ITEM 09
Annex

GREATER MANCHESTER LOCAL ENERGY MARKET
DOING THINGS DIFFERENTLY FOR THE ENVIRONMENT

Greater Manchester Local Area Energy Planning: Overview & Insight

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Client review
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DRAFT

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0. EXECUTIVE SUMMARY

This report sets out an overview of the ten Local Area Energy Plans created for the ten districts in Greater Manchester (GM) and insights into what this means for GM to meet its carbon budget and 2038 carbon neutrality target.

To meet the target, GM will need to lead the way with local action, with £65bn investment required.[*] This report sets out the current position and a roadmap towards that decarbonised future, whilst providing a significant focus on the identification of areas across GM to prioritise and target low regret near-term (over the next 5 years) action and align proposed activity with the carbon budget. This is provided through place-based illustration of several near-term priority zones and opportunity areas for different technologies for each of GM's districts. The roadmap then also identifies key decision points that are needed to determine the longer-term decarbonisation pathway for the city region.

For the near-term activity, the region will need to deliver the following additional measures over the next 5 years:

- 140,000 homes with fabric retrofit
- Nearly 2 GW of rooftop PV on homes
- 190,000 EVs[†]
- 8,000 homes newly connected to heat networks
- 116,000 heat pumps in homes.

Similar levels of interventions in public, commercial and industrial buildings and fleets will also be needed, with public sector buildings making up over 7% of GM's non-domestic building stock. This will include the opportunity for over 2.5 GW of non-domestic rooftop PV.

These figures will need to rise dramatically over the coming fifteen years, with around a million heat pumps in homes (assuming a primarily electrified future for heating) and a million EVs needing charging by 2038, meaning work to enhance GM's local electricity network and find options for flexibility on the grid will also be vital.

This report considers two scenarios, that centre on one of the key decisions regarding the wide-scale decarbonisation of heat across GM: a primary scenario where GM leads the way with local actions, resulting in a predominantly electrified future, and a secondary scenario where hydrogen for heating becomes available as proposed by the HyNet project[‡].

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[*] Includes costs that would be spent even without decarbonisation to maintain the current system (figures are for the primary scenario assuming a largely electrified future). When considered at an individual district level, this typically equates to in the region of 70% of the overall investment cost.

[†] including plug-in hybrid. Domestic/personal vehicles only

[‡] HyNet North West is being delivered by a consortium of partners, each of which will lead a different part of the project. Progressive Energy is leading the development of the low carbon hydrogen production plant and the CO_2 pipeline, while Cadent is leading development of the hydrogen pipeline

The district LAEPs have highlighted a strong case for hydrogen to have a potential role in decarbonising GM. However, there is uncertainty on how prominent that role will be, as aspects such as the carbon content, cost, scale and importantly, timing (of supply) will need to be considered. This is therefore reflected as one of the main decision points within the roadmap. Alongside actively progressing near-term activity, GM should continue to work with the partners involved in the HyNet project to monitor the situation, whilst also being cognisant of the national position on the potential of hydrogen to be used for heat decarbonisation at scale (Government is expected to set out its position in 2025/26). Outcomes regarding the role of hydrogen and from the near-term low regret activity can inform the decision point and establish the divergence between these two pathways at that time. Regardless of this, any potential hydrogen supply would not be available until at the least the end of the decade, therefore urgent action is required across all districts of GM, in the near-term and through to 2030, to achieve the carbon budget and 2038 carbon neutrality target. Therefore, a key focus of the supporting LAEPs (and summarised in this report) is the identification of:

- areas/zones of least regret, where heat pumps and heat networks are cost effective to use, even if hydrogen were to be available. Action in the near terms in these zones would transition the heating systems of around 120,000 homes,
- priority/opportunity areas for the deployment of other components/technologies at pace,
- a need to build capability, capacity and understanding through demonstration projects and pilots to support further wide scale transition, when further evidence surrounding key decisions is available.

In addition, this report (and the supporting district LAEPs) cover carbon emissions associated with provision of energy to the built environment and domestic EVs, whereas other emissions, such as those associated with other forms of transport (e.g. non-domestic fleet and public transport) are out of scope. This means that of the overall future carbon budget of 71 MT CO2e[*], around 52.6 MT can be apportioned to the period of this report. The remainder would need to be considered and managed through other means, with GM supporting activity in areas (such as transport planning) that are more practical to manage at regional level. The carbon budget means that it absolutely essential to commence the near-term activity immediately; there is no time to wait for a 'silver bullet'.

[*] Based on a science-based apportioning of emissions carried out by the Tyndall Centre

Summary of Findings Across GM

The table below summarises of key figures across GM, drawn from the ten district LAEPs. Figures are given as totals to 2038.

	Cost (£m) (Primary)	Cost (£m) (Secondary)	Carbon (Mt CO_2 e) (Primary)	Carbon (Mt CO_2 e) (Secondary)	Homes retrofitted (Secondary*)	Heat pumps in homes (Primary†)	Hydrogen boilers in homes (Secondary)	Home EV chargers (Primary)	Local PV capacity (MWp) (Primary)
Bolton	9,000	7,800	4.9	4.8	98,000	97,000	102,000	46,000	1210
Bury	5,500	6,500	3.5	3.5	70,000	69,000	4,000	38,000	740
Manchester	18,700	17,800	9.9	9.7	136,000	174,000	226,00	72,000	1230
Oldham	7,500	7,100	3.3	3.2	69,000	87,000	85,000	37,000	900
Rochdale	7,300	6,300	3.9	3.7	76,000	71,000	76,000	41,000	1400
Salford	8,700	8,500	5.0	4.8	68,000	88,000	105,000	43,000	600
Stockport	8,300	7,200	4.8	4.7	95,000	98,000	99,000	37,000	890
Tameside	7,300	6,600	3.3	3.4	78,000	73,000	83,000	50,000	780
Trafford	8,500	8,200	5.1	5.0	61,000	98,000	50,000	56,000	770
Wigan	11,200	10,200	5.7	5.4	107,000	145,000	128,000	70,000	1760
GM Total‡	**92,000**	**86,000**	**49.5**	**48.2**	**858,000**	**1,000,000**	**957,000**	490,000	10,300

* Figures given for secondary scenario as these are higher than figures for the primary scenario in most cases and so represent the maximum deployment expected. Figures are total for basic and deep fabric retrofit measures

† Figures given for primary scenario as these are higher and so represent the maximum deployment expected

‡ Totals may not sum due to rounding

Key Insights

The following pages summarise the key insights from each section of this report that will support delivery between Greater Manchester Combined Authority (GMCA) and the ten districts.

Fabric Retrofit:

- Most homes across GM will need some level of fabric retrofit, and the case for this is likely to have increased with recent energy price rises
- Proportionately less fabric retrofit is seen in districts with higher quantities of flats (such as Manchester), but even these areas see large numbers of homes requiring fabric retrofit
- Fabric retrofit is generally low regret across all scenarios, as the later deployment of hydrogen means more carbon savings are required in earlier years from retrofit in the secondary scenario
- Fabric retrofit as part of a package of measures (such as heat pumps and solar PB, where relevant for an individual home) may help to minimise disruption and be more cost-effective for a household overall.

Heating Systems:

- Priority areas for heat pumps have been identified in all districts and can be a focus for low regret near term action to pilot, scale up and roll out installation of heat pumps, regardless of whether hydrogen for heating becomes available
- There are opportunities to consider expanding and even joining up heat networks across district boundaries, particularly at the nexus of Salford, Manchester, and Trafford, where several existing/planned schemes and further heat network opportunities are in close proximity
- Hydrogen could be a valuable option for heating in many parts of GM, should it become available at the necessary quantities, cost, and carbon content. It is most likely to be distributed initially to areas around the ingress point, and so eastern areas of GM could be more likely to move to a predominantly electrically heated future, even if HyNet 3 does progress.

Transport and EV Charging:

- All districts of GMCA see a very extensive shift away from liquid fuels to electric vehicles for personal cars by 2038
- Across all districts, all homes with off-street parking are expected to have EV charging facilities installed by 2038
- Public charging hubs offer a potential solution, amongst other potential options, for charging for those homes that have no off-street parking, and possible sites have been identified within each district
- Co-ordination between the districts, GMCA and TFGM offers opportunities for efficient roll-out programmes that could make use of economies of scale, whilst

also continuing to consider emerging solutions for providing communal and on street EV charging systems.

Local Energy Generation and Storage:

- There is significant potential for local renewable energy generation in GMCA, though the capacity varies between districts depending on geography and level of urbanisation
- It is more beneficial to deploy generation as early as possible, while the national electricity mix is more carbon intensive
- Deploying such high quantities of generation will be very challenging and may present challenges to the electricity network as well as requiring considerable coordination
- Battery storage (whether at building or larger scale) offers potential to alleviate some of these network cost, reinforcement challenges
- Even with successful deployment of high levels of local generation, GMCA will still rely on the grid for a large proportion of its electricity needs, even under the secondary scenario.

Energy Networks – Electricity:

- There is a substantial modelled increase in electricity demand across all districts of GM and all scenarios by 2038, driven by EV charging, even in scenarios where there is less use of heat pumps due to hydrogen being used for heating
- This leads to an overall modelled requirement for increased capacity of over 200% at low voltage substations, and over 80% at high voltage substations. GMCA and the districts should work closely with ENWL to understand how this can be addressed, including exploring flexibility
- Current capacity of the grid to support increased generation and demand varies considerably even within each district
- Each district has areas of higher current capacity that may be more suitable for early testing and roll out of heat pumps alongside EV charging
- Each district has areas with more constrained capacity that may present themselves as good test beds for flexibility and storage solutions.

Energy Networks – Gas and Hydrogen:

- A very small quantity of natural gas remains in 2038 in the primary scenario, for industrial uses that cannot easily be electrified. Equitable solutions will be needed for managing costs of the gas network as heat transitions away from gas to electricity or to other low and zero carbon energy supplies
- However, much of the existing network could be suitable for repurposing to hydrogen, if it becomes available for heat: a key decision will be required in and around 2025 about whether hydrogen will form a substantial part of the decarbonisation pathway across GM. The LAEPs include low regret areas to

deploy heat pumps and heat networks so that progress can be made in the meantime

- Initial priority areas for hydrogen are likely to be near to the proposed Manchester Ship Canal pipeline, in Trafford and Salford.

Energy Networks – District Heat

- Heat networks have the potential to supply a significant proportion of buildings in GM, and can be considered low regret, as they could be converted to be supplied by hydrogen fuelled boilers if hydrogen becomes available
- Collaboration between districts that have an identified heat network zone/s near to their boundary (particularly Manchester and Salford), could accelerate opportunities for connecting additional buildings that might otherwise be missed
- More detailed studies to consider feasibility and configuration of proposed heat networks will be needed, to confirm viability of the identified opportunities.

Cost and Investment

- The total cost of GM's energy system out to 2038 will be £86-92bn; this overall cost also being inclusive of energy import costs (Gas, Hydrogen and Electric) depending on the pathway selected. Although It is recognised a significant proportion of these costs would be incurred even without decarbonisation (from energy import costs as well as ongoing maintenance and replacement of existing equipment)
- The need for investment will accelerate rapidly after the initial five-year period, so there is an opportunity for GMCA and the districts to work with partners to develop and pilot new products and services in the low-regret priority areas in the early years, to enable rapid changes at larger scale in the following period
- The investment needed in each home in GM will be around £17,700 - £18,800, however cost-effective `combined retrofit' packages may offer opportunities to minimise this while also reducing disruption
- GMCA, the districts and other public sector organisations can lead the way by decarbonising their own estates in the near-term. Of the 69,000,000m2 of non-domestic floor space within GM, almost 7% (4,600,000m2) falls within the remit of the public sector and offers a way for GMCA and other public sector organisations to demonstrate solutions in the near-term, making use of available funding streams such as the Public Sector Decarbonisation Scheme.

Carbon Budget

- The energy system changes set out in this report and the individual ten district LAEPs that support it have the potential to keep emissions within the carbon budget for GM, however, this also depends on emissions reductions in areas outside of the scope of the LAEP work, for example, transport related emissions
- The trajectory of emissions reductions in the LAEP may allow some flexibility for large scale trials and smaller pilots in the first time period, which could then

support accelerated emissions reductions in the following periods, helping to bring the trajectory in line with the overall carbon budget

- It is hard to fairly apportion the carbon budget between districts, and so collaboration across GMCA and the districts may be preferable, while also supporting acceleration through knowledge sharing, joint procurement and skills and supply chain development.

1. INTRODUCTION

Greater Manchester is committed to achieving carbon neutrality by 2038. To support this, it has a vision of each of its boroughs transforming their infrastructure, homes, and buildings to be part of a smarter local energy system. Recognising the climate emergency, national Net Zero commitments* and the need to translate the strategic vision to an implementable plan of action, Greater Manchester Combined Authority (GMCA) has supported each borough in the development of a Local Area Energy Plan (LAEP). This document draws together the findings from those ten LAEPs into an overarching Local Area Energy Planning Overview and Insights report for all Greater Manchester. It aims to:

- Define the extent of the transformation needed across the city region as a whole
- Highlight similarities and differences between districts and the reasons for these
- Set out priority areas for different elements of the energy system across GM
- Consider some of the challenges that may arise in meeting GM's carbon budget and target
- Identify opportunities to work collaboratively between GMCA and the districts
- Provide a roadmap for progress with low-regret actions and key-decision points identified.

Energy Systems Catapult developed the concept of Local Area Energy Planning as a mechanism of applying a whole system approach to the planning and design of Net Zero Local Energy Systems. Bury was one of the first Local Authorities in the country to work with Energy Systems Catapult, Electricity North West (ENWL) and Cadent in piloting a data-driven whole system approach in 2018. Since this initial pilot, Greater Manchester has launched its Five-Year Environment Plan, which includes a commitment to be carbon neutral† by 2038, and an accompanying science-based carbon budget. Alongside this, there have been significant updates to the supporting whole system modelling approach, including the latest technology attributes and costs, updated building data and network data, changes in EV uptake projections and more detail in options for decarbonising non-domestic buildings. The most significant update has been the addition of hydrogen in line with HyNet‡ projections, as an option that in certain scenarios can be used to decarbonise heat demand in domestic and non-domestic buildings. This is key as achieving carbon neutrality will require the transition of GM's heating systems from natural gas fired boilers to electrified heating systems, district heating networks or converting the gas network to hydrogen.

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* Climate Change Act 2008 (2050 Target Amendment) Order 2019

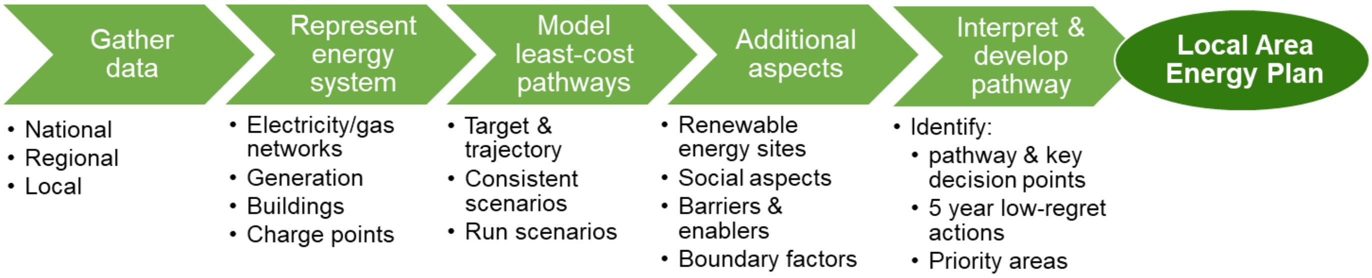
† Carbon neutrality is defined by the Tyndall Institute's study for GM as below 0.6 Mt CO2/year across GM

‡ HyNet North West is being delivered by a consortium of partners, each of which will lead a different part of the project. Progressive Energy is leading the development of the low carbon hydrogen production plant and the CO_2 pipeline, while Cadent is leading development of the hydrogen pipeline

Production of the 10 District LAEPs

The district LAEPs were produced using a consistent process that enabled all the outputs to be comparable, so that they could then be drawn together into this report.

The process, illustrated below, began with the collection of data about the local energy system. Data at national or regional (i.e., GM) level was collected at the start of the project and became a consistent baseline throughout: again, to support comparison of the ten district LAEPs. This data was then supplemented with local information about aspects not covered in the national and regional data sets, such as specific local projects. The full data sets were then used to build a representation of the current energy system of each district.



A consistent set of future scenarios were agreed (see below for further details) and used as the basis of least-cost pathways modelling. For the modelling, each district was geographically sub-divided into a small number (up to 10) of zones for the purposes of assessment and to understand what is needed for decarbonisation at a more local level. The zones were made along the 33-11kV substation boundaries.

The modelling used the ESC-developed EnergyPath Networks tool, which seeks to develop a full range of decarbonisation options for local areas and then use an optimisation approach to identify the combination that best meets the GM's carbon ambitions in a cost-effective way across the whole system.

For the impact of the energy system outside of the boundaries of each district, the national Energy System Modelling Environment (ESME) – an internationally peer-reviewed national whole energy system model – has been used to identify the lowest-cost decarbonisation scenarios for the UK energy system to then feed into the local modelling.

These national scenarios have been used to inform the development of a primary and secondary local scenario that illustrate two potential, but quite different, routes to achieve Greater Manchester's ambitions for carbon neutrality in each district. These explore the actions and investment needed in different areas of Greater Manchester between now and 2038 to reduce its emissions. This report draws together the outputs of that modelling approach from each of the ten districts to understand the picture across Greater Manchester as a whole. It should be noted that each district was modelled independently, and so systems impacts or interactions across district boundaries have not been modelled. Therefore, this report seeks to draw out the risks, opportunities, and challenges across GM as a whole to form as comprehensive a view as possible of the way forward.

The scope of emissions modelled covers those resulting from domestic, industrial, and commercial consumption of electricity, gas and other fuels; home charging of personal electric cars; and process emissions from large industrial installations. Out-of-scope were emissions from agriculture, all usage of liquid fuels for transportation, and electricity use for vehicles other than personal cars. Section 9 explores further the interactions of this scope with the broader scope of the GM carbon budget.

It should be noted that techno-economic optimisations (i.e., the scenarios that have been considered and modelled) are imperfect. Many low carbon solutions have benefits and drawbacks that cannot be easily represented in modelling approaches. This appreciation has been used to shape the district LAEPs and this report; however, as the LAEPs are implemented, new significant insight may result in a requirement to update them. For example, the process has highlighted the potential use of a highly ambitious quantity of solar PV, based on availability of roof space and land; latter sections of this report discuss whether this would be an effective approach when accounting for its potential wider system implications.

Scenarios for achieving Carbon Neutrality in Greater Manchester

A core aspect of the analysis has been the consideration of resulting emissions from the gas and electricity required to serve domestic, commercial, industrial, and public sector energy demands, including the impacts of heating system and building fabric changes within the modelled scenarios, and how these relate to the GM carbon budget. This has strongly influenced the creation of the district LAEPs and this report, recognising the need to cut emissions rapidly.

The two scenarios which have been more deeply analysed to inform the LAEPs are:

- **Primary Scenario – GM Leading the Way:** this scenario focuses on meeting the carbon budget and carbon neutrality target by making use of **measures within GM's and the districts' local control where at all possible**

- **Secondary – An Alternative Future Local Energy Scenario:** this scenario assumes hydrogen for residential heating and non-domestic buildings becomes available in GMCA from 2030 onwards (aligned to HyNet Phase 3[*]), considering where it could be cost-effective to use hydrogen alongside the measures / technologies considered in the primary scenario. The quantity of hydrogen expected to be available under the HyNet plans would not be sufficient to allow all GM districts to pursue this option; therefore, this LAEP considers where to prioritise and target the use of hydrogen[†]**.**

Drawing on the modelled outputs across all ten district LAEPs, total remaining emissions are compared in this report against the carbon neutrality target at a GM level, in the context of the scope differences between this work and the GM carbon budget.

[*] HyNet North West is being delivered by a consortium of partners, each of which will lead a different part of the project. Progressive Energy is leading the development of the low carbon hydrogen production plant and the CO2 pipeline, while Cadent is leading development of the hydrogen pipeline
[†] Cadent's Greater Manchester decarbonisation pathway report anticipates a proportion of homes being met by electric heat pumps out to 2038.

The modelled scenarios for the ten district LAEPs explore uncertainties, considering implications of different choices and behaviours by policy makers, businesses and individuals, the development and take up of technologies and the balance between different options, where they exist. Within the scenarios, the key technologies that are likely to be important in cost effective local system designs have been considered, as well as some that are more expensive but may have popular support. Technologies that consistently appear regardless of scenario warrant prioritisation in preparing for transition; this approach has led to the identification of the priority areas within each district LAEP and subsequently in this report.

Conclusions from the scenario analysis have been used to develop this report. This represents a point-in-time plan of intent, as the basis for GMCA and its districts taking important implementation steps over the next 5 years to engage industry and businesses, build momentum around a shared plan and support the identification and creation of opportunities for smarter local energy systems. Progressing this report can help to realise the potential of a local energy market for GM and support meaningful action and progress on reducing emissions.

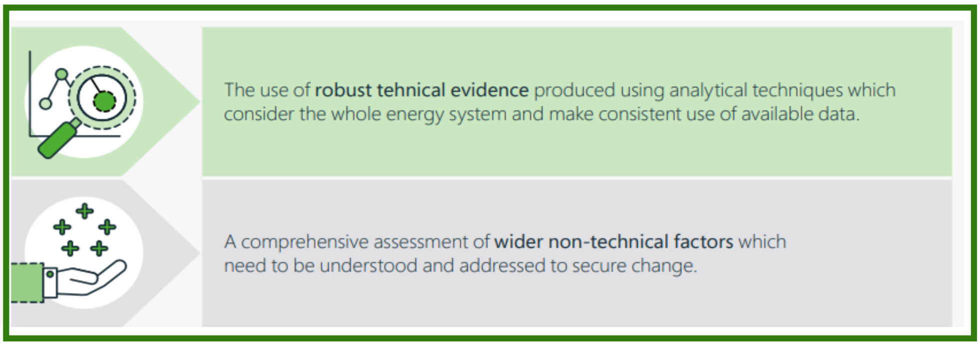
Both the primary and secondary scenarios make assumptions around changes to behaviour, advances in technology and innovation whilst recognising uncertainty in key areas such as the potential use of hydrogen for transport and heating in homes and buildings, as well as advances in energy storage and controls. While the ten district LAEPs are not prescriptive plans to be followed exactly, they do provide a detailed spatial evidence base and supporting data that can be used to inform the planning of activity within each district, and this report seeks to draw together that evidence to enable coordination of activity across GMCA over the coming years. Where hydrogen for building heating does become available (as per the secondary scenario), it is expected that all the components within the primary scenario (heat pumps, district heating, solar PV, EV charging, building fabric retrofit and flexibility and storage systems) will still be needed to decarbonise GMCA; any uncertainty is generally around the scale of deployment. Therefore, it is deemed low risk to demonstrate how to deploy these components and prepare for significant scale-up whilst assessing whether HyNet will be able to cost-effectively provide zero carbon hydrogen, across GM in-line with projections.

In addition, as the secondary scenario has significantly lower modelled cost (£60 bn compared to £65 bn for the primary scenario), there is a need to make major decisions that consider the many associated advantages and disadvantages of each option; however, waiting until there is certainty would be too risky, reinforcing the need to commence demonstration in the identified priority areas. Furthermore, there may be a need to prioritise hydrogen supply in the region, which this document considers.

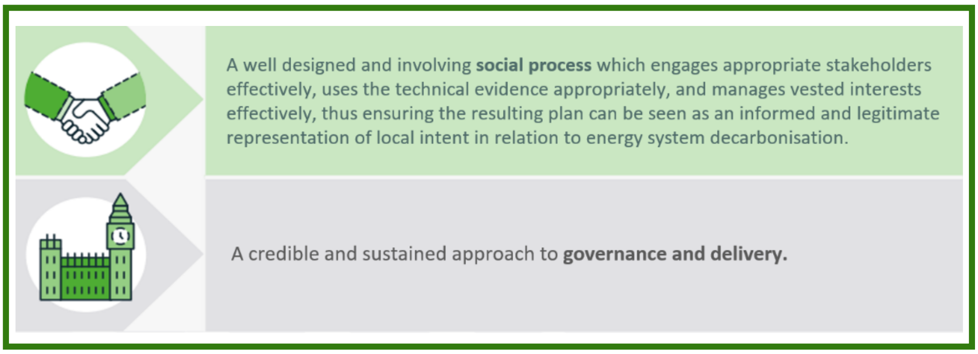
In summary, the scenarios have been developed in response to the science-based carbon budget for GM: defining a credible plan for each district that can be built towards a plan for GMCA as a whole; based on currently deployable technologies, to support an understanding of the actions, pace and scale of change as well as the investment needed. Insights from the scenarios that consider the role of hydrogen (in decarbonising domestic and non-domestic buildings), including aligning with the timeline for phase 3 of the HyNet project (which envisages low carbon hydrogen becoming available at scale from the early 2030s), have been used to set out heat decarbonisation priority areas. The scenarios also seek to understand the costs, benefits, uncertainties, opportunities, and risks to decarbonisation by 2038 that a hydrogen-based approach would bring. Combining the insight from these scenarios across the ten districts informs the overarching plan for GMCA.

The ten district LAEPs also considered previous studies including the Decarbonisation Pathway for Greater Manchester study completed in 2020 by Navigant on behalf of Cadent Gas and Electricity North West* and are generally aligned to the latest guidance on Local Area Energy Planning developed with Ofgem, the ambitions of Greater Manchester and wider UK Net Zero commitments.

In accordance with the Ofgem LAEP Method†, which provides guidance and framework for LAEP done well, the ten district plans were developed using robust technical evidence which considers the whole energy system for GMCA and consistent use of available data and assumptions. They have also sought to consider wider non-technical factors which influence the deliverability, pace and scale of change required for decarbonisation.



The next steps of the development of the district LAEPs are expected to comprise wider stakeholder and public consultation on the plan to inform its further development, as well as the approach of both Greater Manchester and the districts for ongoing governance and delivery.



The approach differs from the Ofgem methodology where it has taken advantage of the data and engagement available at the Greater Manchester Combined Authority level, streamlining the approach and reducing the need for separate processes with each local authority, but also allowing for additional insight across the GM region to be developed in this report.

* Decarbonisation Pathway for Greater Manchester, Reaching carbon-neutrality in a balanced scenario by 2038, Navigant, July 2020
† From LAEP: The method https://es.catapult.org.uk/reports/local-area-energy-planning-the-method/

Report Structure

The report is set out in the following structure. It summarises the key aspects of the plan and its supporting modelling and analysis and is presented in nine chapters, supported by an accompanying technical annex.

Chapter 1: (this chapter) sets out the context and the approach taken for each district to modelling, developing the scenarios, and supporting technical evidence and associated assumptions and limitations and relevant supporting information, and how these are considered across GMCA within this document.

Chapter 2: sets out the vision and primary scenario to carbon neutrality across GMCA, informed by the scenario analysis for each district. The primary scenario demonstrates how GMCA could meet Greater Manchester's decarbonisation ambitions across each of its key areas by 2038 in a practical way. A series of first steps is also presented that focus on demonstration and scale-up of some of the key components that will be needed to decarbonise GM.

Chapters 3-7: set out some of the key aspects of the primary scenario and key insights on how these vary across different parts of GMCA, including Fabric Retrofit (Chapter 3), Heating System Zones (Chapter 4), EV charging and infrastructure (Chapter 5), Local Energy Generation and Storage (Chapter 6), and Energy Networks including electricity, gas and heat (Chapter 7).

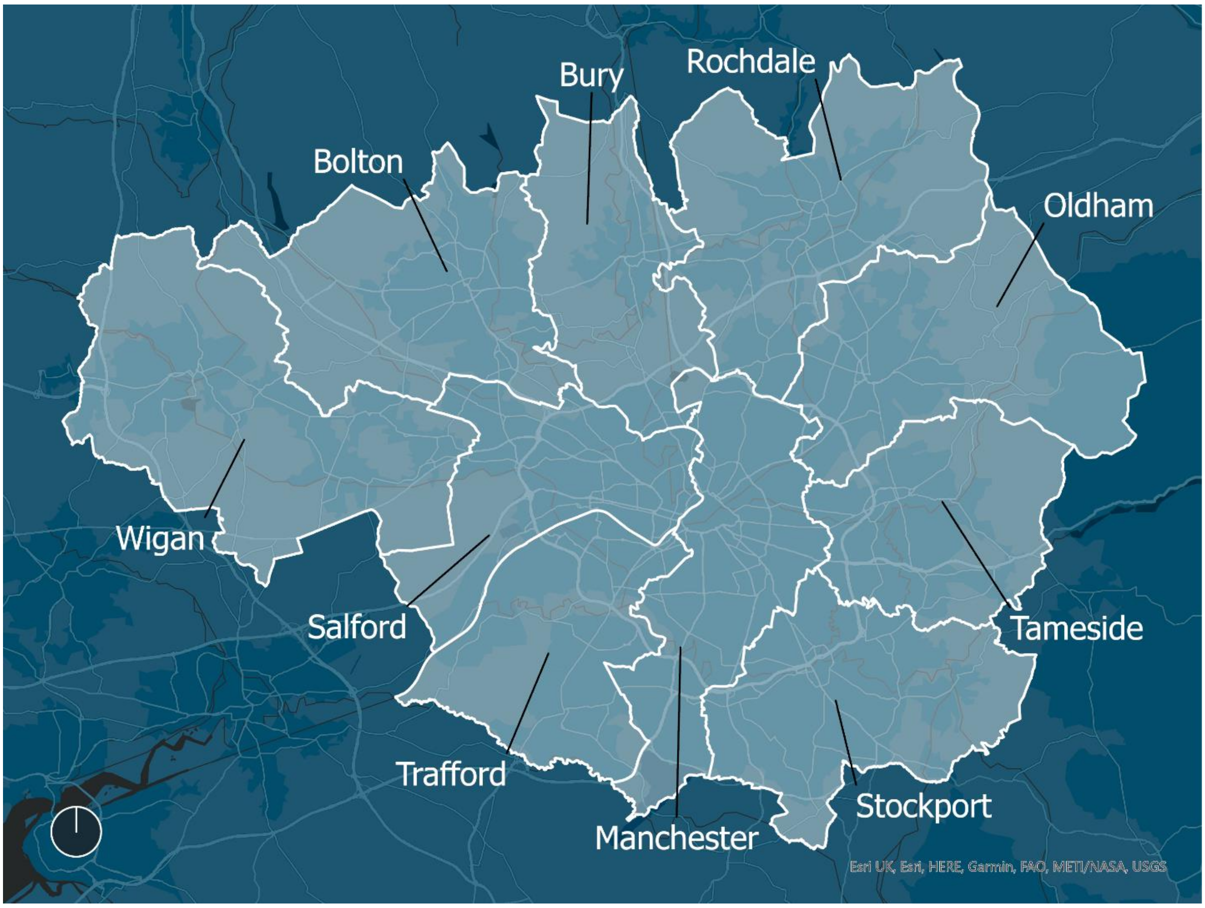
Chapter 8: sets out the estimated system costs and investment needed for implementation of the primary scenario. This includes definition of the total system costs between now and 2038 across different areas of GMCA, the capital investment at key time steps in infrastructure and key technologies within the scope of the analysis.

Chapter 9: considers the emissions pathway for each district and how, when combined, these relate to the overall GM carbon budget.

Chapter 10: looks at what might be needed to make the plan a reality across GMCA, including a roadmap and key decision points, and sets out recommended actions to support implementation and ongoing review and monitoring in the context of national and regional energy strategy, carbon budgets and associated policy and regulation.

2. THE VISION

This report aims to support Greater Manchester to transition to an affordable and decarbonised energy system and to support the delivery of the commitment to carbon neutrality by 2038, by drawing together the pathways for decarbonisation identified in each of the ten districts within GM.



Decarbonising GM's local energy system by 2038 is achievable and expected to require capital investment of between £60 bn (if all districts were to follow the pathway set out in their secondary scenario) and £65 bn (if all districts were to follow the pathway set out in their primary scenario). Total energy costs including capital investments, operations and energy consumed is between £86 bn (secondary) and £92 bn (primary) to 2038.

The following chart illustrates the breakdown of this expenditure over time for different components (for the primary scenario). The subsequent chart shows how implementing the transition reduces carbon emissions*. For both primary and secondary scenarios, a large proportion of these costs will be incurred by maintaining current energy system regardless of the carbon target to meet the energy needs of GM's residents†.

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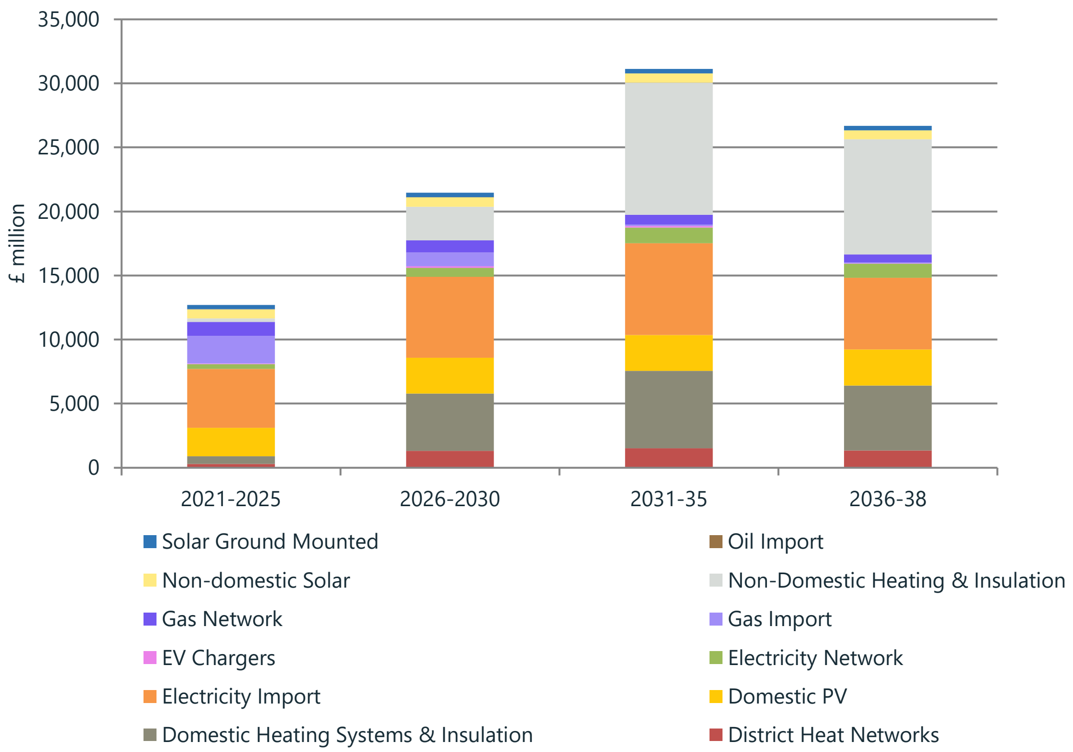
* In-scope emissions are those resulting from domestic, industrial, and commercial consumption of electricity, gas & other fuels, electric vehicle charging and process emissions from large industrial installations. Out-of-scope are emissions from agriculture and existing liquid fuels for transportation.

