically lower in Europe than elsewhere in the world (e.g. the USA; typical value on the order of 10 $gCO_2e/MJ\ H_2$ in the UK[84]); however, ultimately, the whole supply chain for hydrogen should be considered when comparing the emissions benefits of potential future pathways.

[82] Based on stakeholder consultation feedback.
[83] Element Energy for Zemo "*Low Carbon Hydrogen Well-to-Tank Pathways Study*" (2021)
[84] Zemo Low Carbon Hydrogen Well-To-Tank Pathways Study (2021)

3 Implications of Scenarios

3.1 Impact on the electricity network

Overview

Widespread deployment of heat pumps and electric vehicles in the emissions reduction scenarios, without deployment and use of significant flexibility, will result in a rapid increase in peak load on the electricity network. It is therefore important to understand both the scale of these impacts and how soon grid infrastructure will need to be upgraded to cope with an increase in demand.

To understand the scale of these impacts and the potential need for electricity grid reinforcement, the peak load and capacity increase at primary substations was estimated based on the detailed analysis carried out for the *1.5°C Plan*:[85]

- The impact of each sector (electric heating, heat pumps, EVs etc.) on the peak demand was assessed using a derived relationship between peak demand and total demand to provide an estimate of the peak demand each year out to 2050. It should be noted that the modelling assumes that peak loads occur in January, although previous analysis has indicated that a significant minority of substations, predominantly in central London, experience summer peaks.
- The peak demand by sector was distributed across primary substations according to the distribution derived in the previous analysis and the need for reinforcement was determined by the increase in peak demand above existing capacity.[86]

To cope with load growth in the most cost-effective way, load management and flexibility measures such as energy storage and demand side response (DSR) will be required.[87,88] The impact of building-level DSR on the peak demand from each sector was calculated based on the outputs of the original demand modelling (as a % reduction in demand), then the sectoral results were combined to give an estimate of the overall impact of DSR on the total peak demand.

Impact on the network

Figure 3.1 shows the projected peak demand for each scenario (left) and the corresponding grid upgrades that would be required (right). The values were calculated at 5-year intervals then interpolated in between. The dashed lines in the figures show the potential for using DSR to reduce peak demand and defer requirements for grid upgrades.

To understand how the different demand sectors are affecting the demand peak, Figure 3.2 shows the sectoral contributions to the peak. Lighting and appliances (both domestic and non-domestic) are the biggest contributors to the peak electricity demand in 2030 and 2050, however, their contribution remains relatively stable across the timeframe considered and is kept constant across the scenarios.

The change in peak demands out to 2030 observed in Figure 3.1 are most heavily impacted by heat pump deployment (increasing demand) and energy efficiency (decreasing demand). The difference in projections up to 2030 therefore largely reflects the difference in the varying rate of heat pump deployment across the scenarios. The High Electrification, High Hydrogen, and Accelerated Green

[85] Based on detailed analysis of load profiles for each technology; see the study report for details: https://www.london.gov.uk/sites/default/files/element_zero_carbon_energy_systems_report.pdf
[86] The distribution of demand across substations was based on assigning technology uptake per LSOA then calibrating the predicted load to match the observed peak on each primary substation according to data from UKPN.
[87] Energy storage involves storing using methods much as pumped hydroelectric dams or batteries when demand on the grid is low for use when demand is high. Demand side response involves managing the demand on the grid, reducing demand at peak times, examples include reducing set points on heating by half a degree for half an hour at peak times.
[88] Including time of use tariffs (static and dynamic), Direct Load Control, and On-demand

scenarios experience a decrease in peak demand to 2030 due to the high uptake of energy efficiency, which is sufficient to offset increases in demand through electrification of heat and vehicles. In contrast, the rapid rate of electrification in the No Constraints scenario offsets the reduction due to energy efficiency, resulting in an increase in peak demand from 2020.

Post-2030, the peak demands are impacted by decisions around the technology mix used. The High Electrification scenario includes a greater share of direct electric heating than the other scenarios, resulting in High Electrification reaching the highest peak demands by the early 2040s. Despite having the highest peak demand of the scenarios considered in this study, the peak demands for High Electrification in this study are around 20% lower than the High Electrification scenario modelled in the *1.5°C Plan* due to higher levels of energy efficiency improvements in buildings and lower deployment of direct electric heating.

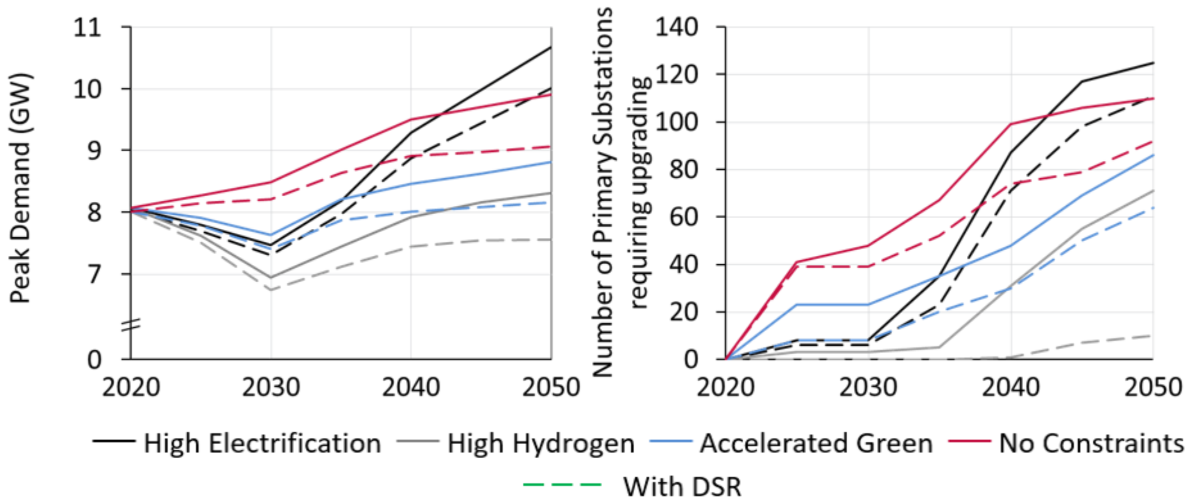

Figure 3.1 Peak electricity demand (left) and number of substations expected to require upgrading in each scenario (right), dashed lines show the impact of DSR.

Without DSR, the scenarios are likely to require reinforcement of around 3-50 of London's 235 primary substations by 2030, with up to 125 by 2050 depending on the technology mix used (Figure 3.1, right). The substation upgrade requirements follow a similar trend to the peak demands and level of heat pump deployment, with No Constraints and Accelerated Green requiring the most upgrades in the 2020s but eventually being overtaken by High Electrification. Although the peak demands in High Hydrogen decrease overall, it is still expected that grid upgrades will be required to accommodate local increases in demand as a result of localised electrification of heat and deployment of EV charging infrastructure.

Differences in energy demand from the transport sector have relatively little impact on the peak demand as electric vehicle charging is not a significant contributor to peak demand (2%-4%).

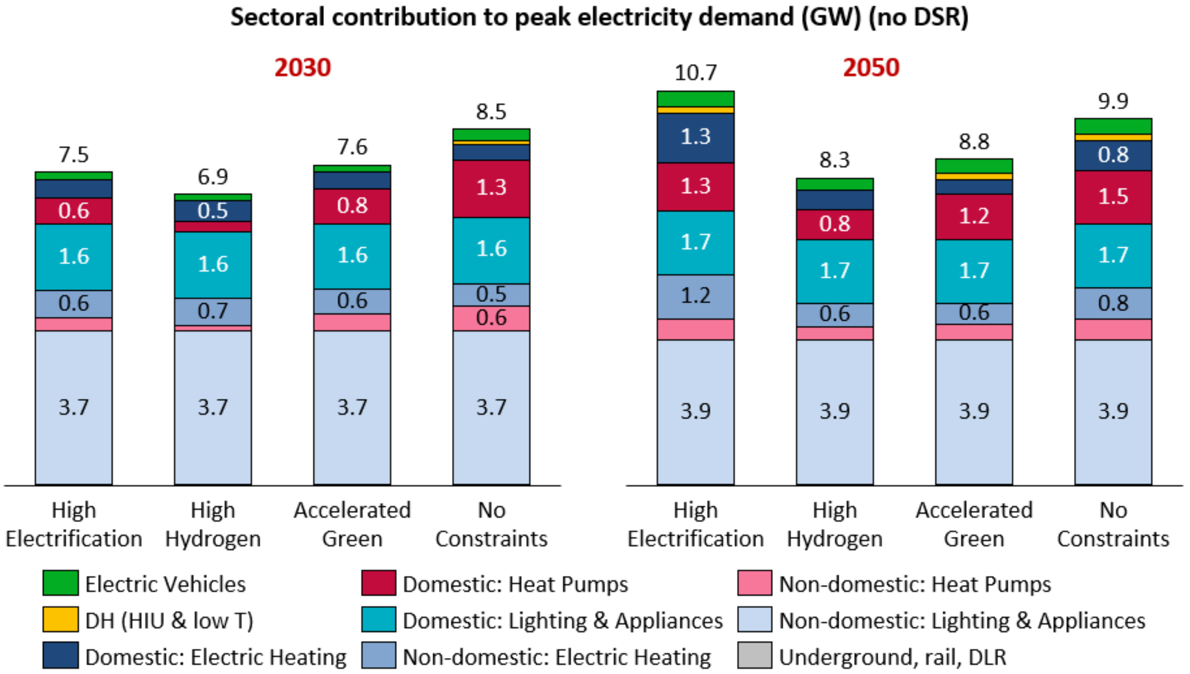

Figure 3.2: Sectoral contributions to peak electricity demand (not including the impact of DSR), in Giga Watts.

Impact of DSR

The impact of DSR is expected to increase out to 2050 as more DSR is deployed (dashed lines in Figure 3.1, left). DSR can reduce the peak demand by up to 10%, with the highest impacts in the High Electrification and No Constraints scenarios. However, it should be noted that there is considerable uncertainty on the potential impact of DSR, as it depends not only on uptake of enabling technologies and technical potential for load shifting but also on consumer participation and behaviour; as such, the figures shown here are indicative only. In the Accelerated Green and No Constraints scenarios, DSR reduces the number of London's 235 primary substations that will require upgrading by 9-15 in 2030, however, by 2050 approximately 20 fewer substations could be upgraded as the demand increases and DSR is rolled out more widely. The use of DSR to manage peak demands will allow the DNOs to manage and defer upgrades, thereby minimising cost and disruption.

Value of flexibility

To understand the value of grid flexibility to the public, high-level estimates of the potential financial savings have been made based on economic modelling work carried out by Imperial College London adapted to the London context.[89] The Imperial College analysis calculated the cost savings from generation, transmission and distribution of energy as a result of implementing flexibility through storage and DSR.

Using London's total expected electricity demand in 2050, the cost savings expected for the UK have been scaled to London giving an estimate of between £1.6 to 3.3 billion in cumulative cost savings by 2050 through implementing flexibility measures (Table 3.1). Much of this value could be passed down to consumers in reduced energy bills both within London and across the UK. Since London is likely to

[89] Carbon Trust and Imperial College London "*An analysis of electricity system flexibility for Great Britain*" https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/568982/An_analysis_of_electricity_flexibility_for_Great_Britain.pdf *published November 2016*

host somewhat less generation capacity than other areas of the country due to space constraints, not all of the savings from reduced electricity generation investment will be seen in London but will instead be spread across the UK more widely. If only 15-25% of generation CAPEX saving associated with London's demand is assumed to be in London,[90] for example, this leads to an estimate of £0.6-2.0bn in energy savings by 2050. However, these are very high-level estimates carrying considerable uncertainty.

Table 3.1: Cumulative savings in 2050 due to flexibility, in £ billion

	High Electrification	High Hydrogen	Accelerated Green	No Constraints	UK
Electricity demand (TWh)	50	41	45	48	510
Energy system cost savings **across the UK** as a result of implementing flexibility in London					
Low (£ bn)	**2.0**	**1.6**	**1.8**	**1.9**	**17**
Average (£ bn)	2.8	2.3	2.5	2.7	**28.5**
High (£ bn)	3.3	2.6	2.9	3.1	40
Energy system cost savings **in London** as a result of implementing flexibility measures in London					
Low (£ bn)	**0.8**	**0.6**	**0.7**	**0.7**	**17**
Average (£ bn)	**1.6**	**1.3**	**1.4**	**1.6**	**28.5**
High (£ bn)	2.0	1.7	1.8	2.0	40

Implications for the Electricity Network

Feedback from UKPN and SSEN as part of this study indicated that the scale of grid upgrades projected is achievable. Upgrading the connections between substations, as opposed to the substations themselves, is likely to be the most disruptive element of the upgrades due to the requirement for groundworks, and the supply chain is likely to be the limiting factor in the rate of carrying out grid upgrades. However, in practice, alternative options to individual substation upgrades will likely be sought, such as installing new substations to relieve demand on other substations in nearby areas (i.e. although 60 substations may go over capacity, it is unlikely that all 60 would be reinforced).

3.2 Costs and Benefits

3.2.1 Investment costs

Scope

The investment costs analysed in this study cover the same scope as in the *1.5°C Plan* and are calculated using the same methodology but with selected costs updated based on up-to-date literature sources, including fuel prices, heating technology costs and transport refuelling infrastructure costs. A summary of the cost elements included in this study are given in Figure 3.3. The cost of implementing

[90] Based on the range modelled in the *1.5°C Plan*and consistent with the ranges modelled in this study

supportive policy – such as scrappage schemes or other incentives – were out of scope of this study and are not included in this analysis.

Unless stated otherwise, the values shown here include a discount rate of 3.5% in line with recommended valuation of Government investment.[91] This social discount rate reflects the present value of public investments that will occur at a later date (reflecting that the present value of costs incurred later is lower than the value of investments made now, accounting for, for example, inflation and interest).

Building Level technology costs

- Energy efficiency and heating systems
- Includes HIU & heat meter for DH
- Technology capex
- Technology installation
- Technology maintenance
- End of life replacement
- Smart home systems
- Storage costs

Infrastructure costs

- District heating
  - Energy centre
  - Network (pipes)
  - Capex, installation, maintenance & replacement
- Electricity grid infrastructure
- Gas grid infrastructure (repurposing to hydrogen)
- EV charging infrastructure
- Hydrogen refuelling

Fuel costs

- Retail fuel costs for all fuels
  - Natural Gas
  - Electricity
  - Petrol
  - Diesel
  - Hydrogen
  - Green gas
- Low and high sensitivities on all fuel costs

Figure 3.3: Summary of cost elements included in investment modelling.

Overview of scenario investment

Figure 3.4 shows the total cumulative discounted investment costs for each scenario in 2030 (left) and 2050 (right). Fuel costs account for the largest portion of investment costs in both 2030 and 2050. Building-level investment by 2030 is highest in Accelerated Green and No Constraints, as these scenarios see high levels of low carbon heating deployed within this timeframe.

No Constraints has the highest cumulative investment by 2030 and 2050, even though it has the lowest fuel costs in both 2030 and 2050. These slightly lower fuel costs in 2030 are largely the result of reduced demand for petrol and diesel due to modal shift while in 2050 the preference for heat pumps over direct electric heating or hydrogen result in lower heating costs for buildings. The overall higher cost is due to higher investment in early years, when technology costs are higher, and subsequent high investment in replacement of these heating systems in the period 2035-2050.

Conversely, the lowest cumulative costs and highest fuel costs, in both 2030 and 2050, are in the High Hydrogen scenario. These higher fuel costs are primarily a result of the reliance on hydrogen for heating, which is not expected to benefit from the same low costs relative to electricity as natural gas does currently. These differences in fuel costs are discussed in more detail in the dedicated Fuel Costs section below.

[91] HMT The Green Book, Central Government Guidance on appraisal and evaluation, Social time preference rate (STPR)

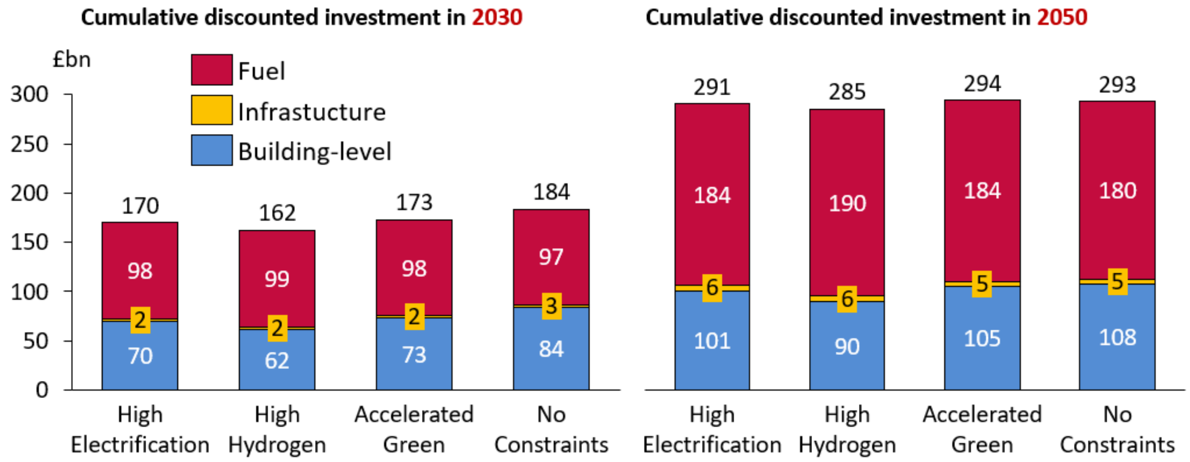

Figure 3.4: Total cumulative discounted investment for each scenario in 2030 (left) and 2050 (right) split by sector.

All scenarios experience a significant peak in investment in the 2020s due to the ambitious energy efficiency deployment across all scenarios (Figure 3.5). The more ambitious trajectories have a higher spending peak in the 2020s with No Constraints requiring over £21bn per year in investment at its peak as energy efficiency measures and low-carbon heating are rolled out across the building stock.

By 2040 all scenarios have largely similar annual costs. The rapid deployment of heating systems in the 2020s in No Constraints leads to a dip in costs in the 2030s while very few heating systems are in need of replacement.

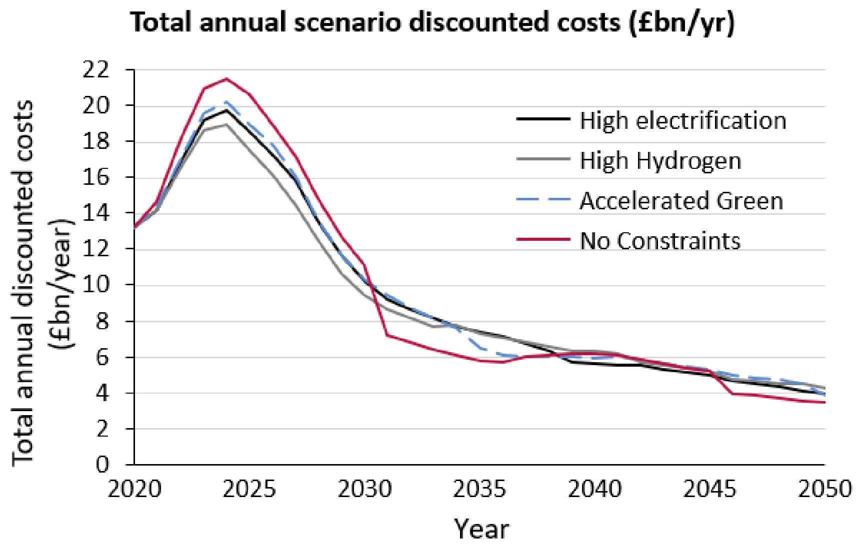

Figure 3.5: Total annual discounted costs for each scenario.

The total costs shown in Figure 3.4 are broadly similar to those in the previous modelling from the *1.5°C plan* (see Appendix, Section 5.2). However, the relative contribution of building-level costs and fuel costs differ considerably. Building level costs in the updated modelling are roughly double those calculated previously due to the increased ambition with respect to energy efficiency measures in buildings and updated assumptions around the cost of energy efficiency.[92] These energy efficiency measures lead to lower heating demand resulting in lower fuel costs across the timeframe studied and beyond.

[92] Based on the modelling carried out by Parity Projects for London Councils.

Building-Level Investment

Building-level costs consider the capital cost of installing heating technology and energy efficiency upgrades, as well as ongoing maintenance costs. The cost of scrappage schemes (e.g. incentives) are not explicitly modelled but the inherent cost of early deployment and early replacement of heating systems is reflected in higher capital investment earlier in the 2020s, when heat pump costs are higher and the costs experience a relatively lower rate of discounting.

Building costs are dominated by energy efficiency upgrades, at £43 billion by 2030 across the scenarios.[93] Energy efficiency improvements are largely complete by 2030 with only an extra £2 billion of investment in energy efficiency between 2030 and 2050 (primarily due to non-domestic sector upgrades). Figure 3.6 shows the breakdown of costs across various aspects of building decarbonisation for each scenario in 2030 (left) and 2050 (right). As energy efficiency contributes equally across all scenarios, it is the CAPEX associated with low-carbon heating systems (primarily heat pumps) that distinguishes the scenarios. The low CAPEX of hydrogen boilers (similar to standard gas boiler) compared to heat pumps means that the High Hydrogen scenario has much lower heating system capex than the other scenarios. This difference is particularly noticeable by 2050 where investment beyond energy efficiency measures is £34 billion in the High Hydrogen scenario compared to between £45 billion and £52 billion for the other scenarios.

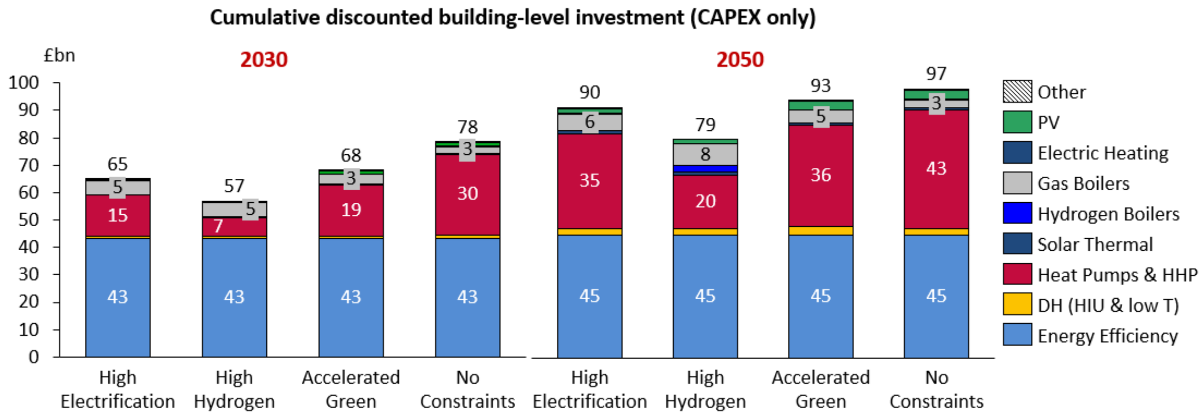

Figure 3.6: Cumulative discounted building-level investment (CAPEX only) showing each contributing subsector for each scenario in 2030 (left) and 2050 (right).

To understand the spread of heating system costs over time, Figure 3.7 shows the annual discounted heating system investment (CAPEX only) for High Electrification (top figure) and No Constraints (bottom figure), which reflects the number of heating systems installed in each year for each scenario (chosen to reflect two scenarios with high electrification of technology but extremes of deployment rates; see Figure 5.7 in the Appendix for the equivalent graphs for the other scenarios). Heat pumps account for the vast majority of low-carbon heat CAPEX (79% in High Electrification, 86% in No Constraints) out to 2050, with a steadily decreasing portion of spending on gas boilers and a small portion on district heating.

The rapid deployment of heat pump retrofits in the 2020s in No Constraints leads to very low heating system installation costs between 2030 and 2040 as new heating systems have been installed across almost all properties over a very short space of time. The second peak in No Constraints between 2035

[93] Domestic building energy efficiency costs were modelled based on work by Parity Projects for London Councils, whereas non-domestic costs were based on modelling by Arup for the *1.5°C Plan*. Understanding the real-world scale of these costs in both sectors will be an important area for further work.

and 2045 represents the replacement of all the heat pumps from the first peak.[94] The second peak is around 60% smaller, primarily due to the reduced cost of replacing heat pumps (and relative discount factor), compared to new installations.

In contrast, High Electrification (and the other scenarios) have much smoother annual installation costs as installation rates of heat pumps are much more consistent across the period to 2050. The peak spending rate in High Electrification is only around half the peak rate in No Constraints; total heating system CAPEX is around 90% of the No Constraints value, reflecting the more even spending in High Electrification. The difference in total spending between the scenarios reflects the costs of early replacement of heating systems, which in turn means more low-carbon heating systems reach the end of their life and need to be replaced again within the timeframe being studied.

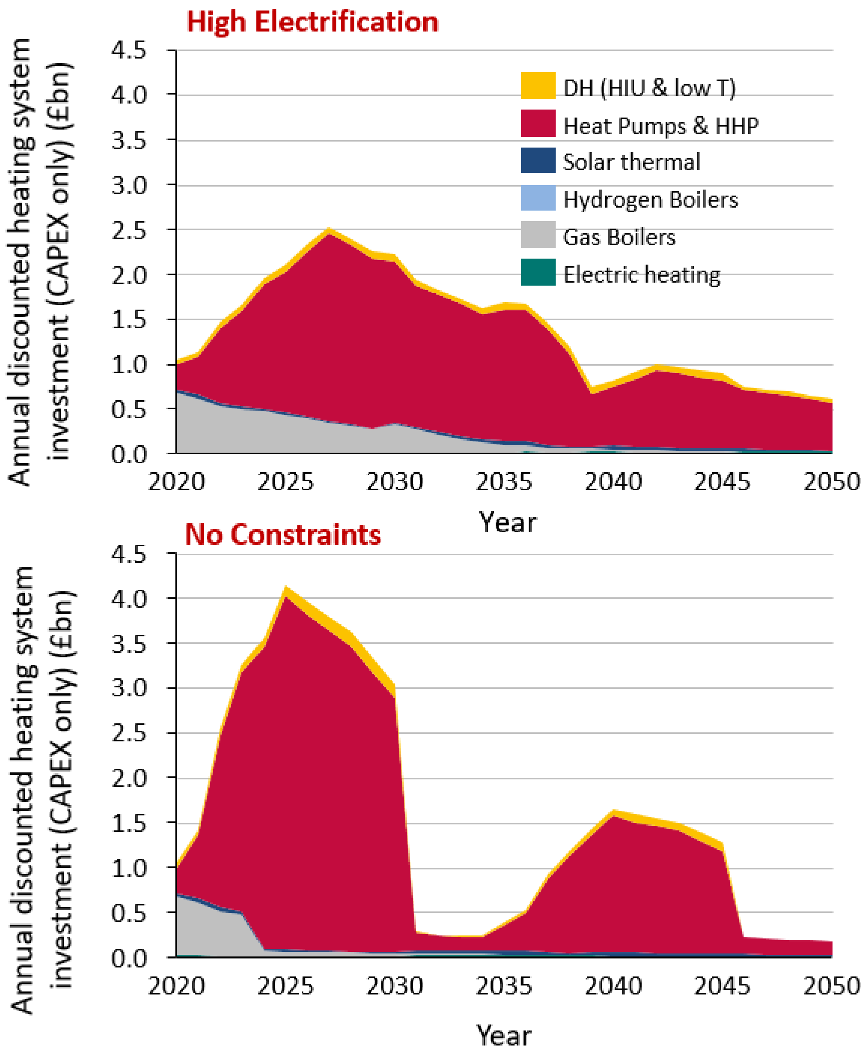

Figure 3.7: Annual discounted heating system investment (CAPEX only) for the High Electrification scenario (upper) and the No Constraints scenario (lower).

Infrastructure Costs

In the scenarios within this study, EV charging and district heating infrastructure account for almost all of the infrastructure costs in 2030 and 2050, as shown in Figure 3.8. The exception is the High Hydrogen scenario, in which costs for converting the gas grid to hydrogen become the single largest contributor

[94] In reality, these peaks would be smoother than Figure 3.7 shows as the lifetime of heating systems varies across a range, rather than being replaced at exactly the average lifetime.

to infrastructure costs by 2050. From Figure 3.8, it can be seen that **the infrastructure investment required to upgrade the gas grid is more than double times that of upgrading the electricity network, even for the most demanding scenarios in terms of electricity use**. Therefore, electricity grid upgrades and gas grid upgrades should not be assumed to cancel each other out depending on technology route taken. Nor does some hydrogen use (e.g. in Accelerated Green) mean incurring the same level of gas grid infrastructure cost as the full gas grid conversion modelled in High Hydrogen.

Wider infrastructure changes to deliver behaviour change – including bus priority lanes, cycling infrastructure, as well as rail capacity upgrades – are not included in the cost modelling but will be critical investment in achieving the pathways[95]. Improvements required to meet the MTS ambition have been estimated to cost £2.9 bn per year (£58 bn between 2021-2041),[96] which is consistent with the change required in the High Electrification and High Hydrogen scenarios. In Accelerated Green, the total cost could remain the same but investment would need to be brought forward and increased to £6.4 bn per year in order to achieve this change faster.[97] No Constraints would need to go beyond this level of investment to ensure higher levels of infrastructure are delivered.

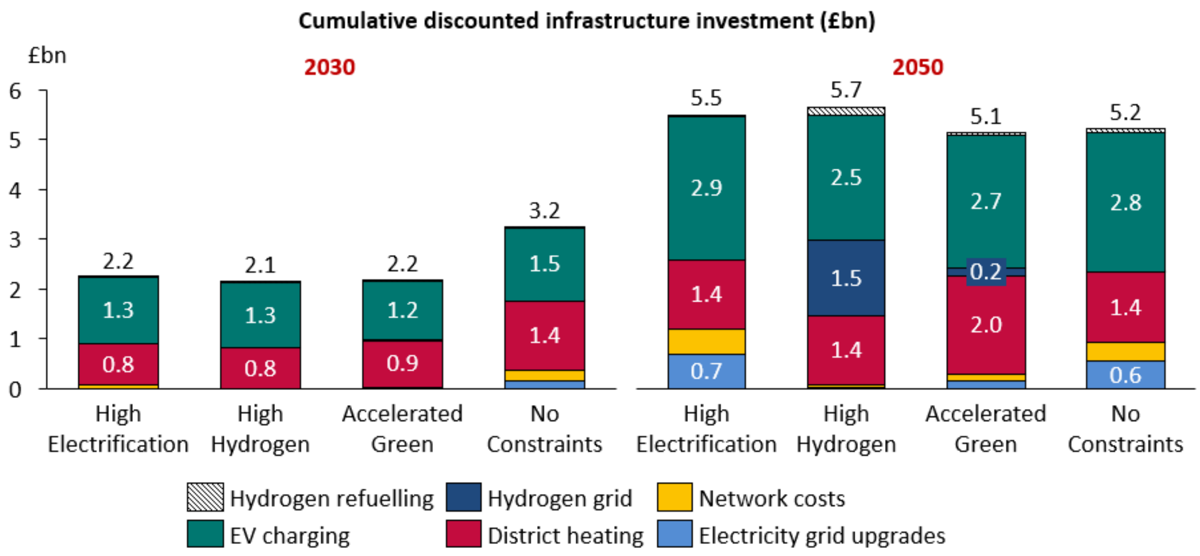

Figure 3.8: Cumulative discounted infrastructure investment in £ billion for each scenario by 2030 (left) and 2050 (right).

Fuel Costs

Across all scenarios, the cumulative fuel costs are dominated by electricity for buildings. In Figure 3.9, cumulative discounted fuel costs are shown for each scenario in 2030 (left) and 2050 (right).

As Figure 3.9 shows cumulative costs (as opposed to a snapshot in 2030 and 2050) all scenarios include some natural gas. The higher cumulative cost of electricity in No Constraints (and lower cumulative costs for natural gas) reflect this scenario's early transition to heat pumps.

The most significant differences between the scenarios are a result of:

[95] Active and public transport infrastructure was not included in the modelling since the precise distribution of travel across modes was not explicitly modelled for the scenarios (see page 14 for details). TfL data has therefore been used as indicative of scale of investment only.
[96] TfL Proposed Revised Budget 2021/2022 https://content.tfl.gov.uk/board-20210728-supplementary-agenda.pdf
[97] Estimated by applying the total annual investment for 2021-2041 across 2021-2030.

- **Hydrogen for heat in buildings**: hydrogen for building heat accounts for 7% of fuel costs in High Hydrogen and just under 4% in Accelerated Green
- **The reduction of petrol and diesel use in transport:** transport accounts for around 20% of energy demand across the scenarios in 2050 but the faster transition to EVs and a lower reliance on private vehicles in No Constraints means petrol and diesel accounts for a lower share of the overall fuel costs in this scenario compared to other scenarios.

While Figure 3.9 shows the cumulative costs to 2050, a slightly different picture emerges when we consider the undiscounted annual costs for 2050 alone (Figure 3.10), which best represents consumers fuel bills in 2050 at the end of the net zero transition. The most noticeable difference between the cumulative fuel costs and the 2050 fuel costs is the contribution of hydrogen to the costs. In the High Hydrogen scenario, hydrogen accounts for less than 10% of cumulative costs in 2050 (less than 5% the other scenarios) but accounts for 30% of annual fuel costs in 2050 (25% for buildings alone). Of the other scenarios, only Accelerated Green has significant contributions from hydrogen in 2050 with 12% of total costs (8% for buildings) with 3% for No Constraints and 1% for High Electrification.

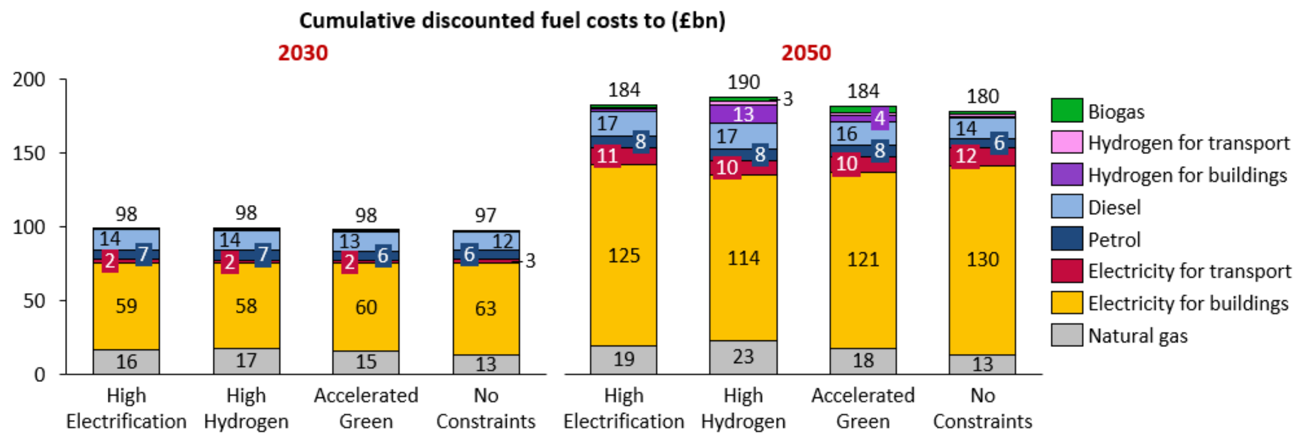

Figure 3.9: Cumulative discounted fuel costs for each scenario in 2030 (left) and 2050 (right).

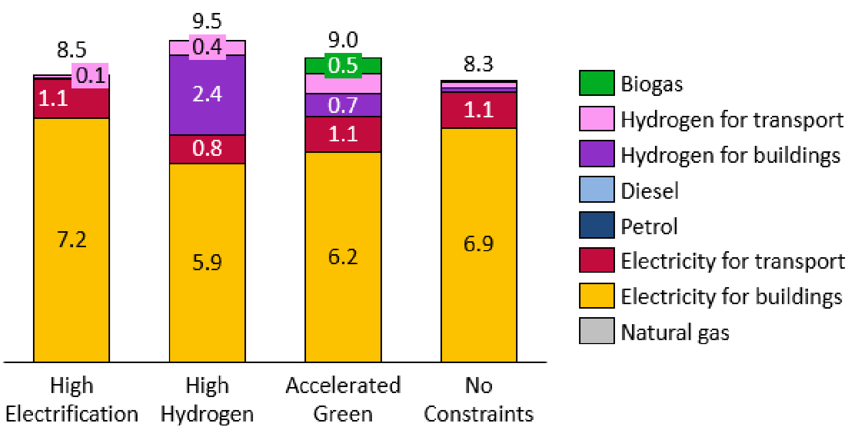

Figure 3.10: Total undiscounted fuel costs in 2050 for each scenario.