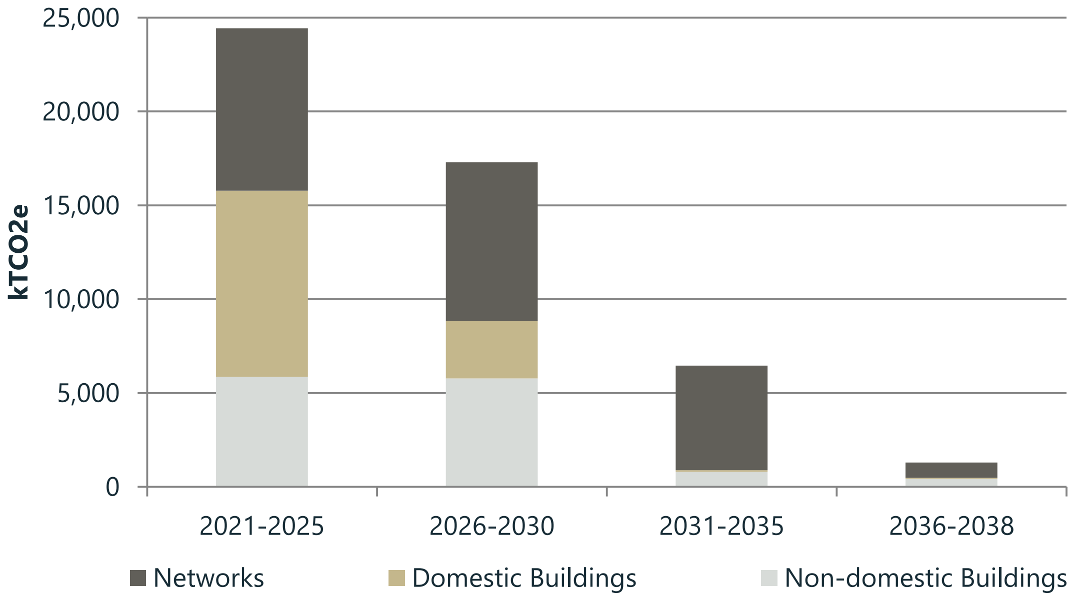
† A study of business-as-usual energy system costs within Oldham shows roughly ~70% of total scenario cost to be incurred regardless of decarbonisation.

CapEx and Energy Costs Over Time



With such a variation (£6 bn) in total projected system cost between the two scenarios, progress on wider national energy planning and policy decisions would be needed, recognising the current uncertainty (regarding the UK's heat decarbonisation strategy) associated with selecting a preference on decarbonising heat in buildings (e.g., either through electrification, district heating or hydrogen). In addition, collaboration between districts should be considered, recognising that major decisions do not stop at a local authority boundary. For example, it may be preferential to prioritise the use of hydrogen in targeted areas of GM, according to the timing and quantity available, which may result in the secondary scenario only being pursued in specific locations in GM – potentially those nearest to the expected initial ingress point – i.e., Trafford and Salford. The proposed approach of regional collaboration also provides the opportunity to build deeper engagement with regional stakeholders (including Cadent and Electricity North West), should support the evaluation and decision making process.

CO2 Emissions Over Time



The cumulative emissions over the period 2021-2038 in the primary scenario are 49.5 Mt of CO_2e (and 48.2 Mt in the secondary scenario).

Summary of Findings Across GM

The table below gives a summary of key figures across GM, drawn from the ten district LAEPs. These are discussed in the remainder of this Vision section, with further detail in the following chapters.

	Cost (£m) (Primary)	Cost (£m) (Secondary)	Carbon (Mt CO_2 e) (Primary)	Carbon (Mt CO_2 e) (Secondary)	Homes retrofitted (Secondary*)	Heat pumps in homes (Primary†)	Hydrogen boilers in homes (Secondary)	Home EV chargers (Primary)	Local PV capacity (MWp) (Primary)
Bolton	9,000	7,800	4.9	4.8	98,000	97,000	102,000	46,000	1210
Bury	5,500	6,500	3.5	3.5	70,000	69,000	4,000	38,000	740
Manchester	18,700	17,800	9.9	9.7	136,000	174,000	226,00	72,000	1230
Oldham	7,500	7,100	3.3	3.2	69,000	87,000	85,000	37,000	900
Rochdale	7,300	6,300	3.9	3.7	76,000	71,000	76,000	41,000	1400
Salford	8,700	8,500	5.0	4.8	68,000	88,000	105,000	43,000	600
Stockport	8,300	7,200	4.8	4.7	95,000	98,000	99,000	37,000	890
Tameside	7,300	6,600	3.3	3.4	78,000	73,000	83,000	50,000	780
Trafford	8,500	8,200	5.1	5.0	61,000	98,000	50,000	56,000	770
Wigan	11,200	10,200	5.7	5.4	107,000	145,000	128,000	70,000	1760
GM Total‡	**92,000**	**86,000**	**49.5**	**48.2**	**858,000**	**1,000,000**	**957,000**	490,000	10,300

* Figures given for secondary scenario as these are higher than figures for the primary scenario in most cases and so represent the maximum deployment expected. Figures are total for basic and advanced fabric retrofit measures

† Figures given for primary scenario as these are higher and so represent the maximum deployment expected

‡ Totals may not sum due to rounding

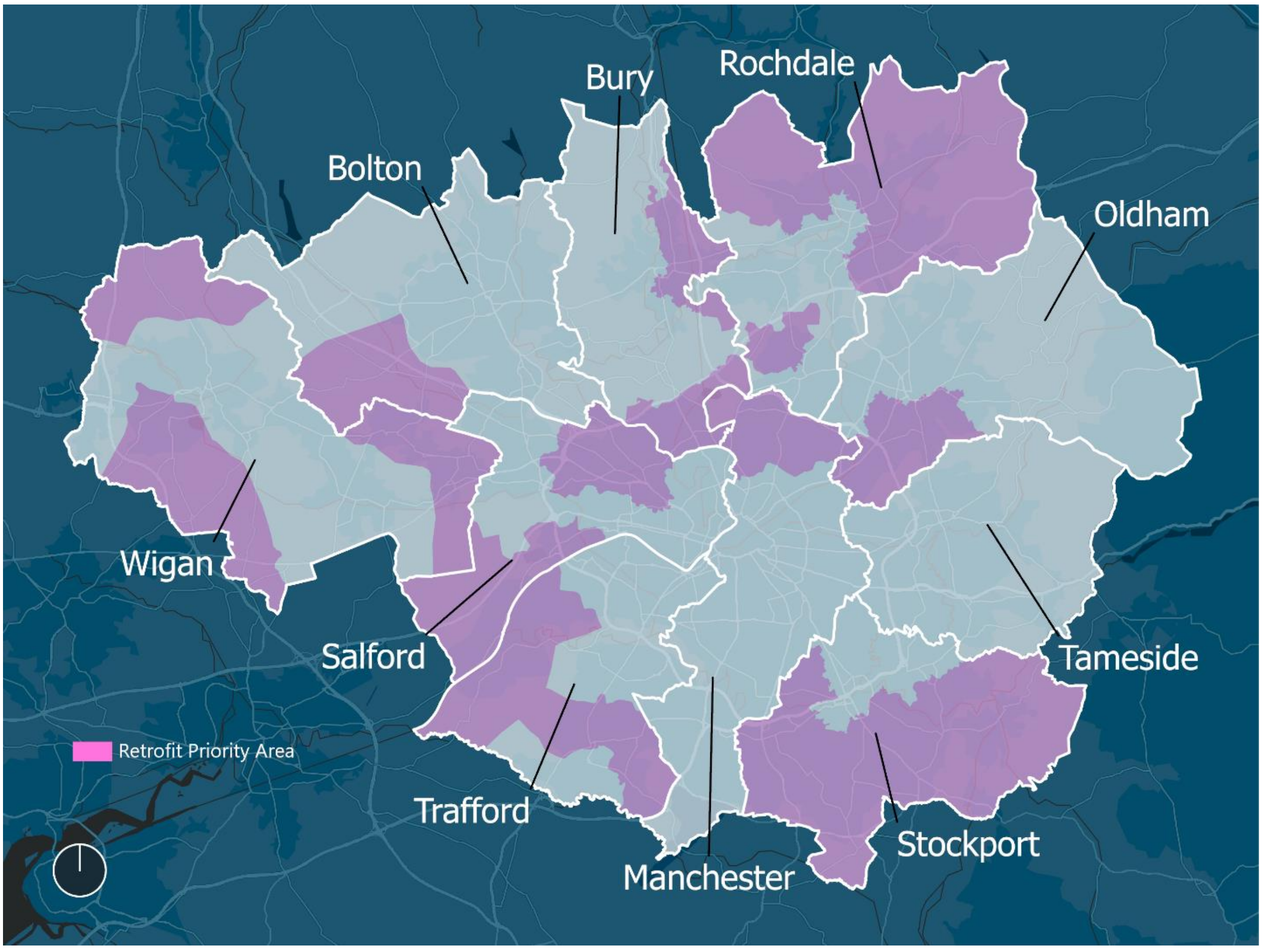
How to Interpret this Vision

This transition will involve the greatest infrastructure change across Greater Manchester for decades; key sections of this report illustrate the scale of change and investment needed, based on a primary scenario, and explore how this differs across the ten districts. An alternative scenario (secondary), incorporating the use of hydrogen for heat, is also considered at key points (along with other variations within the appendix), where the supporting analysis indicates that hydrogen could have an important role in decarbonising GM. Unless explicitly stated otherwise, quoted values in this report will refer to the primary scenario. Given the significance of backing one view of the future (or scenario) now, the report promotes a demonstration and scale-up approach over the coming years to 2025, before moving to full scale implementation. This builds on the identification of several ‘priority areas’ within each of the ten districts, to build capacity and test approaches, across different components, for working with local citizens and stakeholders. Insights from the alternative scenarios have been used to produce these priority areas. It is expected that this report (and the ten district LAEPs that underly it) may need to be updated as lessons are learnt and uncertainties (such as UK policy regarding the decarbonisation of heat) become clearer.

Fabric Retrofit

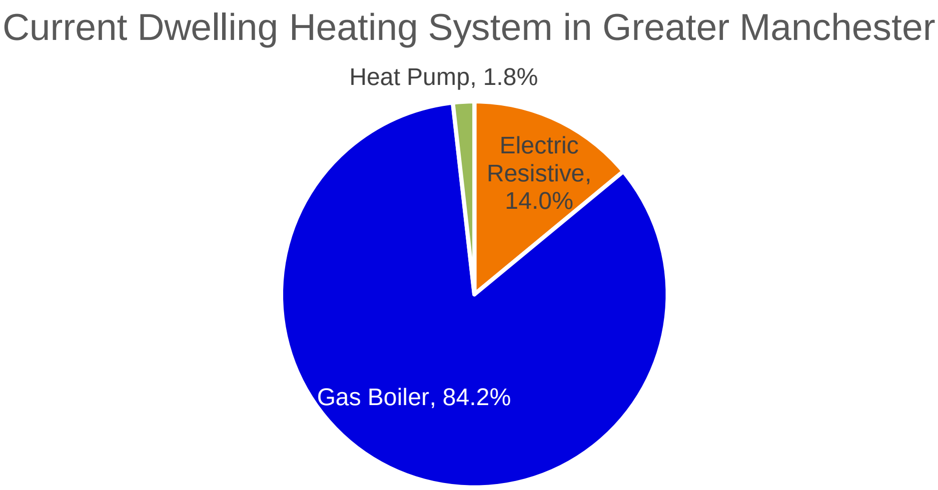
As much as **52% to 59% of the 1.4 million dwellings in GM in 2038 would have received insulation retrofit for the primary and secondary scenario** plan. This corresponds to around **757,000** additional homes compared to today’s levels in the primary scenario, or **858,000** in the hydrogen focused secondary scenario. A greater number of deep retrofits are seen for domestic properties in the secondary, hydrogen dominated, scenario (around **71%** more than the primary). This is to enable earlier demand reduction and thus decarbonisation, which is required to meet carbon budgets due to the later availability of low carbon heating fuel (i.e., hydrogen is not considered until at least 2030). Fabric retrofit and solar PV are low regret measures to progress in the short-term, being cornerstones of both the primary and secondary scenarios.

The map below illustrates the zones within each district that have been identified as priority areas for retrofit, due to a high density of homes that consistently require retrofit across scenarios.



Heat Decarbonisation

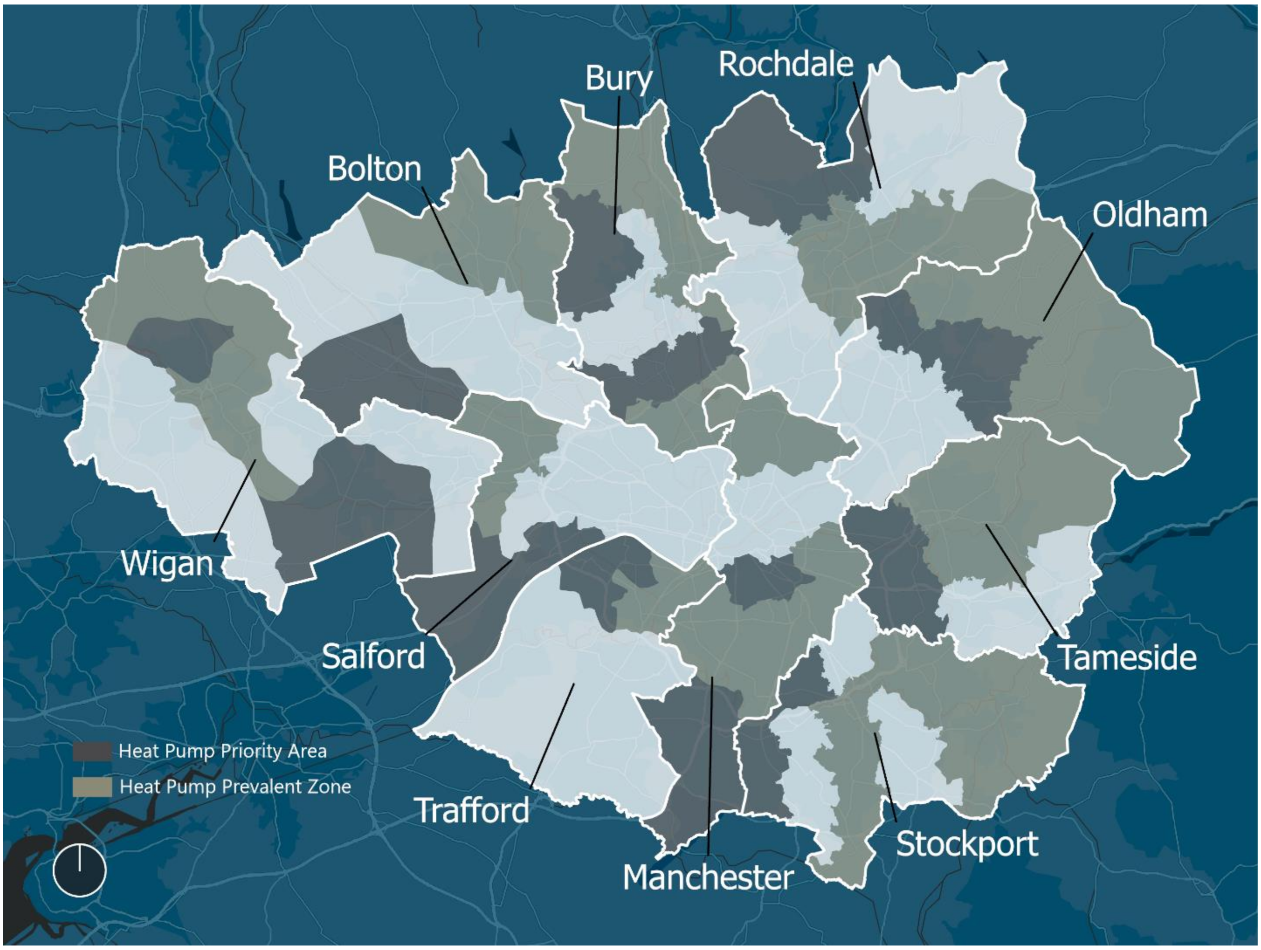
Greater Manchester's current heating system mix is heavily dependent on gas boilers, as demonstrated in the chart below showing current domestic building heating systems.



Three heating options are explored to decarbonise buildings: electric heating (primarily heat pumps), hydrogen to replace natural gas, and district heat networks. For hydrogen to play a significant heat decarbonisation role, certainty would be required that hydrogen will be available to supply relevant parts of GM in a timeframe that supports the delivery of the GM carbon budget; a key decision which will need to be made c.2025, primarily based on the role hydrogen will play in providing heat to buildings. Alternatively, around 1,000,000 heat pumps are deployed – which would supply heat to most dwellings. Most of these would be air source heat pumps with 11% of dwellings identified suitable for ground source solutions where space is not a constraining factor. Opportunities for non-domestic and domestic buildings to be supplied by centralised heat pumps, or other low carbon heat, through district heat networks also has some potential – which would decrease the overall number of heat pumps.

The map below indicates the zones within each district that have been identified as heat pump priority areas and heat pump prevalent zones. Priority areas are seen as low regret for heat pumps whether hydrogen becomes available for heating. These can be a near term focus for GMCA and the districts to work together to develop skills, supply chain and funding models to test and scale up the roll out of heat pumps

Heat pump prevalent zones are predominantly heated by heat pump in the primary scenario, but may transition to hydrogen under the secondary scenario, and therefore could be a more medium-term focus, once there is greater clarity on the likely role of hydrogen for heat in GM.

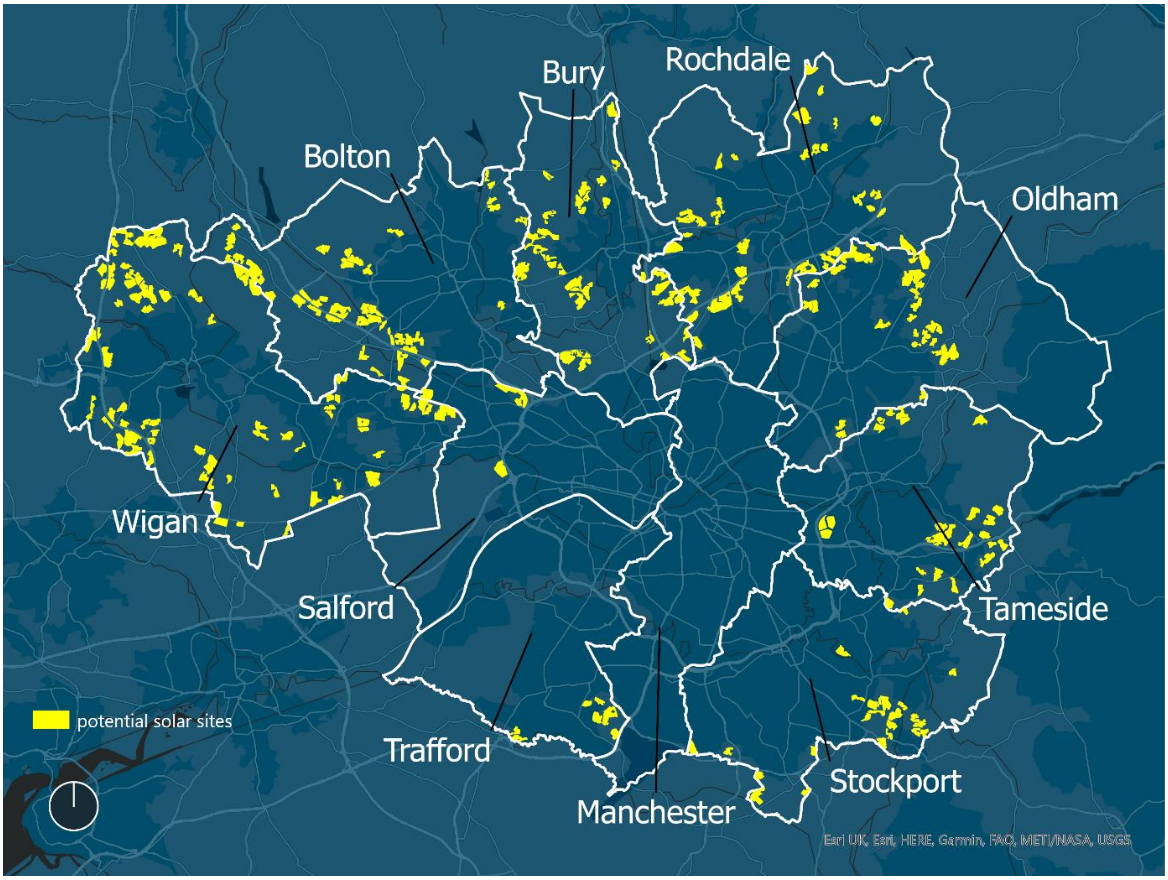


The combined cost of fabric retrofit, and heating system replacement is £16 bn for homes, and £22 bn for non-domestic buildings. The delivery of any option presents comparable challenges and risks, resulting in the need to focus on the demonstration and scale-up approach advocated

Energy Generation & Networks

To reduce emissions in line with the GM carbon budget, local energy generation would need to increase significantly, consisting predominantly of the installation of solar PV on much of the available roof space across all parts of GM (under all scenarios considered), providing up to 7 GWp of installed capacity including both domestic and non-domestic roofs, with 4.4 GWp of installed capacity identified for domestic roof space at a cost of up to £10 bn (mass purchasing solar schemes could help reduce this). The total rooftop capacity equates to a total annual generation of almost 10 TWh across GMCA. Further work is required to understand how achievable and effective this substantial provision of electricity through rooftop solar PV is when considering wider system implications.

Land in the area has been identified for opportunities to deploy a substantial 3296 MWp of potential additional ground mount solar PV for further CO_2 reduction, as illustrated in the map below.



Deploying this capacity would require an estimated land area of 5,458 Ha available. Deploying such large volumes of local generation would be very challenging and is highly ambitious. These solar farms will likely be connected into the transmission network; how this deployment of PV will impact the need for electricity network reinforcement will need to be explored as the modelling in this report is focussed on the effects of demand and generation change within the local distribution network.

Under the primary scenario, the electricity network would require capacity reinforcements of substations and underground feeders to accommodate electrification, at an estimated high cost of £3.5 bn compared to the secondary Hynet scenario at a much lower estimate of £1.5 bn. A significant proportion of the primary scenario is attributed to the peak demands of the large numbers of proposed heat pumps. Further work would be required, under this high electrification scenario, to determine the most cost-effective approach for providing this additional capacity. GMCA and the districts can work with ENWL to understand approaches and identify potential solutions, particularly in the identified flexibility and storage opportunity areas where grid capacity relative to future demand is limited.

EV Infrastructure

The transition to electric vehicles, with uptake increasing from around 40,000 (3% of total fleet) plug-in vehicles today to ~1,050,000 (76% of total fleet) by 2038, drives a demand for EV chargers to be installed across all areas. Around 517,000* domestic chargers would need to be installed (one for every home with potential for off-street parking) at a cost of £279 m, along with multiple public charging stations (or hubs); areas where fewer car owning households have potential for off-street parking rely more on public charging hubs. It is currently estimated that almost 700,000 homes across GM are without off-street parking, a figure likely to increase. These homes are therefore likely to rely on shared on-street charging hubs.

* Based on ESC in-house analysis of EV uptake. Quantities will need to be aligned with local planning policies as it relates to provision of chargers in new developments and existing dwellings.

Consumer Uptake

By the early 2030s all new cars and vans, and all boiler replacements in dwellings and other buildings in GM are low carbon*; most heating systems are either electrified or use hydrogen. The primary and secondary scenario suggests that circa. 1,000,000 of GM's 1,300,000 dwellings could be fitted with a form of heat pump. The secondary HyNet scenario could see up to 960,000 boilers running from 100% hydrogen as an alternative to localised heat pumps. By 2038, nearly 76% of cars are electric vehicles or plug-in hybrids, requiring the provision of around 517,000 electric vehicle charging points for homes with potential for off-street parking, as well as electric vehicle charging hubs for areas of terraced homes and destinations such as offices and shopping centres. By 2035 commercial and industrial activities in GM largely shift to using renewable or zero carbon electricity (either locally generated or grid supplied), or hydrogen instead of fossil fuels; carbon capture such as carbon sequestration through trees may be required to offset remaining residual emissions from grid electricity or non-domestic gas. Alternatively, offsetting through purchasing 100% renewable grid power via a corporate Purchase Power Agreement (cPPA) with a third-party generator could be considered.

Low-carbon energy supplied to and generated in GM

The emissions intensity of UK electricity production is expected to fall by at least 65% from today's levels by 2035[†]. By then, offshore wind would contribute a significant source of renewable electricity generation nationally. Renewable electricity production in GM increases to contribute to the GM carbon budget, predominantly in the form of up to 6978 MWp of rooftop solar PV, with opportunity for a further 3296 MWp ground mounted solar PV. Renewable generation (if the ground mounted PV potential is maximised), provides up to 9,856 GWh annually (39%), with 15,734 GWh (61%) of electricity supplied from the grid. This scale of solar PV is a highly ambitious aspiration and requires further detailed consideration; for example, from a network capacity perspective it may not be the optimal place to locate generation. However, with the 2038 target and GM carbon budget influence, solar PV could provide low carbon electricity earlier than the grid is expected to.

The low carbon electricity is used in heating, industry and vehicle charging, nearly doubling electricity demand over the next 15 years. Total electricity consumption is

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* This report considers the energy and emissions associated with current and projected personal car use and ownership only, providing an important understanding of the impact on GM's future energy system from electrified cars. This report does not provide a fully integrated energy and transport plan where it is recognised that further work will be required to consider and integrate broader transport decarbonisation and net zero plans. This report does not also account for aspects such as modal shift or behaviour change, acknowledging that other measures such as these will be needed to achieve net zero.

[†] Based on current forecasts for electricity grid decarbonisation. If the rate of grid decarbonisation accelerates in line with the UK's recent commitment to reduce emissions by 78% by 2035, grid intensity could reach nearly zero emissions by 2035, eliminating most of the remaining emissions in this plan.

expected to increase by 96% by 2038 in the primary scenario and by 67% by 2038 in the secondary scenario.

Low-carbon hydrogen is likely to be prioritised nationally for the hardest-to-decarbonise sectors such as shipping, heavy transport fuel and energy intensive industry, and therefore the quantity that will be available for building heating is uncertain. However, HyNet is a project which aims to pioneer low carbon hydrogen production, potentially making it available to buildings in the region by 2030. Greater Manchester has a carbon budget that requires immediate action to stay within, and so any delay to HyNet could make it too late to keep within the carbon budget. However, hydrogen may have a significant role to play in combination with other technologies. This has been explored in some of the further scenarios. The similarities across scenarios point to low regret opportunities for heating system options in each district of GM, and areas where hydrogen deployment would be cost effective in comparison to other areas (zones).

Reducing demand for carbon-intensive fuels

Buildings will lose less energy thanks to a series of targeted fabric retrofit programmes, improving insulation and efficiency across GM. Fabric retrofit will prepare buildings for low carbon heating, whilst also making a notable contribution to staying within the carbon budget. By 2038, over 750,000 of GM's 1.4 million dwellings are retrofitted in the plan (circa 59%), with most dwellings requiring basic fabric upgrades for both the primary and secondary scenarios. The option of deeper fabric retrofit has the potential to increase headroom in the carbon budget to give some flexibility for deferring decisions on heating systems.

Energy Networks

A range of opportunities to deploy district heating have been identified across the districts of GM, for both domestic and non-domestic properties. These can be considered in conjunction with ongoing work by AECOM studying potential heat networks in more detail to help inform opportunities to consider and could feed into potential heat zoning in the future.

Annual electricity demand is forecasted to increase from 13,029 GWh to 25,591 GWh by 2038, due to electrified heat and electric vehicle charging. This requires an increase in electricity network capacity, though this is not equally distributed and depends both on current network capacity and expected levels of deployment of new technologies in any given area. Opportunities to consider using flexibility, storage (or other alternative measures) in place of grid reinforcements are highlighted for each of the ten districts.

Depending on the conversion and roll-out of hydrogen for heat, gas networks remain in place in some areas to support some hard-to-decarbonise non-domestic buildings that may not be of the scale to have a dedicated hydrogen connection. However, should HyNet phase 3 be available, up to 960,000 homes could be supplied by hydrogen by

2038, at a 7% lower overall total system (CapEx and Opex inc. energy costs) cost[*] and very similar levels of emissions.

Investment

GM's transition requires a total energy system and building level investment of approximately £65 bn (excluding energy costs). This unprecedented level of investment provides a once in a lifetime opportunity for GM. Urgent focus will be needed to determine how to maximise the local benefit from this opportunity, considering how to develop the local supply chains and skills needed to enable the transition and provide new, green, local jobs.

Local Opportunities

This report provides a vision for a carbon neutral GM. How it is delivered will influence the local benefit, in addition to job creation. For example, there will be opportunities for local/community initiatives to provide components of the future energy system.

Smart local energy systems could be used to provide EV charging hubs, renewable energy generation, communal or locally owned heat networks, energy storage systems, smart/flexible energy systems to avoid electricity network reinforcement or any combination of these or other measures. Greater Manchester is working with partners in developing a Local Energy Market to support the implementation of such solutions through new business models, customer propositions and a trading platform.

Local Impact and Risks

Without changes to national policy, wider energy market reforms or the introduction of new support mechanisms, household energy bills are forecasted to increase, predominantly as heating homes through electricity is more expensive than using gas. However, the proposed investments in building works will help to mitigate this and consideration will be needed to target measures at homes with the most need. Consideration is also needed to determine how to fund an average household investment of £18,800 (CapEx) for the associated measures including heating systems, fabric upgrades and roof PV installation.

An electric focused heat transition (as proposed in the primary scenario), involving changes to building fabric and internal heating systems (e.g., changes to doors, windows, larger radiators, and improved controls) could be more disruptive to residents and it is not clear how this might compare with disruption associated with using hydrogen for home heating[†], where extensive fabric retrofit would also be required to provide emissions reductions aligned to the carbon budget. In either case, compelling consumer propositions would be needed to facilitate it. With extremely challenging rates of deployment, there is an urgent need to scale up and develop skills and supply chains.

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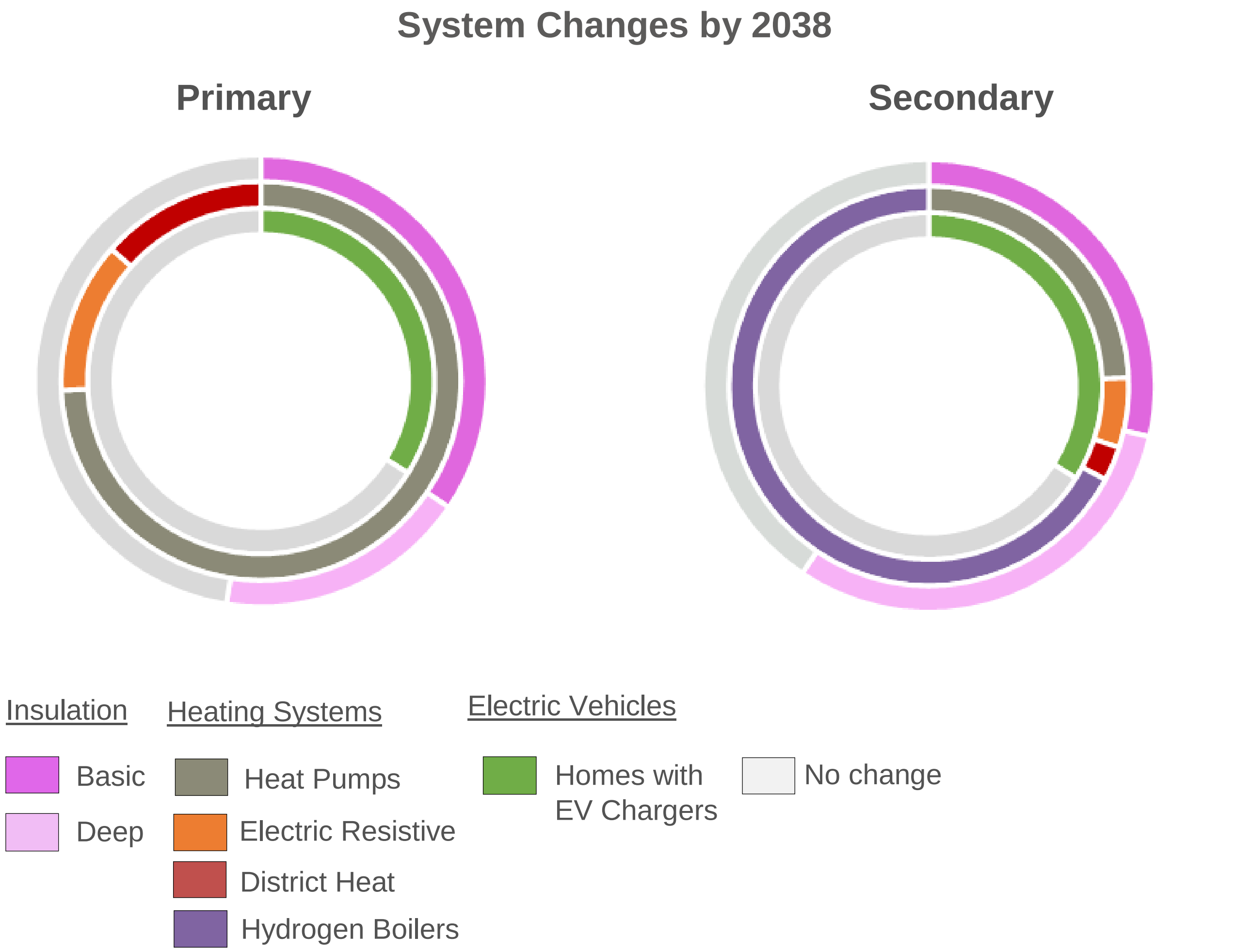
[*] Based on the Hynet projections
[†]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/760508/hydrogen-logistics.pdf

Moving to an electrified heating future also presents a risk of backing a technology 'winner' before national decisions are made on heat strategy. Targeting specific areas and housing types most likely to be suited to electric heating and demonstrating effectively clustered transitions in GM can build knowledge and evidence for policy decisions as well as industry supply chains, making meaningful progress on emissions reduction. Finally, there is a risk that the economic and social benefit may not be captured locally, therefore consideration of how to maximise the opportunity is essential.