Carbon Value

The carbon value is a metric used to estimate the economic damage of releasing CO_2 into the atmosphere. This carbon value provides a quantitative measure of the benefits of preventing CO_2

emissions. For the purposes of this study, three separate carbon price trajectories have been considered based on HMT Green Book;[98] Table 3.2 shows the cumulative costs of carbon in 2050 for each scenario.[99] Using the Medium carbon price, No Constraints saves £13.9 bn to £16.7 bn in these cumulative carbon costs, over the two national target-compliant scenarios by 2050; for the High carbon price, the additional cost of carbon rises to £21-25 bn.

The relative cumulative costs of each scenario (originally shown in Figure 3.4) vary when the carbon value is included, as shown in Figure 3.11, especially when using the high value for the cost of carbon. Despite having the highest cumulative costs (excluding the carbon value) in both 2030 and 2050, the lower cumulative emissions for the No Constraints scenario means that it has the lowest cumulative costs with the carbon value included when using both the medium and high carbon prices.

Table 3.2: Cumulative cost of carbon based on carbon value, calculated for each scenario.

Carbon Cost	2050 Cumulative Cost of Carbon (£bn)			
	High Electrification	High Hydrogen	Accelerated Green	No Constraints
Low	33.4	34.8	30.2	26.5
Medium	66.8	69.6	60.4	52.9
High	100.2	104.4	90.7	79.4

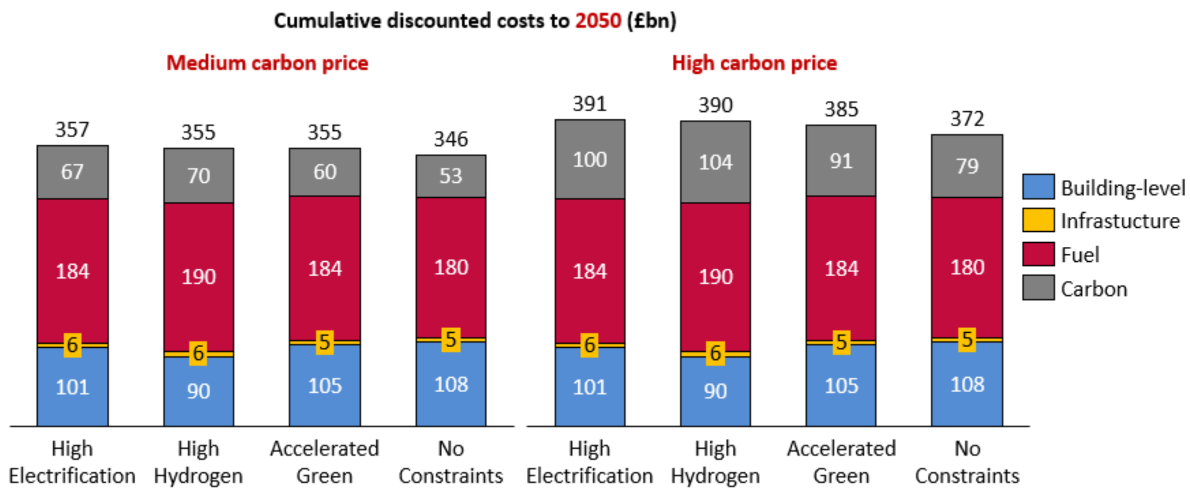

Figure 3.11: Cumulative discounted costs to 2050 for each scenario, shown including the medium carbon value (left) and the high carbon value (right).

[98] HMT: Green Book Supplementary Guidance https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal *last updated 17th October 2021, accessed December 2021.* Values given in Appendix

[99] The carbon price is also discounted using the same discount rate of 3.5%.

Impact of redistributing environmental costs from electricity to gas

In 2020, 25.5% of the electricity retail fuel bill consisted of this 'environmental/social obligation costs', with only 2.5% of the gas retail fuel bill comprising of the equivalent environmental costs.[100] A sensitivity was run, which shifted these environmental costs from electricity to gas,[101] gradually from 2022 to 2025, so that the electricity retail price reduced by 25.5% of the total modelled cost by 2025, and the gas retail price increased by the same absolute amount in p/kWh.

The results of this sensitivity are shown in Table 3.3, both for the annual (undiscounted) total fuel cost difference between this sensitivity and the main scenarios in 2030, and the cumulative total fuel cost difference by 2050.

Table 3.3 Impact of redistribution of environmental costs from electricity to gas on costs of each scenario

Scenario	Difference in annual (undiscounted) fuel cost in 2025 (£m/year) *negative cost = saving*	Difference in cumulative (discounted) fuel cost (£bn) *negative cost = saving*	
		2030	2050
High Electrification	£158 m	-£0.76 bn	-£17.02 bn
High Hydrogen	£316 m	£0.87 bn	-£10.59 bn
Accelerated Green	£49 m	-£1.65 bn	-£17.19 bn
No Constraints	-£356 m	-£4.63 bn	-£23.86 bn

This shift in the environmental costs from electricity to gas results in a net cumulative savings by 2030 in all scenarios except High Hydrogen, and in all scenarios by 2050. In 2025, the only scenario in which this shift provides a net reduction in fuel costs for consumers is in No Constraints, due to the much higher rate of electrification by 2025 in this scenario compared to the other scenarios.

Under this sensitivity, No Constraints becomes the lowest cost scenario in the absence of a carbon price by 2040, and by 2033 with a Medium carbon price.

Discussion

The No Constraints scenario has the lowest cumulative costs once the carbon value is included with the high carbon price. Without including the cost of carbon, High Hydrogen is the lowest cost scenario, largely due to lower technology costs associated with gas boilers (H_2 or methane) compared to heat pumps. Despite the lower CAPEX costs, the higher fuel costs expected to heat a home using a hydrogen boiler over a heat pump, mean that the cumulative costs for High Hydrogen eventually increase above the other scenarios, including No Constraints, which has the lowest fuel costs in 2050. The uncertainty in the future cost of low-carbon hydrogen, yet to be realised at scale, adds an additional risk factor to be taken into account when comparing the future costs for each scenario.

[100] https://www.ofgem.gov.uk/publications/infographic-bills-prices-and-profits
[101] In line with current Government thinking in the recently published Net Zero Strategy.

The point at which No Constraints becomes the scenario with the lowest cumulative costs varies with the carbon price used

- No carbon value included – 2060
- Low carbon value – 2050
- Medium carbon value – 2036
- High carbon value – 2034.

The values above indicate that the No Constraints scenario becomes the most economically favourable on a timeline ranging from the mid-2030s (under a High or Medium carbon price) to 2050 (under a Low carbon price). This result highlights the benefits of early action on decarbonisation. Even without accounting for carbon, No Constraints offers the lowest cost pathway by 2060 with the added benefit of lower ongoing fuel costs than in other scenarios.

The Accelerated Green scenario, designed to reduce emissions more rapidly than the national ambition scenarios, has comparable costs to those of the national target-compliant scenarios. Although it does not result in cost savings compared to the No Constraints scenario, the main advantage of Accelerated Green compared to No Constraints is in its smoother rollout of low-carbon heat, leading to a marginally more consistent spread of the costs.

3.2.2 Job Creation

An understanding of the job opportunities created as part of the drive to net zero is important both to understand the additional societal benefits of the net zero transition but also to understand the magnitude of the workforce that will be required to meet decarbonisation targets. With determination to ensure a just transition, it will also be important to consider where job losses may occur in sectors negatively affected by measures to reduce emissions and where reskilling will be required, and opportunities focused. A number of reports have provided estimates for job creation as part of the transition to net zero and green recovery, both internationally,[102,103,104,105] and in the UK,[106] as well as local[107,108] and sector-specific estimates.[109,110] These studies use a variety of methods ranging from bottom-up calculations based on Gross Added Value to multiplier methods (based on number of installations or £m investment).

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102 IEA "Job creation through investment in heat pumps in the Sustainable Recovery Plan" https://www.iea.org/data-and-statistics/charts/job-creation-through-investment-in-heat-pumps-in-the-sustainable-recovery-plan *last updated June 2020*

103 IRENA *"Measuring the Socio-economics of transition: Focus on Jobs"* (2020) https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Feb/IRENA_Transition_jobs_2020.pdf, *1*

104 The Energy Efficiency Industrial Forum *"How Many Jobs"* (2012) https://euroace.org/wp-content/uploads/2016/10/2012-How-Many-Jobs.pdf

105 "Assessing the Employment and Social Impact of Energy Efficiency" (2015) https://ec.europa.eu/energy/sites/ener/files/documents/CE_EE_Jobs_main%2018Nov2015.pdf

106 London School of Economics *"Jobs for a strong and sustainable recovery from Covid-19"* (2020) https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2020/10/Jobs_for_a_strong_and_sustainable_recovery_from_Covid19.pdf

107 Local Government Association *"Local green jobs – accelerating a sustainable economic recovery"* (2021) https://gemserv.com/wp-content/uploads/2021/06/Local-green-jobs-accelerating-a-sustainable-economic-recovery_final-1.pdf

108 C40 Cities, BuroHappold, Rokwool "*The Multiple Benefits of Deep Retrofits: A Toolkit for Cities"* (2020)

109 The Association for Decentralised Energy *"Market Report: Heat Networks in the UK"* (2018) https://www.theade.co.uk/assets/docs/resources/Heat%20Networks%20in%20the%20UK_v5%20web%20single%20pages.pdf

110 Heat Pump Association *"Delivering Net Zero: A Roadmap for the Role of Heat Pumps"* (2019) https://www.heatpumps.org.uk/wp-content/uploads/2019/11/A-Roadmap-for-the-Role-of-Heat-Pumps.pdf

In this study, high level estimates of jobs and skills needs for the scenarios for London have been developed for the following sectors, based on a multipliers approach:

- Energy efficiency
- Heat pump deployment
- District heating development
- On-site energy generation and management

An estimate for jobs and skills needed for hydrogen boiler installation has also been developed for the High Hydrogen scenario only (see Section 5.5, Appendix).

The primary sources for the analysis are the C40 Cities Toolkit C40 Cities Toolkit (Energy Efficiency)[108] and a recent report by the Construction Industry and Training Board (CITB) (see Section 5.5, Appendix for details).[111] The estimates developed refer to direct jobs, as opposed to indirect or induced jobs as a result of increased demand on the supply chain.[112] It should be noted that the estimates here are very high level and only cover the sectors where relevant sources could be found to estimate job numbers. Notable exceptions include transport infrastructure (e.g. electric vehicle charge point installation and maintenance), and vehicle production (where local production could occur) where robust multipliers were not identified, and the majority of jobs are expected to be in manufacturing which is expected to occur outside London.

Table 3.4 summarises the jobs and skills estimate by sector and scenario (peak FTE and the average FTE in the timeframes of 2020-2030 and 2020-2050).

Energy Efficiency

Installing energy efficiency measures across all buildings in London is the most labour-intensive aspect of retrofitting. Job creation from energy efficiency measures is concentrated within the time period to 2030, which raises issues around the steep increase then decrease in job opportunities through the 2020s caused by the rapid rollout of energy efficiency measures. The values in Figure 3.12 show a 5-year rolling average to smooth out the peaks and any modelling artefacts but the high peak in the FTE requirements remains.[113] The CITB recognise the need to limit drastic increases to the workforce that are not sustained and that would lead to a 'boom bust cycle' for job opportunities.[114]

The direct jobs generated through building retrofits are dominated by those installing the insulation measures themselves, such as general builders and insulation specialists, with additional, more specific, roles such as carpenters and window fitters. There is an additional role for retrofit coordinators to oversee retrofits, a role that is required to be eligible for some retrofit funding schemes. Work by Parity Projects for London Councils estimates that retrofit coordinators make up approximately 2.4% of the retrofit workforce,[115] however, their role is vital to ensuring retrofit work is being carried out to an appropriate standard to ensure the full benefits of retrofits are achieved, both for the building occupier and to achieve decarbonisation targets. **At the peak, the direct workforce for retrofits reaches 37,000 jobs, which means that close to 900 retrofit coordinator roles will be required across London by the mid-2020s.**

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[111] CITB *"Building Skills for Net Zero"* (2021) https://www.citb.co.uk/documents/research/building_skills_net_zero_full_report.pdf
[112] Direct jobs are those created directly by the core activities of the project, such as installer jobs. Indirect jobs are those created upstream of the project, for example in the supply chain for materials etc. Induced jobs are those created in the wider economy that are not linked to the nature of the project but come about as a result of the money spent by those in direct and indirect jobs.
[113] Based on 14.2 FTE per £1m invested, with 33% of FTEs direct jobs.
[114] The CITB highlighted taking a regional approach to deployment of decarbonisation measures but this assumes a workforce that is at least partially mobile and able to relocate every few years.
[115] Parity Projects: London Councils Pathways Report (2021)

Table 3.4: Peak FTE and peak year for building decarbonisation for each scenario.ⁱ

Scenario	High Electrification	High Hydrogen	Accelerated Green	No Constraints
Peak FTE (thousand)ⁱⁱ				
Energy efficiency	32			
Heat pumps	12	4	13	20
District heating	7	7	10	15
On-site energy production/smart technology	6			
Average FTE 2020-2030 (thousand)				
Energy efficiency	20			
Heat pumps	8	3	9	14
District heating	6	6	7	9
On-site energy production/smart technology	5			
Average FTE 2020-2050 (thousand)				
Energy efficiency	7			
Heat pumps	7	2	6	8
District heating	5	5	8	4
On-site energy production/smart technology	4			

ⁱ Energy efficiency jobs primarily reflect installers, although retrofit coordinators will also be needed (not shown in the table); Heat pumps jobs reflect installers and engineers; District heating jobs are primarily in infrastructure construction; On-site energy production refers to installers only.
ⁱⁱNote that the peak quoted is the peak year for that sector, but that the peak year differs for each sector

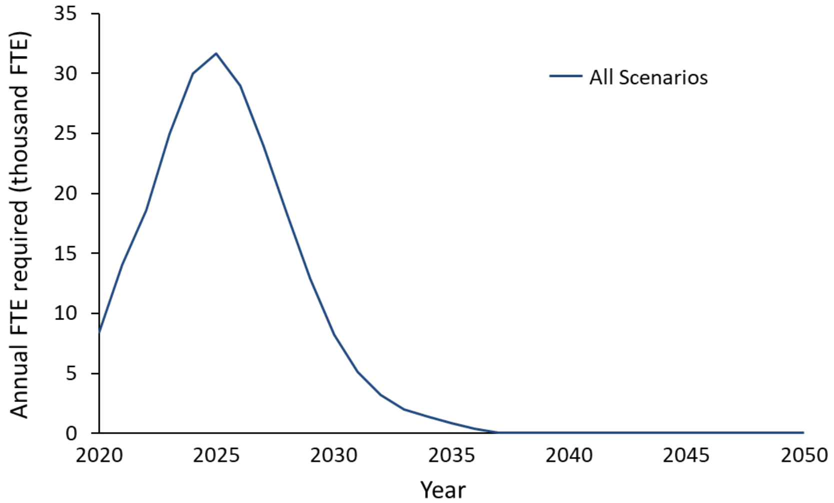

Figure 3.12: FTE (thousand) required for the installation of energy efficiency measures, consistent across all scenarios.

Heat Pumps

Job creation opportunities for heat pump installers have been estimated based on industry estimates of installation capacity of engineers (Figure 3.13). Even when using a 5-year rolling average, as in Figure 3.13, there are still steep increases and decreases in the number of job opportunities created within London. The second set of peaks in Figure 3.13, those after 2035, show the jobs created as heat pumps installed in the first wave of installations need replacing. The second peaks are smaller than the first as replacement is less labour intensive than converting from a gas boiler to a heat pump since elements such as wiring and radiators are not required in the replacement cycle.

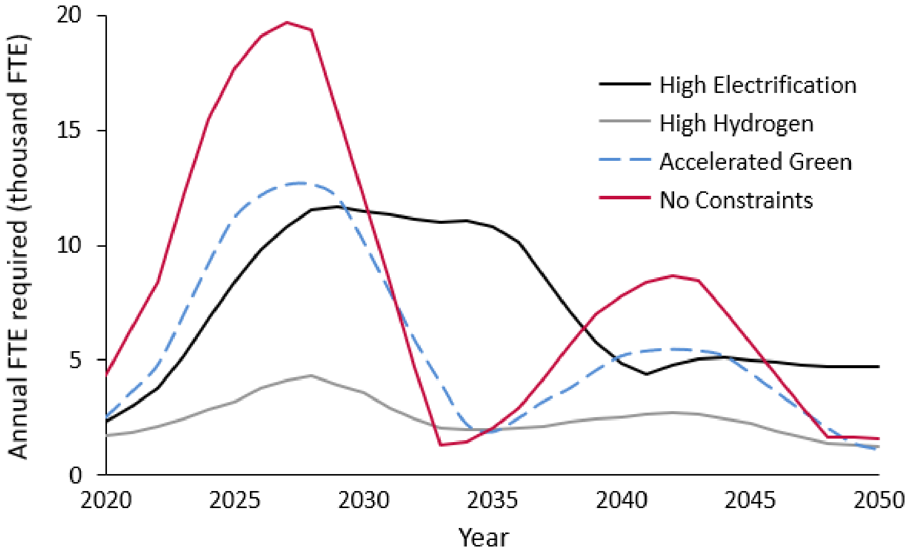

Figure 3.13: FTE (thousand) required for the installation of heat pumps across each scenario. Figures include initial installation and replacements.

The installation numbers expected each year in the CITB report are based on the CCC Balanced Pathway to reach net zero by 2050. London's accelerated pathway means that the number of installers needed in the 2020s is much higher than predicted under the CCC's Balanced Pathway. High level estimates for this study indicate London would need nearly half of the UK's trained heat pump installers by 2022 in the No Constraints Scenario, with Accelerated Green requiring around 20% of the workforce from 2023 through to 2026. It is therefore likely that specialist training will need to be expanded or established within the next 2 years to prevent the workforce being a limiting factor in heat pump deployment.

Heat Networks

The CITB indicates that heat networks are "better considered as infrastructure rather than building energy systems", therefore the estimated job creation numbers are based on generic numbers for jobs created by infrastructure projects rather than being specific to heat networks. By comparing the heat network rollout in the CCC's Balanced Pathway and in the scenarios for this study, it is possible to estimate the number of jobs that will be created through building heat networks, as shown in Figure 3.14.