What GM's transition to carbon neutral could look like

The charts below illustrate the scale of change needed to decarbonise GM in each scenario; the coloured portion of the rings indicating the proportion of homes that receive measures (the grey parts representing homes with no change). This is intended to illustrate the scale of measures and investment needed to the stakeholders who will support and deliver GM's transition.



The primary scenario to 2038 is most suitable if uncertainty remains around converting the gas grid to zero carbon hydrogen (at an acceptable cost) by the mid to late 2020s. It is around this time that it would be deemed too late to rely on hydrogen for heat to meet the Greater Manchester science-based carbon budget, recognising the timescales needed to carry out widescale infrastructure and building investment and adaptation.

This secondary scenario illustrates an alternative future where hydrogen becomes widely available for heating and hot water in buildings from 2030, in accordance with the aspirations of HyNet phase 3. These graphs show some of the key differences in investment and installation between the primary and secondary scenarios. Total costs vary within 7% between the two scenarios – see section 8 for full cost details.

The availability of hydrogen for home heating in the secondary scenario avoids much of the investment in both electricity and heat networks, although investment for repurposing the gas network to distribute hydrogen is needed instead. The need to invest in building retrofit is similar to the primary scenario, as both scenarios require large quantities of fabric retrofit measures to meet the carbon budget. The secondary scenario demonstrates higher level of deep retrofit to enable the earlier decarbonisation required to meet carbon budgets due to HyNet timelines. Most of the cost savings are due to less expensive heating systems installed in buildings (hydrogen boilers rather than heat pumps), and lower energy costs[*] compared to electricity. This energy cost saving is very sensitive to actual hydrogen price, which is highly uncertain at this stage.

While the secondary scenario is found to cost less overall, the focus throughout this report is on the primary scenario. The understanding of the HyNet plans is that insufficient volumes of hydrogen would be produced in the timescale required for all of Greater Manchester to follow a hydrogen-based decarbonisation pathway, so this report assumes that available hydrogen is likely to be prioritised for districts with substantial industrial requirements[†]. This assumption would need to be considered further with relevant stakeholders such as GMCA and Cadent. However, a full cross-GM secondary pathway is included for illustration of a future where progress on hydrogen occurs faster than expected, for example due to strong backing from national energy policy. Further work with Cadent to understand realistic availability and timescales can help inform the scenario focus as this plan is updated going forward.

Both scenarios include a similar amount of roof and ground mounted solar PV, required in both cases to provide early emissions reduction to support the carbon budget. EV related aspects are consistent across both scenarios.

The primary scenario is broken down by district in the map below. This quantifies and shows the different transitions modelled for each district based on their own unique geography and character.

[*] Based on Hynet projections

[†] Cadent's Greater Manchester decarbonisation pathway report anticipates a proportion of homes being met by electric heat pumps out to 2038 as well as a cluster-based approach of converting discrete sections of the gas network to 100% hydrogen starting with sections of the gas grid heavily relied on by industry.

2. THE VISION – BREAKDOWN OF PRIMARY SCENARIO BY DISTRICT

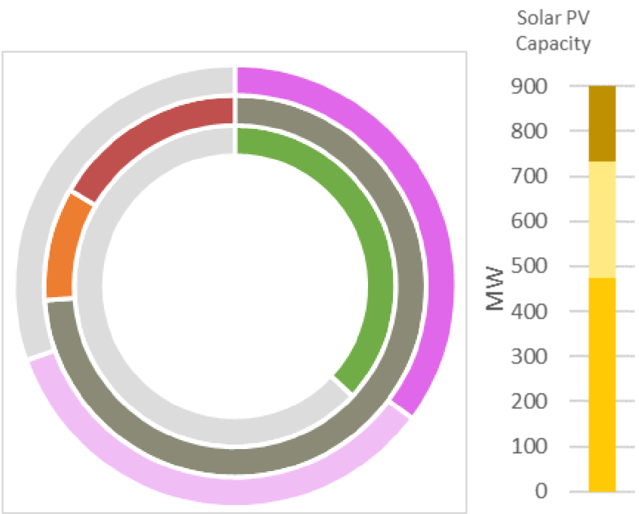
Insulation
- Basic
- Deep

Heating Systems
- Heat Pumps
- Electric Resistive
- District Heat
- Hydrogen Boilers

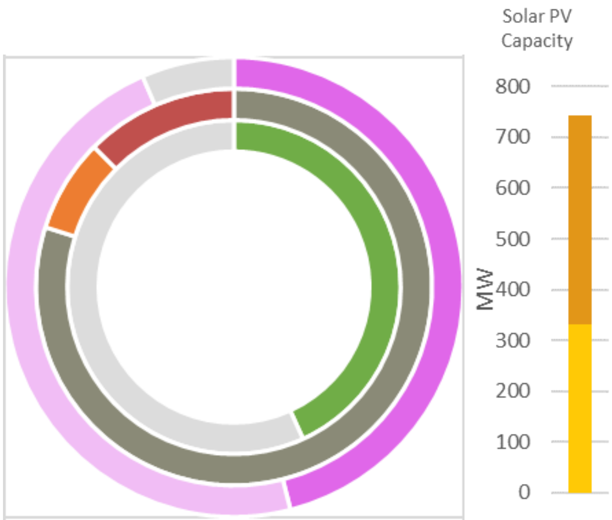
Electric Vehicles
- Homes with EV Chargers
- No change

Solar PV
- Domestic Buildings
- Non-domestic Buildings
- Ground mounted

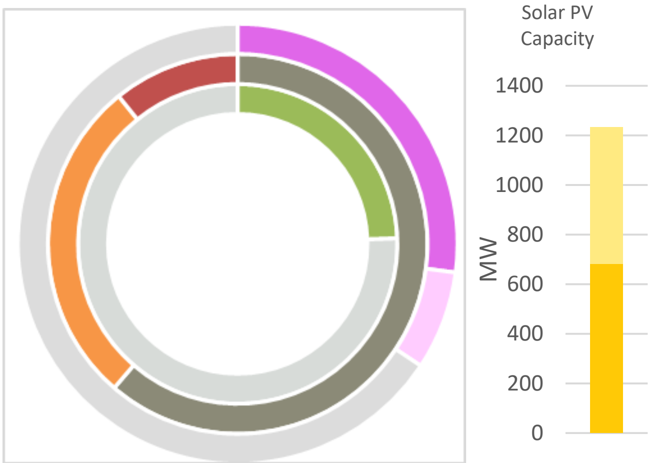
Bolton



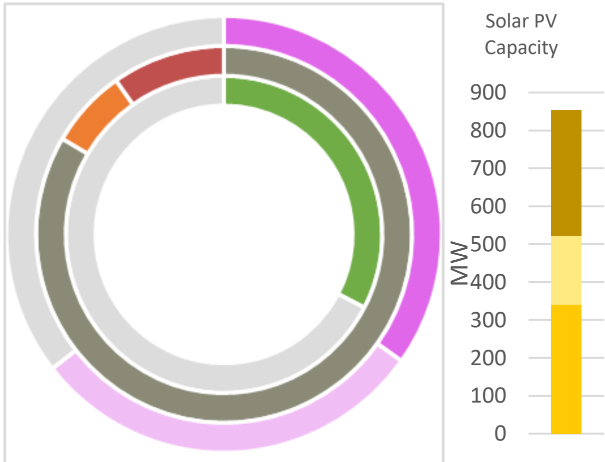
Bury



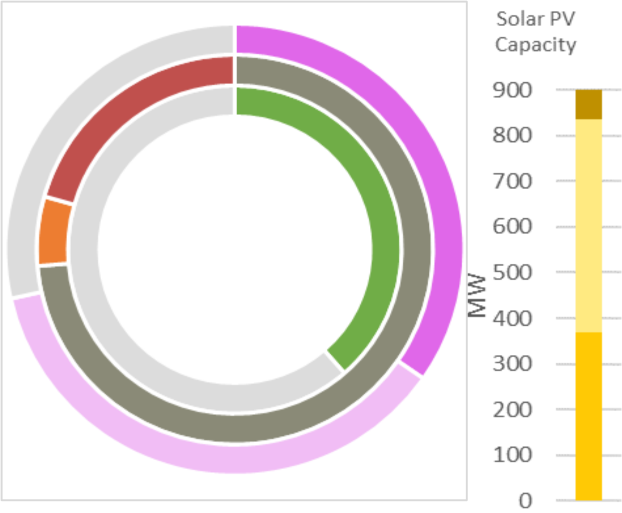
Manchester



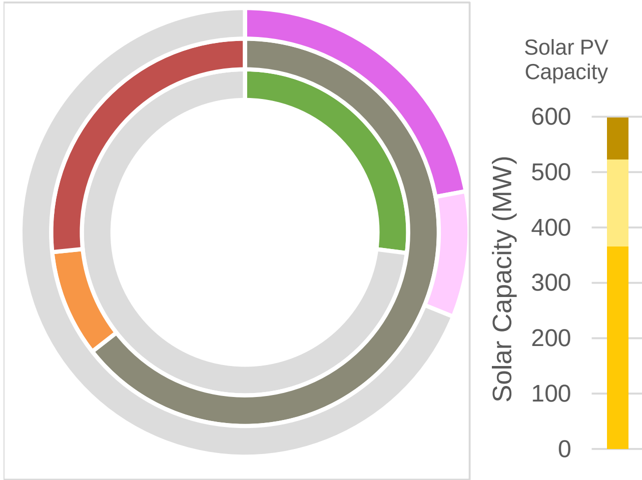
Oldham



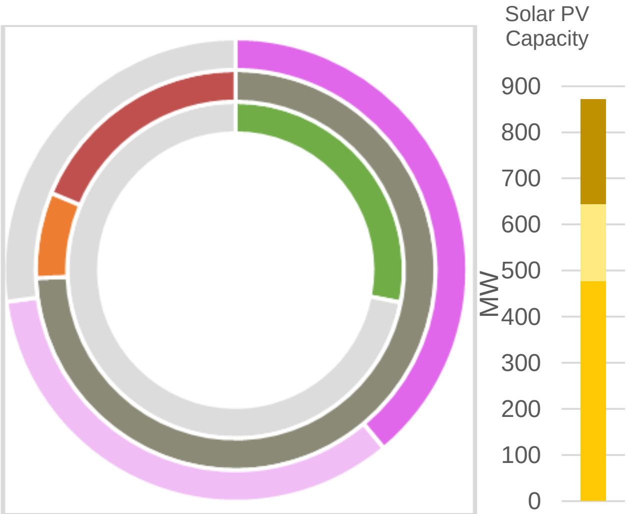
Rochdale



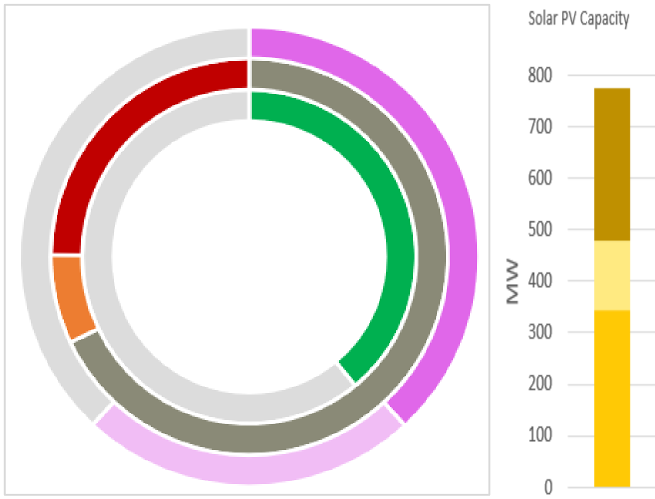
Salford



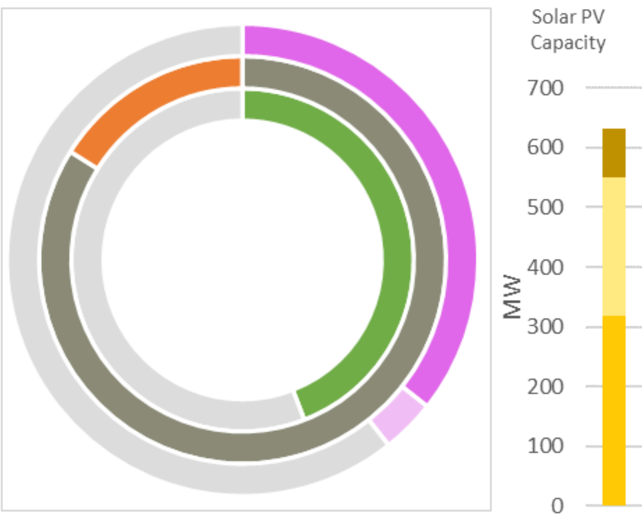
Stockport



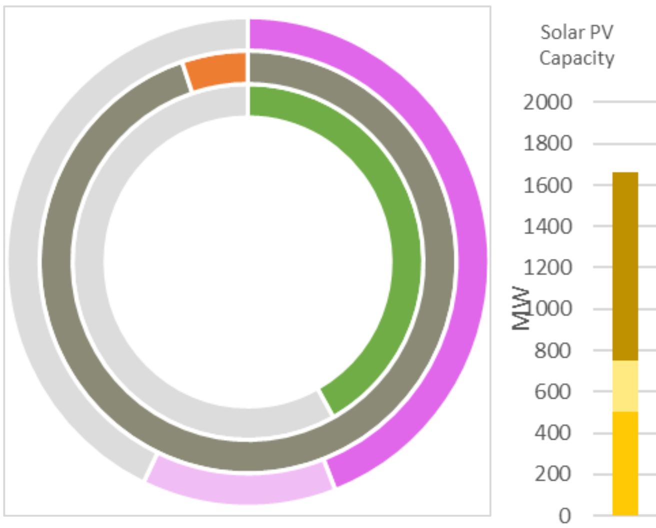
Tameside



Trafford



Wigan



How to use this report

The modelling and LAEP development process was carried out at individual district level for each of the ten GM districts, within which each was geographically sub-divided into a small number (up to 10) of zones for the purposes of assessment and to understand what is needed for decarbonisation at a more local level. The zones were made along the 33-11kV substation boundaries. The figures presented in this report are based on an aggregation of findings across all ten of the district LAEPs.

Each district LAEP has several proposed activities identified to progress towards the carbon budget and target in the near-term, based on a demonstration and scale-up approach, as well as focus areas for changes in the longer term.

These include priority areas to test how to roll out the transition to carbon neutral and work with local citizens in the short-term within each district – the areas illustrated in the maps of GM earlier in this vision section and throughout this report. It is recommended that the impact of these early activities be evaluated by the districts, for example to demonstrate where proposed components of each LAEP are still the cost-effective option, before moving to widescale rollout. This should be done working closely with one another and GMCA to share learning and develop opportunities such as efficiencies of scale from joint procurement. Typical early activities across GM include testing:

- How to roll out heating system and fabric retrofit change alongside renewable energy generation and EV charging infrastructure. Testing how best to combine these components and understand where a whole house retrofit approach may be beneficial
- How additional electricity demand should be provided in an area e.g., through network reinforcement or through providing alternative strategies
- How to engage with stakeholders and provide appealing customer propositions. Should activities be deployed at a neighbourhood level or dispersed across a wider area?
- Taking account of evolving UK energy and heat policy

It is expected that GMCA will work with other key stakeholders, including the ten districts, Cadent, ENWL and delivery partners to develop a co-ordinated approach to this demonstration and delivery programme that maximises the benefits and minimises costs across the whole city region.

To summarise, aspects of this report present a vision (from many possible options), rather than a design, of how GM could move towards carbon neutrality by 2038, built on the outputs of the ten district LAEPs. This is not meant to provide a forecast or recommendation on what GM's actual decarbonisation will be, where it is accepted that technologies, policy, and expectations will evolve over the period of this vision.

The following themes set out both the rationale for how this vision has been produced, identifying several key considerations that will need to be thought about and integrated, alongside demonstration and scale-up activities, as plans to take the ten district LAEPs forward are developed. It is expected that insights from the demonstration activity and considerations of these themes will influence the districts' (and hence GM as a whole's) actual transition.

Modelling Approach and GM Carbon Budget

The GM carbon budget and the modelling approach to develop the ten district LAEPs are the primary drivers for setting out this vision. The GM carbon budget requires an approximate 15% year-on-year emissions reduction. This stringent target drives the need for early decisions and significant action in early years rather than adoption of a 'wait and see' approach with more change in later years. Therefore, the cost-optimised modelling approach used for each district must identify measures from a wide range of options to provide the required short term carbon savings. This results in the identification of measures such as local generation and deep fabric retrofit, which can provide early emission savings. If there wasn't a carbon budget, or there were a later carbon neutrality target, different options would be identified, some of which may have provided a more cost effective (from a whole system perspective) transition or one that would be easier to roll out and less disruptive to building occupants.

There are risks and benefits associated with each of the options discussed and either of the scenarios presented. Because of these, each district's (and therefore GM's) actual transition may result in a combination of the primary and secondary scenario. Before making any widescale and significant commitment to one option or technology over another, evaluation of multiple factors will be needed.

Evaluation

Demonstration of low-regrets and priority actions in the short term (3-5 years) feeds into key decisions in the plan. These decisions also require further evaluation of the following aspects, so that trade-offs between different options and their impacts on consumers are considered before moving from demonstration to large scale implementation, considering associated risks and benefits.

- Local generation is most effective at reducing carbon in the earlier years of the plan, while grid emissions are higher. This contributes to the near-term carbon budget however is less critical for reaching long term targets as grid emissions fall. The large quantity of ground-mounted PV suggested in this plan will require assessment around feasibility, whole energy system integration and public acceptability.

- The timing (regarding the delivery) of HyNet compared to the rate of electricity grid decarbonisation
- The ability to scale-up and install options rapidly aligned to the carbon budget
- The practicality and cost of installing measures in dwellings and non-domestic buildings, for instance air source heat pumps in existing flats
- The disruption associated with options – both within homes and at community level (e.g., traffic disruption from street works)
- Maintaining the gas network to supply sites (e.g., industrial) in areas that are expected to be heat pump prevalent
- How an electrified heat future would be paid for, recognising the greater in-building investment required to move off-gas
- Coordination between GM districts in relation to energy network options, where GMCA has a potential role to play as convenor and coordinator
- Social and community benefits
- How to fund options and the preferences of investors

Consultation

Further consultation will be needed with key stakeholders, including the ten districts, Cadent, ENWL and delivery partners to consider these factors when developing demonstration and scale-up activity.

In addition, consultation with GM's citizens is essential to help understand attitudes towards the carbon neutrality transition, whilst also forming part of the evaluation process. This will help GM and the ten districts communicate with their citizens so that they understand the transition and can help to inform plans to take forward the ten district LAEPs.

Citizen consultation will help to:

- Communicate GM and the districts' intentions
- Understand what people want and which options they are supportive of
- Identify areas to focus demonstration and then wider roll-out activity
- Provide confidence to the organisations that will be involved in the delivery of GM's transition that there is a demand for solutions, products, and services

An initial consultation has been held for each of the ten district LAEPs using the zerocarbon.vote tool, as described in section 10 of this report.

Vision to 2038

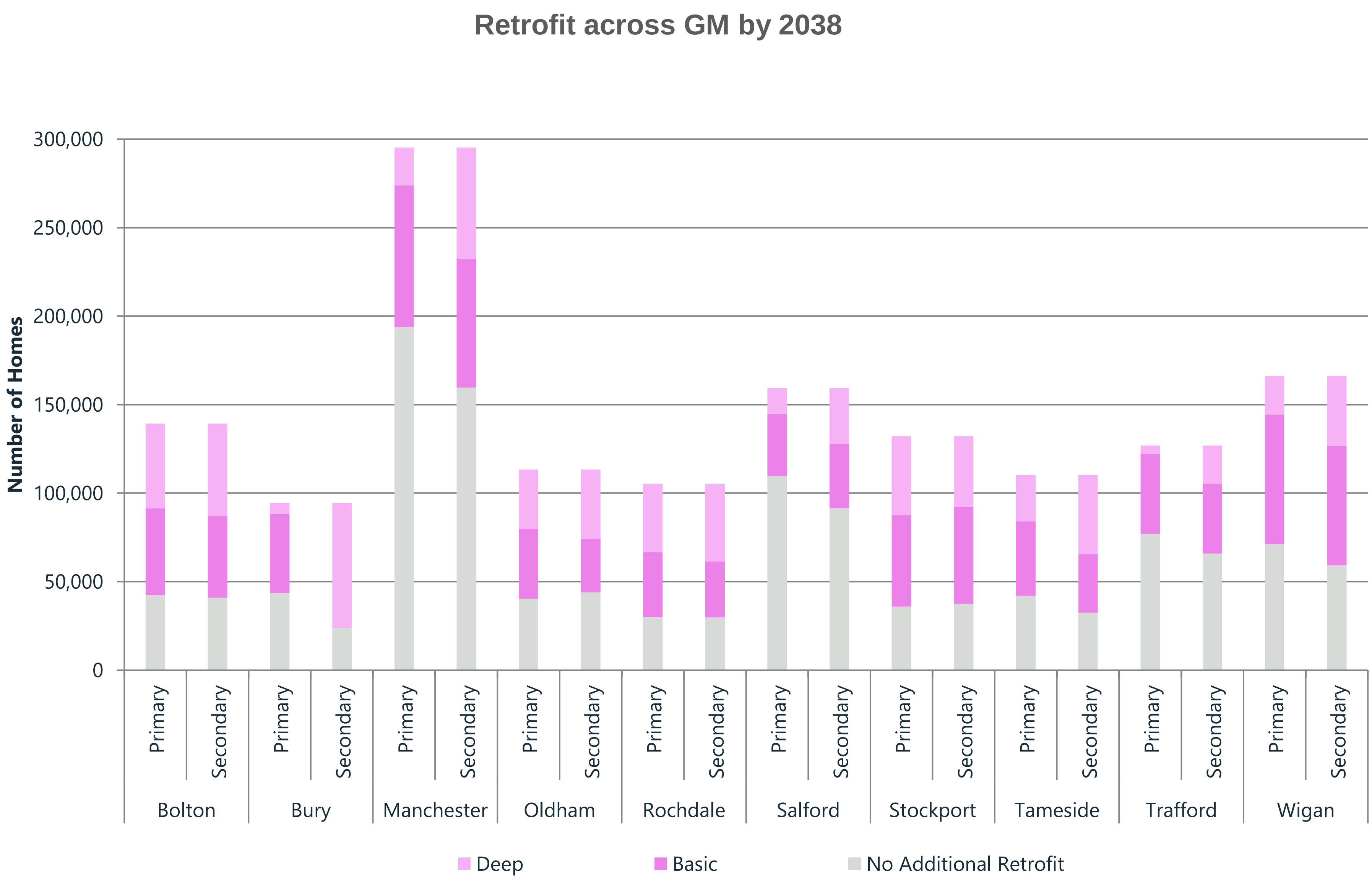
A significant portion of existing homes and buildings in GM will require further retrofit, carrying out insulation in **more than 750,000 dwellings.** This is true for both scenarios, whether electrification or hydrogen forms the bulk of the heating solution, so early focus and investment in fabric retrofit would be a low regret step. **More dwellings receive deep retrofits in the secondary (hydrogen) scenario** (almost 450,000, compared to 250,000 in the primary scenario). This is because of a need to reduce emissions in the early years to comply with the carbon budget while waiting for hydrogen to become available. In contrast, heating systems are decarbonised earlier in the primary scenario by installing heat pumps, therefore, the requirement to reduce emissions through fabric retrofit is reduced.

However, regardless of the heating system used, additional level of fabric retrofit may be needed to address affordability issues, for example, there is an expected higher cost of hydrogen compared to gas*. Retrofits are deeper in the secondary scenario, and there are over 100,000 more overall, despite hydrogen boilers being able to supply radiators at higher temperatures than heat pumps, making insulation less critical for good performance. This is because of a need to use retrofit to reduce carbon emissions earlier in the period to 2038, as hydrogen will not be available until later and so carbon emissions reductions associated with it will be late.

Fabric retrofit could be combined with other measures such as heating system replacement, PV installation and EV chargers to minimise number of visits required to homes, as in the “cost effective retrofit” option later in this section.

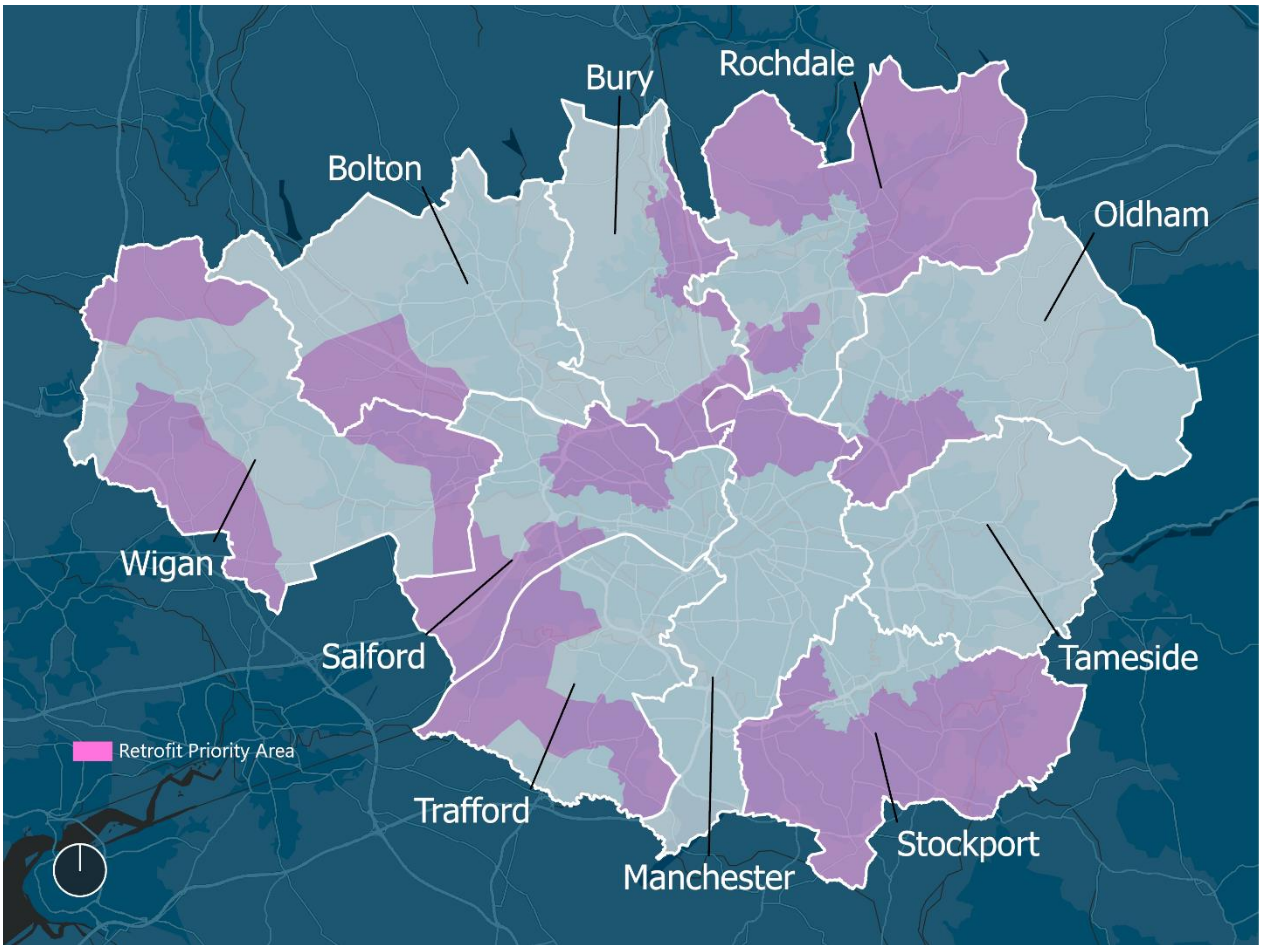
Flats, which tend to have lower heat loss, show lower benefits from fabric retrofit, so are less of a focus area, and therefore districts with higher proportions of flats see overall lower quantities of insulation. However, further specific consideration will be needed at a building level to determine buildings that would benefit. For example, if a block of flats were to pursue a communal heating system, then the optimum balance between fabric improvement (to reduce heat loss and demand) and internal heating distribution systems would need to be specified, dependent on the heating system design strategy, recognising that a whole energy system approach will always be needed at a building level. Newer houses often already have better standards of insulation and fabric energy efficiency, but many will still need some treatment, unless built to the most recent building standards.

* Estimates vary - see for example projections for initial HyNet cost of hydrogen at around 150% uplift over natural gas https://hynet.co.uk/wp-content/uploads/2021/06/14368_CADENT_PROJECT_REPORT_AMENDED_v22105.pdf [page 15]


Retrofit across GM by 2038
Number of Homes
300,000
250,000
200,000
150,000
100,000
50,000
0
Primary
Secondary
Bolton
Bury
Manchester
Oldham
Rochdale
Salford
Stockport
Tameside
Trafford
Wigan
Deep
Basic
No Additional Retrofit

First Steps – Priority Areas

Whilst large numbers of dwellings will need to be retrofitted to improve energy efficiency across all areas of GM, several retrofit priority zones have been identified in each district. The purpose of providing these priority zones is to highlight areas where demonstration and scale-up could be prioritised over the near-term (<5 years)*. The areas have been selected as they are regarded as low regret, are considered to be cost effective to receive fabric retrofit measures, regardless of the type of heating system (e.g., hydrogen or a heat pump) that is used to replace natural gas boilers. The map below sets out the priority areas for retrofit in each district.



* Fabric retrofit measures have been identified following a whole energy system approach, considering the cost-effectiveness of fabric retrofit measures alongside other options to achieve carbon neutrality in GM. This does not mean that individual dwellings or buildings would not benefit from additional retrofit measures when considered on a case-by-case basis, particularly as part of a package of wider measures that could include heating system change and PV installation. During the development of any activity or plans to progress the ten district LAEPs, consideration will be needed to determine the optimum approach for deployment, when appraised alongside the approach for taking forward any of the other components of the LAEPs. For example, in some cases a whole house retrofit may be beneficial, taking account of other GMCA activity, such as the Pathways to Healthy Net Zero Housing for Greater Manchester report and recommendations: https://democracy.greatermanchester-ca.gov.uk/documents/s13523/07%20Pathways%20to%20Healthy%20Net%20Zero%20Housing%20GM_Report.pdf

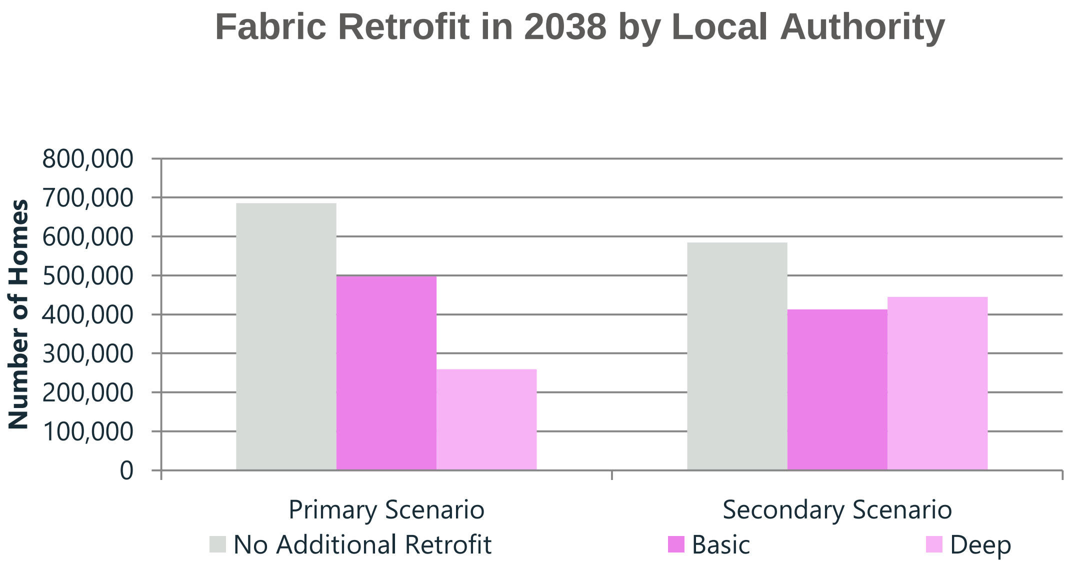
Fabric Retrofit Approach

Retrofit measures should be tailored for the individual dwelling, taking account of its type, age, construction, existing insulation, and likely future heating system. For example, cavity wall insulation will only be applicable to dwellings that have suitable* cavities (usually post-1920 properties) that are not already filled. Narrow cavities, common in interwar houses, are likely to be unfilled, having been considered "hard to treat" during previous rounds of cavity treatment; targeting these dwelling types is a key focus.

The retrofit zones identified for each district are designed to allow the coordinated targeting of interventions within each district in such a way that supports and aligns with their wider local energy system transformation. There is an opportunity for wider collaboration across GM and between the districts to develop funding and financing packages, develop supply chains and make use of efficiencies of scale in procurement.

There is uncertainty in the specific measures needed and most suitable for individual homes as exact details of the existing fabric efficiency of any given dwelling are not known. Survey work will be needed before any works are undertaken.

The difference between difference insulation measures across GM is shown below. In both scenarios this account for most of the housing stock within GM receiving further insulation – 52% in the primary scenario, and 59% in the secondary.



In both scenarios at least 250,000 homes receive deep retrofit with over 400,000 receiving basic retrofit. Carrying out basic measures in earlier years would not preclude deeper measures being installed in homes in later years. Therefore, basic measures and most of the deep measures are considered low regret across all scenarios and heating system selections.

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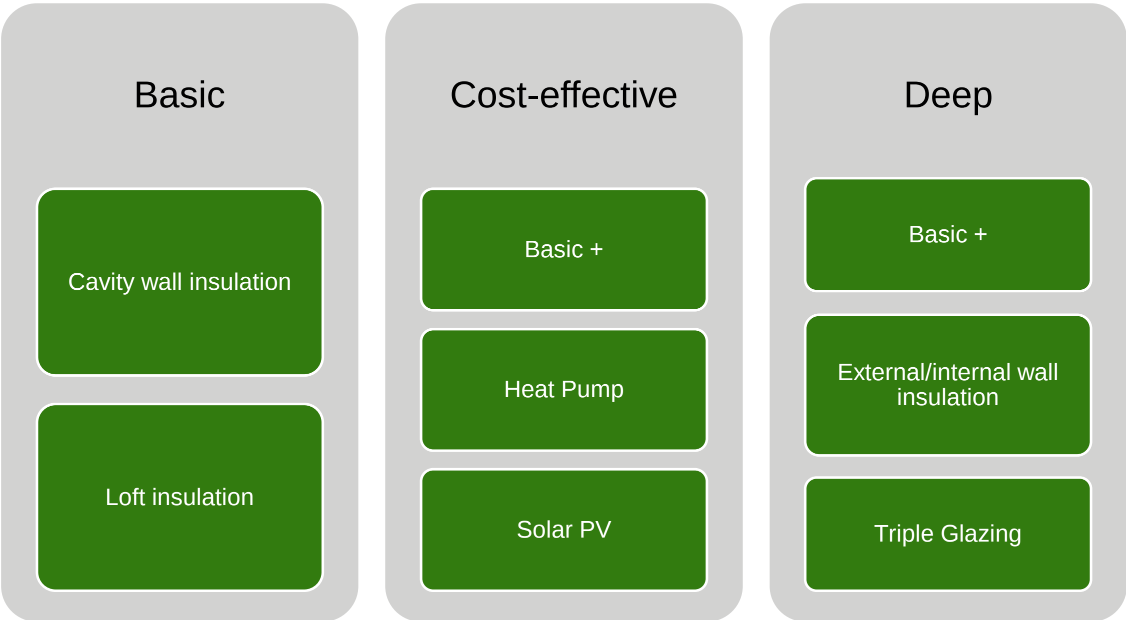
* Consideration will be needed to identify a suitable approach for insulating inter-war cavity walls, noting cavity widths are generally smaller than more modern dwellings; considering aspects such as insulation type and damp prevention, where solid wall insulation may be needed on some dwellings with cavity walls

Cost-Effective Deployment

The proposed approach centres on ensuring fabric retrofit measures are implemented in the vast majority of suitable homes in GM, which is found to be the most cost-effective approach for the whole system. However, deployment of measures should not be considered in isolation: integration with other components (such as heating system changes, PV installation and EV chargers) can help minimise disruption and offer cost savings, and so opportunities to develop cost-effective whole-house approaches will need to be considered during the development of any activity to take forward the ten district LAEPs. The range of different potential packages is illustrated in the diagram below*.



Rapid deployment of retrofit measures could be a relatively easy intervention in the near term, which is especially beneficial for staying within the carbon budget. The rate of deployment that is possible will depend on the development of a supply chain and business models; developing this in the next few years could allow for higher deployment rates in the medium term to support progress with decarbonisation where there may not yet be clarity on heating systems across all parts of GM. Collaboration between GMCA and the districts would be key to optimising delivery.

In a hydrogen scenario, the number of dwellings expected to need deep retrofit would be even greater than in an electrified scenario. This is due to the later introduction of hydrogen than heat pumps, meaning that emissions savings need to be achieved by other means in the early years to stay within carbon budgets.

* The modelled packages align loosely with packages in the Pathways to Healthy Net Zero Housing for Greater Manchester, with some differences due to the modelling approach. The 'deep' package here is like the fabric measures in the 'deep' package in Pathways. The 'basic' package in this report is loosely comparable to the fabric measures in the 'cost-effective' package in the Pathways report, but generally does not include external/internal wall insulation. The cost-effective package illustrated here was not part of the modelling but may be a useful 'real life' approach for individual houses when wider factors are considered.

Deeper Retrofit

The approach described is based on finding the most cost-effective route for decarbonising GM overall, in line with the carbon budget. However, there may be strong reasons for additional retrofit work and so deeper and more extensive retrofit for individual dwellings is possible, with the potential to bring benefits including:

- Increased comfort and reduced running costs for individual households. This could also be important for some households to reduce fuel poverty and improve health and general quality of life, particularly after considering recent energy price rises
- Potential to reduce energy consumption and associated carbon emissions across GM more quickly. This would give greater headroom in the carbon budget, especially if carried out early in the plan, allowing strategic decisions to be made later (e.g., around the future of the gas grid). Or, to replace emissions savings that are currently proposed through other measures (e.g., the significant quantify of local electricity generation)

Supporting Low Carbon Heat

The improvement of building insulation supports the roll out of low carbon heat in several ways. By reducing the heat demand, less powerful heating systems can be installed, reducing capital costs. The reduced demand for heat will also compensate for a shift to a more expensive energy source (gas to electricity or hydrogen). Finally, reduced heat losses enable heat pumps and district heat networks to run at lower temperatures, improving their efficiency and running costs, and may also reduce the need for radiator upgrades in homes.

It therefore makes sense to carry out retrofit either before or at the same time as heating system replacements to capture these benefits. Carrying out both activities at the same time would minimise the number of disruptions experienced by households, while insulating earlier would provide further emissions reductions compared to the modelled scenarios.

Key insights

- Most homes across GM will need some level of fabric retrofit, and the case for this is likely to have increased with recent energy price rises
- Proportionately less fabric retrofit is seen in districts with higher quantities of flats (such as Manchester), but even these areas see large numbers of homes requiring fabric retrofit
- Fabric retrofit is generally low regret across all scenarios, as the later deployment of hydrogen means more carbon savings are required in earlier years from retrofit in the secondary scenario

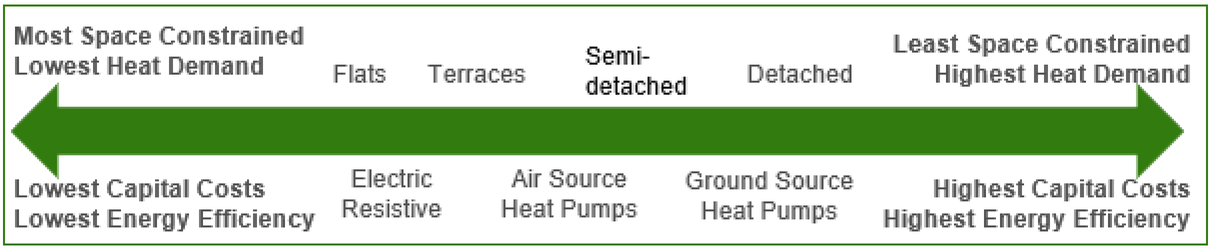
- Fabric retrofit as part of a package of measures (such as heat pumps and solar PB, where relevant for an individual home) may help to minimise disruption and be more cost-effective for a household overall.

Vision to 2038

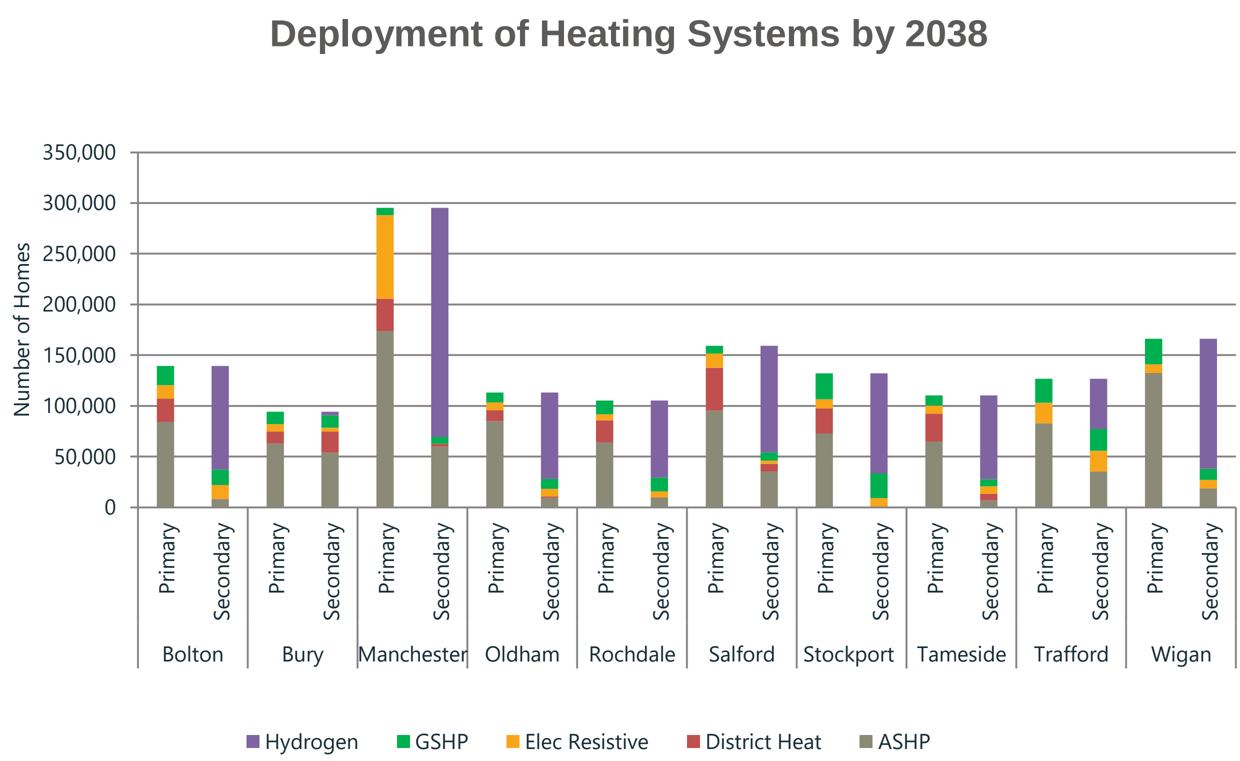
Building characteristics and existing network characteristics inform the low carbon heating system best suited to each building, and this causes patterns to emerge between the zones across Greater Manchester. In the primary scenario, the decarbonisation of heat is primarily achieved through installation of electric heat pumps in existing and new homes, comprising over 1,000,000 domestic heat pump installations. Other electric systems are also present in less significant numbers. Some districts see relatively limited uptake of hydrogen in the secondary scenario (Bury and Trafford), while in others it is more predominant. However, in all districts it has been possible to identify areas of low regret where heat pumps would make sense even if hydrogen becomes available. Opportunities for district heat networks are also present in all districts, but with a stronger case for this sort of system in some areas than in others.

Heating System Selection

Standalone electric heating systems are selected according to building characteristics as shown in the diagram below.



Air source heat pumps are the most widely suited electric heating technology, though a small proportion of homes in most areas was found to be suitable for ground source heat pumps, where greater outdoor space permits the installation of a ground collector, and larger properties may justify the higher upfront cost with greater savings in running costs. These properties would also be suitable for air source if preferred. The ASHP category includes high temperature, low temperature, and hybrid types, according to the needs of individual buildings. Electric resistive (conventional heaters) remains a viable option when heat demand and losses are low, such as in flats. This can be seen in more urban areas such as Manchester and Trafford, as demonstrated in the graph below that shows deployment of heating systems across GM by 2038.



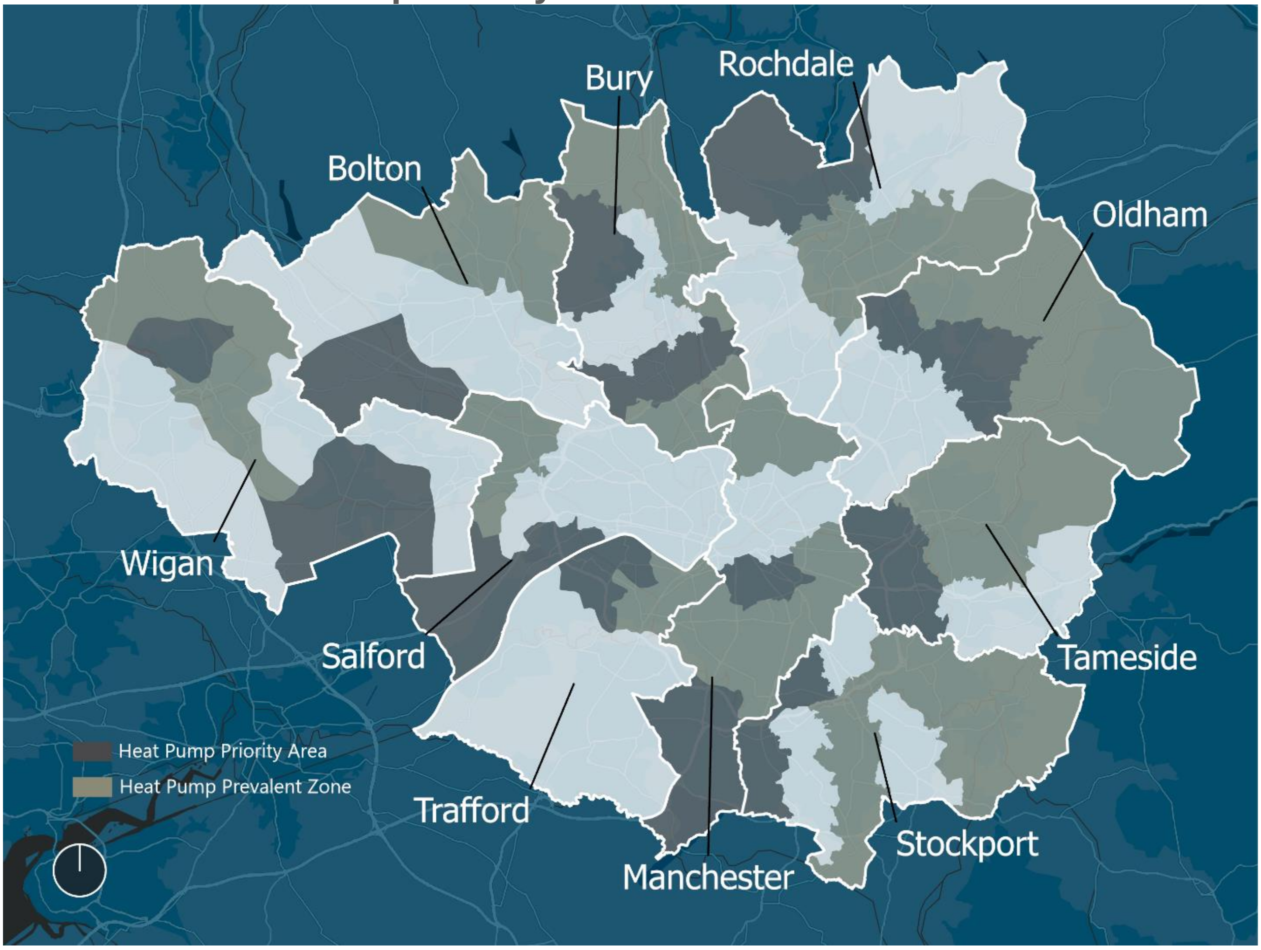
Heat pumps are a proven and mature renewable heating technology, capable of delivering deep emissions reductions today. They can be rolled out to individual households gradually, without the requirement for large scale area transitions and buy-in from multiple households that district heating and hydrogen require. Some disruption within the home is typically required for radiator replacements and the installation of a hot water cylinder in homes which do not have one already. These indoor space requirements, together with the need to manage disruption to the household and locating a space for the outdoor unit where it will not cause noise issues for neighbouring properties, must be considered in the design, and can make heat pumps unsuitable for some properties. These issues would be avoided with hydrogen boilers, which would be a like-for-like replacement for natural gas boilers.

Heat pumps perform best in homes with good levels of insulation, so building retrofit should be considered alongside heat pump installations to minimise disruption to dwelling occupants. This would also reduce overall cost by allowing smaller heat pumps to be used and fewer radiators to be upgraded due to reduced heat demand.

First Steps: Heat Pump Priority Areas

The findings of the ten district LAEPs show that heat pumps would be used significantly even when there is hydrogen available, providing heat to over 360,000 homes. By correlating these areas of high concentration between both the primary and secondary scenarios, a series of prevalent zones and low regret priority areas have been identified, as indicated on the map below.

Heat Pump Priority Areas and Prevalent Zones



Heat pump priority areas have been identified as low regret for heat pumps whether hydrogen becomes available for heating. These can be a near term focus for GMCA and the districts to work together to develop skills, supply chain and funding models to test and scale up the roll out of heat pumps

Heat pump prevalent zones are predominantly heated by heat pump in the primary scenario, but may transition to hydrogen under the secondary scenario, and therefore could be a more medium-term focus, once there is greater clarity on the likely role of hydrogen for heat in GM. Even if some hydrogen does become available for heating, it may not be enough to supply all of GM so, as discussed in the hydrogen sections of this report, it may be necessary to prioritise which districts receive it. This would feed into decisions on how to progress the heat pump prevalent zones. For example, eastern parts of Oldham and Tameside are not identified as hydrogen opportunity areas (see Hydrogen for Heating section below) and are also considerably distanced from the likely initial ingress point of hydrogen into GM. Therefore, these areas may be lower down the GM-wide priority list for roll out of hydrogen, and so the heat pump prevalent zones identified in these areas might be more likely to indeed end up with a heat pump-predominant future. Conversely, areas of Trafford and Salford identified as heat pump prevalent zones are much nearer the ingress point, and so may be more likely to have hydrogen for heating feature in the future.

Zones not specifically identified as priority or prevalent areas for heat pumps zones (i.e., the unshaded areas), have either been identified as potential heat network or hydrogen zones, or are areas where there is no clear dominant technology. It should be noted that in practice there will be a mix of technologies need in every area, and just because an area is indicated as a priority zone for a certain technology, doesn't mean that every home in that area will be suited for that technology. Equally, in areas not identified as heat pump priority or prevalent areas, many buildings may be suitable for that technology, and individual building owners may still decide to install heat pumps: this should not be discouraged as this will still be a beneficial move in support of the carbon savings that GMCA has committed to.

District Heat Networks

Heat supplied through underground pipes from a centralised energy centre tends to be most suitable for denser urban areas, particularly where there are large numbers of dwellings which are either too expensive or impractical (e.g., due to space limitations) to make suitable for heat pumps.

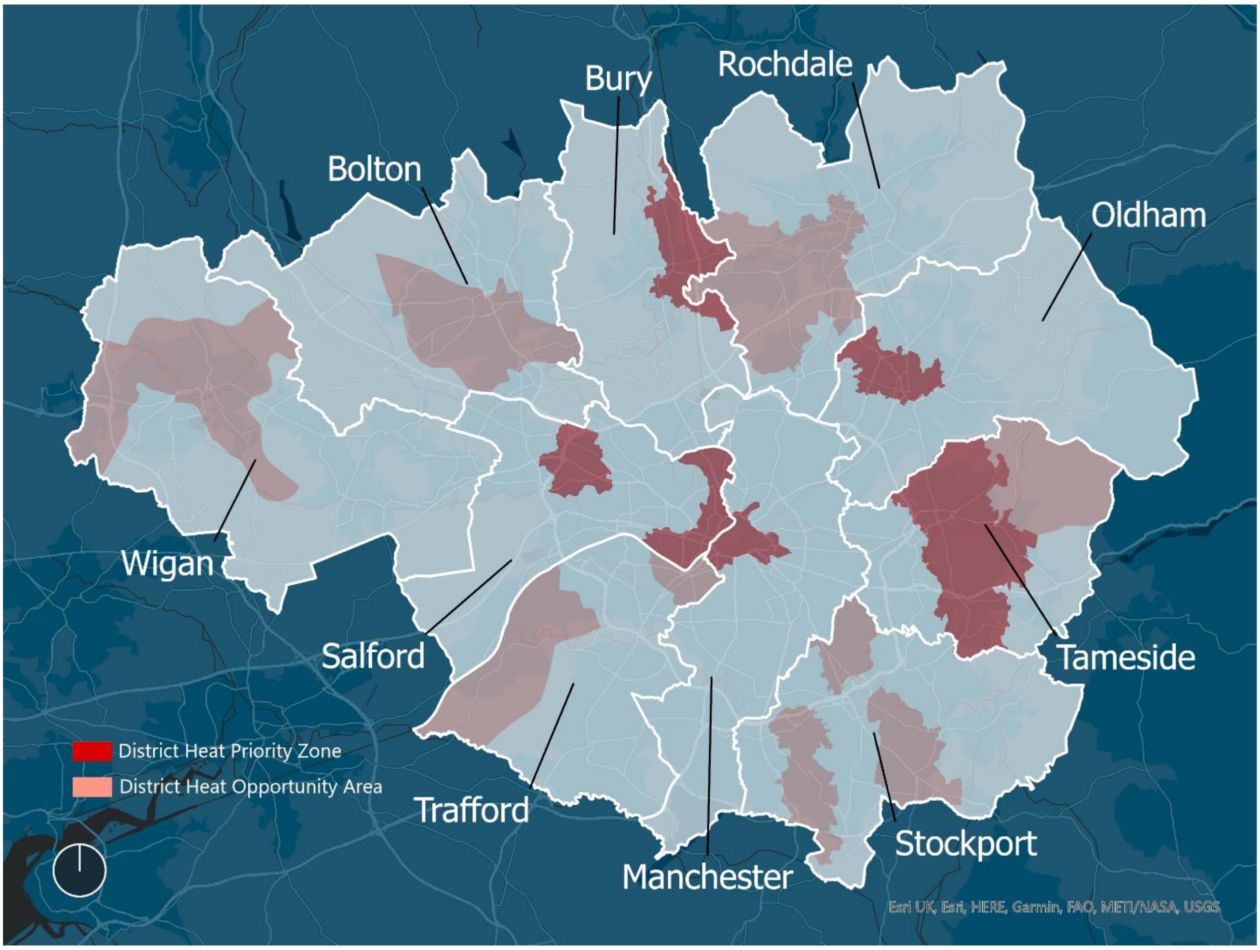
Heat networks can have the advantage of causing less disruption in dwellings during installation compared to some other options, though there are wider considerations such as disruption to roads during pipe laying, and space restrictions in town centres.

Areas potentially suited to heat networks as an effective heat decarbonisation solution have been identified in most of the districts of GM. Those identified as 'priority zones' are considered to have the strongest case, whereas those identified as 'opportunity areas' may be more marginal or are supported by other existing studies. Greater Manchester's ambitious carbon targets, along with the set of possible technologies available within the scope of modelling, drive the model to select high levels of heat network deployment to minimise emissions. However, in the 'opportunity areas' the assumed additional carbon savings from heat networks can be marginal for the additional cost, resulting in a high cost to carbon saving ratio. There may be alternative options in other sectors or in emerging technologies (such as carbon sequestration, agricultural practices, etc.) which could deliver more cost-effective carbon emissions reduction. These areas should therefore be regarded as initial opportunity areas for further consideration, where more detailed assessment would be required, as would be the case with any heat decarbonisation option. In addition, the specific feasibility and configuration of all district heating networks, including energy centre locations, plant design etc. will require appropriate assessment to take forward.

It should also be highlighted those opportunities identified in the modelling work are based on carbon being a driver, an overall cost to society (excluding taxes and funding availability) and a long term focus out to 2038. Therefore, commercially viable heat networks may be identified in other areas since these are likely to be focussed on short term payback, prioritisation around cost from the investor's perspective and based on the current policy landscape and funding availability.

When developing heat networks near the boundary of a district, there is an opportunity for GM and the districts to consider potential to extend across into the neighbouring districts, where there are suitable buildings. This is considered particularly likely in northern Salford and western Manchester, and potentially also northern Trafford, which represent the most densely built-up areas of GM where several district heating schemes are already in existence or under development. In this wider cluster there may also be the opportunity to join up more than one network, which could bring advantages such as greater resilience through having multiple heat sources connected.

District Heat Priority Zones and Opportunity Areas



Hydrogen for Heating

The representation of hydrogen in the analysis for this plan has been aligned with the proposals for HyNet in the Northwest of England, and the associated opportunities for the GMCA area.

The primary scenario reflects phases 1 and 2 of HyNet, where low carbon hydrogen may be available from 2025 onwards for the largest industrial sites in the region, primarily in Trafford. The secondary scenario includes the possibility of HyNet phase 3, where low carbon hydrogen becomes available for homes and the full range of non-domestic buildings from the early 2030s onwards. This would require the repurposing of areas of gas grid to serve hydrogen to the buildings. Under this scenario it is found to be cost effective to provide hydrogen to domestic and non-domestic buildings in many areas of GM, resulting in a potential shift to hydrogen dominated heating. One of the key considerations is that the hydrogen based secondary scenario is assumed to be significantly cheaper than the primary scenario (£60 bn compared to £65 bn); however, this is dependent on HyNet phase being delivered on time and at the cost and carbon projections provided by HyNet. Taking a wait-and-see approach is therefore deemed extremely risky when there is a 2038 carbon target; the scale-up and demonstration approach in the identified priority areas are therefore provided so that short to medium term activity can take place in areas of least regret.

A further scenario was also studied where hydrogen was tested as the only low carbon option (detailed in the appendix). Further analysis of both this and the secondary scenario showed that the total carbon emitted was very sensitive to the exact year that low carbon hydrogen became available in suitable quantities, which has a high level of uncertainty.

Under scenarios where HyNet phase 3 happens and low carbon hydrogen is available to the grid in the early 2030s, hydrogen heating displaces much of the electric and district heating across most districts. This would occur as individual boilers in homes, although in district heating areas, the energy centre could use hydrogen boilers, making district heating a low regrets option in the face of hydrogen uncertainty.

Sensitivity analysis exploring a range of hydrogen cost and carbon content by zone, and consideration of other factors such as presence of dense industrial areas, led to the identification of a number of areas across GM where hydrogen would most likely be cost-effective to deploy, as shown in the map below.

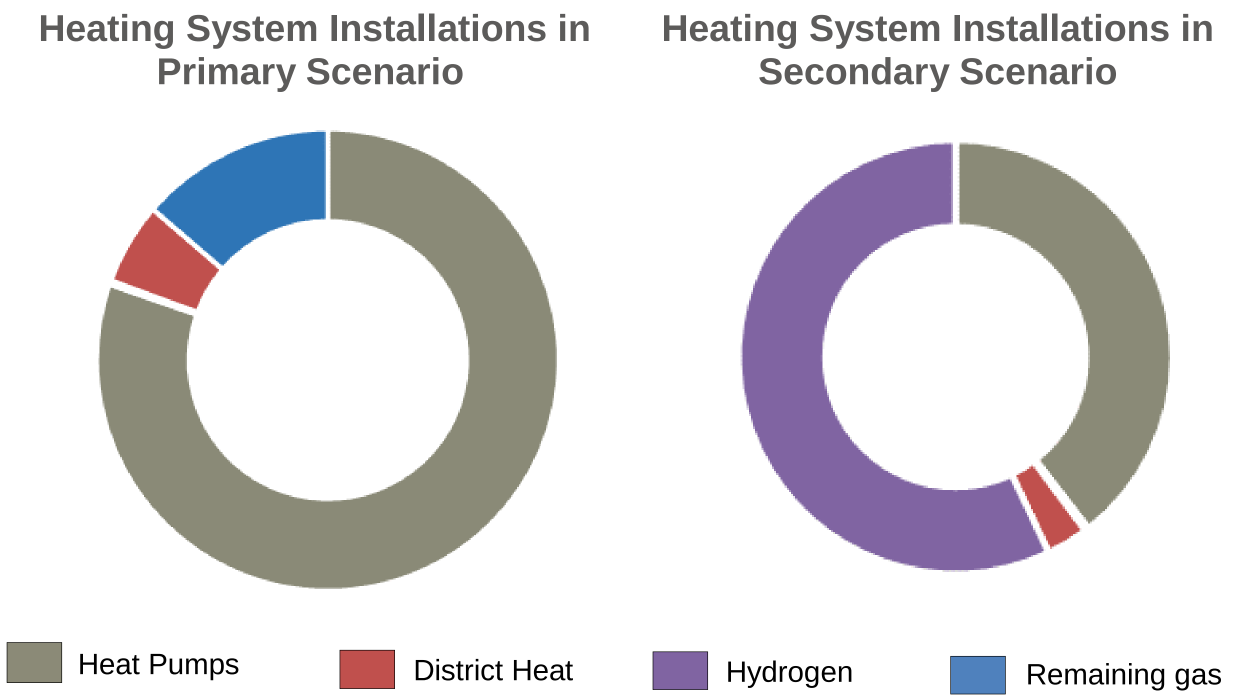
Hydrogen for Heat Opportunity Areas

The initial ingress point for hydrogen into GM is expected to be along the Manchester Ship Canal, as shown on the map above. This may affect which districts are more likely to have access to hydrogen for heating soonest, should phase 3 of HyNet go ahead. In the case that quantities of hydrogen are limited and cannot supply all areas of GM, GMCA will need to work with the districts, Cadent, the promoters of the HyNet scheme and other stakeholders to establish how supply could be prioritised. An initial focus is likely to be areas near to the ingress point (particularly Salford and Trafford), with western parts of Wigan also having potential due to proximity to another branch of the proposed HyNet pipeline. Conversely, eastern areas may be less obvious starting points. Of note, the opportunity areas identified highlight the areas within each district where there is the strongest evidence for potentially utilising hydrogen for heat decarbonisation. Within the secondary scenario many other neighbouring zones within each district were also shown as being cost-effective to use hydrogen, therefore, were hydrogen to be available (in line with the projections/assumptions considered in the LAEPs), then consideration would need to be given to how hydrogen would be deployed, which could result in more area wide provision, rather than at targeted/specific zones.

Non-domestic Buildings

With the requirement to rapidly reduce CO_2 emissions in line with the GM's carbon budget, the primary scenario is based on an individual heat pump transition for most of GM's non-domestic buildings; however, district heating may be suited to specific buildings, particularly in areas identified as district heating priority zones or opportunity areas (see above). More detailed analysis is needed that considers buildings at a more granular level to determine which buildings are suitable, but certain types of buildings can play in important role in developing heat networks. These include publicly owned buildings, where it may be easier for GMCA and the districts to gain commitment from the owners for buildings to be connected to a heat network, and buildings that have consistent high heat usage and a good baseload (such as hospitals and swimming pools), that can act as anchor loads.

The graphs below show the estimated proportion of heating system types in GM's non-domestic buildings by 2038. The estimated combined investment (for improving the energy efficiency and installing heat pumps) is in the region of £22bn.



- Most GM's non-domestic buildings (80% by floor area) have been deemed able to transition to a heat pump option,
- 6% (by total floor area) has been deemed able to transition to district heat networks.
- A small proportion (14% by floor area) are deemed to be reliant on either gas or hydrogen for use in industrial processes
- Further area-specific and detailed consideration is required to identify the most appropriate non-domestic solutions.

Non-domestic Buildings Priority Areas

Several non-domestic building priority areas have also been identified in the district LAEPs. These are where clusters of certain use types make it more likely that a certain heating type will predominate, and so would be useful areas for GMCA and the district to develop and test ways to roll out decarbonisation to these buildings.

Key insights

- Priority areas for heat pumps have been identified in all districts and can be a focus for low regret near term action to pilot, scale up and roll out installation of heat pumps, regardless of whether hydrogen for heating becomes available
- There are opportunities to consider expanding and even joining up heat networks across district boundaries, particularly at the nexus of Salford, Manchester, and Trafford, where several existing/planned schemes and further heat network opportunities are in close proximity
- Hydrogen could be a valuable option for heating in many parts of GM, should it become available at the necessary quantities, cost, and carbon content. It is most likely to be distributed initially to areas around the ingress point, and so eastern areas of GM could be more likely to move to a predominantly electrically heated future, even if HyNet 3 does progress.

Vision to 2038

Electric Vehicle (EV) ownership is expected to grow significantly across all districts of Greater Manchester to support local decarbonisation targets and in alignment with national policy, which will see the phasing out of internal combustion engine vehicle sales by 2030 and hybrids by 2035.

Fully electric and plug-in hybrid vehicles (PHVs) in GM are expected to grow from around 40,000 today to around 1,050,000 cars by 2038 – 76% of the total fleet. Charging infrastructure will need to be installed to encourage this transition and keep up with this demand, providing confidence that owners will be able to recharge when needed. A mixture of publicly accessible and private residential chargers will be required to provide this amenity.

Greater Manchester's Transport Strategy 2040 sets out an ambition that no more than 50% of daily trips (across all modes) will be made by car in 2040, down from 61% today. Considering an expected overall growth in trips, the strategy sets out that meeting this target would mean a reduction of car trips from the current 3.7m per day to 3.4m. This however still represents a significant demand for EV charging within GM.

Since EV transition, supported by publicly accessible and home chargers, is a consistent result across all scenarios in all districts, all moves to make first steps in charger deployment can be considered low regret across GM.

Scope of Transport

The scope of the district-by-district modelling that forms the basis of the ten district LAEPs, and therefore this report, includes home charging of personal electric cars within each district but excludes emissions from all usage of liquid fuels for transportation, and electricity use for vehicles other than personal cars (including public transport such as Metrolink). Therefore, it should be noted that not all the transport emissions within the scope of the GM carbon budget are included here.

The following points discuss some of these wider transport aspects:

- Current liquid fuel use (primarily petrol and diesel) has very limited interactions with the wider energy system (within the boundaries of GMCA) and therefore is not part of the scope
- Personal vehicles are currently expected to transition primarily to electric vehicles and are assumed to be primarily charged at or close to home (e.g., in public charging hubs). This means that relevant energy system impacts are generally within the district, and that the impact of in/out-commuting is considered limited under a future where electrified transport has largely eliminated tailpipe emissions
- The decarbonisation route for larger vehicles (including HGVs) is less certain and may include a variety of solutions such as hydrogen fuel cells as well as batteries;

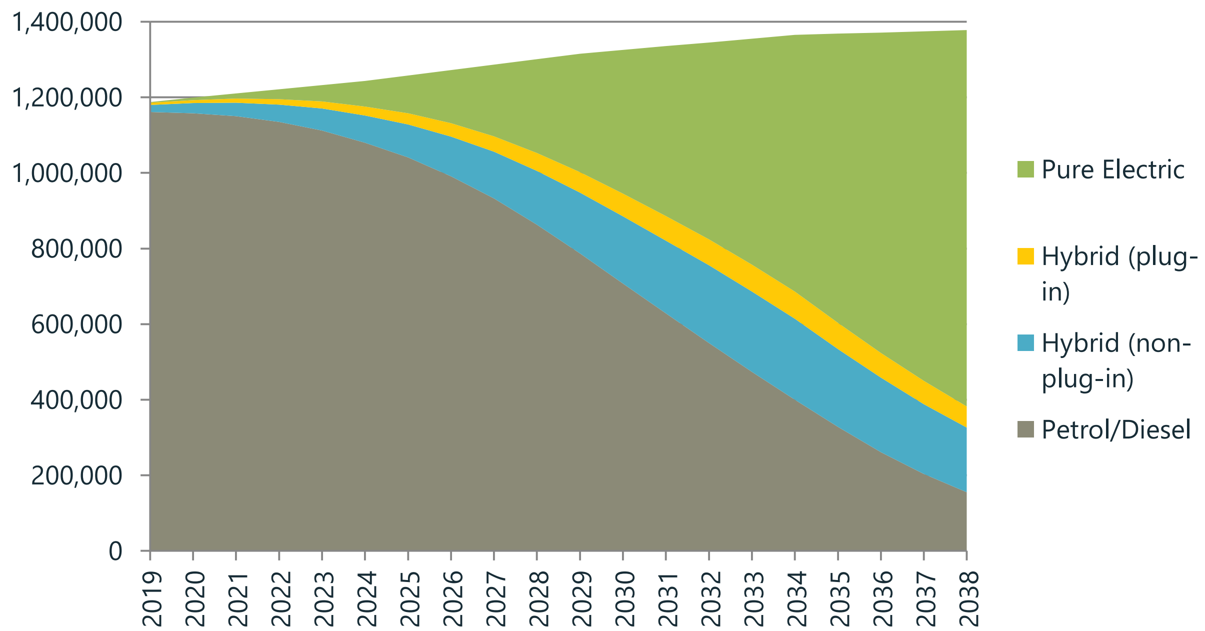
infrastructure to support these may require bespoke consideration dependent on supply chain and/or network impacts.