As with energy efficiency and heat pump deployment, the accelerated deployment of heat networks in No Constraints leads to a steep peak and the drop off in jobs created through the construction of heat networks in London. The scenarios other than No Constraints, however, have prolonged FTE requirements from the early 2020s through to the late 2040s, a span of more than 20 years due to the more sustained rate of heat network rollout. It should be noted that the drop to zero FTE requirements in No Constraints from 2033 is not wholly realistic as it does not account for ongoing maintenance roles or replacement of the heat interface units (HIU) in properties; therefore this drop to zero is artificial. The infrastructure associated with district heating has a much longer lifetime than that of an individual heating system and therefore does not need replacing within the timeframe modelled.

The scale of heat networks means they require many sectors to come together, this mix of skills is reflected in the job types that are included in the CITB numbers for job creation: project planners, engineers, developers, design engineers, control systems/PLC specialists, welders and general installers. These job roles include those required for tasks such as identifying a suitable source of low-carbon energy but it unclear if they include installation of systems in homes, which may be assigned to a buildings-level specialist included elsewhere.

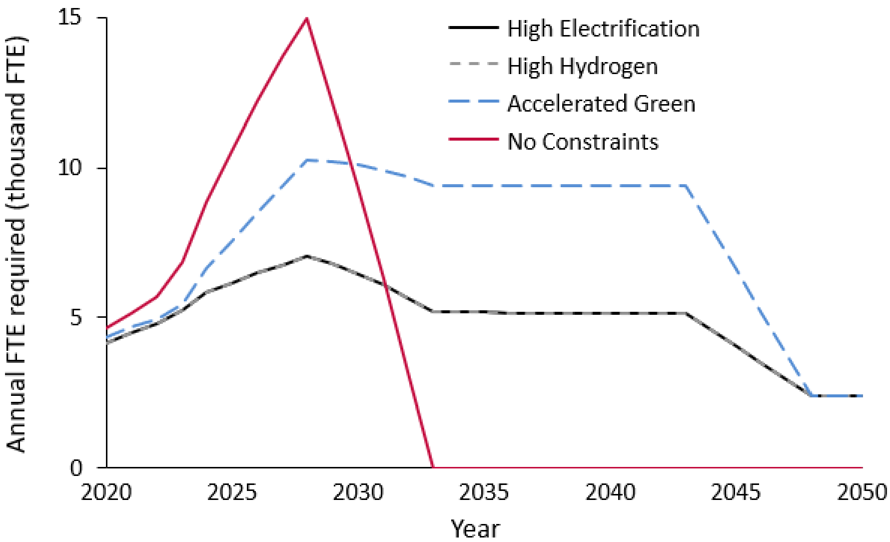

Figure 3.14: FTE (thousand) required for the installation of heat networks across each scenario. Note that these estimates do not include in-building replacements of heating technology.

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On-Site Energy

The CITB additionally considers installer requirements for on-site energy, including:

- On-site energy generation such as solar thermal and solar PV
- Energy storage systems
- Smart energy systems
- Interaction between the above systems.

Small scale wind generation is not included, as it is rarely appropriate on building scale, and neither is CHP due to CHP's limited capacity for decarbonisation.

The CITB estimate that around 5,000 additional FTE will be required in the short term, with a reduction to 450 additional FTE required in 5-10 years across the UK as a whole. These numbers are relatively small compared to the FTE required for energy efficiency and low-carbon heat installations. A high-level estimate has therefore been used assuming at least 10% of the UK workforce would be required in London (based on population) but based on the portion of UK wide installers required by London reaching up to 40% in other sectors, 40% of the UK wide FTE has been applied to the CITB numbers to generate an upper bound of installers required.

Additional Job Creation Opportunities and limitations of the estimates

The consideration of job creation in the above sectors is largely focused on direct jobs – those associated directly with deployment of the technology. However, indirect opportunities and jobs associated with supply chain building will also be generated within London and more widely across the UK including, for example, manufacture of technology, mining and transportation. As such, early decarbonisation and skills generation within London will provide positive benefits for the rest of the UK.

The job creation opportunities discussion in this section have focussed solely on the buildings sector. Although the transport sector is a major part of this study, few sources are available with comprehensive and robust estimates of direct job impacts. The impact of EV uptake on jobs in car manufacturing is primarily associated with upstream job creation within the automotive industry (indirect jobs) and where EV manufacturing takes place. The rollout of EV charging infrastructure is likely to create jobs within the construction sector but it is unclear how jobs created through infrastructure projects for active travel and public transport may be offset by reducing investment in projects more focused on private travel. For comparison, the Local Government Association estimate a total of approximately 9,000 direct jobs in London associated with low carbon transport in 2030 (2,502 in Alternative Fuels and 6,619 in Low emissions vehicles & infrastructure).[116]

It should be noted that the estimates provided here are based on current industry trends and the types of jobs created in future may differ. For example, roles with more diverse skill sets may appear, in which one installer can carry out multiple roles, which will lead to lower overall FTEs created. Additionally, existing engineers are an aging workforce[117] that may not be willing or available to retrain to low carbon heating technologies. The future generation of gas boiler installers for both natural gas and hydrogen installations, will need to be considered to different degrees over coming years depending on the expected technology roll out.

[116] https://www.local.gov.uk/local-green-jobs-accelerating-sustainable-economic-recovery
[117] The Parity Project report indicates that the average age of a Gas Safe engineer is 56

4 Delivery of the Net Zero 2030 Target

4.1 Policy and Other Actions

London's 2030 net zero target represents a substantially accelerated timeline for emissions reduction relative to the UK Government's target of net zero by 2050. Meeting this target will require a wide range of ambitious actions that go beyond current policy and likely entail higher risk and cost in the short term. However, the transition to net zero also offers opportunities for London to deliver benefits outside the region by moving more quickly than the national ambition (such as job creation, flexibility through higher deployment of district heating) as well as opportunities to become a leader in decarbonisation across sectors.

The GLA, TfL, London Boroughs, regulated utilities, the private sector and other public bodies have a critical role in driving the net zero transition and will need to take a proactive role in both leading local change and in working to put London in a strong position to take advantage of national opportunities as they arise. It is important to note that:

- The Mayor can't deliver net zero emissions in London alone and many measures will rely on national-level decisions and coordinated action with relevant partner stakeholders.
- All actors will require additional resource, funding and financing to deploy these policies and take crucial actions.

The following sections outline the likely additional policy and actions required to meet a 2030 net zero target compared to a 2050 target. All scenarios fall far short of zero residual emissions by 2030 (Table 4.1) and the remaining emissions will need to be offset to meet net zero.

The policy recommendations focus on the highest emitting sectors and highest impact interventions (primarily focused on reducing emissions from buildings and road transport); recommendations regarding minor sector emissions sources (including river transport, non-road mobile machinery, Waste and AFOLU) are not given here; however, these sectors have an important role to play in decarbonising London and so represent an important area of future work. The recommendations given here aim to indicate the type of policy and level of ambition required to meet key outcomes, but do not aim to specify the exact form of policy required.

The policy analysis presented here is intended to compare the level of ambition required for each scenario and does not seek to recommend one scenario over another. The policies also do not aim to define the precise roles of key stakeholders in delivering the necessary levels of action. More detailed planning will be required, such as further developing sectoral delivery plans and more local spatial area energy plans.

Table 4.1 Summary of residual emissions by sector across scenarios in 2030 (in $MtCO_2e$).

	High Electrification	High Hydrogen	Accelerated Green	No Constraints
Buildings	6.0	7.3	5.2	2.6
Transport	4.7	4.7	3.8	2.8
Industry & IPPU	0.7	0.7	0.4	0.4
AFOLU and Waste	0.6	0.6	0.6	0.6
Total	12.0	13.3	10.1	6.3

The key target outcomes and supporting policy measures to deliver each of the pathways are summarised in Table 4.2 to Table 4.5, and described in more detail in the following sections. The policy measures are described according to target measure but the order in which they are presented is not intended to signify priority.

4.1.1 Actions to decarbonise buildings

Energy efficiency

High levels of energy efficiency retrofit are required in all scenarios to both reduce energy demand and to facilitate the rollout of low carbon heating technologies, as well as reducing costs for consumers. The level of energy efficiency improvement assumed in the scenarios reflects the high ambition of the London Councils' target for domestic buildings and is significantly above that required under a national 2050 target (and therefore the "national target-compliant scenarios" go beyond national ambition in this respect). Achieving the modelled reductions in heat demand will require a wide range of urgent action including:

- **Retrofit programmes and plans** including mapping out opportunities for upgrade of buildings to set informed targets for each building, and local government-initiated programmes similar to Retrofit Accelerator – Homes and Retrofit Accelerator - Workplaces to support sub-groups of the market in most need of support
- **Financial incentives** such as grants and low-interest loans to support retrofit
- **Fiscal incentives** such as stamp duty, council tax and business rates that favour high energy efficiency
- **Development of delivery models** to support retrofit, such as larger-scale procurement
- **Supportive planning policy** to enforce retrofit at key trigger points, such as consequential improvement, and to set minimum energy efficiency standards above the National Planning Policy Framework where possible; it will be critical that Boroughs have the resources necessary to enforce standards and ensure energy savings are realised.
- **Development of retrofit skills** across London
- Support, guidance and funding to support local residents and businesses to undertake retrofit

GLA and the London Boroughs have the strongest influence over public buildings and new buildings and, as such, early action should target change in these sectors to lead by example, build evidence, and support supply chain development. Retrofitting the private-rented and owner-occupier sectors will require a combination of supportive national policy, as well as engagement, information, and strong incentives and financial support (at local and national level) as set out above.

Low carbon heating

All scenarios require a significant increase in deployment of low carbon heating within the next year.

The key differentiating measure between No Constraints and the other scenarios is the need for widespread **scrappage** of existing heating systems in No Constraints ~5 years earlier than the expected natural lifetime (average age of ~10 years, assuming an average lifetime of 15 years for existing heating systems). Suitable scrappage schemes, supported by financial incentives and mandating policy, must be in place early enough to achieve above-replacement rate installation of low carbon heating systems from 2024.

Additional policy actions are similar across scenarios but differ in relative strength and urgency, with No Constraints requiring the highest strength of policy in the shortest timeframe to achieve the levels of deployment projected. These include:

- **Ban on installation of fossil heating systems** both in new build developments and in replacement of heating systems in existing buildings. For No Constraints and Accelerated Green, mandates to prevent fossil fuel heating systems are needed from the early to mid-2020s whereas High Electrification requires replacement heating systems to be low carbon by 2035.

The Accelerated Green scenario has some buildings connected to a reduced gas grid (fully converted to biomethane) out to 2050 and therefore homes and businesses in these defined areas may be exempt from a ban. The High Hydrogen scenario does not require a ban on boilers but a switch to Hy-ready boilers will be required in areas designated for conversion to hydrogen to minimise the need for early scrappage as the grid converts, and a switch to hybrid heat pumps rather than standalone gas boilers should be encouraged where possible.

- **Zoning of heat** to define areas to prioritise for each heating technology. This should take into account the characteristics of the local building stock, proximity to suitable large heat sources (e.g. waste heat, the river, etc.), local electricity grid constraints that would favour either shared electric heating supply (e.g. district or communal heating) or strategic use of hydrogen. Even in areas where the electricity grid is constrained, zoning will allow the electricity DNOs to plan and prioritise grid upgrades to manage rollout. Government is expected to release guidance for zoning by 2025; however, the urgency of emissions reduction means that No Constraints and Accelerated Green require London to plan ahead of this guidance becoming available.
- **Funding and support** to address financial barriers. This may be through:
  - access for London's residents and businesses to a higher share of national funding opportunities as they arise, or through dedicated funding or support to develop financing approaches from London stakeholders.
  - investigation of alternative business models, such as "Heat As A Service", to address equity issues associated with the high purchase costs of low-carbon heating technologies.
  - Communication and engagement with consumers to ensure their access to time-of-use tariffs to enable ongoing savings from low carbon heat to be realised. This could include requirements such as making consideration of use of time-of-use tariffs to deliver savings a planning condition for new developments, alongside wider communication through appropriate channels (for example, through the Low Carbon Accelerator programmes and other GLA information webpages).
- **Communication of plans** to give confidence to the installer industry to build the skills and supply chain. A key barrier to (re)training of engineers is the lack of market to give confidence to spend time and/or money on building skills in low carbon heating installation. The job creation numbers projected in this study suggest that specialist training will need to be expanded or established within the next 2 years to prevent the workforce being a limiting factor in heat pump deployment.
- **Reviewing planning policies to remove potential barriers** such as permitted development requirements that prevent multiple heat pumps being installed in one development.
- **Securing supply of hydrogen for heat networks**. No Constraints requires strategic deployment of hydrogen in peaking boilers and FC CHP to accelerate decarbonisation of district heating supply; however, achieving this is subject to uncertainties in achieving local production of hydrogen. While many of the uncertainties are outside of GLA's control, supporting local hydrogen production projects in line with London's assessment of its strategic needs for hydrogen will be an important step to help secure necessary funding and regulatory approval.

4.1.2 Actions to decarbonise transport

Behaviour change

All scenarios require a significant decrease in car use that goes beyond national ambitions, as well as enhanced ambition for freight travel reduction measures in No Constraints and Accelerated Green.

For road transport, the broad types of policy required across scenarios are similar but No Constraints requires significantly higher strength and/or accelerated timeframes for implementation. Key actions across all scenarios include:

- **Implementing London-wide road user charging**. The MTS considers this type of policy as a potential lever to achieve car vkm reductions by 2041,[118] in which the levels of vkm reduction are lower and achieved much later than in the No Constraints scenario. The High Hydrogen and High Electrification scenarios therefore are likely to require a form of this type of policy with implementation in the late 2030s. Accelerated Green requires an acceleration of this policy of at least 10 years (e.g. bringing it forward to the mid-to-late 2020s) while No Constraints will need measures to be in place from the early to mid-2020s. Nonetheless, all scenarios would benefit from London-wide road user charging being introduced as early as possible. Road user charging has the potential to be a powerful lever to reduce emissions quickly and effectively, and transport is one of the areas where the Mayor has the strongest powers and the ability to make the quickest, guaranteed progress – as seen with the impact of the congestion charge. As a result, it should be considered as one of the key early building blocks of any package. This is especially relevant given the challenges decarbonising other sectors, especially where support from the government or other partners is needed. Road user charging also delivers wider benefits, including reducing air pollution, promoting active travel, improving road safety and reducing congestion. However, it is likely that a road user charging scheme will need to be introduced gradually to enable consumers to plan and adapt, with an appropriate balance being struck to ensure a fair transition. It would require significant funding to implement. Unless properly designed, road user charges also risk increasing transport poverty by unfairly impacting lower income households who already pay a higher share of their disposable income on travel[119] and will need to wait longer to access running cost benefits of switching to zero emission options in the second-hand market. Any scheme must therefore be designed carefully to ensure that inequity impacts are minimised – for example, by using appropriate exemptions, discounts and other mitigations (e.g. income-based charging bands, having higher rates for newly registered vehicles early on, or scrappage incentives; see also emission zones in the next section).
- **Significant changes to how the city functions to reduce travel need** such as the '15 minute city' concept, in which housing, employment, and services are co-located to reduce the distance travelled between destinations and enabling more of these journeys to be taken by active modes. Significant change across London, in both new and existing developments, will be required in No Constraints by 2030. Given the long lead times involved in planning over large areas, such changes will be challenging to implement. In comparison, Accelerated Green, High Electrification and High Hydrogen require less widespread change, with changes delivered in selected areas (likely primarily new developments), and playing a greater role in delivering travel behaviour change post-2030.
- **Road space reallocation** to public transport (such as bus priority lanes), improved cycling and walking infrastructure, and shared car provision (including car clubs and traditional car sharing, such as shared commutes). The MTS assumes a minimum deployment of these measures to achieve behaviour change by 2041; however, the increased ambition of No Constraints means that a higher level of ambition of road space reallocation than the MTS must be delivered by 2030.
- **Improved public transport offering** including extended bus, tram and rail networks, and improving frequency and capacity of existing services. As above, these measures are assumed in the MTS but must be delivered much earlier in No Constraints and Accelerated Green. While

[118] TfL *Mayor's Transport Strategy: Supporting Evidence Outcomes Summary Report* (2017)
[119] 2019 ONS data on expenditure on motoring for households owning a car

bus changes can be delivered relatively quickly, major infrastructure delivery requires long lead times so fewer tram and rail network improvements are likely to be able to be delivered before 2030. Therefore No Constraints is likely to rely more on other interventions to deliver travel behaviour change.

- **Expanding traffic and parking control measures** such as strategic road closures to improve safety and uptake of active travel, and parking controls to discourage car use. As above, these measures are assumed in the MTS but must be delivered much earlier (by 2030) in No Constraints.
- **Freight consolidation** and shift to sustainable last mile delivery, such as cycle freight, to reduce van and HGV vkm. Consolidation options have already been considered by TfL[120] to identify key cases where consolidation could be cost-effective and deliver emissions savings. No Constraints will likely require deployment across all feasible areas as quickly as possible, whereas the other scenarios likely only require deployment in selected areas.
- **Shift of freight to non-road modes** such as rail or river travel, which both reduces HGV vkm and enables shift of more freight onto last-mile vehicles which are more likely to be suitable to transition to ULEVs. This action is assumed only in the No Constraints scenario where HGV vkm reduction is significantly reduced.

Aviation emissions have a large impact on the level of residual emissions from transport, representing 20% of the difference in emissions between No Constraints and High Electrification. As such, limiting growth of aviation as far as possible is a crucial action for achieving the Mayor's climate ambitions. Key measures include:

- **Ensuring that aviation growth is not a priority** in local growth or recovery plans going forward
- **Working with Boroughs and lobbying Government to limit further expansion of airports** through reviewing its Airport National Planning Statement and to limit aviation travel demand growth
- **Encouraging businesses to commit to reducing air travel** for example as part of corporate net zero commitments.
- **Encouraging tourism by rail** from suitable destinations, such as UK and Europe.