Projected Vehicle Mix Over Time

The projected vehicle mix is based on annual data published by the Department for Transport* on registered vehicle types by local authority. For these projections it is assumed that the average number of vehicles per household remains the same, therefore the number will increase proportionally with housing growth. This allows a worst-case scenario in terms of demand and network reinforcement that may be required.

The projections are forecast around the government's proposed 2030 ban on the sales of new purely internal combustion engine (ICE) vehicles and 2035 ban on hybrid (battery + ICE) vehicles. It is expected that, due to vehicles sold before these dates still being on the road in 2038, that battery electric and plugin vehicles will make up 76% of vehicles on the road in Greater Manchester. This projection can be seen below.

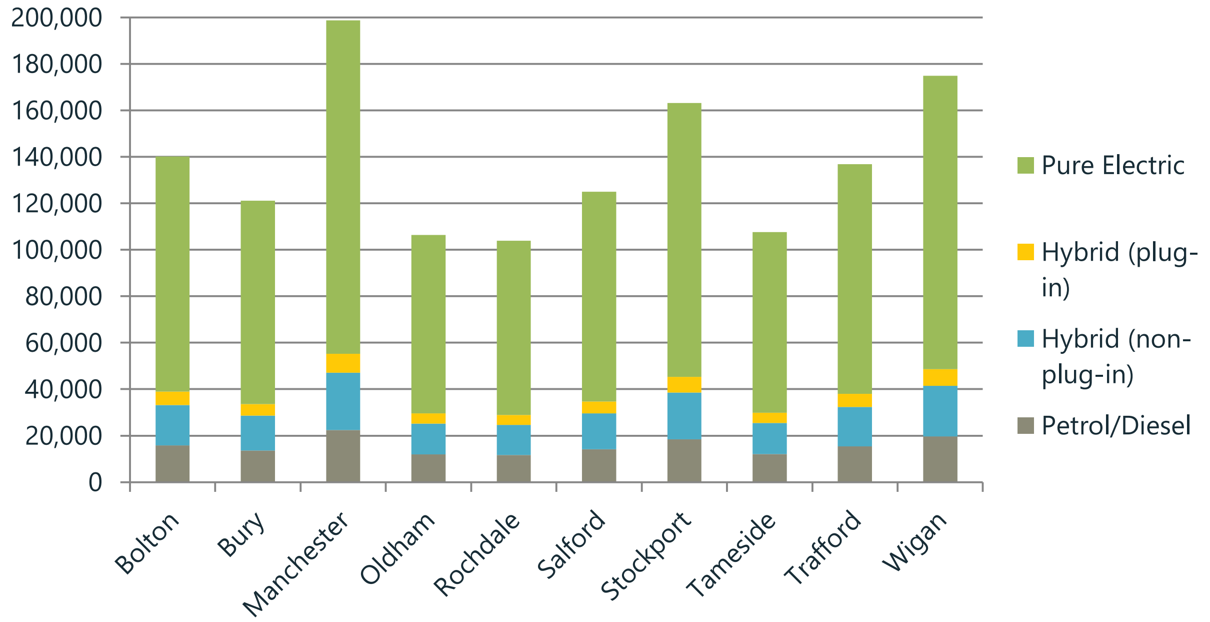
Projected Vehicle Mix across GM to 2038



The following chart shows the numbers of different vehicle types by district in 2038. Absolute figures are closely related to population, but the proportions are very similar between districts, driven by national policy changes that drive the phasing out of ICE vehicles. However, there are minor differences associated with varying socio-demographics between districts, with better off areas expected to show a somewhat more complete transition by 2038.

*Dataset VEH0105 https://www.gov.uk/government/statistical-data-sets/all-vehicles-veh01

Numbers of different vehicle types by district in 2038



Publicly Accessible EV Charge Points

Charge points will be a mixture of at-home and at-destination (such as workplaces and shopping centres). Transport for Greater Manchester (TFGM) is developing plans for the expansion of the existing network of publicly accessible charge points, to help overcome the inability to charge an EV at home, as experienced by many GM residents, to aid an accelerated transition to EV; aspects of this have been incorporated in this plan.

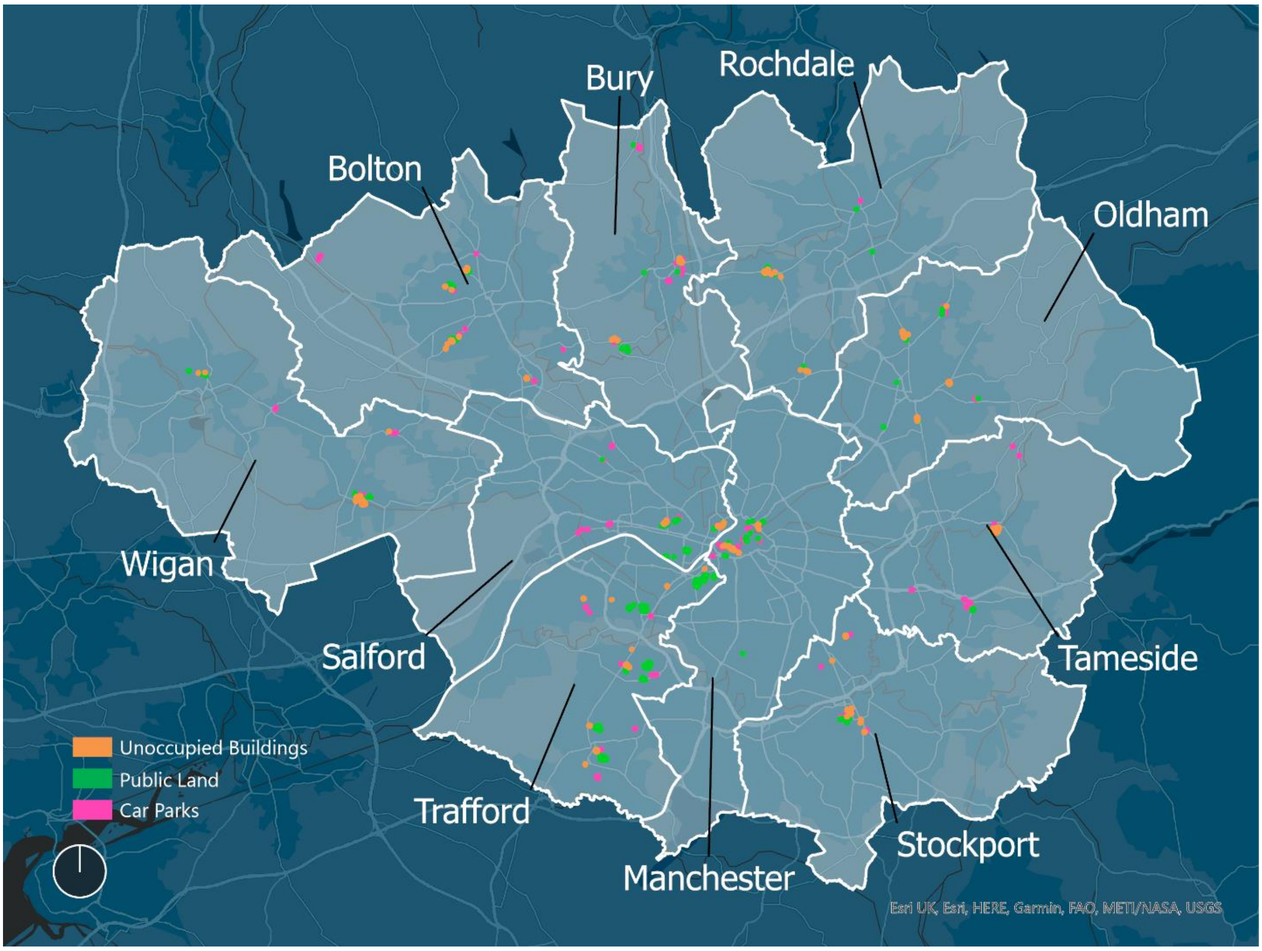
At-home charging for dwellings that have off-street parking is a solution which is well developed, but for dwellings without that potential, other solutions will be needed. One solution may be public charging hubs located in residential areas with limited potential for off-street parking. Other alternatives include developing an EV car club offer and expanding levels of workplace and destination charging provision.

Each of the ten district LAEPs identifies potential prioritised charging hub locations, based on dwellings without potential for off-street parking, projected EV use and potentially suitable land. Suitable land is based on spatial data provided by GM of unoccupied buildings, public land and car parks. These are typically within denser locations closer to town or neighbourhood centres. Further consideration will be needed for each of these by the districts, working with TFGM to identify and develop public/hub charge points across their areas*. Some districts are already working with third parties to progress such schemes. Co-ordination between the districts, GMCA and TFGM could offer opportunities for economies of scale and efficiency through bulk purchasing or

* It is also recognised that EV charging provision should not be considered in isolation from other transport related decarbonisation plans. Boroughs will need to work with GMCA, TFGM and other relevant stakeholders to ensure a joined-up transport decarbonisation approach is developed and implemented. As well as aligning with local planning policies as it relates to provision of chargers in new developments and existing dwellings

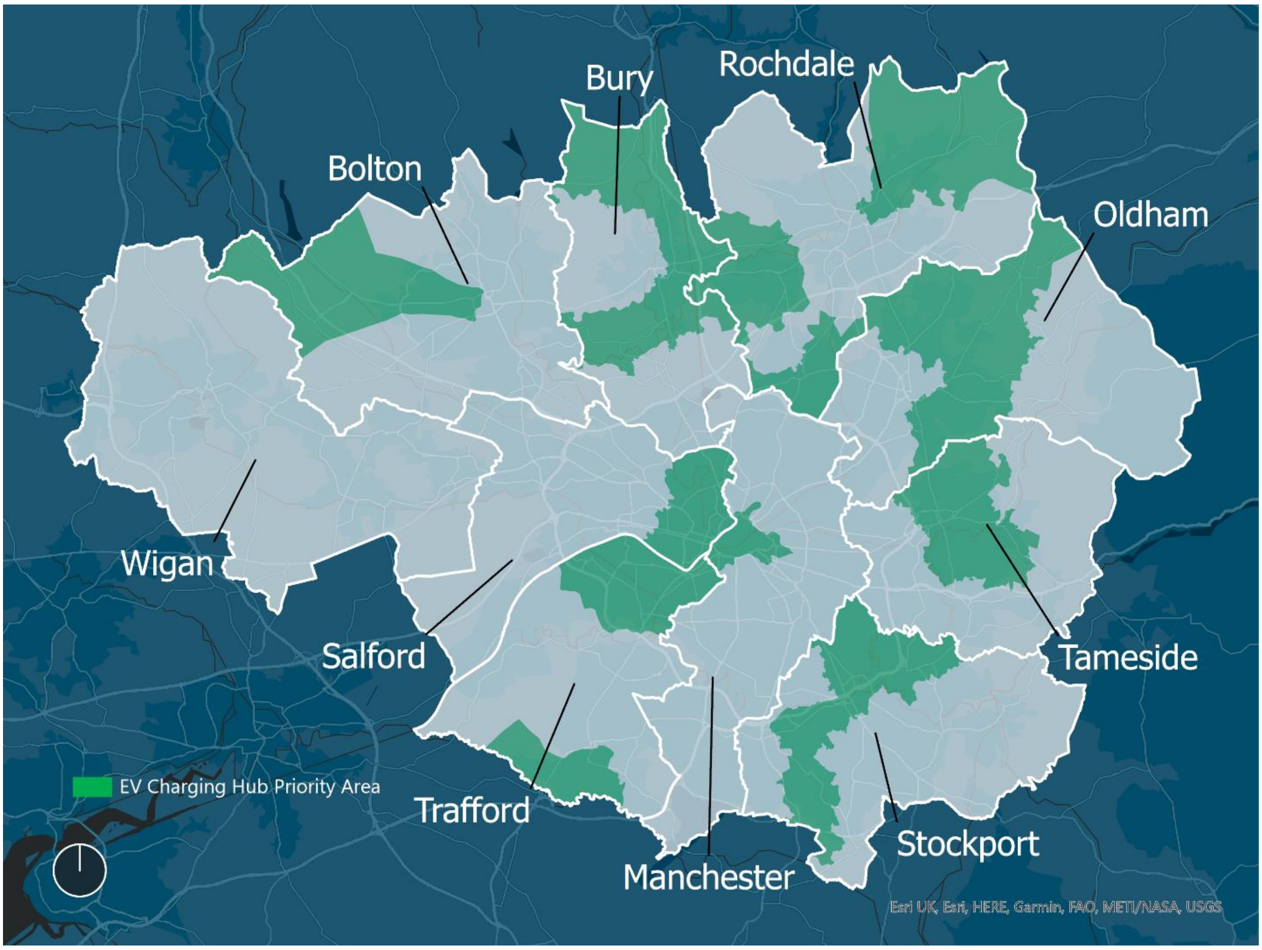
similar arrangements. This could include work through existing GMCA projects such as Go Neutral 2.0.

EV Charging Hub Locations Identified in GM



Based on the identification of these charging hub locations, and considering also the availability of grid capacity, a number of EV charging hub priority areas have been identified across the districts.

EV Charging Hub Priority Areas Identified in GM



Home Charge Points

Homes with potential for off-street parking are considered able to install private chargers. EV ownership is projected to significantly outstrip the number of homes with off-street parking, and every home with off-street parking sees a charger installed, amounting to over **517,000 home chargers**. The installation of these chargers could be coordinated with other home interventions, such as PV installation, heating system replacement and insulation, to minimise disruption experienced by households, and avoid multiple changes to wiring. Opportunities should also be explored for smart system integration between these different technologies.

Key insights

- All districts of GMCA see a very extensive shift away from liquid fuels to electric vehicles for personal cars by 2038
- Across all districts, all homes with off-street parking are expected to have EV charging facilities installed by 2038
- Public charging hubs offer a potential solution, amongst other potential options, for charging for those homes that have no off-street parking, and possible sites have been identified within each district
- Co-ordination between the districts, GMCA and TFGM offers opportunities for efficient roll-out programmes that could make use of economies of scale, whilst also continuing to consider emerging solutions for providing communal and on street EV charging systems.

Vision to 2038

The shift to electricity for heating and transport increases the importance of using low carbon electricity sources across Greater Manchester. Although the electricity grid will need to reach almost zero carbon by 2050 for the UK to meet its net zero commitments, with very low or even negative levels of emissions anticipated as early as 2035, GM will need to shift to zero carbon electricity earlier than the nation as a whole to stay within the carbon budget. This will mean generating much more zero carbon energy locally. All modelled scenarios across all districts found increases in locally generated renewable energy, primarily through rooftop solar PV.

Additional studies have also identified considerable opportunities for further large-scale generation in many of the districts, largely through ground mounted PV. This would require significant investment and transformation of land which may have other beneficial uses. In the context of an electricity grid which is already rapidly decarbonising, the relative merit of large-scale solar PV rollout should be considered. Additionally, analysis of matching supply and demand should be conducted to determine the optimal configuration of local renewable assets versus grid supplied electricity (taking a whole energy systems approach), alongside demand side response, flexibility, and energy storage; these aspects are discussed further on in section 7. It should also be noted that the potential for generation varies significantly between districts, depending on a variety of practical factors including the extent to which they are built up, and planning considerations such as the amount of land covered by protected designations (such as the Peak District National Park). This may mean that some districts are more easily able to adhere to a ‘share’ of the GM carbon budget than others due to their inherent geography. Therefore, GMCA and the districts may wish to consider how this could be fairly be accounted for, should there be a move to apportion budgets.

This local generation is particularly beneficial in staying within the carbon budget in the early years, while grid emissions are still relatively high. Consequently, early deployment is key to reaping the benefits of renewable generation, although it is recognised that deploying such large volumes of local generation in such timescales would be extremely challenging. If some of the capacity can’t be deployed until later years, the carbon benefit will be diminished as the generation displaces cleaner grid electricity. Reassessment of the cost-benefit of such deployment would then be advisable.

Increased levels of generation, alongside increased demand for electricity from heat pumps and EV charging, will have impacts on the local electricity distribution network (see also section7). Battery storage solutions may be able to address part of this impact. This could be at both building scale and larger sites, potentially associated with large scale ground mount PV sites. The ten district LAEPs have identified opportunity areas that may be particularly well suited to pioneering storage and flexibility, having less demand and generation headroom relative to the proposed increase of heat pumps, EVs and solar PV (see also section 7). GMCA’s Local Energy Market and Go Neutral 2.0 projects offers the opportunity to explore and scope the potential for this further.

Rooftop Solar and Batteries

Building rooftops are used to meet a portion of energy requirements in each district – both on domestic and non-domestic properties. Every modelled scenario utilised all suitable rooftop space (generally South East to South West), resulting in approximately 6978 MWp rooftop PV capacity installed by 2038. In other words, all buildings with suitable roofs are low regrets opportunities to install solar PV, meaning there is plenty of flexibility around the approach for this.

Within any given district, there will be many homes which are suited to both rooftop PV and EV chargers. Combining the installation of these two measures would mean that the design of electrical works (such as cable routing) will integrate the needs of both measures, reducing disruption and potentially reducing overall cost. This opportunity could also be taken to create additional electrical capacity for future heat pump power supplies.

Alongside rooftop PV, there is an opportunity to install home battery energy storage systems. These can store generated energy for times when there is no generation and potentially provide flexibility services to the electricity network; new market incentives which value flexibility may boost the economic case for domestic batteries going forward.

Large Scale Solar PV Wind and Hydroelectric

Studies to determine the areas of land in each district of GM suitable for ground mounted solar PV, small-scale hydroelectric and wind turbines[*] (including land not owned by the councils) were carried out, accounting for factors such as flood zones, protected natural spaces and habitats, infrastructure, agricultural quality of land and future developments. This study found substantial opportunities for solar and limited hydro developments. 250 potential sites for ground mounted solar PV were identified, covering a total of up to 5458 hectares. Such large-scale deployment of solar on the land would clearly require careful consideration around feasibility and public acceptability. If the full extent of solar capacity in this plan could not be deployed in practice, the largest impact would be on near-term carbon budget, whereas beyond 2035, the National Grid emissions are expected to be very low, so local generation becomes less critical to reaching low emissions.

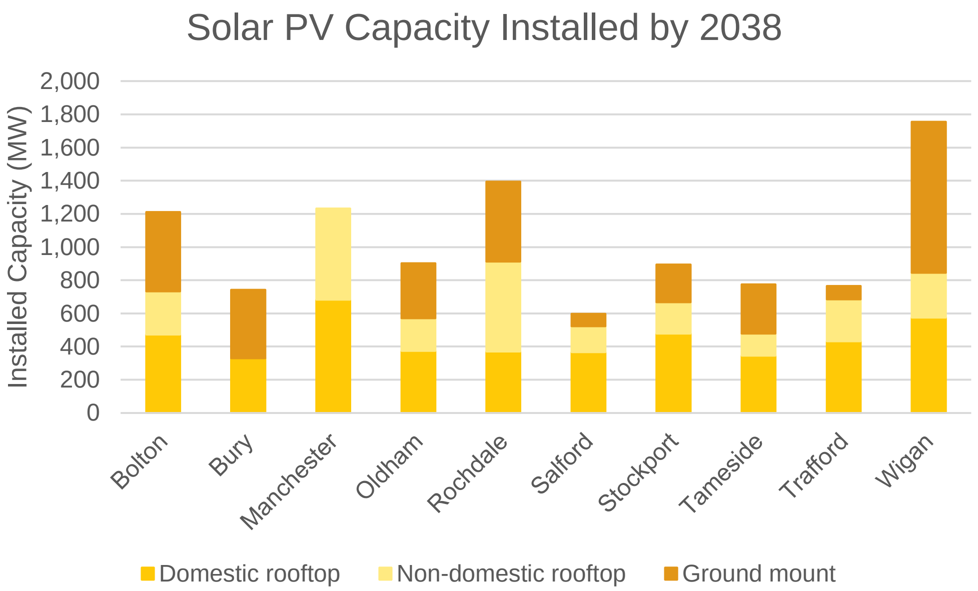
A total of 3296 MWp of PV capacity could be deployed on this land, yielding 2784 GWh of energy per year. Potential for 45 hydro sites was also identified in GM with generation capacity of 7.5MW, yielding 24.7 GWh per year.

[*] Opportunities for local energy generation have been identified following a high-level screening studies in support of the ten district LAEPs. Further assessment will be required to consider renewable energy generation opportunities in detail. Screening has been carried out through assessing constraints surrounding location/land suitability e.g., considering aspects such as proposed development, protected areas, land classification, flood risk and available resource (e.g., wind speed and solar irradiance). Impact of large-scale renewables on grid constraints and potential curtailment requirements have not been assessed and will need consideration to ensure optimal integration.

The studies did not identify any opportunities for large scale wind, due to the constraints that were applied to represent current planning considerations, which make it very difficult to develop onshore wind in most circumstances. However, it should be noted that:

- There may still be opportunities to develop smaller scale wind, particularly where there is strong community support
- Recent government announcements including the British Energy Security Strategy* have indicated a move towards easing the development of onshore wind, where there is strong community support, which may make it possible to increase wind generation in GM in the future.

The chart below shows the distribution of all three types of solar between the ten districts. More built-up areas typically show greater opportunities for rooftop solar, while districts with more open land have higher potential for ground mounted solar, but only where this land is not covered by protected designations. No opportunities for ground mount solar were found within Manchester City Council's boundaries, as this district is so built up, though it should be noted that smaller sites may be found, as the studies focussed on the most significant opportunities with space for 5MW capacity or more to be installed.



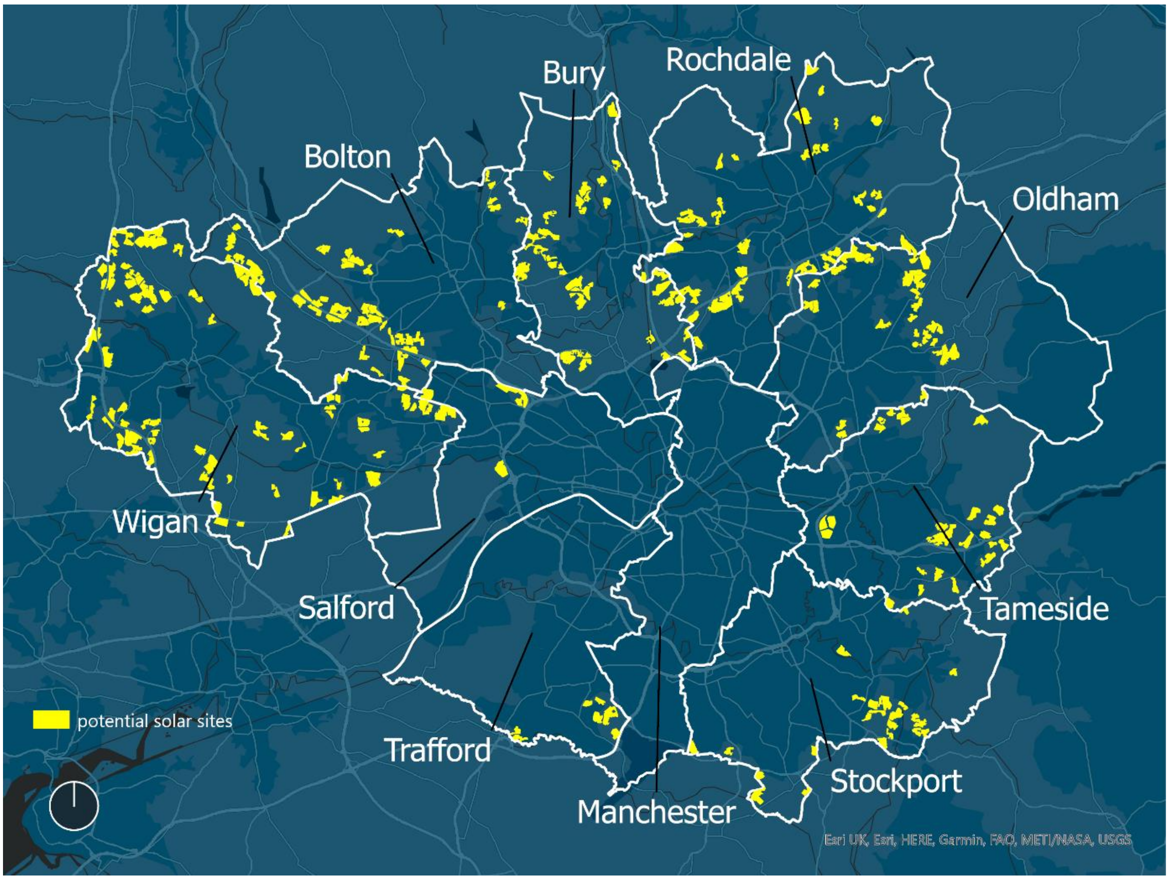
No rooftop solar on non-domestic buildings is shown for Bury as the methodology for modelling this had not been established at the time of completing Bury's LAEP. However, there is a strong indication from all other districts that there is value for the system in rolling out rooftop PV to all suitable non-domestic rooftop in the early periods of the plan, while there is still a significant amount of carbon in grid electricity. It is expected that this would be the same in Bury.

Of the 6,978 MW of rooftop PV, 2,553 MW is provided on non-domestic building roof space. Time of electricity demand and generation and their impact on the electricity

* https://www.gov.uk/government/publications/british-energy-security-strategy

network should be considered alongside the practicalities of rolling out this amount of rooftop PV.

Potential sites for large scale ground mounted solar PV in GMCA



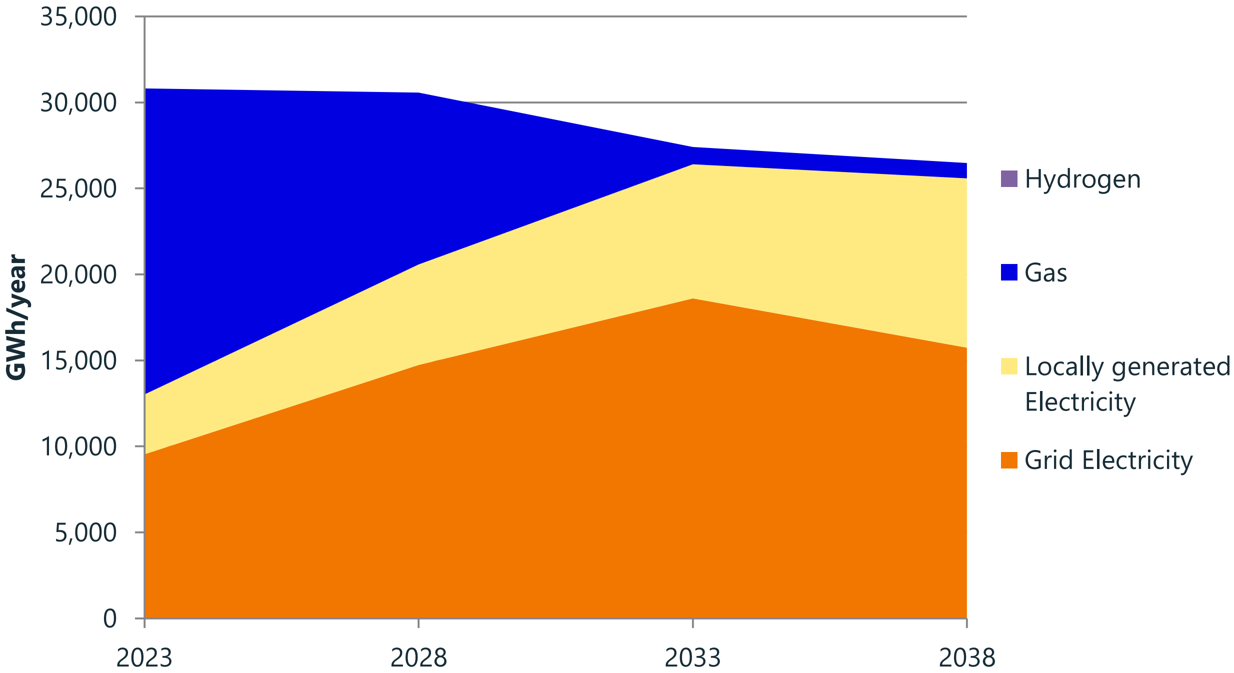
In addition, the impact of the wider energy system (beyond GM) should be borne in mind: unexpected changes to the wider system may impact the case for deploying some technologies within GM. For example, if the national electricity mix decarbonises considerably more quickly than anticipated then the case for deploying high quantities of PV locally is reduced.

Energy Supply and Demand

The overall trend in the energy balance is an increase in the consumption of electricity to replace fossil fuels, with a shift towards some of that electricity being generated by local renewables. This is a transformation in the way energy is used, meaning the energy system must evolve rapidly. This is explored in the next section: Energy Networks. The increase in energy produced and consumed locally offers the potential to explore local energy market arrangements.

The shift towards electricity is particularly pronounced in the primary scenario, a shown in the chart below. This scenario includes small amounts of hydrogen under Hynet Phase 2 in Trafford, which serves specific heavy industry that is very likely to be unsuitable for electrification.

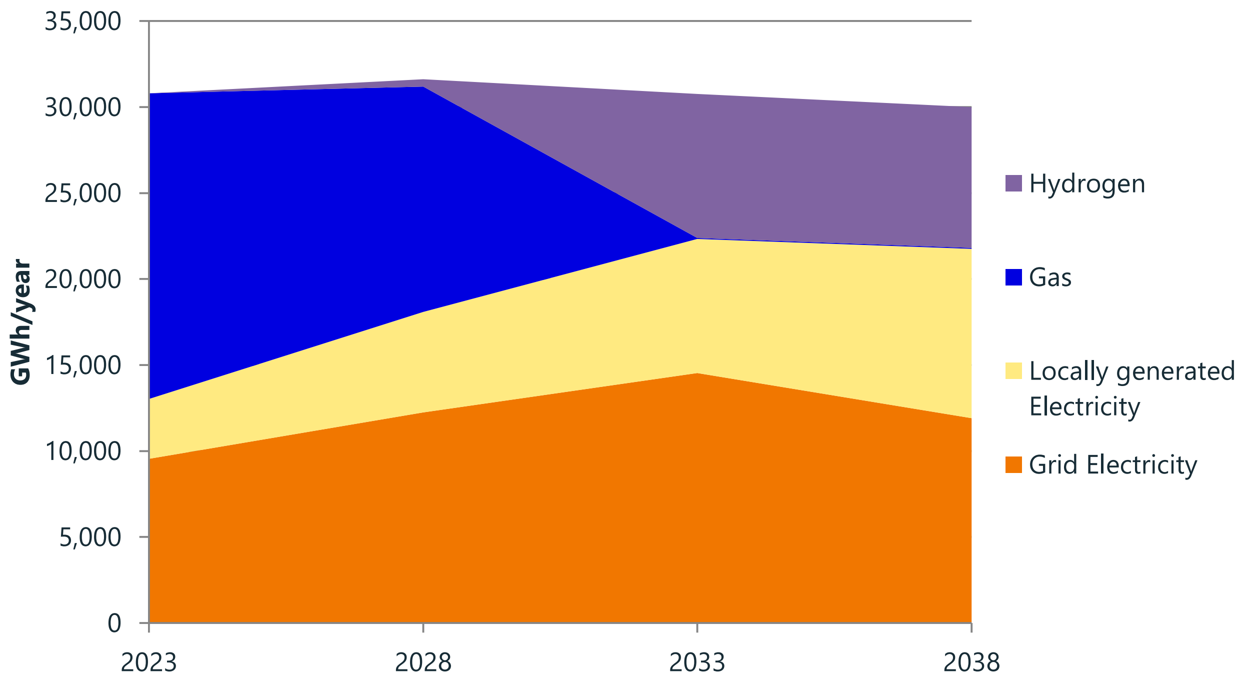
Changes in Energy Supply in Primary Scenario



Figures shown exclude petrol and diesel fuel consumed for transport. The overall reduction in energy consumption due to increased efficiency is therefore greater than shown, since the reduction in transport fuel consumption is not shown here, whereas the new electrical consumption by vehicles is shown. Overall, electric vehicles use substantially less energy than petrol or diesel vehicles.

The following chart shows the position in the secondary scenario, which involves much higher levels of hydrogen, which is used to decarbonise heating. However, electrification of heat and transport still lead to a large increase in electricity demand.

Changes in Energy Supply in Secondary Scenario



Key insights

- There is significant potential for local renewable energy generation in GMCA, though the capacity varies between districts depending on geography and level of urbanisation
- It is more beneficial to deploy generation as early as possible, while the national electricity mix is more carbon intensive
- Deploying such high quantities of generation will be very challenging and may present challenges to the electricity network as well as requiring considerable coordination
- Battery storage (whether at building or larger scale) offers potential to alleviate some of these network cost, reinforcement challenges
- Even with successful deployment of high levels of local generation, GMCA will still rely on the grid for a large proportion of its electricity needs, even under the secondary scenario.

Vision to 2038

Energy networks are the backbone of Greater Manchester's carbon neutral future; the large-scale changes in the way we use energy described in the previous sections will require networks to adapt and evolve in significant ways. For GM to reach carbon neutrality, major changes to the existing gas and electricity networks will be required, as well as the development of new networks including district heat and potentially hydrogen networks to meet future demand without the carbon emissions.

The electrification of heat and transport is likely to drive a major shift towards greater dependency on the electricity network. Greater demand for electricity will require investment in generation capacity and storage and distribution network infrastructure upgrades, even in a scenario where all heating is provided by hydrogen, largely due to EV charging.

In the primary scenario for each district gas demand is reduced to a small residual level by 2038, due to its use in some non-domestic and industrial applications which are more difficult to electrify. A small amount of hydrogen is also expected in the primary scenario to supply the limited number of intensive industrial energy users that are expected to connect to Phase 2 of Hynet (in Trafford).

This section of the report provides an overview of the impact on each of the energy networks of the primary scenario as well as insight from the other modelled scenarios and other key considerations given the uncertainties.

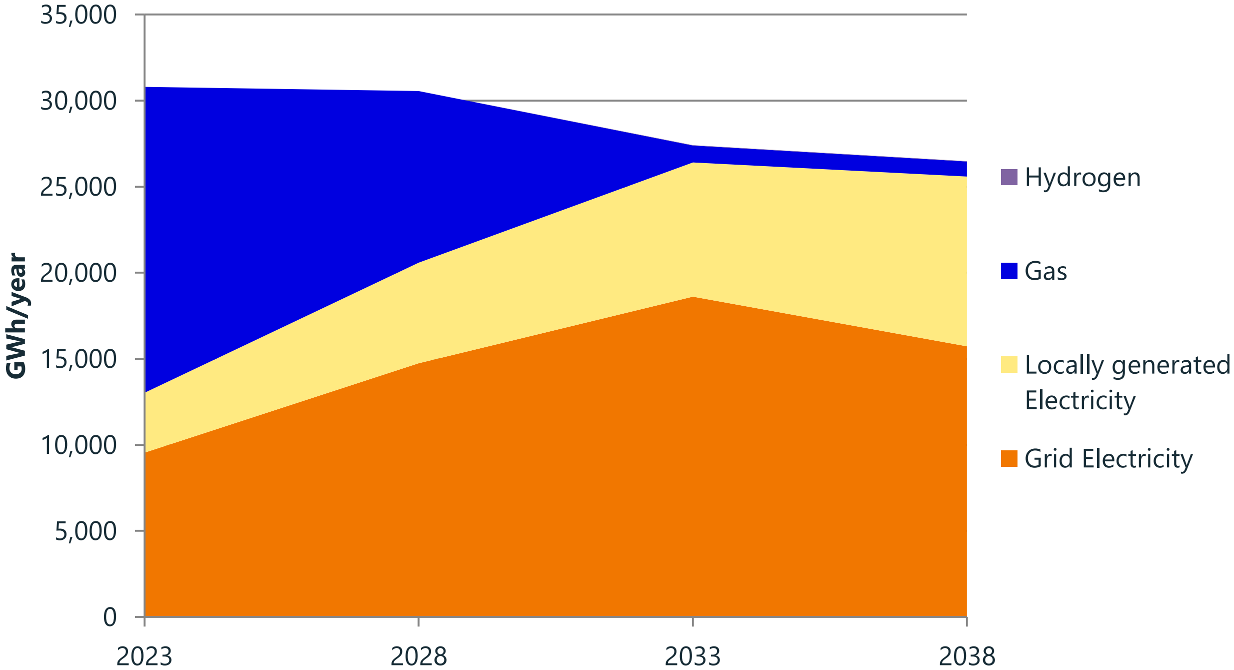
The primary scenario sees gas consumption reducing from c. 17777 GWh per year currently down to around 880 GWh by 2038, and lower still in the secondary scenario where hydrogen can replace many remaining uses of gas.

There is uncertainty currently about the role of hydrogen to replace heating, including when and where it may be available, in what quantities, the associated carbon emissions, and the cost compared to other solutions. Where hydrogen does become available for heating, it may be necessary to prioritise its use between different areas as quantities may not support roll out across the whole of GM.

The modelled scenarios considered the possible role of hydrogen for heating aligned to the development of HyNet infrastructure (secondary scenario), serving businesses and dwellings throughout GM.

All scenarios show that some gas or hydrogen remains in use by 2038, largely to support hard-to-decarbonise non-domestic premises, including high-temperature process heat for industry. If hydrogen does not become available to support decarbonisation of these uses, alternatives may need to be considered to achieve the carbon target and budget, such as carbon capture and storage technologies. The chart below shows how the energy supply changes over time in the primary scenario.

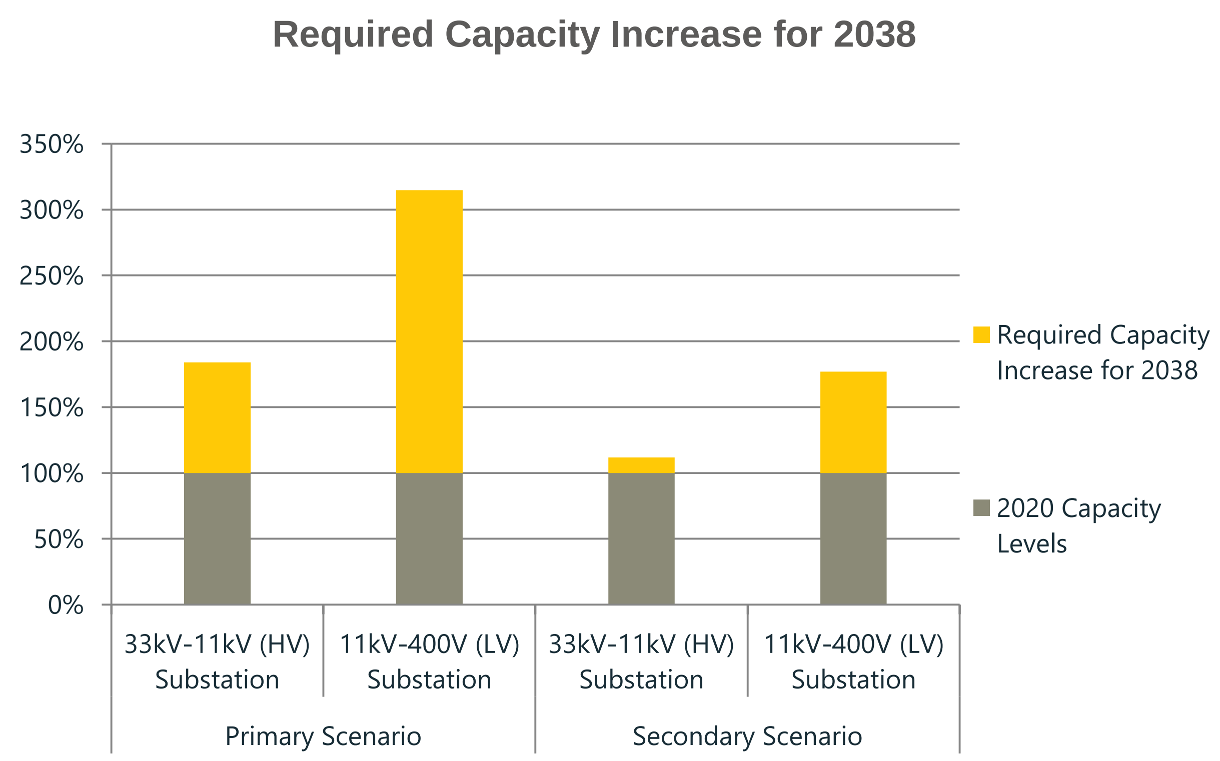
Changes in Energy Supply in Primary Scenario



Capacity Requirements for 2038

The local electricity distribution network operated under license by Electricity North West Limited (ENWL) supplies electricity to most dwellings and industry in GM today (with smaller areas supplied by Northern Power Grid (NPG) and Scottish Power Energy Networks (SPEN)). Modelling indicates the capacity that would be required to meet all projected demand growth through conventional investment, but some of this demand could instead be accommodated through alternative investments, such as flexibility and storage, so the physical capacity increase required could be less than shown here. Areas with large increases in required capacity present opportunities for innovation and smart technology. Smart EV chargers and smart heat pump controls could make demand flexible, while storage technologies and vehicle-to-grid could help meet peaks in demand locally and provide other grid services.

The modelled capacity requirements at high and low voltage levels are shown in the following chart, with an increase of over 200% in low voltage substation capacity in the primary scenario, and over 80% for high voltage substations. The distribution of these impacts is determined by a combination of factors, such as electric vehicle ownership, potential for off-street parking and existing spare capacity in the current electricity infrastructure. For example, a zone may see a large increase in demand for home EV chargers, but not require large capacity increase because it currently has significant spare capacity. The difference in capacity requirement increase is evident between the primary scenario where heat is mostly electrified, and the secondary scenario where heating is mostly provided by hydrogen.



The additional capacity requirement highlights the additional opportunity that flexibility approaches could bring to the local network. Many such approaches will already be under consideration by ENWL, whose detailed network modelling is able to account for a greater variety of diversity and flexibility approaches (to complement traditional reinforcement) than was possible in the broader energy system modelling supporting this work. GMCA should therefore work with ENWL to explore how impact can be minimised.

The distribution of capacity change (at high and low voltage substations) across each district is shown in the table below, for the primary scenario.

	33kV-11kV (HV) 2021	33kV-11kV (HV) 2038	11kV-400V (LV) 2021	11kV-400V (LV) 2038
Bolton	445	712	361	1388
Bury	401	644	581	845
Manchester	1033	2346	809	2154
Oldham	336	861	286	1345
Rochdale	468	474	320	1270
Salford	575	844	421	1416
Stockport	361	1307	314	1268
Tameside	317	601	266	1716
Trafford	462	862	409	1415
Wigan	775	859	550	772
Total	5172	9511	4317	13587

Present Day Capacity and First Steps

Examining present network capacity gives some indication of where deployment of low carbon technologies could be prioritised without immediately running into network constraints.

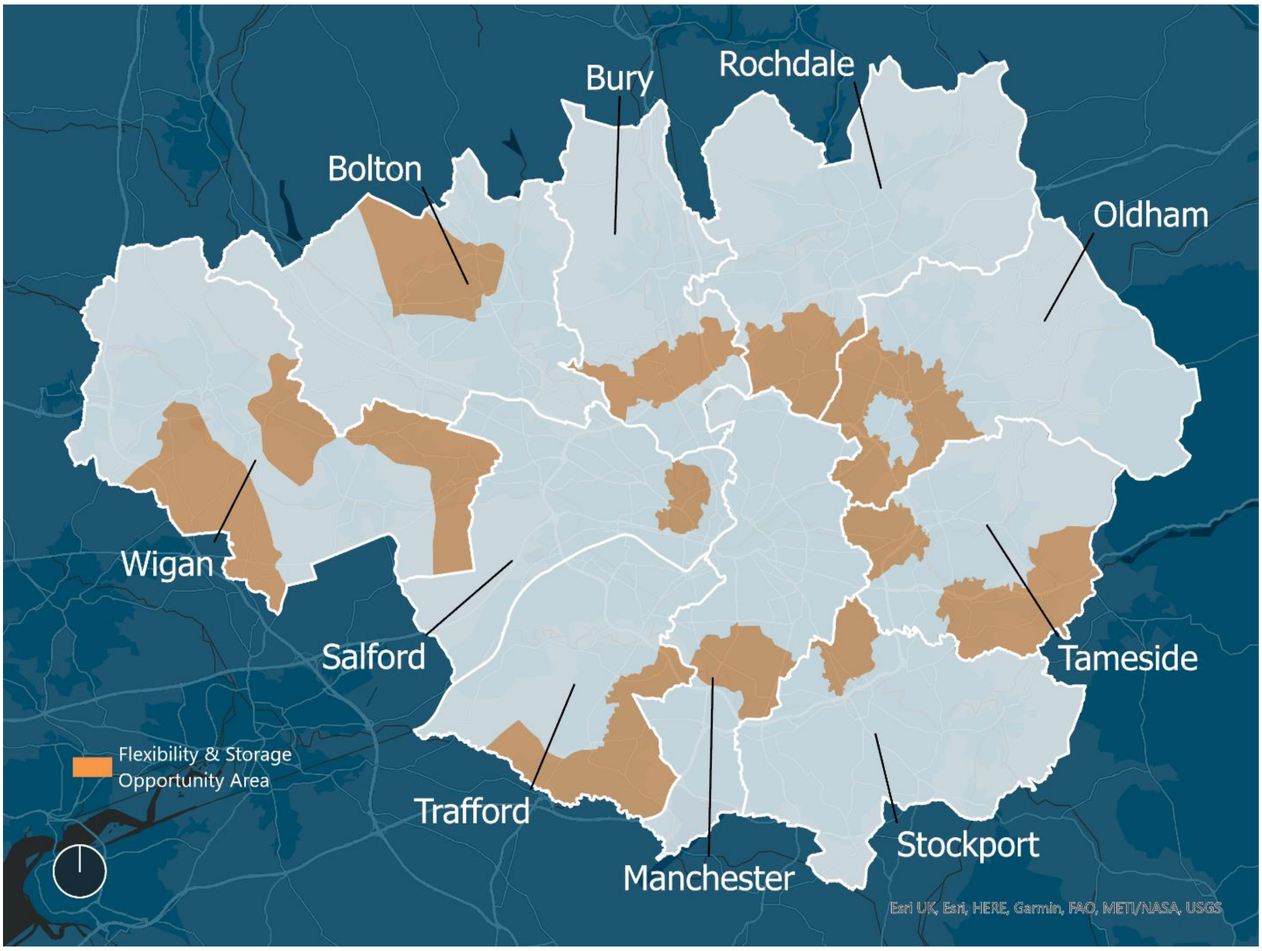
Within each district there are areas with higher levels of capacity headroom for demand, suggesting that heat pumps and EV chargers could be installed at scale in these areas before network upgrades are required – these have typically been identified as EV charging, heat pump or solar PV priority areas within the individual district plans.

In contrast, other areas show limited spare capacity. This suggests that although significant early progress can be made, the need for infrastructure reinforcement to deliver the full plan should be assessed early in these areas to ensure that it doesn’t delay progress.

The LAEPs provide an indication of projected energy demand and associated impact on energy networks, and the modelling process translates this into providing additional capacity. However, there are limitations with this approach, therefore it is recommended that early engagement is undertaken with ENWL, aligning with existing network/business planning processes, to understand what actions more fully may be needed. GMCA and the districts will need to work with ENWL to understand potential solutions.

Local flexibility, storage and generation could be trialled to overcome demand constraints, and so areas identified by the modelling as constrained are typically identified as flexibility and storage opportunity areas within the district plans. However, it's worth noting that peak network demand typically occurs on winter evenings, when solar generation is negligible, and electrification of heat is likely to compound this, so technologies that can provide diurnal and seasonal shift could have value.

Identified Flexibility and Storage Opportunity Areas within GM



Key insights

- There is a substantial modelled increase in electricity demand across all districts of GM and all scenarios by 2038, driven by EV charging, even in scenarios where there is less use of heat pumps due to hydrogen being used for heating
- This leads to an overall modelled requirement for increased capacity of over 200% at low voltage substations, and over 80% at high voltage substations. GMCA and the districts should work closely with ENWL to understand how this can be addressed, including exploring flexibility
- Current capacity of the grid to support increased generation and demand varies considerably even within each district

- Each district has areas of higher current capacity that may be more suitable for early testing and roll out of heat pumps alongside EV charging
- Each district has areas with more constrained capacity that may present themselves as good test beds for flexibility and storage solutions.

Gas Network Today

The gas network operated under license by Cadent supplies gas to most dwellings in GM today, predominantly for heating and hot water but also cooking. It also supports a range of non-domestic and industrial local energy demands. The current total gas consumption across GM is around 17,777 GWh.

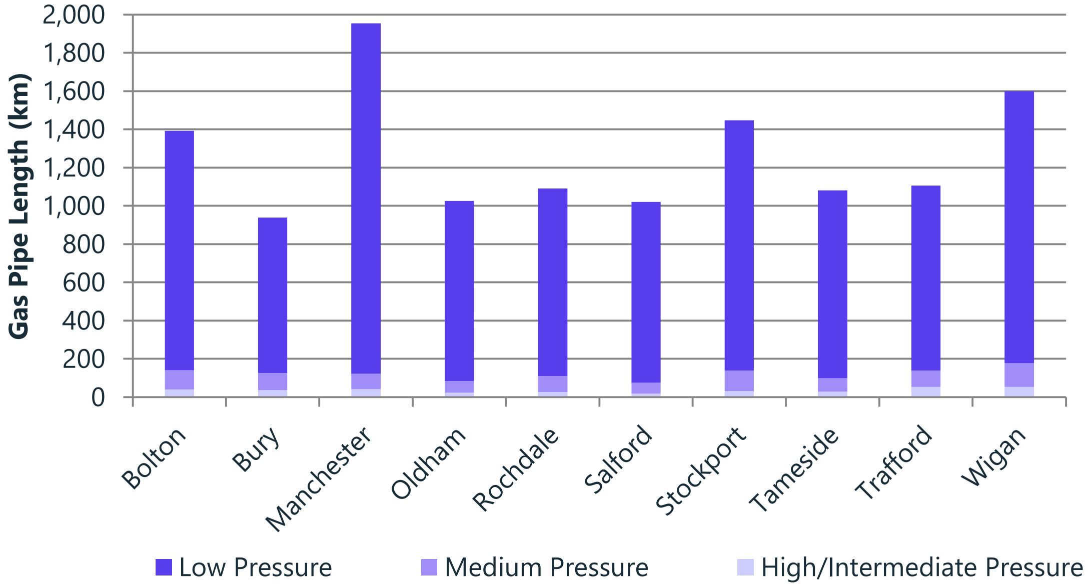
To deliver GM's carbon budget and target, it is expected that most dwellings will no longer use natural gas by the early 2030s to avoid the budget being exceeded. Most non-domestic buildings will also transition away from gas.

Future of Gas and Hydrogen for Heat

The primary scenario for each district in GM sees most dwellings converting their heating systems to either be

- Connected to a district heat network or, more commonly,
- Converted to electric heating, predominantly in the form of different types of heat pumps depending on different factors such as location, energy efficiency and house type.

This would necessitate phased disconnection of homes from the gas network as they are converted to electric or district heating, which would need coordination. However, the secondary scenario sees most buildings supplied by hydrogen, meaning they would remain connected to a repurposed gas network. Around £5 bn of investment would be required for this network conversion. Of Greater Manchester’s approximately 12,657 km of gas pipework, around 76% is already made of polyethylene, suggesting that much of the network could already by suitable for carrying hydrogen.



Hybrid heating (air source heat pump/gas boiler hybrid) is an option in certain circumstances and could provide a valuable transition technology to manage uncertainty around the role of the gas network in domestic heating through the 2020s. Around 28,615 dwellings may be best suited for this technology: generally larger properties where a hybrid solution may become more cost effective than an air source heat pump alone, but where a ground source heat pump is unsuitable due to exterior space and access requirements.

Even in the electrification scenario, gas networks may need to be retained for longer in areas where hybrids are a useful transition option due to property types.

There are a small number of non-domestic properties that are harder to electrify, particularly with industrial uses that require high temperature process heat; these will remain on the gas network under the primary scenario and use hydrogen where possible in the secondary. Most non-domestic gas use can be electrified.

Equitable solutions for dealing with the ongoing gas network maintenance costs for remaining customers will need to be explored for the case where usage falls to very low levels. These properties may also be well suited to using hydrogen for heat under a scenario where hydrogen becomes available.

Each of the ten district LAEPs identify opportunity areas for focussing the use of hydrogen for heating, should it become available. These areas were identified based on several factors including ease/cost of retrofitting housing stock for other heating solutions, proximity to the expected initial ingress point for hydrogen into GM (via the proposed pipeline along the Manchester Ship Canal) and density of potential industrial users. The map below indicates the location of the hydrogen opportunity areas in each district and the route of the proposed pipeline.

Hydrogen for Heat Opportunity Areas

Areas closest to the proposed pipeline, particularly Trafford and Salford may be candidates for earlier access to hydrogen for heating. GMCA and the ten districts should work closely with one another, as well as Cadent and the operators of the Hynet project to understand timing of hydrogen availability and how a roll out could be managed.

There is also the potential for a limited quantity of hydrogen to be blended into the existing natural gas supply, without the need to change any equipment in homes, up to the current limit of 20%. This has the potential to be done through the existing gas bulk supply points rather than requiring a dedicated pipeline and so might be more easily distributed around GM. However, this approach brings limited carbon benefit, due to the low energy density of hydrogen relative to natural gas, and so has not been explored in detail in this work.

Key insights

- A very small quantity of natural gas remains in 2038 in the primary scenario, for industrial uses that cannot easily be electrified. Equitable solutions will be needed for managing costs of the gas network as heat transitions away from gas to electricity or to other low and zero carbon energy supplies
- However, much of the existing network could be suitable for repurposing to hydrogen, if it becomes available for heat: a key decision will be required in and around 2025 about whether hydrogen will form a substantial part of the

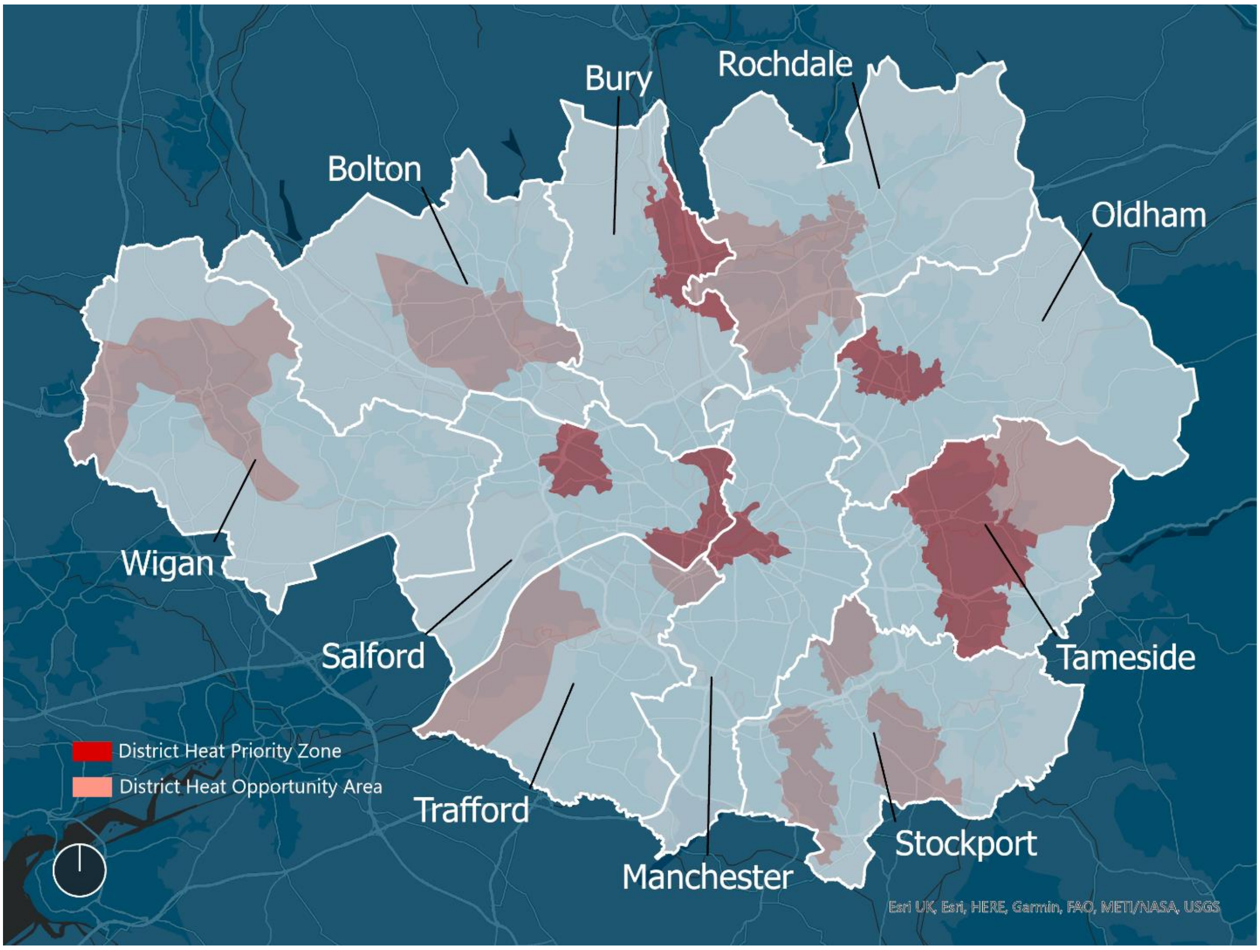
decarbonisation pathway across GM. The LAEPs include low regret areas to deploy heat pumps and heat networks so that progress can be made in the meantime

- Initial priority areas for hydrogen are likely to be near to the proposed Manchester Ship Canal pipeline, in Trafford and Salford.

District heating could supply in the region of at least 13% (195,000) of GM's dwellings, as well as many non-domestic buildings. The role of district heating is diminished in the secondary scenario where hydrogen meets much of the demand, although in practice district heating could be supplied by hydrogen boilers in the energy centres, meaning that investment in the heat networks would remain a relatively low regrets option if hydrogen for heating materialised. By centralising the hydrogen boilers, the need to replace gas pipework in streets and buildings to make them compatible with hydrogen would be reduced.

The greatest opportunities for district heat are within the central areas of Manchester and Salford, however opportunities are also identified in many other areas. Several existing heat networks are identified as having potential to be expanded to reach more of the buildings identified as suitable. Further potential opportunity areas for district heat are also identified in many of the districts, as shown on the map below.

District Heat Priority Zones and Opportunity Areas



Where identified heat network opportunities are near the boundary of a district, collaboration with neighbouring districts will be important to ensure that practical opportunities to expand to suitable nearby buildings are identified. This is considered particularly likely in northern Salford and western Manchester, and potentially also northern Trafford, which represent the most densely built-up areas of GM where several district heating schemes are already in existence or under development. In this wider cluster there may also be the opportunity to join up more than one network, which could bring advantages such as greater resilience through having multiple heat sources connected

Heat generation is assumed to be primarily based on large scale heat pumps, with over 400 MWp of heat delivered from heat pumps. However, opportunities to make use of any waste and water heat sources (including potentially mine water) should be explored, as these could improve the cost and carbon credentials of a district heat scheme further. A number of existing proposals are already considering sources such as water from rivers (e.g., the Rother), and these are included within the identified heat network opportunities.

The specific feasibility and configuration of any district heating networks, including energy centre locations, plant design etc. will require appropriate assessment to take forward, providing opportunities for the consideration of smart local energy systems or community schemes to support network development. Recent government consultation and pilots on heat zoning[*] may also see an emerging route to take forward these heat network opportunity areas and support the development of heat networks in GM.

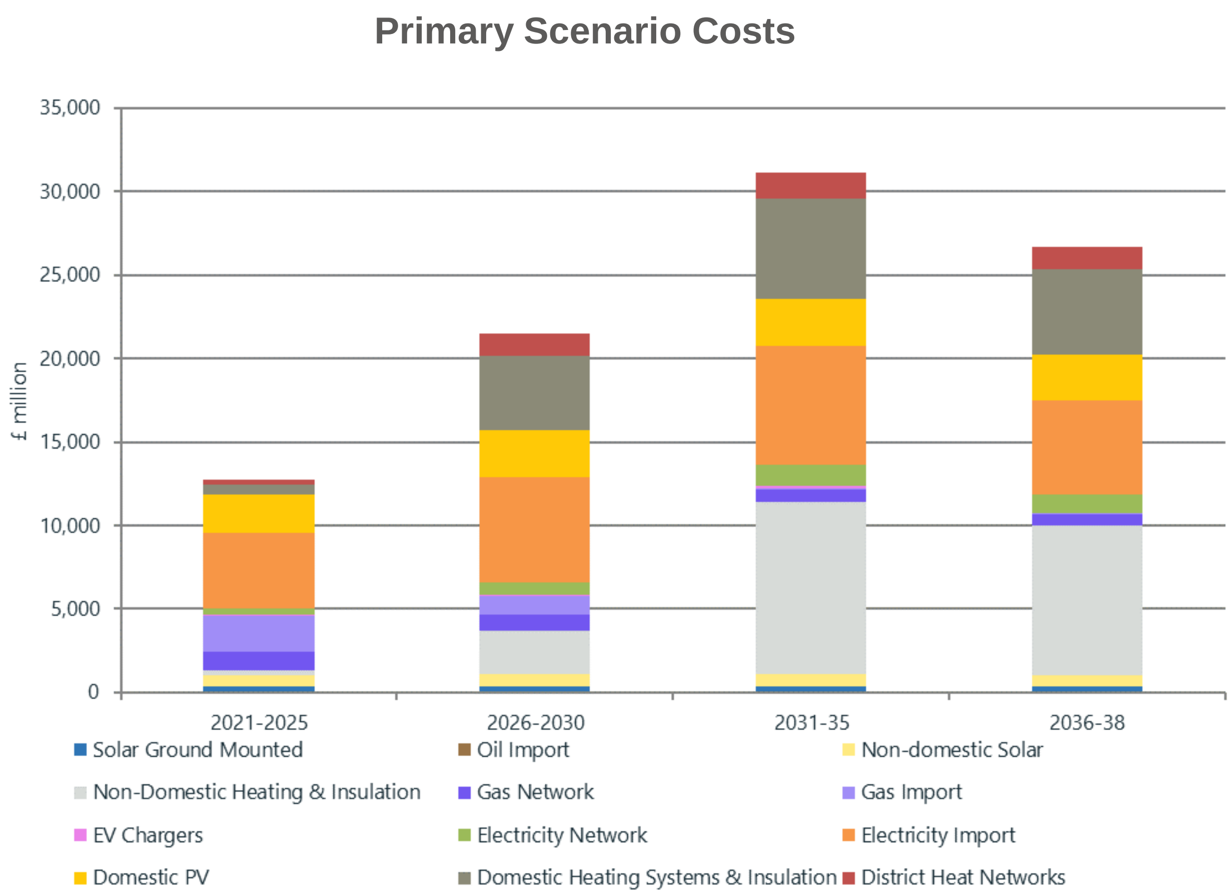
Key insights

- Heat networks have the potential to supply a significant proportion of buildings in GM, and can be considered low regret, as they could be converted to be supplied by hydrogen fuelled boilers if hydrogen becomes available
- Collaboration between districts that have an identified heat network zone/s near to their boundary (particularly Manchester and Salford), could accelerate opportunities for connecting additional buildings that might otherwise be missed
- More detailed studies to consider feasibility and configuration of proposed heat networks will be needed, to confirm viability of the identified opportunities.

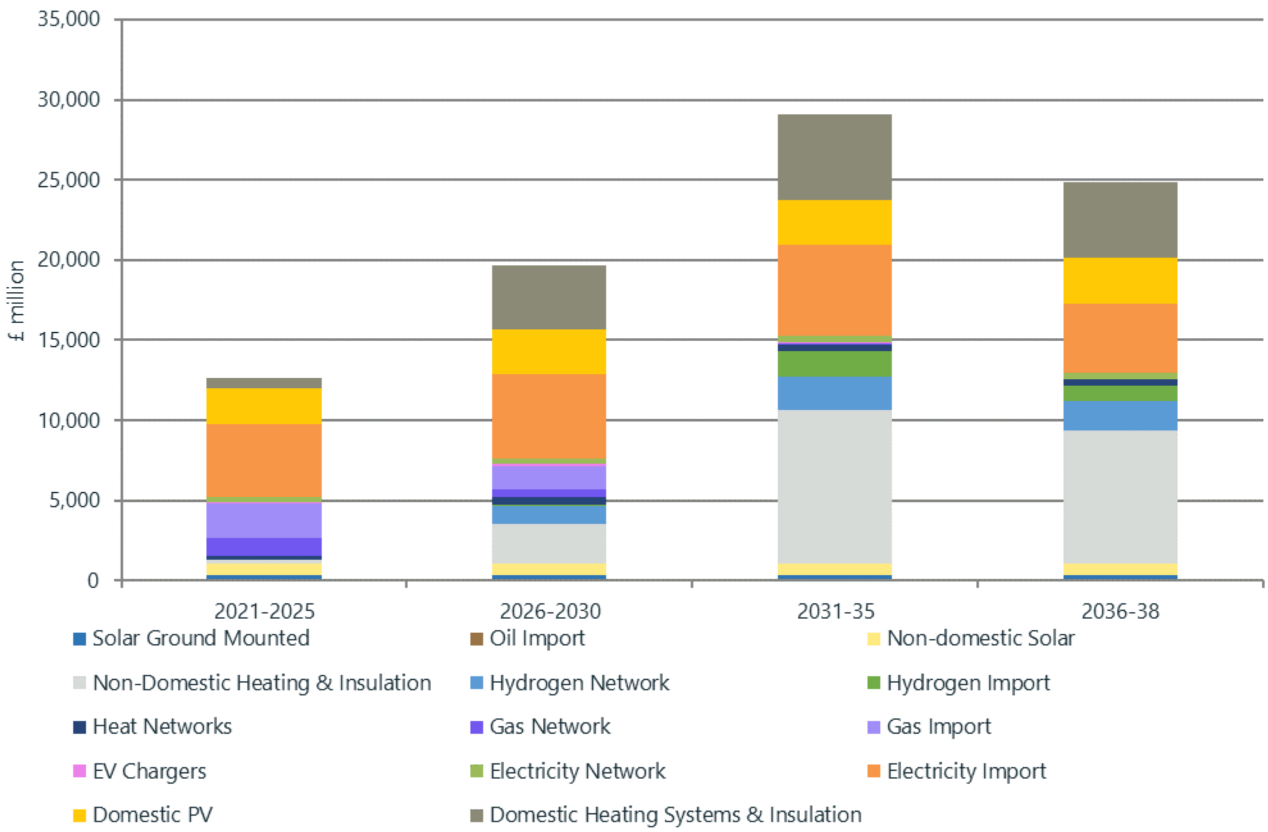
[*] https://www.gov.uk/government/consultations/proposals-for-heat-network-zoning

Total cost (including energy consumption)

The primary scenario is based on a total energy system spend of £92 bn (compared with £86 bn in the secondary scenario). The cost is attributed to investment in energy networks, in buildings (for components such as fabric retrofit, heating system change and roof mounted PV) and for energy consumed. The charts below illustrate the split between these components. Notably, a significant proportion of this cost would have been spent without accounting for decarbonisation; noting that money is spent every day on maintaining existing energy systems, replacing old or failed systems (e.g., gas boilers in dwellings), improving energy efficiency and paying gas and electricity bills. The ten district LAEPs, and therefore this report, set out an approach for redirecting some of that business-as-usual expenditure, boosted with additional investment, to the areas needed to achieve the carbon neutral target. For example, energy costs are re-directed to electricity use in place of natural gas.



Secondary Scenario Costs



Investment (exclusive of energy consumption)

The tables below illustrate the total investment needed in the energy system to deliver the plan, equating to a total of £65 bn for the primary scenario and £60 bn for the secondary, with the following charts breaking this down district and then by technology. Again, a significant proportion of this investment will be required without working towards carbon neutrality, for example expenditure on replacement gas boilers is instead targeted at low carbon heating systems.

District	Total Investment (£m)	
	Primary Scenario	Secondary Scenario
Bolton	9,000	7,800
Bury	5,500	6,500
Manchester	18,700	17,800
Oldham	7,500	7,100
Rochdale	7,300	6,300
Salford	8,700	8,500
Stockport	8,300	7,200
Tameside	7,300	6,600
Trafford	8,500	8,200
Wigan	11,200	10,200

Investment type	Total Investment (£m)	
	Primary Scenario	Secondary Scenario
Domestic Heating Systems & Insulation	16,164	14,638
Domestic Solar	10,651	10,649
Domestic EV Chargers	280	280
Non-domestic Heating Systems & Insulation	22,186	20,599
Non-domestic Solar	2,855	2,855
Large Scale Ground-mounted Solar	1,375	1,390
Electricity Network	3,405	1,469
District Heat Network*	4,476	1,558
Gas Network	3,480	1,705
Hydrogen Network	0	5,007

Basis of modelled costs

It should be noted that the costs within the modelling that support the ten district LAEPs and hence this report are calculated without considering the effect of policies, subsidies and incentives (for example Home Upgrade Grants), as this allows a full picture of system costs to be understood and makes it possible to understand the least cost pathway to decarbonise irrespective of whether such schemes may come and go over time. This also means that it may be possible to progress some technologies and solutions further or more quickly than envisaged in this plan, where funding is available to do so.