Low emissions vehicle uptake

Across road transport sectors (with the exception of TfL buses), No Constraints is the only scenario which assumes significantly accelerated deployment of low emissions technology beyond that which can be achieved with national-level policy. While Accelerated Green will require key asks of Government in enforcing sales bans and deploying infrastructure, only No Constraints assumes significant action beyond this at London level. Key actions to drive low emissions vehicle uptake include:

- **Emission zones** that accelerate uptake of electric vehicles, building on the Congestion Charge zone or the Ultra Low Emission Zone, alongside rollout of a central London Zero Emission Zone and local Zero Emission Zones. This type of policy is only considered to be required in the No Constraints scenario which has the most ambitious local uptake of zero emission vehicles; however, other scenarios would benefit from emission zones to support uptake in line with national ambition. These will also deliver wider benefits, e.g. for air quality. For cars, applying a price differential between zero emission vehicles and petrol/diesel vehicles equivalent to the current ULEZ charge (£12.50 per day) would be sufficient to create a total cost of ownership (TCO) benefit in favour of battery electric vehicles for users entering the zone more than 200

[120] WYG Transport and PBA for TfL, *'London Freight Consolidation Feasibility Study'* (2019)

times per year in 2021 (reducing to those entering over 80 times per year by 2024).[121] However, the exact form and scale of the charge must be carefully designed to achieve emissions savings; for example, many users do not typically make purchase decisions on a TCO basis (instead prioritising upfront purchase costs),[122] and blanket charges are likely to unfairly penalise second-hand vehicles owners who cannot afford to switch to low emissions options (and are likely to be disproportionately from lower income households). As for London-wide road user charging, any scheme must therefore be designed carefully to ensure that inequity impacts are minimised – for example, by providing appropriate exemptions, discounts and other mitigations (e.g. scrappage). No Constraints requires local sales of petrol and diesel vehicles to be significantly deterred in the mid-2020s and, as such, full measures must be in place by 2025. A ramp up rate will be required to strongly communicate changes to drivers and fleets and to enable them to adapt and, where possible, switch to low emissions vehicles (including car clubs) or to shift to other modes such as walking, cycling or public transport.

- **Scrappage incentives** for older polluting vehicles (greater than 10 years old for cars and vans, greater than 15 years for rigid HGVs) are only required in No Constraints where high fleet turnover is required in combination with high ULEV sales. However, scrappage can play a key supporting role for other schemes, such as road user charging or emission zones, to mitigate impacts, for example on those with low incomes or with disabilities.
- **Measures to encourage ULEV uptake in high mileage vehicles**. High mileage users account for a disproportionate share of vkm travelled and therefore emissions. This includes taxis, private hire vehicles (PHVs), shared cars (including car clubs), company car users, and other regular long-distance drivers. Measures to target these user groups include using licencing requirements for commercial drivers – already in place for taxis and PHVs but not yet in place for car clubs – to encourage electrification, and lobbying Government for changes to company car tax incentives to encourage users to choose EVs. These measures are necessary for No Constraints, but are also assumed to be beneficial in the other scenarios to achieve the projected ULEV share of vkm by balancing vkm reduction (and associated sales) with shift of more high mileage use to the ULEVs in the fleet.
- **Increasing national and local charging/refuelling infrastructure** to encourage uptake. While a mix of on-street, rapid hub, and destination EV charging is required in all scenarios to serve the light duty sector (cars, vans, taxis, PHVs, and car clubs), HGV public refuelling infrastructure is increasingly important at an earlier timeframe in the No Constraints scenario than may otherwise be achieved nationally, since this will enable more ULEV HGVs to carry more freight in and around London (for example, to allow refuelling en-route rather than requiring vehicles to go back to base).
- **Coordinating joint purchasing among fleets** to aggregate demand and stimulate supply chains. This has successfully been demonstrated by the H_2 Energy initiative for hydrogen HGVs in Switzerland and is currently being trialled in the UK Aggregated Hydrogen Freight Consortium.[123]

4.1.3 Actions to support energy infrastructure rollout

The core outcomes include delivery of hydrogen to strategic sites in London and reinforcing the electricity network to enable widespread electrification of heat and transport. Across all scenarios, this

[121] Based on a new car owner buying a large car in 2021. Source: Element Energy analysis for Green Alliance "*Accelerating the electric vehicle revolution*" (2020)
[122] It should be noted that TCO for medium cars is already lower for EVs than petrol and diesel cars, and TCO differentials for large and small cars are expected to decrease out to 2025.
[123] https://www.trl.co.uk/projects/uk-aggregated-hydrogen-freight-project

will require ongoing and early engagement with the electricity and gas DNOs as key delivery partners, as well as the wider supply chain to ensure that technology can be rolled out.

There are actions that GLA can take to support the electricity DNOs to manage grid upgrades such that grid capacity does not become a limiting factor in the rollout of decarbonisation measures, including:

- **Data sharing** will continue to be critical, as early communication as to where and when increases in electricity demand are expected will help to manage upgrade requirements
  - The **DNOs require strong evidence of need for upgrade** in order to justify spending to Ofgem, especially given the current upward pressure and political focus on energy bills. So, this **will require strong policy** to be in place with high confidence in the likely resulting deployment of technology.
  - The heat pump projections in this study are significantly higher than those included in the DNOs' Distributed Future Energy Scenarios and therefore are likely to require higher levels of reinforcement than the DNOs are already planning for. This increased ambition must be communicated to DNOs to ensure that they can plan effectively.
- A zoning approach to electrification (and decarbonisation of heat more generally, as outlined in Section 4.1.1) will enable DNOs to target grid upgrades where they can have the biggest impact.
  - Zoning may involve decisions such as favouring communal heat pumps over individual building-level heat pump deployment, as communal systems have a lower impact on the grid
  - District heating can also act as a means of relieving pressure on the grid where it is highly constrained through thermal storage and demand response generation; however, transitioning from gas CHP to heat pumps for DH supply is additionally challenging since it removes a local source of embedded electricity generation at the same time as increasing demand on the grid. As such, in areas of high constraint, there may be a case for strategic hydrogen deployment and thermal storage in energy centres serving district heat networks and building the case further for strategic local area energy planning.

In addition, both network-level and building-level storage and flexibility measures offer a means of managing demand on the supply chain by flattening the rate of required upgrades.

In order to ready the supply chain more generally, it is important to increase knowledge and awareness of low-carbon technologies. While the impact of electric vehicles on the grid is well-understood, the impact of low-carbon heating technologies is still relatively unknown. This lack of awareness is an issue both within the relevant industries and amongst the wider public. Heat-related innovation projects are taking place across the UK and London already, such as under the Electrification of Heat Demonstration Project funding stream.[124] Disseminating the insights and knowledge gained from such projects will be critical to achieving the upswing in low-carbon heating installations required for decarbonisation of the buildings sector.

4.1.4 Summary of actions

The key target outcomes and supporting policy measures to deliver each of the pathways are summarised in Table 4.2 to Table 4.5, and compared across scenarios in Table 4.6 (note that these are non-exhaustive lists). It should be noted that the modelling in this study focused on the required target outcomes to achieve emissions reduction, and did not aim to model the specific outcomes of specific policies (e.g., the impact of policy levers on uptake of heat pumps was not the basis for the modelling). The degree of detail in the modelling also varied between measures – for example, dates for ending

[124] https://www.gov.uk/government/publications/electrification-of-heat-demonstration-project-successful-bids

sales of polluting vehicles or replacements of fossil heating systems were inherent in the trajectories, but the precise shift from private car use to other modes (and the associated level of necessary infrastructure to support it) was not modelled. These aspects would need to be studied in more detail to inform the precise form of action to support the pathways for London going forward. The example policies given in the following tables are intended to be from the perspective of local action (for example, supporting uptake compared to lobbying for change) but do not aim to identify the precise roles of individual actors.

Table 4.2 Summary of key outcomes and examples of policies and measures to support delivery of the No Constraints pathway

<table>
<tr><th colspan="2"></th><th>Key target outcomes</th><th>Key policies to support delivery</th></tr>
<tr><td colspan="4">Buildings</td></tr>
<tr><td colspan="2">Energy Efficiency</td><td>• Average domestic space heating demand brought to 65 kWh/m²
• Average total heat demand savings of 37% across domestic buildings and 39% across non-domestic buildings by 2030 compared with 2020</td><td>• Rollout of supportive measures for all tenure types, including action plans, delivery models, financing and funding, supportive planning policy (including enforcement of energy efficiency standards) and lobbying
• Support of supply chain through training and early communication of requirements</td></tr>
<tr><td rowspan="3">Low-Carbon Heating</td><td>General</td><td>• 90% of domestic heating systems are low carbon by 2030</td><td rowspan="3">• Scrappage incentives for existing fossil fuel heating systems from 2024 for boilers more than ten years old
• Funding, financing and support to address financial barriers ramped up to peak levels by 2024
• Zoning of heat to define areas to prioritise for each heating technology
• Communication of plans to give confidence to the installer industry to build the skills and supply chain as soon as possible
• Review planning policies to remove potential barriers
• Lobby for rebalancing of gas and electricity energy taxation to incentivise low carbon heating</td></tr>
<tr><td>Heat pumps</td><td>• 3.3 m heat pumps installed by 2030
• 410 k heat pumps installed annually at the peak deployment</td></tr>
<tr><td>District heating</td><td>• 610 k domestic district heating connections installed by 2030</td></tr>
<tr><td colspan="2">Phase out of fossil fuel heating systems</td><td>• Fossil fuel heating systems banned from new developments from 2023
• Fossil fuel heating system replacements banned from 2024</td><td>• Planning requirement for new developments to have low-carbon heating systems from 2023
• Mandate preventing fossil fuel heating system replacements</td></tr>
<tr><td colspan="2">Solar PV on rooftops</td><td>• 1.5 GW by 2030; 3.9 GW by 2050</td><td>• Increased ambition in action to support rooftop solar, such as through increasing ambition for GLA and other public sector stock, additional financial support, strengthening planning support, and support for community energy projects</td></tr>
<tr><td colspan="2">Hydrogen</td><td>• 0.8 TWh of hydrogen used in district heating by 2030</td><td>• Secure supply of hydrogen for use in peaking boilers and FC CHP by working with local production projects
• Zoning of heat to identify strategic sites and communication with DNOs</td></tr>
<tr><td colspan="4">Transport</td></tr>
<tr><td colspan="2">Modal Shift</td><td>By 2030
• 40% reduction in car vkm relative to 2018
• 1% growth in van vkm relative to 2020
• 0% growth in HGV vkm relative to 2018</td><td>• Introduce London-wide road user charging from the early to mid 2020s
• Traffic and parking control measures, such as modal filters and changes to parking supply and pricing, likely going beyond MTS aims
• Widespread co-location of services, housing and employment across new and existing developments to reduce travel need by 2030</td></tr>
</table>

	• **No recovery in air travel demand** by 2030 following COVID-19 levels (remain at 40% of 2018 levels) • Aviation growth beyond 2030 limited to 85% of 2018 levels by 2050	• Measures beyond those outlines in the MTS for road space reallocation to public, shared and active travel infrastructure • Significant improvement in public transport offering by 2030, with a focus on a comprehensive bus network to compensate for slow rollout of rail and other public transport offering • Support consolidation of freight and use of sustainable solutions for last mile deliveries, such as through funding, financing and working with freight operators • Shift of freight to non-road modes as far and fast as possible e.g. through mode shift grants and investment in non-road freight infrastructure. • Review inclusion and support for aviation in recovery and growth with the aim of not increasing passenger numbers beyond 2020 (COVID) levels • Lobbying for limits to further expansion of airports, e.g. through a review of the Airports National Policy Statement • Encourage businesses to commit to reduce air travel

Zero emission road transport	• Share of vkm by ZEVs by 2030
	  ○ Cars: 67%
	  ○ Vans: 55%
	  ○ All HGVs: 48%
	• End to ICE sales
	  ○ Cars: 2025
	  ○ Vans: 2027
	  ○ Rigid HGVs: 2025
	• Zero emission TfL bus fleet by 2030
		• Emission zones ramped up from early to mid 2020s
		• Scrappage incentives for older polluting vehicles continued and strengthened and widened in scope
		• Maximum levers on measures to encourage uptake in high mileage vehicles, such as enhanced licencing requirements for taxis, PHVs and car clubs, and encouraging company car EV adoption
		• Accelerate deployment of public EV charging network (36,000 EVCPs by 2030)
		• Lobby for accelerated national public HGV charging/refuelling infrastructure
		• Lobby for enforcement of petrol and diesel vehicle sales bans
		• Lobby for accelerated increased taxes for polluting vehicles, alongside measures to mitigate equity impacts
		• Coordinate aggregated demand (joint purchasing) across commercial fleets
		• Funding for uptake of zero emission buses by 2030

Other fuels	• 5% blending of synthetic aviation fuel (SAF) by 2030	• Lobby for high uptake targets for SAF (at least 5% blending by 2030 and 50% by 2050)
Infrastructure		
Electricity Grid	• Infrastructure upgrades to support and mitigate an **8% increase in peak demand** (50 primary substations needing upgrading without DSR)	• Engage early and regularly with DNOs and key stakeholders to share data and plans
Hydrogen	• 1.5 TWh of hydrogen delivered to London by 2030	• Secure supply for strategic use of hydrogen

Table 4.3 Summary of key outcomes and examples of policies and measures to support delivery of the Accelerated Green pathway

		Key target outcomes	Key policies to support delivery
Buildings			
Energy Efficiency		• Average domestic space heating demand brought to 65 kWh/m^2 • Average total heat demand savings of 37% across domestic buildings (space heating and hot water) and 39% across non-domestic buildings by 2030 compared with 2020	• Rollout of supportive measures for all tenure types, including action plans, delivery models, financing and funding, supportive planning policy (including enforcement of energy efficiency standards) and lobbying • Support of supply chain through training and early communication of requirements
Low-Carbon Heating	**General**	• 60% of domestic heating systems are low carbon by 2030	• Funding, financing and support to address financial barriers ramped up to peak levels by 2026 • Zoning of heat to define areas to prioritise for each heating technology • Communication of plans to give confidence to the installer industry to build the skills and supply chain • Review planning policies to remove potential barriers • Lobby for rebalancing of gas and electricity energy taxation to incentivise low carbon heating
	Heat pumps	• **2.2 m heat pumps** installed by 2030 • **280 k heat pumps installed annually** at the peak deployment	
	District heating	• **460 k domestic district heating connections** installed by 2030	
Phase out of fossil fuel heating systems		• Fossil fuel heating systems **banned from new developments** from **2025** • Fossil fuel heating system **replacements banned from 2026**, with exceptions in areas expected to remain connected to grid (using biomethane)	• Planning requirements for new developments to have low-carbon heating systems from 2025 • Mandate preventing fossil fuel heating system replacements, with exceptions in appropriate locations
Solar PV on rooftops		• 1.5 GW by 2030; 3.9 GW by 2050	• Increased ambition in action to support rooftop solar, such as through increasing ambition for GLA and other public sector stock, additional financial support, strengthening planning support, and support for community energy projects
Hydrogen		• 0.2 TWh of hydrogen used in district heating by 2030	• Secure supply of hydrogen for use in peaking boilers and FC CHP by working with local production projects • Zoning of heat to identify strategic sites and communication with DNOs
Transport			
Modal Shift		By 2030 • **27%** reduction in **car** vkm relative to 2018 • **1%** growth in **van** vkm relative to 2020	• Introduce London-wide road user charging by the mid-**late 2020s** • Traffic and parking control measures, such as changes to parking supply and pricing, in line with MTS but accelerated by 10 years – meeting the majority of MTS aims by 2030

	• **0%** growth in **HGV** vkm relative to 2018 • **Limited recovery of air travel demand** by 2030 following COVID-19 levels (reaching **50%** of 2018 levels) • Aviation growth beyond 2030 limited to 85% of 2018 levels by 2050	• Co-location of services, housing and employment in selected areas to reduce travel need by 2030 • Measures meeting MTS aims for road space reallocation to public, shared and active travel infrastructure, accelerated by 10 years • Significant improvement in public transport offering by 2030, with likely focus on acceleration of bus network improvements to compensate for slower rollout of rail and other public transport modes • Support consolidation of freight and make use of sustainable solutions for last mile deliveries in selected areas, such as through funding, financing and working with freight operators • Review inclusion and support for aviation in recovery and growth with the aim of minimising growth beyond 2020 (COVID) levels • Lobby for limits to further expansion of airports, e.g. through a review of the Airports National Policy Statement • Encourage business to agree a high level of commitment to reduce air travel

Zero emission road transport	• Share of vkm by ZEVs by 2030
	  ○ Cars: 46%
	  ○ Vans: 34%
	  ○ All HGVs: 14%
	• End to ICE sales
	  ○ Cars: 2030
	  ○ Vans: 2030
	  ○ Rigid HGVs: 2035
	• Zero emission TfL bus fleet by 2030
		• Emission zones ramped up post-2030
		• Measures to encourage uptake in high mileage vehicles such as enhanced licencing requirements for taxis, PHVs and car clubs, and encouraging company car EV adoption
		• Accelerate deployment of public EV charging network (34,000 EVCPs by 2030)
		• Lobby for national public HGV charging/refuelling infrastructure by 2040
		• Lobby for enforcement of ban on petrol and diesel ICE vehicle sales
		• Coordinate aggregated demand (joint purchasing) across fleets
		• Funding for zero emission bus uptake by 2030

Other fuels	• 5% blending of synthetic aviation fuel (SAF) by 2030	• Lobby for high uptake targets for SAF (at least 5% blending by 2030 and 50% by 2050)
Infrastructure		
Electricity Grid	• Infrastructure upgrades to mitigate localised increases in peak demand (23 primary substations needing upgrading without DSR by 2030)	• Engage early and regularly with DNOs and key stakeholders to share data and plans
Hydrogen	• 1.0 TWh of hydrogen delivered to London by 2030	• Secure supply for strategic use of hydrogen

Table 4.4 Summary of key outcomes and examples of policies and measures to support delivery of the High Hydrogen pathway

		Key target outcomes	Key policies to support delivery
Buildings			
Energy Efficiency		• Average domestic space heating demand brought to 65 kWh/m^2 • Average total heat demand savings of 37% across domestic buildings (space heating and hot water) and 39% across non-domestic buildings by 2030 compared with 2020	• Rollout of supportive measures for all tenure types, including action plans, delivery models, financing and funding, supportive planning policy (including enforcement of energy efficiency standards) and lobbying • Support of supply chain through training and early communication of requirements
Low-Carbon Heating	**General**	• 30% of domestic heating systems are low carbon by 2030 • Heat zones established after 2025	• Funding, financing and support to address financial barriers ramped up to peak levels by 2031 • Zoning of heat to define areas to prioritise for each heating technology • Communication of plans to give confidence to the installer industry to build the skills and supply chain • Review planning policies to remove potential barriers • Lobby for rebalancing of gas and electricity energy taxation to incentivise low carbon heating
	Heat pumps	• **0.9 m heat pumps** installed by 2030 (including hybrids; 0.8 m standalone heat pumps) • **150 k heat pumps installed annually** at the peak deployment (inc. hybrids)	
	District heating	• **380 k domestic district heating connections** installed by 2030	
Phase out of fossil fuel heating systems		• Fossil fuel heating systems **banned from new developments** from **2025** • Ban on fossil gas-only replacement heating system replacements by 2025-2030	• Planning requirement for new developments to have low-carbon heating systems from 2025 • Mandate for Hy-Ready boilers in areas suitable for hydrogen conversion (phased with expected rollout plan)
Solar PV on rooftops		• 0.8 GW by 2030; 2 GW by 2050	• Action in line with current ambition, including leading by example, financial support, and support for community energy projects
Hydrogen		• 0.3 TWh of hydrogen used in district heating by 2030	• Secure supply of hydrogen for use in selected areas by working with local production projects
Transport			
Modal Shift		• **12%** reduction in **car** vkm relative to 2018 • **2%** growth in **van** vkm relative to 2020 • **3%** growth in **HGV** vkm relative to 2018	• Ramp up London-wide road user charging from the **late 2030s** • Traffic and parking control measures, such as modal filters and changes to parking supply and pricing, in line with MTS • Co-location of services, housing and employment to reduce travel need in selected areas