A further important point is that the modelled scenarios are, by their nature, not able to account for social factors such as how the cost of the energy transition can be equitably shared within GM. GMCA, and the districts will need to consider how the roll out of new technologies can be planned and financed such that costs are shared fairly and particularly so that those in fuel poverty are not unfairly disadvantaged. Recent rises in gas prices make this consideration even more important.

Cost per home

The investment costs for the energy system can also be considered on a per-home basis, to give a further sense of the scale of change needed. Across the ten districts of GM, the average cost of investment needed within each home during the period to 2038

* While existing work has shown the potential for district heat networks in many parts of GMCA, further work needs to be undertaken to understand the full opportunity.

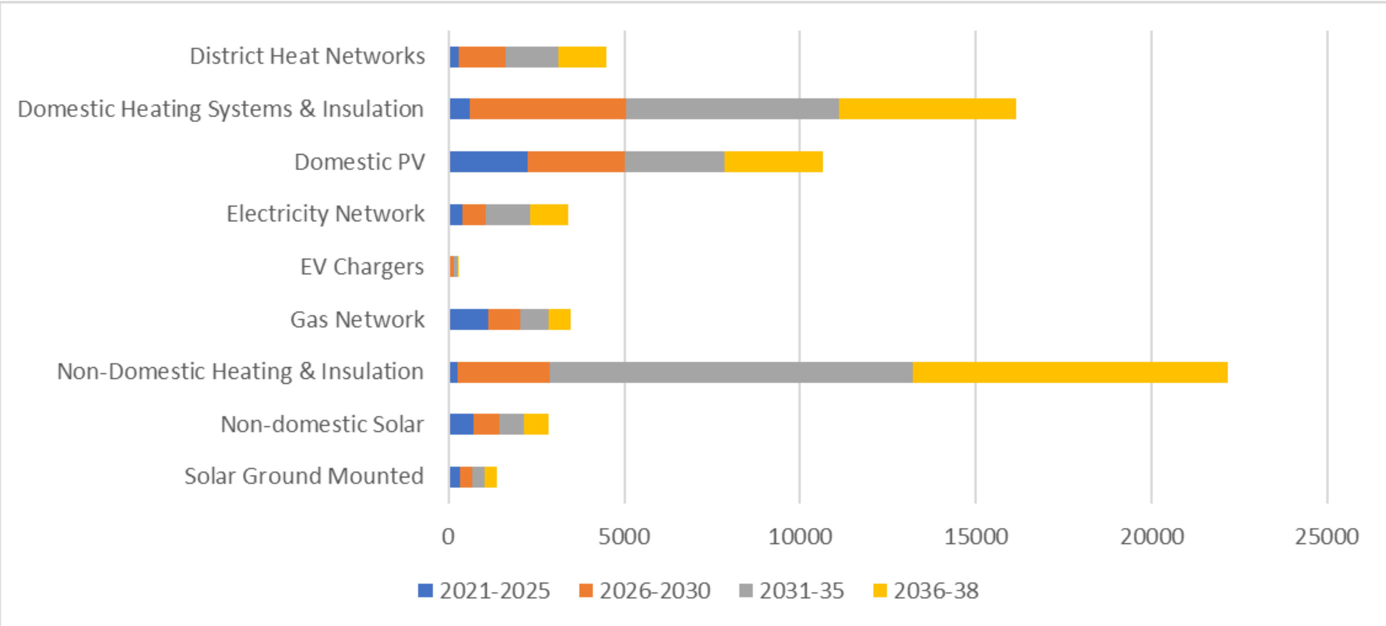
is £18,800 under the primary scenario. This covers heating system changes, fabric retrofit measures (such as insulation), rooftop solar PV and EV charging equipment, but not energy costs. The figure for the secondary scenario is a little lower, at £17,700: this is because many homes under the secondary scenario would move to hydrogen heating rather than heat pumps, which is likely to require less change within the home.

There may be the opportunity to reduce these costs through the creation of cost-effective retrofit packages that address several aspects of a home's energy use at once, for example by installing heat pumps, PV, and EV charging at the same time. This would also have the benefit of reducing disruption.

The costs per home do not include an apportionment of the investment needed in networks (electricity, gas, district heat or hydrogen); however, these are typically also recovered from consumers through energy bills currently. As mentioned above, consideration will be needed in the future as to how these costs can be equitably managed.

Investment in GM's energy system (£m) by time period

The chart below shows the investment needed in GM's energy system broken down by period under the primary scenario.



In general, the requirement for investment accelerates after the initial five-year period to 2025. This allows GMCA and the districts a window in to work with partners to develop trials and pilots of new products and services for low carbon solutions, targeted towards the low-regret technology priority zones. After this, there will be a need for a key decision around whether hydrogen forms a significant part of the heating mix, followed by more rapid deployment of solutions along the preferred pathway.

As can be seen from the scale of investment needed, there will be a considerable requirement for solutions targeted at the non-domestic sector. Currently this sector is harder to address than domestic, due to the huge variation in use types and building age and construction. There will be particular benefit in developing data sets to better understand the current state of these buildings in the first years, so that targeted solutions and offerings for these buildings can be developed in the second period and be rolled out subsequently. GMCA and the districts can show leadership here by decarbonising their own estates in the near term (through existing funding routes such as the Public Sector Decarbonisation Scheme[*]), and by working with partners such as other public organisations representing small businesses to address the wider non-domestic sector.

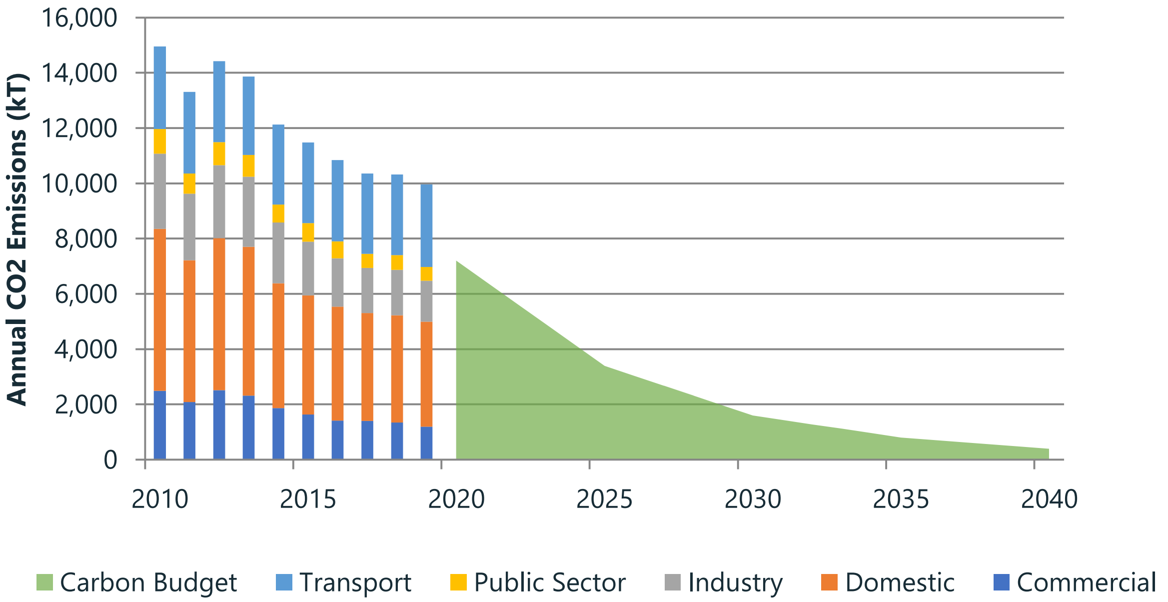
Key insights

- The total cost of GM's energy system out to 2038 will be £86-92bn; this overall cost also being inclusive of energy import costs (Gas, Hydrogen and Electric) depending on the pathway selected. Although It is recognised a significant proportion of these costs would be incurred even without decarbonisation (from energy import costs as well as ongoing maintenance and replacement of existing equipment)
- The need for investment will accelerate rapidly after the initial five-year period, so there is an opportunity for GMCA and the districts to work with partners to develop and pilot new products and services in the low-regret priority areas in the early years, to enable rapid changes at larger scale in the following period
- The investment needed in each home in GM will be around £17,700 - £18,800, however cost-effective `combined retrofit' packages may offer opportunities to minimise this while also reducing disruption
- GMCA, the districts and other public sector organisations can lead the way by decarbonising their own estates in the near-term. Of the 69,000,000m2 of non-domestic floor space within GM, almost 7% (4,600,000m2) falls within the remit of the public sector and offers a way for GMCA and other public sector organisations to demonstrate solutions in the near-term, making use of available funding streams such as the Public Sector Decarbonisation Scheme.

[*] Public Sector Decarbonisation Scheme

Greater Manchester has committed to achieving carbon neutrality by 2038, while also keeping to an overall future carbon budget of 71 MT CO_2e based on a science-based apportioning of emissions carried out by the Tyndall Centre)[*]. Of this total carbon budget, around 52.6 MT can be apportioned to the period of this report. The chart below illustrates the scale of carbon emissions reduction that will be required:

2010-19 Emissions in GM[†] vs Carbon Budget

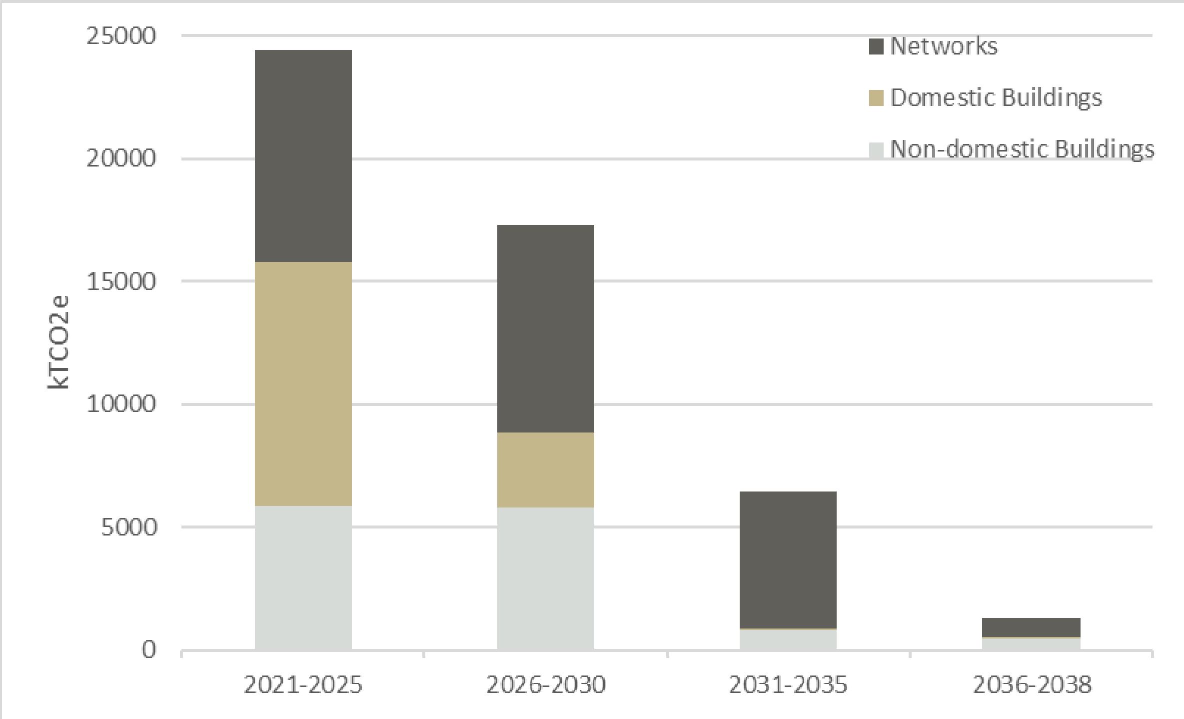


The scope of the carbon budget for GM is wider than the scope covered in this report and the ten district LAEPs that it is based on, particularly regarding transport, with this report focussing on domestic EV. Other aspects of transport, such as non-domestic fleet and public transport are harder to consider at the individual district level that the modelling was carried out at, and so were not included, however GMCA should consider reviewing this at GM level to gain better understanding of the remaining scope of emissions.

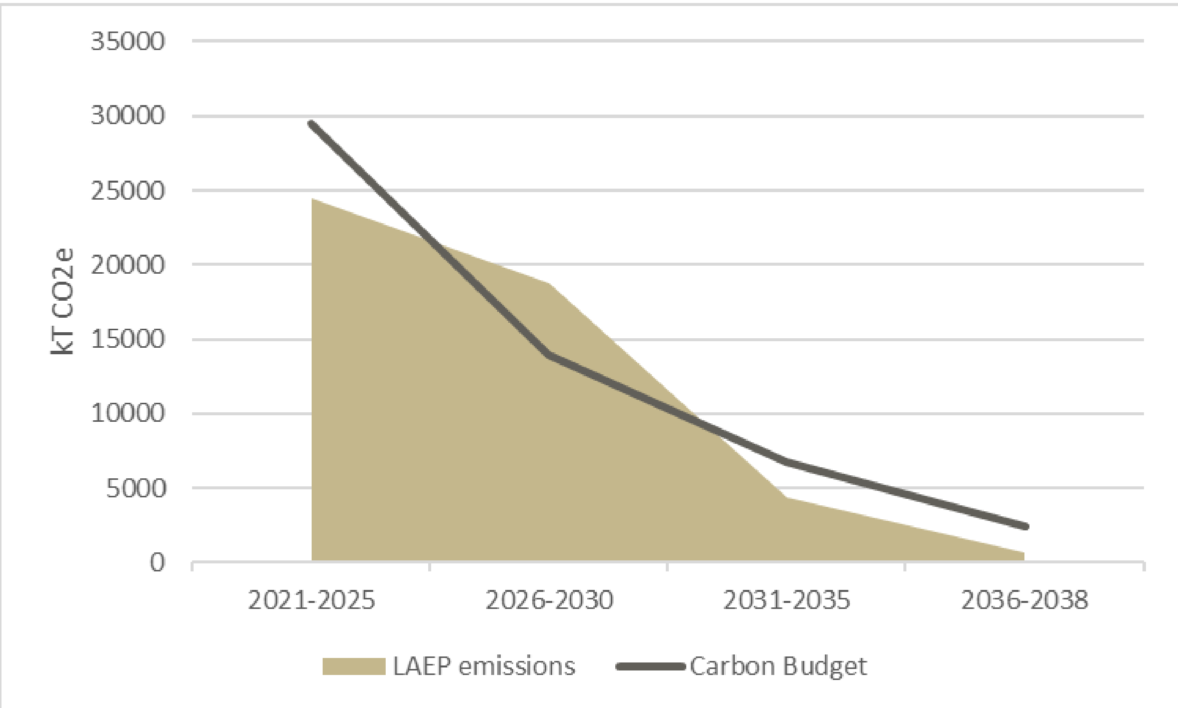
Emissions during the LAEP period

The chart below shows total carbon emissions over time across GM, broken down by period and sector. The cumulative emissions over the period 2021-2038 in the primary scenario are 49.5 Mt of CO_2e (and 48.2 Mt in the secondary scenario).

[*] Quantifying the implications of the Paris Agreement for Greater Manchester
[†] https://data.gov.uk/dataset/723c243d-2f1a-4d27-8b61-cdb93e5b10ff/uk-local-authority-and-regional-carbon-dioxide-emissions-national-statistics-2005-to-2019



The trajectory of emissions reduction in the primary scenario of 49.5 MT is shown compared to that set out in the carbon budget in the chart below. The total emissions LAEP emissions are a little lower than the 52.6 MT carbon emissions apportionment from the budget over the period, but it GMCA and its districts should consider what allowance is needed for emissions that are out of scope of the LAEP work, such as non-domestic and public transport. If the 3 MT difference is not adequate to cover these emissions, then it will be necessary to consider other options to reduce emissions further or find acceptable means of offsetting.

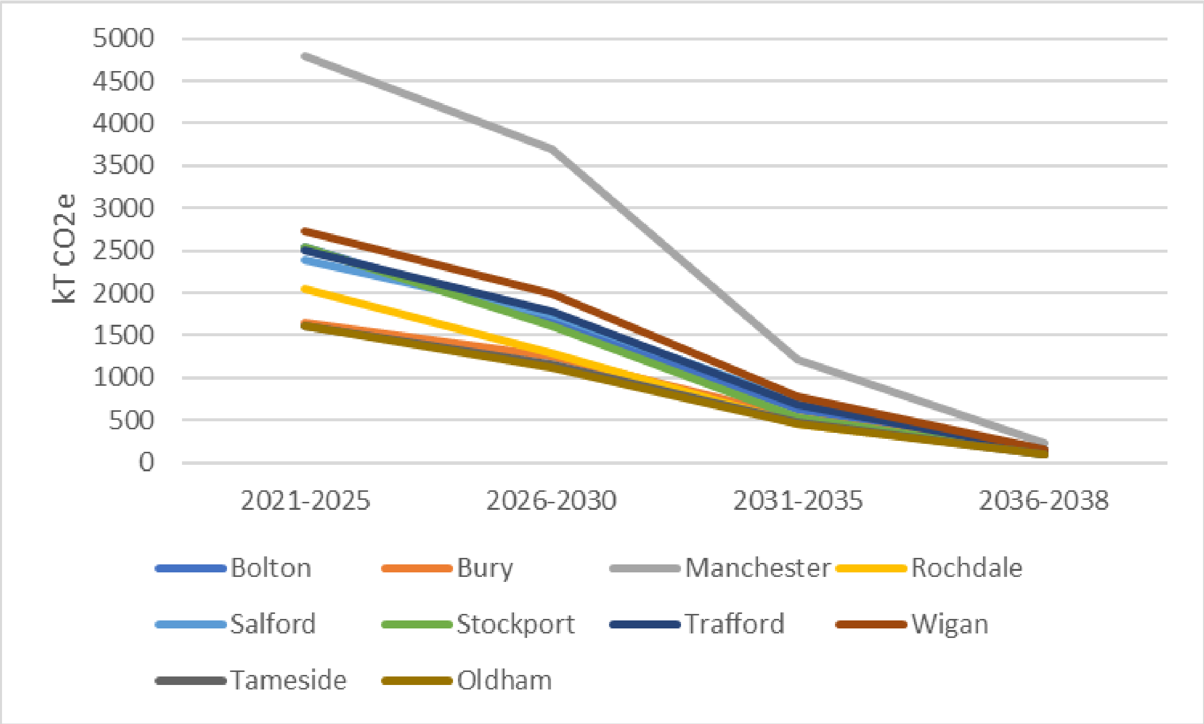


In addition, the trajectory of emissions in the LAEP work shows that, while the total emissions are underneath the budget allocation, the trajectory does not match across all time periods, with emissions in the LAEP somewhat lower than the budget in the first period and higher in the second. This may indicate a small amount of flexibility to trial and develop solutions (for example to make decarbonising private homes easier and more attractive) in the first period in low regret areas, which could then support a more accelerated roll out in the second period, in order to reduce emissions rapidly in line with the carbon budget trajectory.

Emissions across GM districts

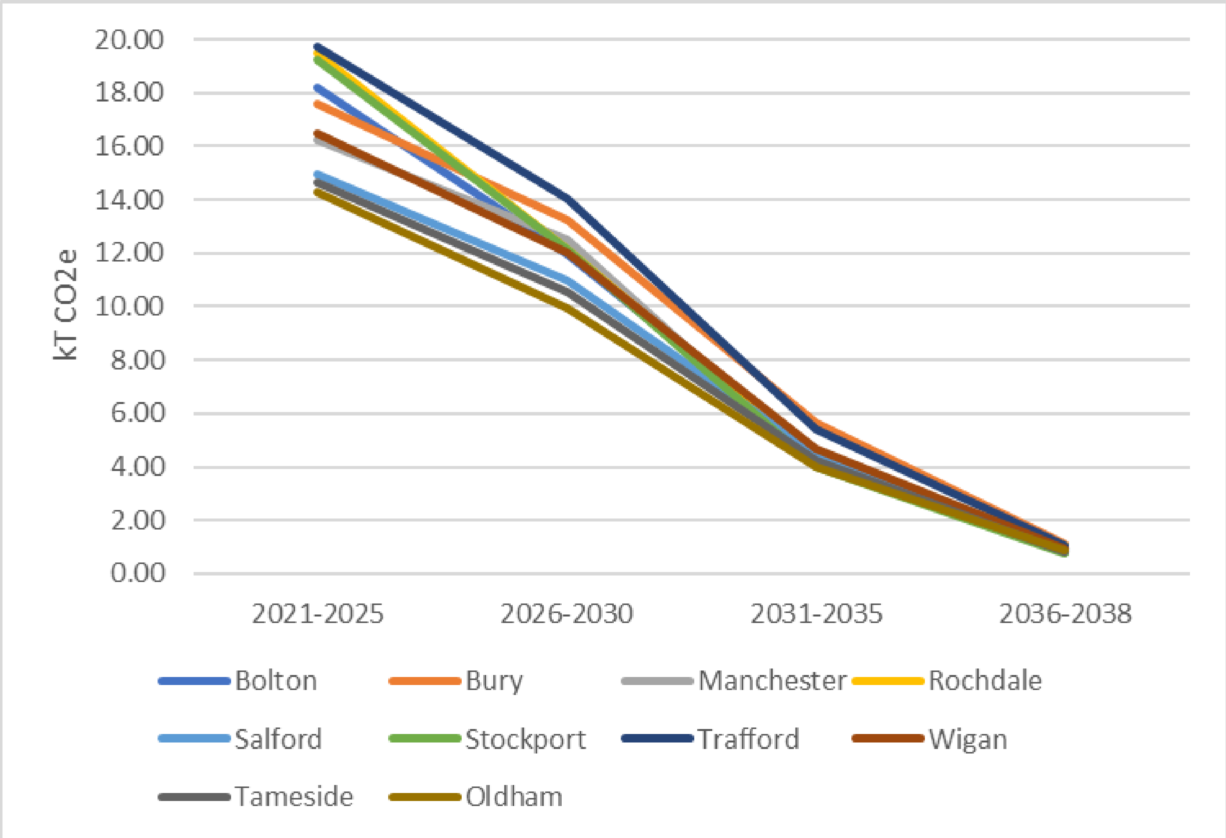
The emissions trajectory across the districts of GM follows a similar pattern, as shown by the following graph. Emissions start off significantly higher in Manchester owing to the density of this district, and therefore the scale of the challenge in absolute terms is highest there.

District Emissions Reduction Trajectories



However, when the emissions reductions are normalised by the number of homes in each district, the differences are considerably less stark, with a very similar trajectory across all districts, as seen in the following chart. It should be noted that the values per home here do not equate to the emissions reduction that each home is required to make based on their own energy usage, as they also include emissions associated with networks and non-domestic buildings, but instead this metric gives a more like-for-like comparison of the rate of decarbonisation needed in each area. Remaining variations between the districts reflect a range of factors, including varying network lengths in more or less urban areas and differing proportions of non-domestic buildings.

District Emissions Reduction Trajectory (normalised by homes in each district)



Irrespective of these variations, the LAEPs have shown that significant emissions reductions that support the GM carbon budget are possible in all districts. However, the differences do mean that any apportionment of emissions between the districts to create more local targets and budgets would have to be considered very carefully to ensure that these are fair. As well as the different emissions trajectories, some districts have greater potential than others for local renewable generation, as explored in section 6, and some districts have higher proportions of harder-to-decarbonise industrial emissions, and so any apportionment would need to account for the different constraints and resources of each district. It may therefore be more useful to consider carbon budget (and generation capacity) across GM, and to instead foster cooperation and collaboration between GMCA and the districts to support acceleration of emissions reduction through actions such as knowledge sharing, joint procurement and skills and supply chain development.

Key insights

- The energy system changes set out in this report and the individual ten district LAEPs that support it have the potential to keep emissions within the carbon budget for GM, however, this also depends on emissions reductions in areas outside of the scope of the LAEP work, for example, transport related emissions

- The trajectory of emissions reductions in the LAEP may allow some flexibility for large scale trials and smaller pilots in the first time period, which could then support accelerated emissions reductions in the following periods, helping to bring the trajectory in line with the overall carbon budget
- It is hard to fairly apportion the carbon budget between districts, and so collaboration across GMCA and the districts may be preferable, while also supporting acceleration through knowledge sharing, joint procurement and skills and supply chain development.

10. ROADMAP AND CONCLUSIONS

There are less than twenty years until 2038, the date by which Greater Manchester aims to be carbon neutral, and less than thirty years until 2050, the latest date by which the UK must reach Net Zero emissions.

The technologies and infrastructure that make up the energy system typically last for decades, whilst the development, planning, design, delivery, and operation of new energy infrastructure can have lead-times of five to ten years.

Whilst there is some flexibility to meet carbon neutrality in different ways depending on societal changes and technology innovation, there is an urgency for GM to prepare to start the transition now and over the next few years, focusing on low regret activities, building capacity and supply chains, etc. The key decision point of how to decarbonise heat will need to be made around 2025, primarily based on the role hydrogen will play in providing heat to buildings. The longer the delay in making this decision, the more unrealistic it would be to achieve the 2038 carbon neutral target.

Future Local Energy System in GM

The key opportunities and uncertainties can be categorised into four key areas:

- Reducing energy demand
- Increasing uptake of low carbon solutions
- Increasing local low carbon electricity production and storage
- The future role of the gas grid

It must be recognised that achieving carbon neutrality by 2038 is hugely ambitious and challenging and will require major local policy interventions, investment by government and industry and both technology and business innovation.

A key challenge for GM over the next five years is to build collective and coordinated action such that long-term investment in low carbon infrastructure is made in the 2020's and investment, scale-up and mass market deployment of low carbon technologies is achieved through the 2030's.

Achieving this will require action in the 2020s to act as the catalyst for change and to ensure supporting infrastructure is invested in as the backbone of a carbon neutral energy system for GM. It will require systematic changes in consumer and business behaviours, GM's local energy networks, the use of energy in its buildings and the ways people move around.

A roadmap for GM

Drawing together the pathways developed in each of the ten district LAEPs, a roadmap for decarbonisation of GM has been developed. The roadmap considers the actions needed in GM alongside wider contexts, particularly:

- The carbon budget for GM over time
- Announced changes to policy, including the ending of gas boilers in new builds and the ending of sales of internal combustion engine vehicles, which will be drivers for change in GM as in the rest of the country

This has allowed several key decision points to be identified for GM:

- Prior to 2025: it will be critical to progress the identified near-term low regret actions, in order to maintain progress towards the carbon budget and target.

- Around 2025: decision on whether hydrogen is likely to be to be a significant factor decarbonising heating in GM. This is illustrated on the following page. Factors in this decision will include:

    - Expected time frame for hydrogen becoming available and the quantity
    - Cost and carbon content of hydrogen
    - Progress with developing and rolling out other solutions, particularly heat pumps

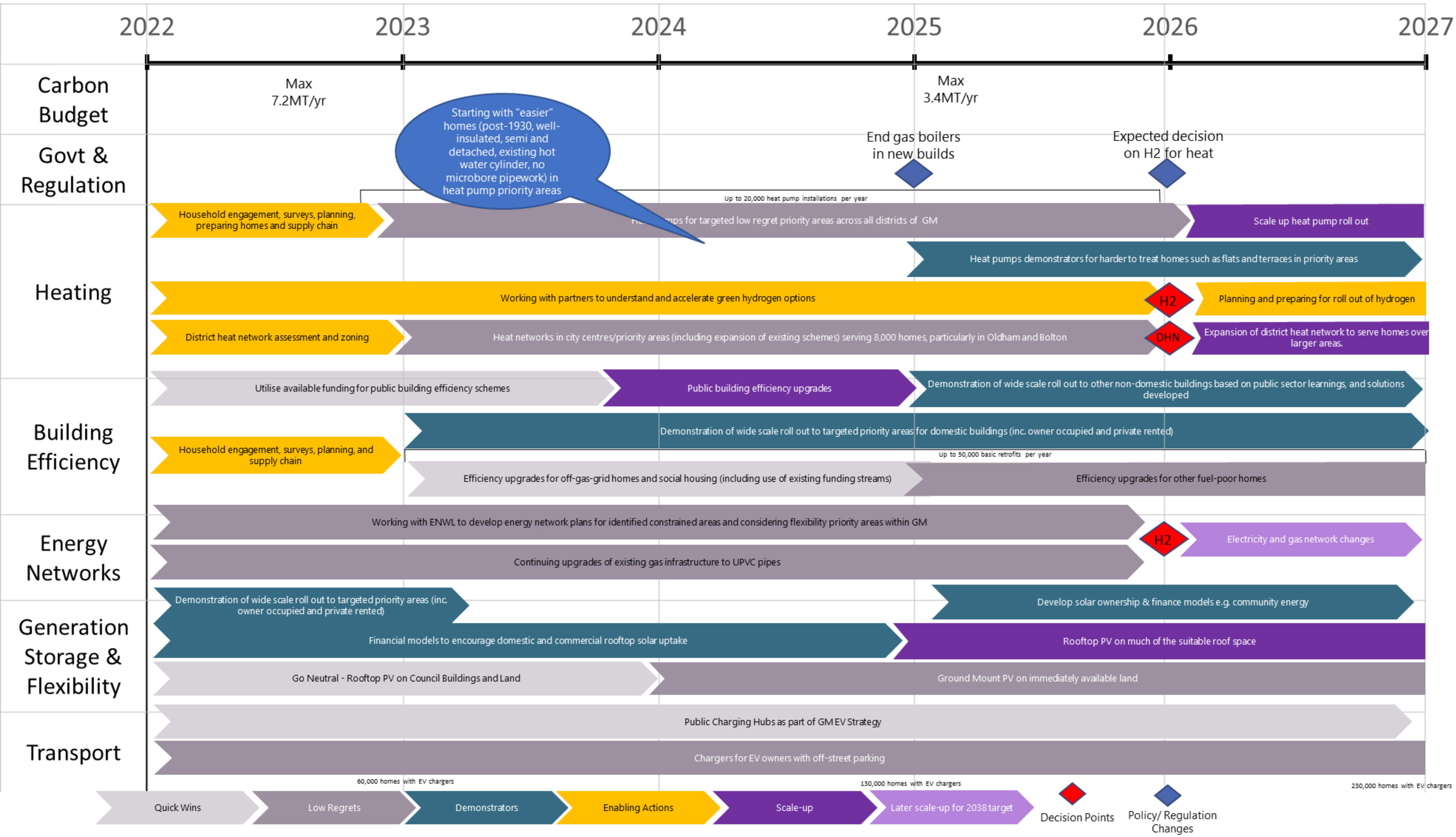
- Around 2025: consideration of whether heat networks can be expanded beyond the low regret priority zones to the wider opportunity areas that have been identified, where the case for deployment is more marginal. This decision will depend on factors such:
    - Reduction of costs for heat network deployment over time
    - Willingness of anchor heat loads to commit to heat networks
    - Development of heat zoning that may support easier and more rapid deployment of heat networks

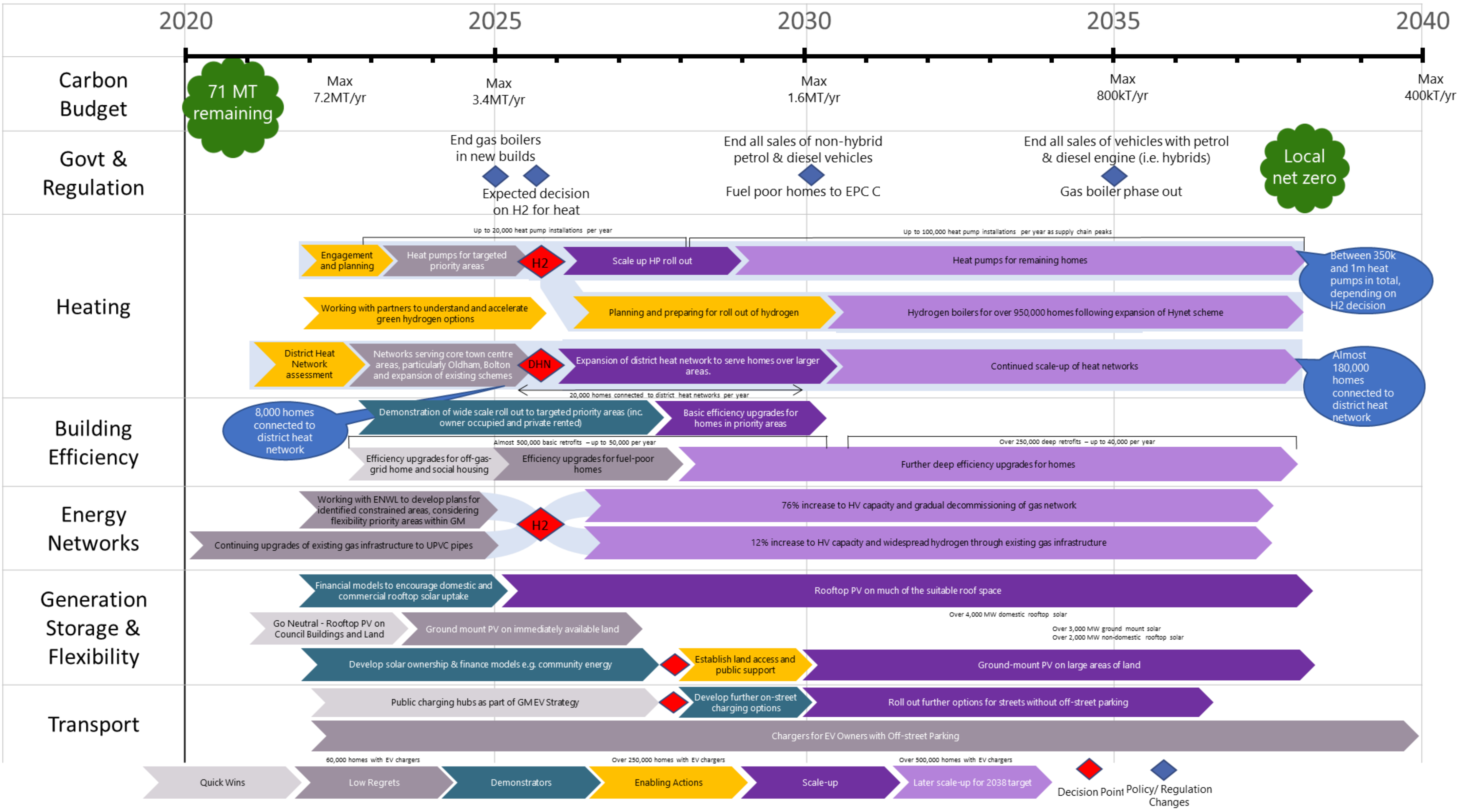
- Around 2027: consideration of whether a major drive for more local generation (particularly ground mounted PV) on non-publicly owned land remains needed to support the carbon budget. Influencing factors for this decision will include:
    - Development of business models and supply chain to support rapid roll out
    - Availability of solutions to support rapid and cost-effective connection to the grid, even in constrained areas (for example including co-located batter storage and active network management)
    - Willingness of landowners (once options for developing public land have been exhausted earlier in the period) and planning considerations
    - Rate of decarbonisation of the national grid electricity mix, where more rapid than expected decarbonisation would reduce the need for local generation (and vice versa).
- Around 2027: consideration on whether further charging options are needed to support EV ownership for homes without access to off-street parking. This could include various forms of kerbside charging such as pop-up and lamp post chargers. Influencing factors in this decision will include:
    - Success of public charging hubs (utilisation rates, user feedback)
    - Rate of EV adoption among homes with no off-street parking
    - Development of technologies (and associated business models) for alternative charging solutions.