	• **Recovery in air travel demand** following COVID-19, reaching 2018 levels by 2030 • Aviation growth beyond 2030 limited to 25% above 2018 levels by 2050	• Measures in line with the MTS for road space reallocation to public, shared and active travel infrastructure • Improvement in public transport offering in line with the MTS, including improvements to bus, rail and tram services and network • Support consolidation of freight and make use of sustainable solutions for last mile deliveries where most suitable, such as through targeted funding or financing • Review inclusion and support for aviation in recovery and growth with the aim of limiting post-COVID recovery to 2018 levels • Lobby for limits to further expansion of airports, e.g. through a review of the Airports National Policy Statement • Encourage businesses to limit air travel as much as possible

Zero emission road transport	• Share of vkm by ZEVs by 2030:
	  ○ Cars: 45%
	  ○ Vans: 33%
	  ○ All HGVs: 6%
	• End to ICE sales
	  ○ Cars: not enforced
	  ○ Vans: not enforced
	  ○ Rigid HGVs: 2035
	• Zero emission TfL bus fleet by 2030
		• Accelerate deployment of public EV charging network (40,000 EVCPs by 2030)
		• Lobby for national public HGV charging/refuelling infrastructure by 2045
		• Lobby for enforcement of ban on petrol and diesel ICE vehicle sales
		• Increased taxes for polluting vehicles potentially required
		• Consider coordinating aggregated demand (joint purchasing) across commercial fleets
		• Funding for zero emission bus uptake by 2030

Other fuels	• 5% blending of synthetic aviation fuel (SAF) by 2030	• Lobby Government for high uptake targets for SAF (at least 5% blending by 2030 and 50% by 2050)
Infrastructure		
Electricity Grid	• Low number of infrastructure upgrades (3 primary substations needing upgrading without DSR)	• Engage early and regularly with DNOs and key stakeholders to share data and plans
Hydrogen	• 1.9 TWh of hydrogen delivered to London by 2030	• Secure supply for strategic use of hydrogen

Table 4.5 Summary of key outcomes and examples of policies and measures to support delivery of the High Electrification pathway

		Key target outcomes	Key policies to support delivery
Buildings			
Energy Efficiency		• Average domestic space heating demand brought to 65 kWh/m^2 • Average total heat demand savings of 37% across domestic buildings (space heating and hot water) and 39% across non-domestic buildings by 2030 compared with 2020	• Rollout of supportive measures for all tenure types, including action plans, delivery models, financing and funding, supportive planning policy (including enforcement of energy efficiency standards) and lobbying • Support of supply chain through training and early communication of requirements
Low-Carbon Heating	**General**	• 50% of domestic heating systems are low carbon by 2030	• Funding, financing and support to address financial barriers ramped up to peak levels by 2028 • Zoning of heat to define areas to prioritise for each heating technology • Communication of plans to give confidence to the installer industry to build the skills and supply chain • Review planning policies to remove potential barriers • Lobby for rebalancing of gas and electricity energy taxation to incentivise low carbon heating
	Heat pumps	• **1.8 m heat pumps** installed by 2030 • **250 k heat pumps installed annually** at the peak deployment	
	District heating	• **380 k domestic district heating connections** installed by 2030	
Phase out of fossil fuel heating systems		• Fossil fuel heating systems **banned from new developments** from **2025** • Fossil fuel heating system **replacements banned from 2035**	• Planning requirement for new developments to have low-carbon heating systems from 2025 • Mandate preventing fossil fuel heating system replacements from 2035
Solar PV on rooftops		• 0.8 GW by 2030; 2 GW by 2050	• Action in line with current ambition, including leading by example, financial support, and support for community energy projects
Hydrogen		• No use of hydrogen in heat networks	• No specific action required
Transport			
Modal Shift		By 2030 • **12%** reduction in **car** vkm relative to 2018 • **2%** growth in **van** vkm relative to 2020 • **3%** growth in **HGV** vkm relative to 2018 • **Recovery in air travel demand** following COVID-19, reaching 2018 levels by 2030	• Ramp up London-wide road user charging from the **late 2030s** • Traffic and parking control measures, such as modal filters and changes to parking supply and pricing, in line with MTS • Co-location of services, housing and employment to reduce travel need in selected areas Measures in line with the MTS for road space reallocation to public, shared and active travel infrastructure • Improvement in public transport offering in line with the MTS, including improvements to bus, rail and tram services and network.

	• Aviation growth beyond 2030 limited to 25% above 2018 levels by 2050	• Support consolidation of freight and make use of sustainable solutions for last mile deliveries where most suitable, such as through targeted funding or financing • Review inclusion and support for aviation in recovery and growth with the aim of limiting post-COVID recovery to 2018 levels • Lobby for limits to further expansion of airports, e.g. through a review of the Airports National Policy Statement • Encourage businesses to limit air travel as much as possible

Zero emission road transport	• Share of vkm by ZEVs by 2030
	  ○ Cars: 45%
	  ○ Vans: 33%
	  ○ All HGVs: 6%
	• End to ICE sales
	  ○ Cars: not enforced
	  ○ Vans: not enforced
	  ○ Rigid HGVs: 2035
	• Zero emission TfL bus fleet by 2030
		• Accelerate deployment of public EV charging network (40,000 EVCPs by 2030)
		• Lobby for national public HGV charging/refuelling infrastructure by 2045
		• Lobby for enforcement of ban on petrol and diesel ICE vehicle sales
		• Increased taxes for polluting vehicles potentially required
		• Consider coordinating aggregated demand (joint purchasing) across fleets potentially required
		• Funding for zero emission bus uptake by 2030

Other fuels	• 5% blending of synthetic aviation fuel (SAF) by 2030	• Lobby Government for high uptake targets for SAF
Infrastructure		
Electricity Grid	• Infrastructure upgrades to mitigate localised increases in peak demand (3 primary substations needing upgrading without DSR by 2030)	• Engage early and regularly with DNOs and key stakeholders to share data and plans
Hydrogen	• 0.8 TWh hydrogen delivered to London by 2030	• Work with gas DNOs and producers to secure supply for strategic use of hydrogen, primarily through grid blending

Table 4.6 Summary of key outcomes and example policies to support delivery of the scenarios modelled in this study, compared to the Patchwork scenario developed in the *1.5°C Plan*

Scenario (residual emissions in 2030):	No Constraints (14%)	Accelerated Green (22%)	High Electrification (27%)	High Hydrogen (30%)	2050 patchwork (40%)
Retrofit	37% reduction in total heat demand of domestic buildings and 39% reduction in total heat demand of non-domestic buildings by 2030. Heat demand of non-domestic buildings halved by 2034. 210,000 homes retrofitted each year between now and 2030 (approximately 420,000 at peak). 26,500 commercial and public buildings retrofitted each year between now and 2030 (approximately 45,000 at peak). Key policies: Retrofit programmes. Financial incentives (grants, low interest loans), fiscal incentives (stamp duty, council tax rates, business rates that favour high energy efficiency), supportive planning policy to enforce retrofit at key trigger points (consequential improvement), development of retrofit skills. Acceleration of standards. Greater government funding.				Peak of 160,000 homes retrofitted in mid 2020s
Mandate for no replacement boilers	Yes – 2024 3.3m heat pumps by 2030	Yes – 2026 (with exception for specific zones) 2.2m heat pumps by 2030	Yes – 2035 1.8m heat pumps by 2030	No – but H_2 ready boiler mandate by 2025-2030 0.9m heat pumps by 2030 (including hybrids)	No 0.9m heat pumps by 2030
Scrappage for boilers	Boilers more than ten years old from 2024	Not needed		Not widely needed (some early H_2 areas only)	Not needed
Scrappage for cars	Yes, for cars more than 10 years old from 2022	Not needed			Not needed
Scrappage for HGVs	Widespread scrappage of rigid diesels more	Not needed			Not needed

Scenario (residual emissions in 2030):	No Constraints (14%)	Accelerated Green (22%)	High Electrification (27%)	High Hydrogen (30%)	2050 patchwork (40%)
	than 15 years old from 2022				
Policies to support modal shift - including road space reallocation, improved transport offering, traffic and parking policies	40% reduction in car vkm Go beyond the MTS by 2030	27% reduction in car vkm Bring forward MTS outcomes by 10 years	12% reduction in car vkm In line with MTS		12% reduction in car vkm In line with MTS
Road user charging	Yes – from early/mid 2020s	Yes – from late 2020s/early 2030s	Yes – post-2030		Yes – post-2030
End of sales of ICE cars and vans	2025	2030 with enforcement			2030s
Solar PV on roofs	3.9GW by 2050 Policies above current ambition, including funding and financing, increased ambition for public buildings, supporting community energy projects		2GW by 2050 Policies in line with current ambition, including funding and financing, leading by example by deployment on public buildings, supporting community energy projects		2GW by 2050
Support heat networks	610,000 connections by 2030	460,000 connections by 2030	380,000 connections by 2030		340,000 connections by 2030
	Policies: Implement Heat Network Zoning across London, designate zones and tailor policy and funding to support delivery, e.g. existing and new domestic and non-domestic buildings mandated to connect where HN operator is willing and able to connect and offer market competitive cost of heat. Design, develop, build and/or expand district energy networks in designated 'Heat Network Zones'.				380,000 by 2030

4.1.5 Addressing residual emissions

Despite ambitious action, there are residual emissions in all scenarios in 2030. To achieve carbon neutrality, these emissions must be balanced either by negative emissions measures or by offsetting. Offsetting refers to any activity which results in the lowering of external carbon emissions (i.e. those emissions outside of London's scope, as defined in section 1.3).

A truly 'additional' offset – that is, one which would not have occurred otherwise – has the same physical impact on climate change as the equivalent direct emissions reduction, since the state of the atmosphere is the same whether carbon dioxide is emitted in one location or another. However, **offsetting in this way is only available as an option in the near and medium term**, as ultimately carbon neutrality will need to be achieved globally, meaning that emissions will need to be reduced to very low levels across all jurisdictions, with negative emissions measures required to balance any remaining emissions. As such, London will need to seek to reach net zero without offsetting as soon as possible after 2030.

Various kinds of negative emissions approaches and offsets are possible but likely options include:

- **Renewable electricity to address remaining grid emissions:** Electricity use accounts for 36% of residual emissions in the No Constraints scenario (2.3 $MtCO_2e$). With deployment of all measures assumed in the high-level power modelling (EfW with CCUS and 1 TWh local renewable generation), emissions could be reduced by 0.3 $MtCO_2e$ (Figure 4.1). Fully balancing grid emissions within London would require a total of ~270 km^2 ground-mounted solar PV (close to 20% of the total GLA area). More realistically, investment outside the GLA could be explored through Power Purchase Agreements, as is in place for the City of London and is being put in place for TfL.[125,126] This option has the advantage that emissions savings are immediate and measurable, but is limited in the long-term by the need to decarbonise the grid as a whole and care must be taken to avoid double-counting emissions savings across jurisdictions. In addition, even with a fully renewable electricity supply, between 3.7 and 11.3 $MtCO_2e$ emissions will still need to be addressed through other means, depending on the emissions reduction trajectory (Figure 4.1).
- **Land use change for carbon sequestration within Greater London, the UK or elsewhere**, for example through afforestation (such as the Cities4Forests programme) or peatland restoration. Currently, only woodland and peatland offsetting projects have certification mechanisms in the UK (the Woodland Carbon Code[127] and the Peatland Code[128]); however, recent reviews of offsetting options detail the potential for a much wider range of solutions, [129,130] and a range of service providers offer offsetting options outside the UK.[131] Carbon credits associated with woodland and peatland projects have the disadvantage that they will not directly deliver carbon savings in the year that they are purchased since natural solutions take time (on the order of decades) to reach full sequestration potential. However, they offer long-

125 https://www.solarpowerportal.co.uk/news/city_of_london_corporation_signs_first_of_its_kind_40m_ppa_for_dorset_solar
126 https://airqualitynews.com/2021/04/01/mayor-of-london-announces-plans-to-power-tfl-on-renewables/
127 https://www.woodlandcarboncode.org.uk/
128 https://www.iucn-uk-peatlandprogramme.org/funding-finance/introduction-peatland-code
129 Environment Agency, *'Achieving Net Zero: A review of the evidence behind potential carbon offsetting approaches'* (2021)
130 Element Energy and UK CEH for BEIS *Greenhouse Gas Removal Methods and their potential UK deployment* (2021)
131 For example, https://ecologi.com/, https://www.carbonfootprint.com/, and https://www.myclimate.org/carbon-offset/ among others

term emissions savings as well as potential co-benefits of contributing to other aims, such as biodiversity and climate risk mitigation.

- **Direct purchase and subsequent retirement of emissions allowances** within trading schemes (e.g. EU ETS)
- **Emerging technologies** such as Direct Air Capture with Carbon Capture and Storage (DACCS), Bioenergy with Carbon Capture and Storage (BECCS) at industrial and power sites, enhanced weathering, and Biochar. These options are at a relatively low technology readiness level compared to established natural solutions, with higher uncertainties over costs, resource needs and timelines for deployment.[133] As such, further evidence will need to be gathered in the short-to-medium term to establish their suitability for greenhouse gas removal as part of an offsetting strategy.

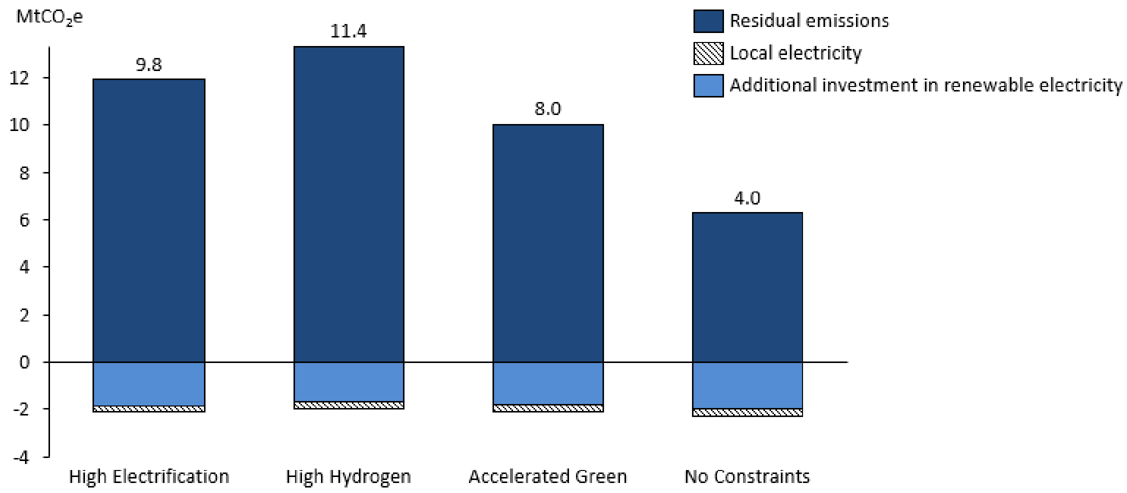

Figure 4.1 Illustrative impact of sourcing fully renewable electricity on net emissions across scenarios in 2030

The costs associated with emissions savings are not uniform across different emissions sources and so offsetting can often be significantly cheaper than the same magnitude of direct carbon saving within London. This is especially true if international offsets are used. For example, offsetting options are available for as little as £3-5/tCO_2; however, caution must be exercised in considering these types of options and real, credible, and truly "additional" savings are only likely to be realised with significantly higher investment. The costs for offsetting via UK afforestation and peatland restoration projects can range from £20-30/tCO_2[132,133] but there is limited potential for their use within the UK, estimated to be in the range of 3-5 MtCO_2e per year achievable across the whole of the UK in 2030;[133] this means that offsetting London's emissions in this way would require all of the UK's potential under the No Constraints scenario, and require further investment either outside the UK or in a wider range of technologies for all other scenarios. Finally, the EU ETS has historically traded at prices below €10/tCO_2 but has recently reached over €50/tCO_2,[134,135] whereas emerging technologies have been estimated to cost in the range of £50-900/tCO_2.[133] As sectors of the global economy decarbonise, the supply of opportunities for offsetting will diminish, and offsetting is likely to become more expensive.

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[132] For example: https://www.forestcarbon.co.uk/clubs/carbon-club
[133] Element Energy and UK CEH for BEIS *Greenhouse Gas Removal Methods and their potential UK deployment* (2021)
[134] CNBC news article (accessed 26th October 2021)
[135] https://tradingeconomics.com/commodity/carbon

Considering the range of offsetting options and costs, the annual cost of achieving net zero in 2030 could range from £317m up to a maximum of £5.6bn (assuming a weighted average of UK opportunities in the central case, up to an upper limit defined by the high carbon price used in Section 3.2).

Table 4.7 High-level estimated costs of off-setting across scenarios. Central = weighted average of UK potential for Greenhouse Gas Removal projects (average £80/tCO_2), High = cost using High carbon price used in Section 3.2 (£420/tCO_2).

	High Electrification	High Hydrogen	Accelerated Green	No Constraints
Residual emissions in 2030 (MtCO_2e)				
Absolute	11.9	13.3	10.0	6.3
With zero emission electricity	9.8	11.4	8.0	4.0
Annual cost of offsetting - based on absolute emissions (£m)				
Central	£943	£1,054	£792	£499
High	£5,003	£5,591	£4,204	£2,649
Annual cost of offsetting - with zero emission electricity supply (£m)[136]				
Central	£776	£903	£634	£317
High	£4,120	£4,793	£3,363	£1,682

Articulating the preferred options for offsetting and key mechanisms for delivery can include developing a framework for assessing different offsetting options against a range of metrics including: alignment with Mayoral priorities (such as biodiversity, climate change adaptation), cost, technical maturity, and evidence of savings achieved. A guidance framework is currently being developed in collaboration between Anthesis and 12 local authorities (including two London Boroughs, Richmond and Wandsworth) and may provide insights for developing London's own strategy.[137]

In the coming years, London will need to consider how offsetting is paid for and who is responsible. As a target set by GLA, GLA retains ultimate responsibility for guiding the focus and scale of investments in projects outside the region; however, TfL, Boroughs, developers, and large emitters all have a responsibility to decarbonise their own activities, and mechanisms such as taxation and offsetting contribution funds (similar to GLA's existing carbon offset fund)[138] could be considered as means to fund offsetting activities. These stakeholders must be engaged during development of London's offsetting strategy to ensure consensus in the approach taken.

Additionally, a number of organisations are setting corporate net zero strategies, which can include a degree of offsetting. It will therefore also be important to engage with local businesses to understand their potential contribution to London's targets and how efforts can be aligned (either through setting minimum agreed standards for offsetting or a London-wide scheme) to ensure appropriate investment and to avoid double-counting.

[136] Does not include the costs of decarbonizing local electricity supply or offsetting grid emissions through PPAs; PPAs are expected to be competitive with grid electricity on a p/kWh basis therefore may be considered cost-neutral or may also generate revenue.
[137] https://www.anthesisgroup.com/insetting-solution-for-uk-local-authorities/
[138] https://www.london.gov.uk/sites/default/files/carbon_offsett_funds_guidance_2018.pdf; however it should be noted that carbon offset funds should not be used in place of achieving the emissions savings required by each scenario (since this would result in higher emissions requiring offsetting overall).

4.2 Next steps

Low regrets actions

The analysis underpinning the *1.5°C Plan* outlined a series of low regrets actions that could be pursued to ensure delivery of a minimum level of technology deployment and mitigation in the short-term to ensure emissions savings and to build skills while a decision on the long-term decarbonisation pathway is made (summarised in Table 4.8).

The 2030 net zero target represents a significantly accelerated target and therefore the level of ambition required against these low-regrets actions must be increased (No Constraints scenario included in Table 4.8 for comparison as the most ambitious option). The urgency of a net zero 2030 target means that substantial action must be taken now and that “low regrets” actions do not apply in the same context as for a 2050 target – waiting to make a decision before aiming for the highest level of ambition risks either under-delivery by 2030 or more challenging action and investment in the mid-to-late 2020s to compensate for earlier under-delivery. As such, action that goes beyond the low regrets actions required for a 2050 pathway in the next 5 years will be necessary, and high ambition in this period is essential to ensure the highest chance of success.

Table 4.8 Summary of selected low regrets actions recommended for a 2050 target and the associated increased level of ambition required to meet a 2030 net zero target.

Action	Minimum ambition for 2050 target	Ambition in No Constraints net zero 2030 scenario
Energy efficiency in buildings	Bring **70% of London’s buildings to EPC C or above**	Bring **all homes to an average space heating demand of 65 kWh/m^2** (compliant with achieving EPC B after low carbon heating installed)
Rollout of heat networks	An additional **70,000 homes by 2025**	An additional **78,000 homes by 2025**
Deployment of heat pumps	More than **300,000 buildings by 2025**	More than **1m buildings by 2025**

In addition to the above, further low regrets actions needed to deliver the 2030 target include:

- **Ongoing engagement and data sharing with DNOs and wider stakeholders** to communicate plans and ensure the infrastructure is in place to facilitate the net zero transition
- **Actions to address aviation emissions** including lobbying for limits on expansion of airports and for high targets for synthetic aviation fuel uptake
- **Measures to encourage travel behaviour change** including road space reallocation and accelerated improvements to public transport offering[139]
- **Zoning of heat** to enable prioritisation of heat solutions and to coordinate with DNOs to support necessary infrastructure upgrades

Next steps

This analysis will be used by the Mayor to select a preferred pathway for meeting net zero emissions by 2030. The GLA will then use this analysis to engage key stakeholders across London, the UK and

[139] Note that these actions are necessary for delivery of both a 2050 and 2030 pathway under the Mayor’s Transport Strategy objectives, but were not explicitly highlighted in the work underpinning the *1.5°C Plan*

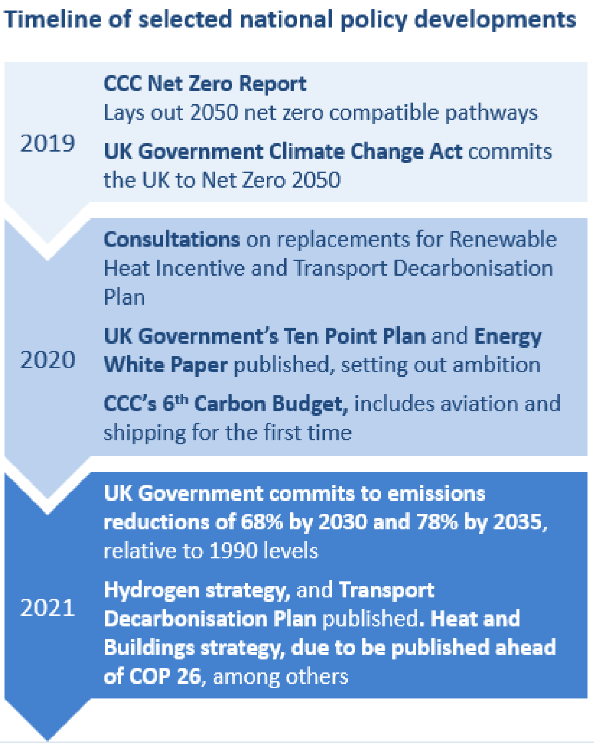
national government on how they can together achieve net zero emissions by 2030, and to build public consensus around the urgent changes needed to tackle climate change and achieve a green economy.

5 Appendix

5.1 Policy Review

Since the *1.5°C Plan,* the UK Government has committed to reaching net zero by 2050, with support including:

- £9.2bn investment in energy efficiency of buildings
- £450m Boiler Upgrade Scheme, with grants of up to £5,000 per home for low carbon heating
- Ambition to end the sale of new petrol and diesel cars by 2030, and plug-in hybrids by 2035
- £1.3bn to aid electric vehicle charge point deployment and £4.2bn investment in city public transport
- Ambition for 5 GW low-carbon hydrogen production capacity by 2030, and 2.8 TWh biomethane supported by the Green Gas Support Scheme



5.2 Comparison with Previous Modelling

Scenarios in the *1.5°C Plan*

Five scenarios were developed to each represent a different pathway to meeting London's decarbonisation goals. The scenarios relied on various technologies and required different supporting policy, but were intended to represent a similar overall level of policy ambition:

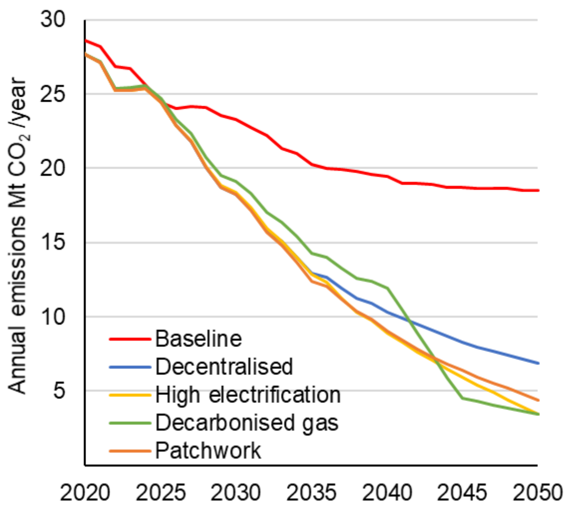
- **Baseline (with high energy efficiency uptake) scenario** represents the likely outcome with minimal change to current policies on low-carbon technologies, with the exception of energy efficiency, for which the same high level of uptake is applied as for all scenarios. There will be a relatively low uptake of most low carbon technologies beyond 2025.
- **Decentralised scenario** promotes decentralised energy production and distribution. This results in high uptake of heat networks and solar PV, as well as some additional decarbonisation through blending of biomethane and bio-synthetic natural gas into the gas grid.
- **High electrification scenario** promotes electrification of heat and transport using an increasingly decarbonised electricity grid. There will be high uptake of heat pumps and electric vehicles and a

requirement for significant application of DSR and energy storage. It is assumed that the gas grid is no longer economically viable in 2050. *Similar to High Electrification scenario in current study.*

- **Decarbonised gas scenario** promotes the conversion of London's gas grid to 100% hydrogen by 2045. Heating remains predominantly gas (hydrogen) boilers, with some heat networks. Transport includes a large share of hydrogen fuel cell electric vehicles. *Similar to High Hydrogen scenario in current study.*
- **Patchwork scenario** aims to represent a pragmatic, mixed pathway, encompassing aspects of all the above scenarios to meet carbon targets. *Similar to Accelerated Green scenario in current study.*

Emission Results

Figure 5.1 shows the emission results for each scenario from the 2018 study. The analogous scenarios to those in the current study all reach ~10% emissions by 2050, similar to the current study, but the rate of decarbonisation is much slower, still with 40% emissions in 2030 in the lowest scenario.



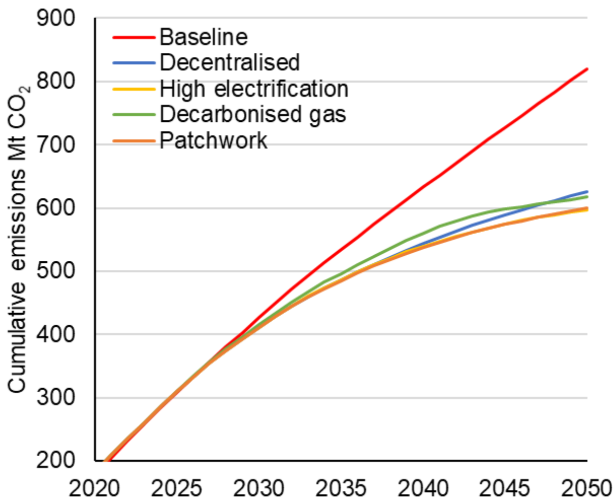


Figure 5.1: Annual (left) and cumulative (right) emissions trajectories of the scenarios to 2050.

Costs

Cumulative costs from the previous study are largely similar to those from the current study. The main difference is the split of costs in terms of building-level costs and fuel costs: the increased ambition with respect to energy efficiency means pushes up the building-level costs but reduces fuel costs for many decades.

Table 5.1 Summary of scenario emissions and discounted cumulative scenario investment results to 2050

Results summary		Baseline	Decentralised	High Electrification	Decarbonised Gas	Patchwork
Total cumulative cost £ bn	**Central**	**£278**	**£279**	**£292**	**£274**	**£287**
Central cumulative cost £bn	Building level	£39	£49	£57	£42	£56
	Infrastructure	£1.8	£6.5	£4.4	£5.8	£5.1
	Fuel	£238	£224	£231	£227	£226

5.3 Supporting information for sectoral decarbonisation

5.3.1 Low carbon gases

Biomethane and Bio-SNG

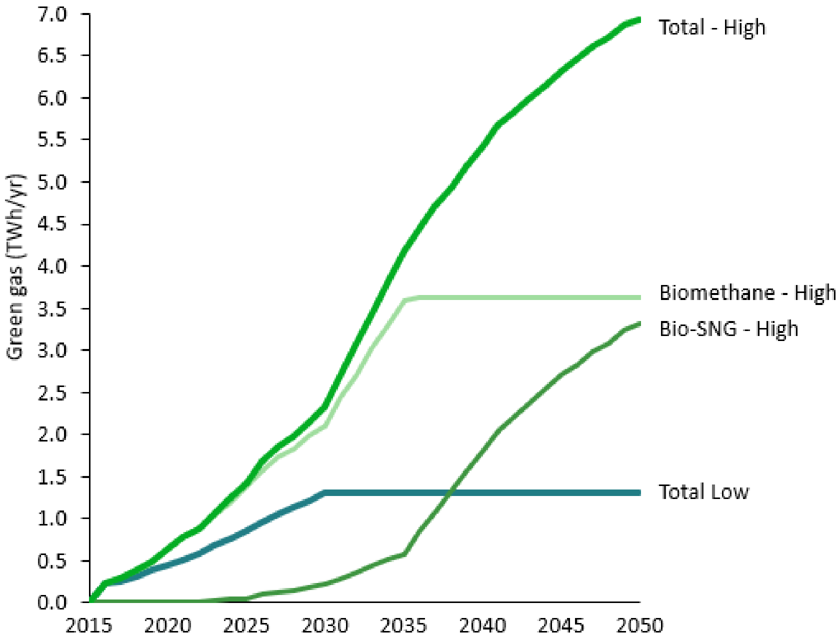


Figure 5.2 Green gas trajectories used in the scenarios.

Hydrogen

For the purposes of this study, three primary hydrogen production methods are considered:

- Autothermal reforming with carbon capture and storage (ATR with CCUS) (blue hydrogen)
- Electrolysis using grid electricity (grid dependent)
- Electrolysis directly connected to renewables (green hydrogen).

The efficiency of hydrogen production methods used in this study are given in Table 5.2.

Table 5.2: Efficiency of hydrogen production methods and carbon capture used in this study.

Production Method	Unit	2020	2025	2030	2035	2040	2045	2050
Electrolysis	kWh elec/kWh H_2	1.76	1.67	1.58	1.52	1.52	1.52	1.52
ATR	kWh gas/kWh H_2	1.36	1.36	1.26	1.26	1.26	1.26	1.26
CCUS	capture efficiency	95%	95%	95%	95%	95%	95%	95%

Table 5.3: Share of hydrogen production methods used in this study.

Production Method	2020	2025	2030	2035	2040	2045	2050
SMR	100%	100%	0%	0%	0%	0%	0%
Grid electrolysis	0%	0%	0%	24%	30%	36%	42%
Electrolysis from renewables	0%	0%	0%	2%	7%	11%	16%
ATR + CCUS	0%	0%	100%	74%	63%	53%	42%

5.3.2 Buildings

Deployment trajectory comparison

To illustrate the impact of slower ramp-up of deployment on peak installation/retrofit rates compared to the linear rates used in the core modelling, a slower deployment trajectory was modelled for both energy efficiency and heat pump deployment based on heat pump supply chain limit curves developed for analysis underpinning the CCC's 6th Carbon Budget. As shown in Figure 5.3, a slower rollout would result in a much higher share of required installations occurring in the late 2020s (with close to 20% of final installation numbers being installed each year for the final three years to 2030).

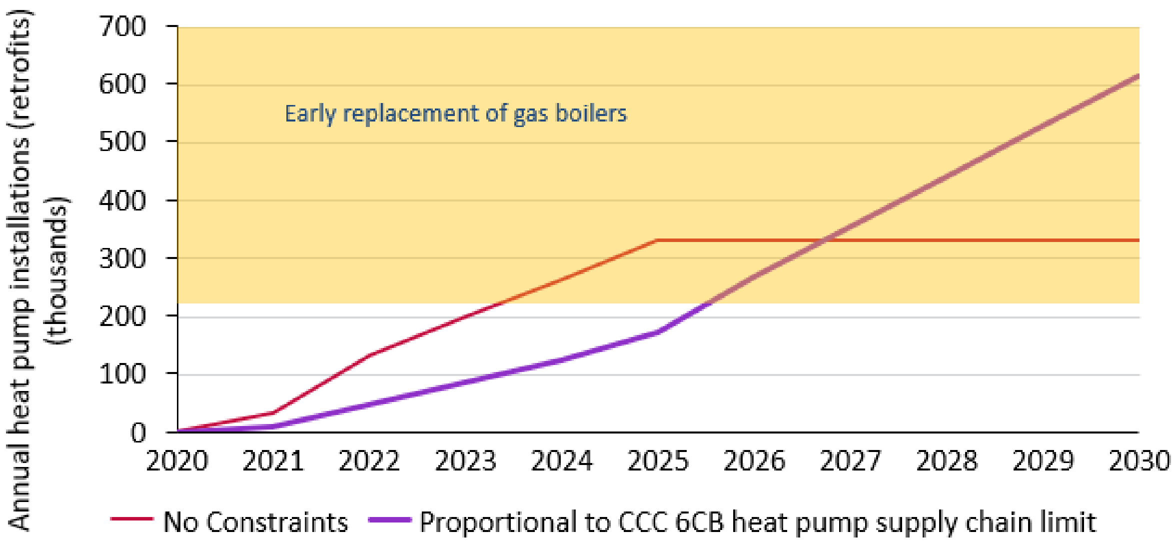


Figure 5.3 Comparison of modelled (No Constraints) and slower (CCC 6CB) trajectories for heat pump deployment

Technology mix

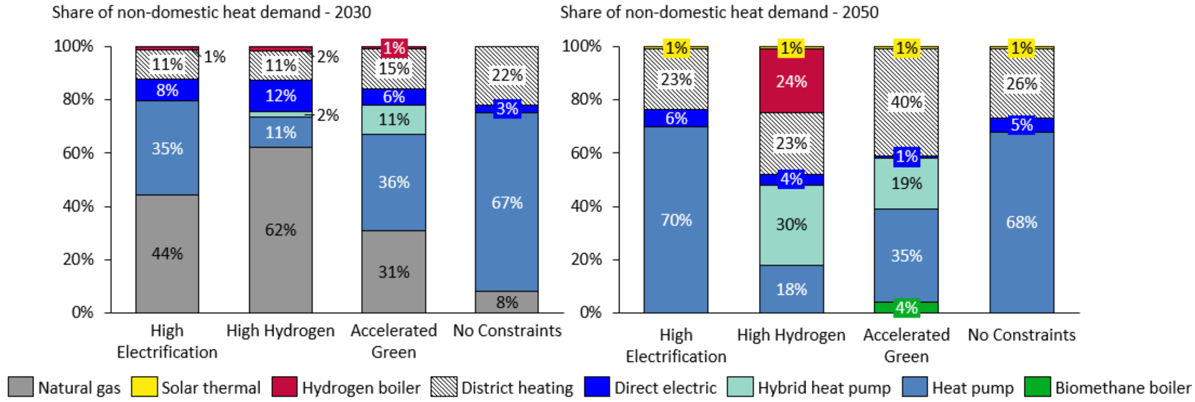


Figure 5.4 Low carbon heating technology mix in the non-domestic buildings sector in 2030 (left) and 2050 (right)

5.3.3 Transport

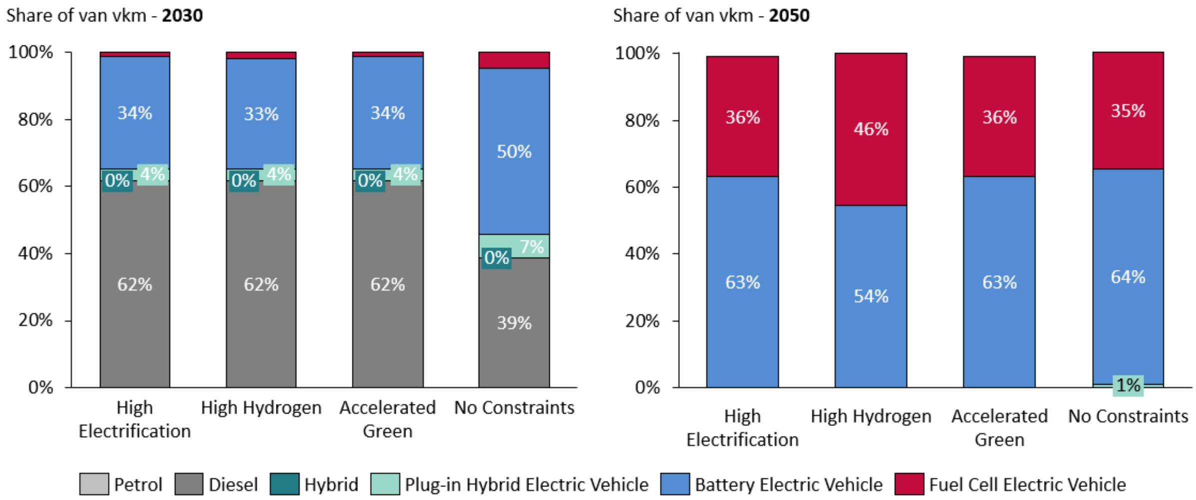


Figure 5.5 Van fleet mix by powertrain across scenarios in 2030 and 2050

5.3.4 Industry

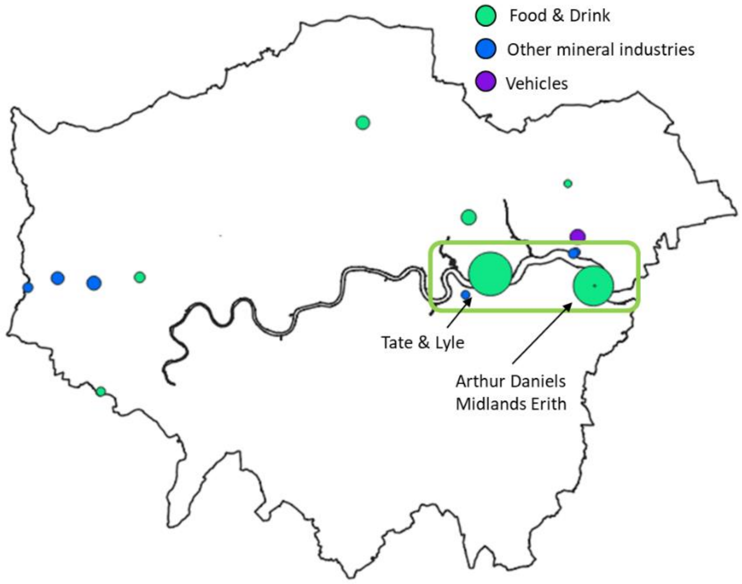


Figure 5.6: Map of industrial sites with largest direct CO_2 emissions. Size of marker is proportional to emissions.

5.4 Costs

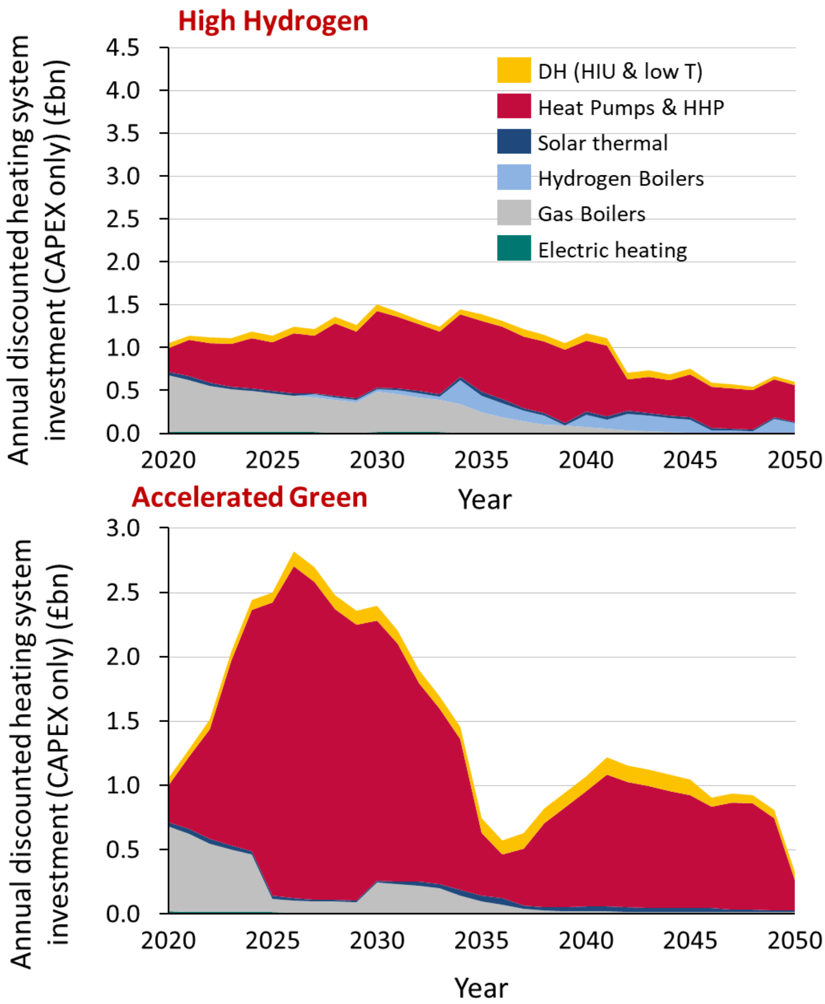


Figure 5.7 Annual discounted heating system investment (CAPEX only) for the High Hydrogen scenario (upper) and the Accelerated Green scenario (lower).

5.4.1 Building technology costs

The technology costs and future price projections in the two tables below were updated using cost data developed for the CCC's 6th Carbon Budget analysis,[140] with the exception of the prices for heat interface units and solar PV costs. The heat interface unit costs and solar PV costs were taken from the detailed district heating modelling done as part of the analysis underpinning the *1.5°C Plan*. The assumed thermal size for domestic technologies was calculated based on the average heating demand per property after energy efficiency improvements and the average technology load factor from the CCC's 6th Carbon Budget Analysis.[140] For non-domestic technologies the domestic load factor was used.

[140]https://www.theccc.org.uk/publication/development-of-trajectories-for-residential-heat-decarbonisation-to-inform-the-sixth-carbon-budget-element-energy/

Table 5.4 Key cost assumptions for Building Technology (for 2020)

Building technology	Assumed thermal size (kW)	Tech (including installation) cost (£)	Lifetime (years)	Maintenance cost (£/year)
Domestic				
Gas Boiler	11.9	£2,719	15	£104
Electric Heating	5.4	£871	15	£104
Low temperature heating system	N/A	£3,512	N/A	N/A
Heat interface unit (inc. meter)	N/A	£1,900	15	£104
Heat pumps	2.9	£8,326	15	£104
Hybrid heat pumps	1.9	£9,462	15	£158
Solar thermal	N/A	£1,987	25	£54
Hydrogen boiler inc. internal pipework	11.9	£2,819	15	£104
Additional thermal storage	N/A	£1,752	N/A	£0
PV	N/A	£4,547	20	£21
Non-domestic				
Gas Boiler	38.9	£4,773	15	£104
Electric Heating	17.7	£2,311	15	£104
Low temperature heating system	N/A	£11,477	N/A	N/A
Heat interface unit (inc. meter)	N/A	£6,894	15	£207
Heat pumps	9.5	£12,516	15	£104
Hybrid heat pumps	6.2	£12,813	15	£158
Solar thermal	N/A	£37,637	20	£610
Hydrogen boiler inc. internal pipework	38.9	£4,873	15	£104
Additional thermal storage	N/A	£5,726	N/A	£0
PV	N/A	£14,517	20	£194

Table 5.5 Relative cost reduction of building technology over time. Note that it is assumed that by 2030 smart systems will be installed as standard in appliances and heating systems, therefore zero additional cost.

Summarised cost curves	2020	2025	2030	2035	2040	2045	2050
Heat pumps	100%	90%	80%	80%	80%	80%	80%
Hybrid heat pumps	100%	93%	85%	83%	81%	81%	81%
Solar thermal	100%	95%	90%	90%	90%	90%	90%
PV cost curve - Capital	100%	88%	87%	86%	85%	84%	83%
PV cost curve - Operational	100%	82%	81%	80%	80%	79%	78%
Building scale storage	100%	81%	62%	62%	62%	62%	62%
Network Scale storage	100%	79%	66%	60%	54%	49%	44%
Smart system installation	100%	50%	0%	0%	0%	0%	0%

5.4.2 Refuelling infrastructure

EV charging infrastructure needs were estimated from energy demand in vehicles based on charging behaviour assumptions used by the ICCT.[141] Costs for EV charging were based on those developed for Greenpeace.[142] Rapid charging costs were based on costs developed for GLA[143] and assuming an increasing share of 150 kW chargers (from 4% in 2020 to 17% in 2030) based on assumptions used in the ICCT methodology (giving rise to the increase in price of rapid charge points in Table 5.7, row 4). It should be noted that the modelled share of 50 kW devices in 2030 (83%) is close to the current London deployment share of rapid charging devices, and London is targeting an increasing share of ultrarapid (100 kW+) chargepoints going forward. In practice, this means that the costs represented here are lower than for sites planned to be developed; however, fewer rapid chargepoints are required as the power rating increases and, overall, the total investment cost remains similar to that modelled here.

Hydrogen refuelling station costs are based on published literature.[144]

Table 5.6 Cost assumptions for transport refuelling infrastructure

Technology	Tech (including installation) – first fit cost (£)	Tech – replacement cost (£)	Lifetime (years)
Home charge point	£882	£882	15
Workplace charge point	£1,058	£1,058	15
Public charge point	£6,745	£5,202	15
Rapid charge point	£70,733	£28,790	15
Depot, LGV	£1,000	£1,000	15
Depot, HGV and bus	£25,000	£25,000	15
Hydrogen refuelling station – 0.8 t/day	£3,697,500	£3,697,500	15
Hydrogen refuelling station – 1.2 t/day	£4,552,500	£4,552,500	15

Table 5.7 Relative cost reductions (and increases) over time. Note that rapid charge point costs increase over time as the share of 100 kW and above power ratings increases.

Summarised cost curves	2020	2025	2030	2035	2040	2045	2050
Home charge point	100%	88%	75%	75%	75%	75%	75%
Workplace charge point	100%	85%	71%	71%	71%	71%	71%
Public charge point	100%	91%	81%	81%	81%	81%	81%
Rapid charge point	100%	108%	112%	115%	115%	116%	116%
Hydrogen refuelling station	100%	100%	100%	100%	100%	100%	100%

Carbon Value

Figure 5.8 shows the annual carbon price used to calculate the carbon value in section 3.2.1. The values are taken from HMT Green Book.

[141] https://theicct.org/publications/London-ev-charging-nov2020
[142] *The impact of a 2030 ICE phase-out in the UK* (2020) Element Energy for Greenpeace
[143] *GLA Public Charging Study*, Element Energy for GLA (2020)
[144] *Zero Emission HGV Infrastructure Requirements* (2019) Ricardo for CCC

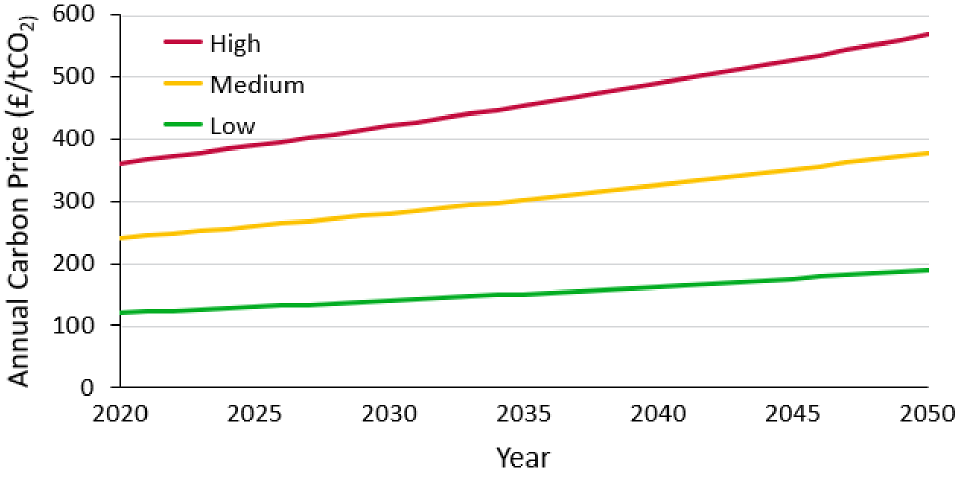


Figure 5.8: Annual carbon price assumptions

5.5 Supporting information for Job Creation

Methodology

Energy Efficiency

From its own literature review on job creation figures, the GLA has recommended the use of the C40 Cities toolkit published March 2020[145] to estimate jobs created per £1 million invested,[146] as given below:

- Lower bound 14.2 FTE per £1 million
- Median bound 20.2 FTE per £1 million
- Upper bound 31.1 FTE per £1 million

As it is not clear from the literature whether the figures quoted above are gross or not jobs (i.e. whether they account for job losses elsewhere), the GLA recommends the use of the lower bound figure, which has therefore been used in this study.

The C40 Cities Toolkit further splits the jobs created into direct, indirect and induced jobs according to the following ratio:

- 33% direct jobs
- 52% indirect jobs
- 15% induced jobs.

Heat Pumps

The Heat Pump Association's *Heat Pump Roadmap* estimates the following are required for heat pump installation [147]:

[145] C40 Cities, BuroHappold, Rokwool 'The Multiple Benefits of Deep Retrofits: A Toolkit for Cities' *published March 2020*

[146] The impacts are originally given in jobs per €1 million euro invested but are converted by the GLA using a conversion rate of 1 EUR = 0.900321 GBP (as of 21 August 2020).

[147] Heat Pump Association *Delivering Net Zero: A Roadmap for the Role of Heat Pumps* https://www.heatpumps.org.uk/wp-content/uploads/2019/11/A-Roadmap-for-the-Role-of-Heat-Pumps.pdf *published 2019*

- 6 working days for a new build that has been constructed to allow 55°C flow temperatures
- 8 working days in a retrofit home
- 3 working days to replace a heat pump with a new one.

The numbers of working days quoted above are for installers only, they are considerably higher than for the installation of a gas boiler recognising the fact that there are additional requirements when installing a heat pump such as sizing the system to the building and hydraulic balancing.

From these numbers, job creation numbers have been estimated for heat pump installers across each of the scenarios according to the scale and rate of heat pump uptake in each.

Hydrogen

The CITB recognises in its report that the transition from natural gas to hydrogen boilers may be relatively simple switch to convert a hydrogen ready boiler at the time of the grid conversion, there are a number of aspects to the transition to consider:

- An initial survey (expectation that three surveys could be carried out per day by a trained individual)
- Property updates (pipework): ½ per building (variable)
- Boiler conversion: 1 day
- Hobs/ovens/fires: ½ day each

Based on the number of hydrogen boiler installations in the scenarios within this study, demand for hydrogen boiler installers reaches a maximum of 1,800 FTE in High Hydrogen, but not until 2042. The training estimates given in CITB are similarly small compared to those for heat pumps, energy efficiency and district heating, even when working under the assumption that all properties currently on natural gas would transition to hydrogen.

There is, however, a narrative contained within these numbers that is not drawn out by considering FTE alone. The Parity Project report indicates that the average age of a Gas Safe engineer is 56; [115] a large portion of that workforce will therefore not be in place to installer hydrogen boilers come the late 2030s and 2040s and will not be inclined to upskill for a small number of installations. The future generation of gas boiler installers for both natural gas and hydrogen installations, will need to be considered to different degrees over coming years depending on the expected technology roll out.

In terms of surveying the wider pipework across the gas network to ensure it is ready to cope with a transition from methane to hydrogen, Cadent and SGN indicated that this process is already underway or completed within London. As a result, these additional surveying jobs need not be included as part of the job creation exercise.

Jobs associated with hydrogen production and transmission are not expected to be concentrated in or around London and are therefore not included as part of this job creation exercise. However, the UK Government's 10 Point Plan sets a target for 5 GW of low-carbon hydrogen production by 2030 for the UK,[148] with the expected creation of 8,000 jobs. By driving up demand for low-carbon hydrogen, London will be contributing to the creation of these jobs in other areas of the UK.

[148] UK Government's 10 Point Plan https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/936567/10_POINT_PLAN_BOOKLET.pdf *published November 2020*

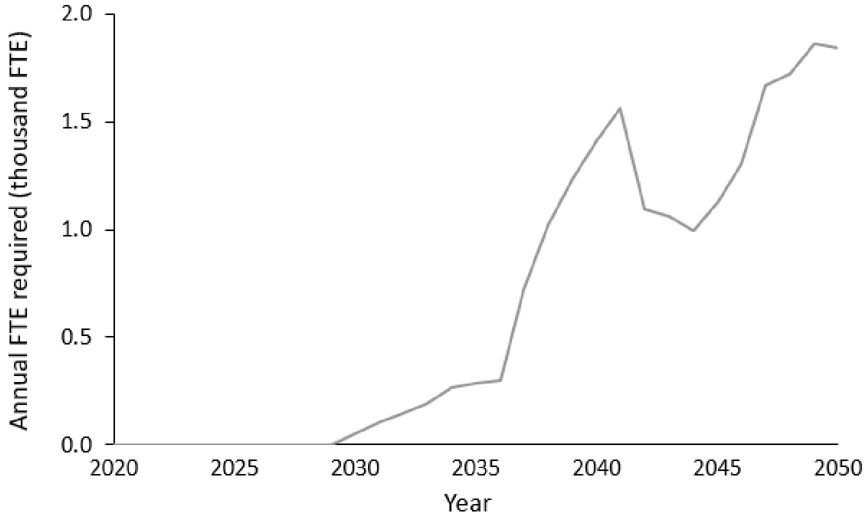


Figure 5.9 Estimated FTE requirements for installing hydrogen boilers in the High Hydrogen scenario