The roadmap is provided in two parts on the following pages:

- An overview of activity for the near-term (next 5 years)
- An overview of activity from 2022 to 2038

The roadmap is intended to provide an initial indication of the main activities for GM to focus on over the coming years, summarising the outputs of each district LAEP, where there are consistent themes of proposed activity. Further work would be required to develop the roadmaps into more concrete plans/actions; which GMCA would need to work with the districts and other partner organisations to develop.


2022
2023
2024
2025
2026
2027
Carbon Budget
Max 7.2MT/yr
Max 3.4MT/yr
Govt & Regulation
Starting with "easier" homes (post-1930, well-insulated, semi and detached, existing hot water cylinder, no microbore pipework) in heat pump priority areas
End gas boilers in new builds
Expected decision on H2 for heat
Up to 20,000 heat pump installations per year
Heating
Household engagement, surveys, planning, preparing homes and supply chain
for targeted low regret priority areas across all districts of GM
Scale up heat pump roll out
Heat pumps demonstrators for harder to treat homes such as flats and terraces in priority areas
Working with partners to understand and accelerate green hydrogen options
H2
Planning and preparing for roll out of hydrogen
District heat network assessment and zoning
Heat networks in city centres/priority areas (including expansion of existing schemes) serving 8,000 homes, particularly in Oldham and Bolton
DHN
Expansion of district heat network to serve homes over larger areas.
Building Efficiency
Utilise available funding for public building efficiency schemes
Public building efficiency upgrades
Demonstration of wide scale roll out to other non-domestic buildings based on public sector learnings, and solutions developed
Household engagement, surveys, planning, and supply chain
Demonstration of wide scale roll out to targeted priority areas for domestic buildings (inc. owner occupied and private rented)
Up to 50,000 basic retrofits per year
Efficiency upgrades for off-gas-grid homes and social housing (including use of existing funding streams)
Efficiency upgrades for other fuel-poor homes
Energy Networks
Working with ENWL to develop energy network plans for identified constrained areas and considering flexibility priority areas within GM
H2
Electricity and gas network changes
Continuing upgrades of existing gas infrastructure to UPVC pipes
Generation Storage & Flexibility
Demonstration of wide scale roll out to targeted priority areas (inc. owner occupied and private rented)
Develop solar ownership & finance models e.g. community energy
Financial models to encourage domestic and commercial rooftop solar uptake
Rooftop PV on much of the suitable roof space
Go Neutral - Rooftop PV on Council Buildings and Land
Ground Mount PV on immediately available land
Transport
Public Charging Hubs as part of GM EV Strategy
Chargers for EV owners with off-street parking
60,000 homes with EV chargers
130,000 homes with EV chargers
230,000 homes with EV chargers
Quick Wins
Low Regrets
Demonstrators
Enabling Actions
Scale-up
Later scale-up for 2038 target
Decision Points
Policy/ Regulation Changes



2020
2025
2030
2035
2040
Carbon Budget
71 MT remaining
Max 7.2MT/yr
Max 3.4MT/yr
Max 1.6MT/yr
Max 800kT/yr
Max 400kT/yr
Govt & Regulation
End gas boilers in new builds
Expected decision on H2 for heat
End all sales of non-hybrid petrol & diesel vehicles
Fuel poor homes to EPC C
End all sales of vehicles with petrol & diesel engine (i.e. hybrids)
Gas boiler phase out
Local net zero
Heating
Up to 20,000 heat pump installations per year
Up to 100,000 heat pump installations per year as supply chain peaks
Engagement and planning
Heat pumps for targeted priority areas
H2
Scale up HP roll out
Heat pumps for remaining homes
Between 350k and 1m heat pumps in total, depending on H2 decision
Working with partners to understand and accelerate green hydrogen options
Planning and preparing for roll out of hydrogen
Hydrogen boilers for over 950,000 homes following expansion of Hynet scheme
District Heat Network assessment
Networks serving core town centre areas, particularly Oldham, Bolton and expansion of existing schemes
DHN
Expansion of district heat network to serve homes over larger areas.
Continued scale-up of heat networks
Almost 180,000 homes connected to district heat network
20,000 homes connected to district heat networks per year
8,000 homes connected to district heat network
Building Efficiency
Demonstration of wide scale roll out to targeted priority areas (inc. owner occupied and private rented)
Basic efficiency upgrades for homes in priority areas
Almost 500,000 basic retrofits – up to 50,000 per year
Over 250,000 deep retrofits – up to 40,000 per year
Efficiency upgrades for off-gas-grid home and social housing
Efficiency upgrades for fuel-poor homes
Further deep efficiency upgrades for homes
Energy Networks
Working with ENWL to develop plans for identified constrained areas, considering flexibility priority areas within GM
H2
76% increase to HV capacity and gradual decommissioning of gas network
Continuing upgrades of existing gas infrastructure to UPVC pipes
12% increase to HV capacity and widespread hydrogen through existing gas infrastructure
Generation Storage & Flexibility
Financial models to encourage domestic and commercial rooftop solar uptake
Rooftop PV on much of the suitable roof space
Over 4,000 MW domestic rooftop solar
Go Neutral - Rooftop PV on Council Buildings and Land
Ground mount PV on immediately available land
Over 3,000 MW ground mount solar
Over 2,000 MW non-domestic rooftop solar
Develop solar ownership & finance models e.g. community energy
Establish land access and public support
Ground-mount PV on large areas of land
Transport
Public charging hubs as part of GM EV Strategy
Develop further on-street charging options
Roll out further options for streets without off-street parking
Chargers for EV Owners with Off-street Parking
60,000 homes with EV chargers
Over 250,000 homes with EV chargers
Over 500,000 homes with EV chargers
Quick Wins
Low Regrets
Demonstrators
Enabling Actions
Scale-up
Later scale-up for 2038 target
Decision Point
Policy/ Regulation Changes

Deployment

Delivering this roadmap across GM will be a considerable challenge, requiring changes to almost every building in the region as well as significant changes to the existing electricity and gas networks, and development of much new infrastructure. A suggested deployment rate for domestic properties each of the key technologies is set out below, to support this roadmap*.

	2020-25	2025-30	2030-35	2035-40
Heat pumps	116,000	572,000	941,000	1,000,000
District heat connections	8,000	107,000	177,000	180,000
Hydrogen boilers	0	500	909,800	909,800
Insulation (basic) - primary	81,000	302,000	440,000	497,000
Insulation (basic) - secondary	*67,000*	*250,000*	*365,000*	*413,000*
Insulation (advanced) - primary	42,000	158,000	230,000	260,000
Insulation (advanced) - secondary	*73,000*	*271,000*	*394,000*	*445,000*
EVs	44,000	248,000	598,000	995,000
EV chargers	60,000	269,000	483,000	517,000
Rooftop PV (MWp)	1,900	2,900	3,600	4,400

Deployment within the non-domestic sectors will need to show similar acceleration from the second period to support the carbon budget, building on the learnings from near-term actions in the public sector. This will include the opportunity for over 2.5 GW of non-domestic rooftop PV

Delivering this massive change will require new skills and supply chains, as well as products and services to make the transition more desirable for residents and businesses and may need policy and funding support. Within this context, collaboration between GMCA and the districts will be vital to:

- Ensure that an informed and coordinated approach is taken that considers the energy system in GM as a whole and avoid issues of actions being taken in one district having unexpected consequences in others
- Develop a joint approach to governance, evaluation, and monitoring, incorporating a mechanism to evaluate how interventions are aligned to GM's carbon budget
- Consider a process for cross border LAEP reconciliation and interaction across GM, noting the difficulties described in section 9 of trying to apportion carbon budget between the districts.
- Maximise the benefits from learnings (such as of pilots and trials) by sharing these across the region and avoiding duplication

* All figures given are for the primary scenario, except hydrogen boilers, where the figures are for the secondary scenario (as no domestic hydrogen for heating is deployed in the primary scenario), and for insulation, where figures are given for both scenarios to illustrate the diverging insulation requirements between the scenarios.

- Take advantage of economies of scale through joint procurement, to drive down overall costs to GM and its residents
- Develop coherent approaches to training and upskilling that will ensure the supply chain can support the rapid roll out of new solutions that will be needed
- Determine the approach working with energy and technology suppliers and service providers to develop novel product and service offerings that will make decarbonising (particularly for GM's homes) easier and more cost-effective
- Engage most efficiently with partners who cover the whole district, and whose assets run across boundaries, in particular ENWL and Cadent regarding electricity, gas, and hydrogen networks
- Spot and take advantage of opportunities that run across boundaries, such as to expand heat networks where they are close to boundaries and suitable buildings can be identified in a neighbouring district
- Build understanding and evidence around practical approaches to challenging or novel building modifications, such as fabric retrofit of terrace rows, or installation of air source heat pumps to existing flats.
- Take forward heat network zoning and consider how the heat network priority zones and opportunity areas identified could feed into this
- Work with government and other key stakeholders to establish policy and funding mechanisms

Consultation

Wider stakeholder collaboration, engagement, and consultation will be needed to deliver the vision of this report across GM. As part of the work to develop the ten district LAEPs that support this report, an initial public consultation process was undertaken using the tool zerocarbon.vote, to begin to understand how householders in the districts of GM would prefer to decarbonise their homes, and how this aligns with the pathways set out in the LAEPs. GMCA and the districts can use the insights from this consultation to refine target priority areas and understand where further engagement may be needed, utilising outcomes to support the creation of a detailed action plan and delivery programme.

Wider LEM Project Partners

GMCA Greater Manchester Combined Authority
bruntwood
ovo energy
Carbon Co-op
HITACHI Inspire the Next
DAIKIN
CORNWALL INSIGHT CREATING CLARITY
GrahamOakes Community & Municipal Energy
Cadent Your Gas Network
regen transforming energy
electricity north west
Northwards Housing North Manchester's Council Homes

ACKNOWLEDGEMENTS

This report was prepared by Energy Systems Catapult on behalf of Greater Manchester Combined Authority. Support on renewable energy generation opportunities and engineering feasibility review was provided by Buro Happold.

Local knowledge, data, direction, and guidance were provided by Greater Manchester Combined Authority.

Information relating to existing energy networks, and wider input to the development of this Plan were provided by the electricity distribution network operator Electricity North West and gas distribution network operator Cadent.

The following stakeholders also provided input during the development of this Plan: Department of Business, Energy, and Industrial Strategy, Ofgem and Innovate UK.

About the GM LEM project

This report was produced as part of the Greater Manchester Local Energy Market (GM LEM) project, which forms a key part of Greater Manchester Combined Authority's plans for decarbonisation, set out in the 5 Year Environment Plan, complemented by the Whole System Smart Energy Plan. Together these enable Greater Manchester to work towards the target for a zero-carbon emissions city region by 2038. The GM LEM project is an ambitious integrated, whole system energy vision that addresses how energy is generated, traded, transported, supplied, and used across the city region. Co-ordinated by the Greater Manchester Combined Authority (GMCA), it brings together a diverse array of partners from the private, public and third sectors, including commercial and legal advisors, service design consultants, financial and regulatory specialists and the energy, technology, and systems resources. The two-year project is funded by Innovate UK.

About Local Area Energy Planning

Energy is a core part of national and local economies and infrastructure. Decarbonisation of the UK will require significant changes to energy systems, yet every local area is unique, and the changes needed to decarbonise will be specific to each area. Energy Systems Catapult (ESC) pioneered a new whole system approach to Local Area Energy Planning (LAEP) with pilots in three different local areas of the UK – Newcastle, Bury in **Greater Manchester**, and Bridgend in Wales. ESC has since worked with others to evolve this approach, including with Ofgem and Centre for Sustainable Energy to define a method for LAEP[*] 'done well', which we have sought to follow in the creation of the ten district LAEPs that this report draws on, within the constraints of the GM LEM[†] project. In this project the ESC's EnergyPath Networks toolkit has been used to perform the local analysis.

[*] https://es.catapult.org.uk/reports/local-area-energy-planning-the-method/
[†] https://es.catapult.org.uk/reports/local-area-energy-planning/

About Energy Systems Catapult

ESC was set up to accelerate the transformation of the UK's energy system and ensure UK businesses and consumers capture the opportunities of clean growth. ESC is an independent, not-for-profit centre of excellence that bridges the gap between industry, government, academia, and research. We take a whole systems view of the energy sector, helping us to identify and address innovation priorities and market barriers, to decarbonise the energy system at the lowest cost. We work with innovators from companies of all sizes to develop, test and scale their ideas. We also collaborate with industry, academia, and government to overcome the systemic barriers of the current energy market to help unleash the potential of new products, services and value chains required to achieve the UK's clean growth ambitions as set out in the Industrial Strategy.

About Buro Happold

Buro Happold is an international, integrated consultancy of engineers, consultants, and advisers. Operating in 26 locations worldwide, with 55 partners and over 1,900 employees; for over 40 years we have built a world-class reputation for delivering creative, value led solutions for an ever-challenging world.

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	Name	Position
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Reviewer		
Approver		

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Date	Version	Comments
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29/04/22	0.2	Internal draft for review
07/06/22	0.3	Client review
28/06/22	0.4	Addressing Client Comments

GREATER MANCHESTER LOCAL ENERGY MARKET

DOING THINGS DIFFERENTLY FOR THE ENVIRONMENT

Technical Annex

The technical annex summarises aspects of the evidence base that has been used to develop this LAEP; based on scenario based whole energy system modelling and analysis

THE FOUR SCENARIOS

A variety of energy system scenarios are possible to deliver Greater Manchester's future energy vision. It is not practical to consider every possible configuration of local energy systems in a limited number of scenarios, therefore four main scenarios were considered; these represent the prominent cost-effective options that could materialise. The same four scenarios were used consistently in the modelling for each of the ten districts, so that the results could be combined into this report.

The scenarios are not predictions or forecasts of the most probable outcomes. They represent plausible and affordable futures based on available information and have been used to inform a plan for each of the ten districts in GM, which have then been combined to form this report. The decarbonisation of any local energy system will require considerable co-ordination, planning and investment as well as consumer and social engagement. This is particularly the case when consider GM as a whole, where GMCA will need to work together with the districts in implementing the plan.

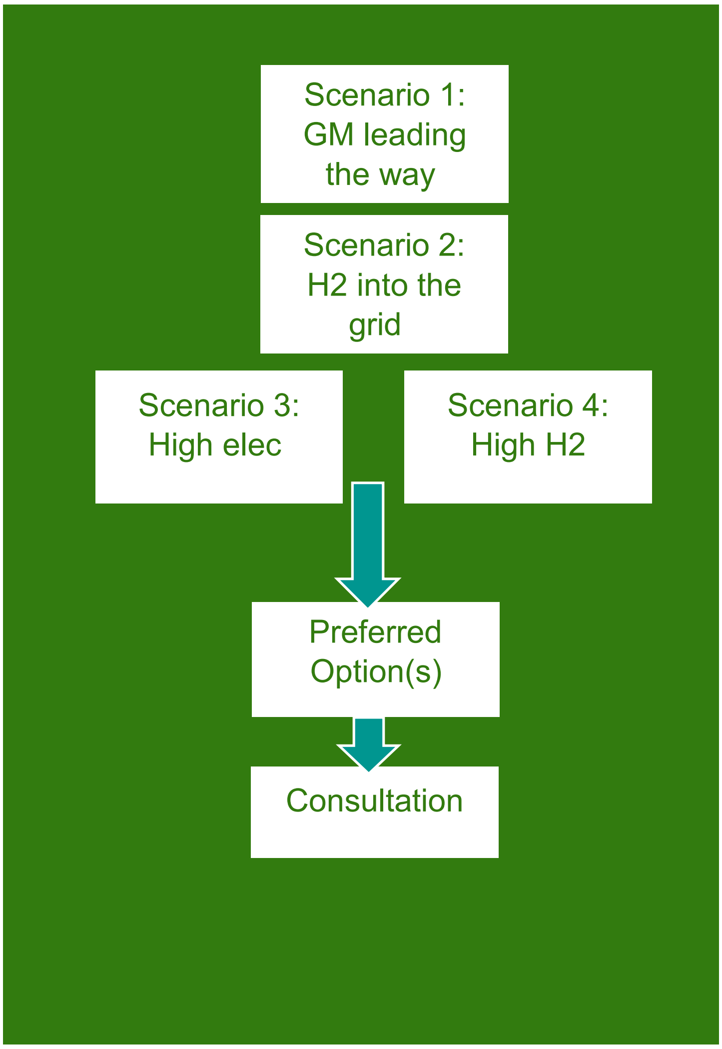
The scenarios have been developed through frequent engagement with GMCA, as well as consulting with a wider group of stakeholders including Cadent and Electricity Northwest. Consultation and engagement with residents was carried out as part of the wider Greater Manchester Local Energy Market project and will continue to inform the development and refinement of the ten district LAEPs and therefore the wider GM findings set out in this report.

A brief description of the different scenarios developed and used to inform the plan is given here, with summarised modelling outputs from the key primary and secondary scenarios provided in the following pages.

Importantly, each future local energy scenario has been developed to reach carbon neutrality by 2038, aligned to Greater Manchester's decarbonisation ambition and to also act as counterfactuals and alternative futures for GM. These scenarios are constructed using location specific information on the existing energy networks, buildings, local constraints and resources in each of the ten districts, in combination with data on technology performance and costs, and modelled using ESC's EnergyPath Networks modelling toolkit.

Modelled scenarios and plan development

These scenarios provide an understanding of pace and scale of activity needed, costs and investment needed for local implementation in support of decarbonisation goals and the commonality and variation of measures across the different future local energy scenarios. The scenarios help to explore choices around how to reach carbon neutrality using different technologies and known solutions where they exist. Each scenario was modelled for each district to inform their own district LAEPs, and the results were then amalgamated to GM level to inform this report.*



Scenario 1 – Leading the Way: this scenario focuses on meeting the carbon budget and target by making use of **proven measures within GM's (and the districts') local control** where at all possible.

Scenario 2 – An Alternative Future Local Energy Scenario: we have assumed hydrogen options for residential heating and non-domestic buildings become available in GM from 2030 onwards, aligned to HyNet Phase 3 and the repurposing of the gas grid to hydrogen is an option

* It should be noted that modelling covering the whole of GMCA has not been carried out, as the size of the area makes this mathematically too complex to be workable, and such an approach would also lose some of the local detail and insight that makes the ten district LAEPs valuable.

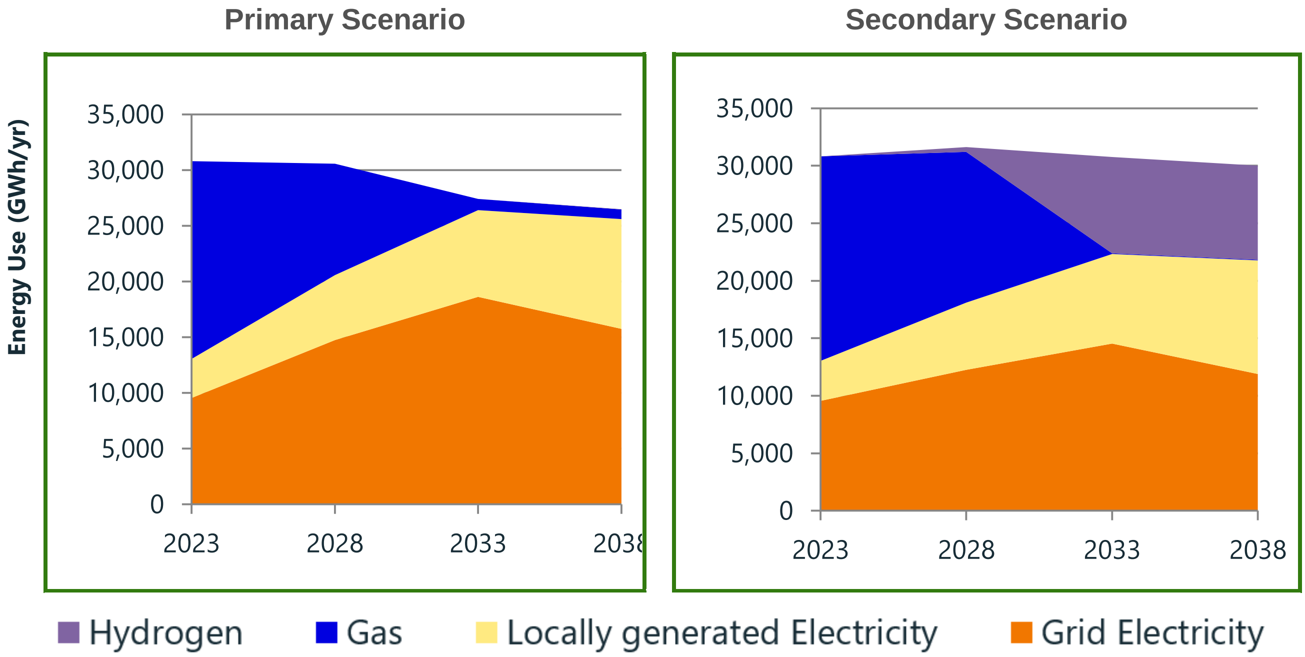
Scenario 3 – High Electrification: we have assumed the only low carbon options for buildings heating and hot water demand are electric based. This includes energy centres feeding local heat networks

Scenario 4 – High Hydrogen - we have assumed the only available low carbon options for buildings' heating and hot water demand are hydrogen based from 2031 onwards

Scenarios 3 and 4 provide context and evidence for what would happen if either hydrogen or electrification were pursued as the sole solution for the decarbonisation of homes and buildings in GM. Whilst this is considered to have a number of practical limitations to feasible implementation by 2038, these were considered useful as comparative scenarios in the ten districts.

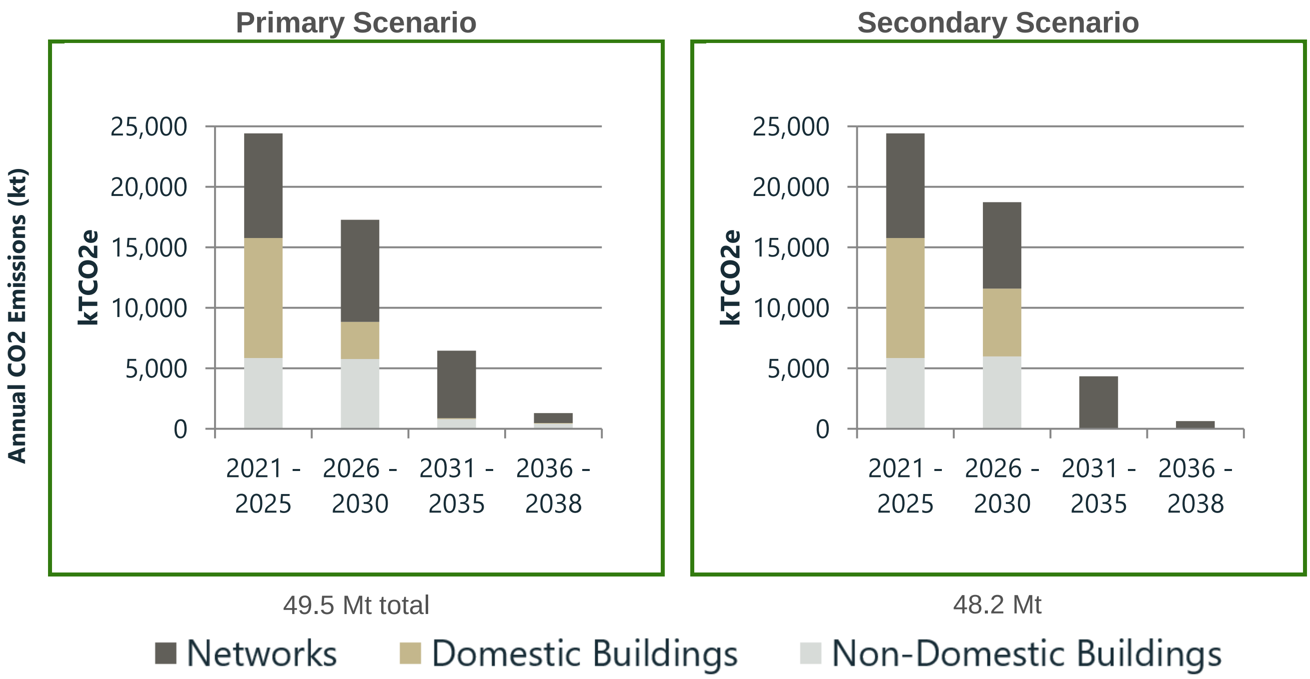
However, for all ten districts, the final LAEP pathway (including costs, carbon emissions and identified priority zones/opportunity areas) are based on the primary and secondary scenarios only. Because scenarios 3 and 4 act as extreme counterfactuals, these were less significant in drawing together the combined findings of the ten districts into this report, and therefore only results for scenarios 1 and 2 are presented in the following pages.

Energy Consumption Over Time



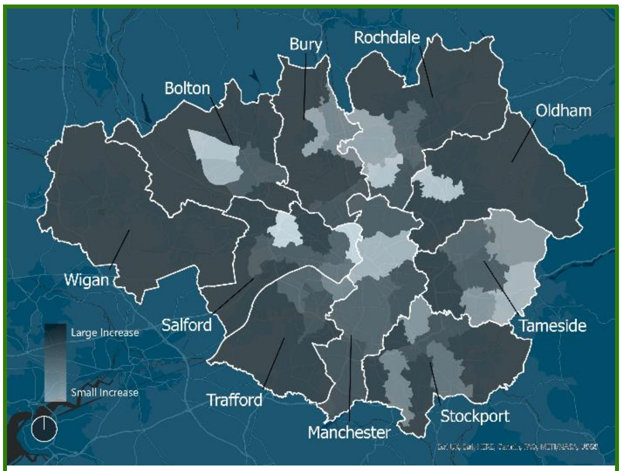
Figures shown exclude petrol and diesel fuel consumed for transport. The overall reduction in energy consumption due to increased efficiency is therefore greater than shown, due to the reduction in transport fuel consumption.

Emissions Over Time

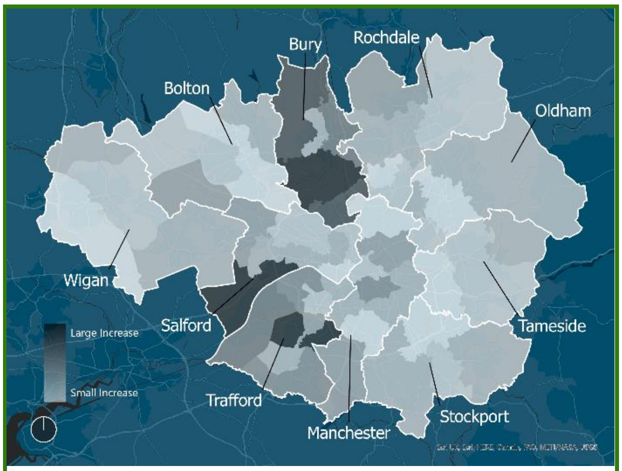


Heat Pump Deployment by 2038

Primary Scenario

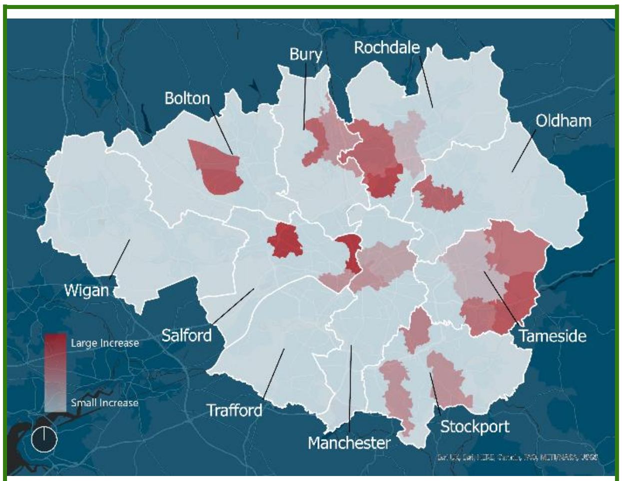


Secondary Scenario

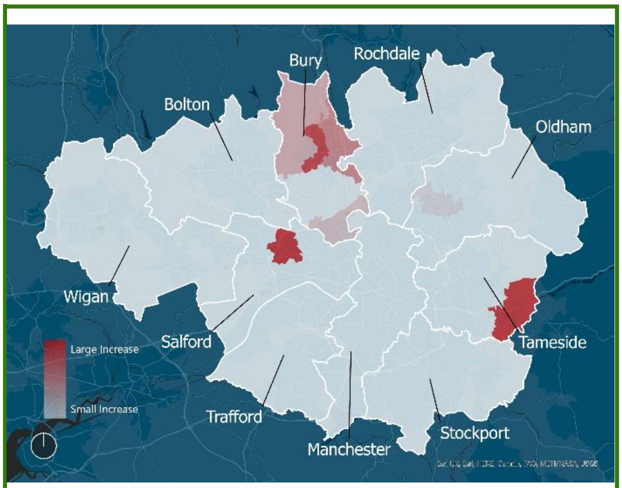


District Heating Connections by 2038

Primary Scenario

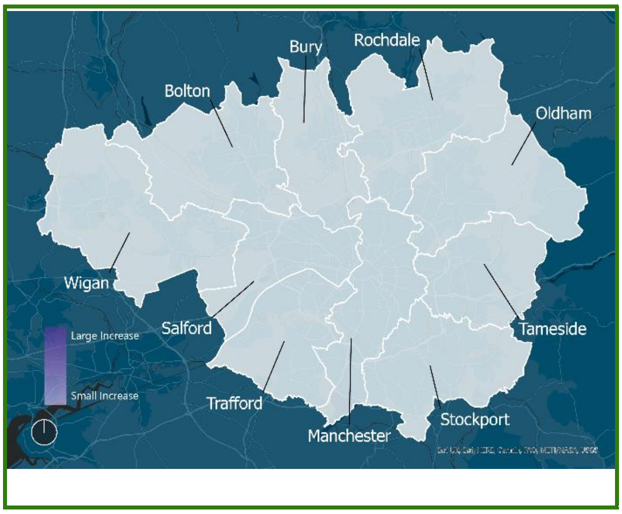


Secondary Scenario

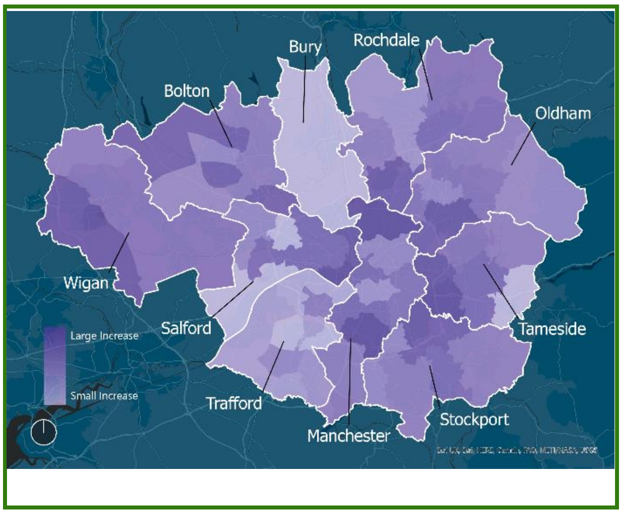


Hydrogen Boiler Deployment by 2038

Primary Scenario



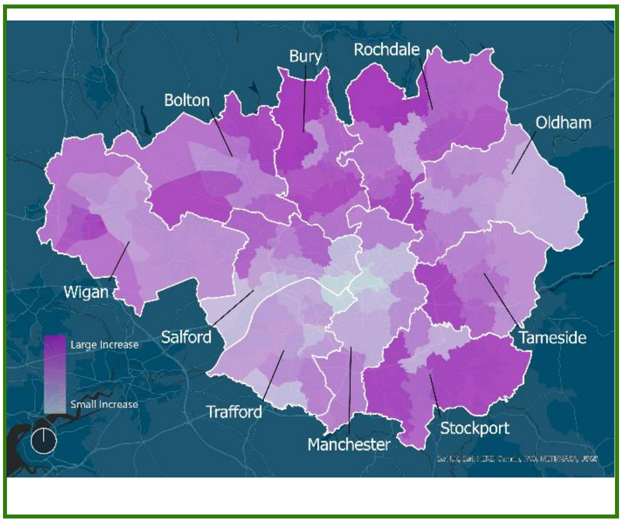
Secondary Scenario



Retrofit by 2038

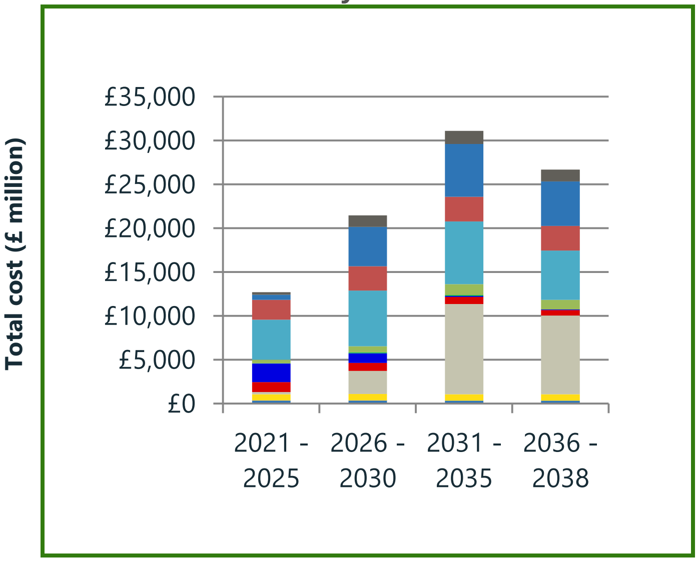
Primary Scenario

Secondary Scenario



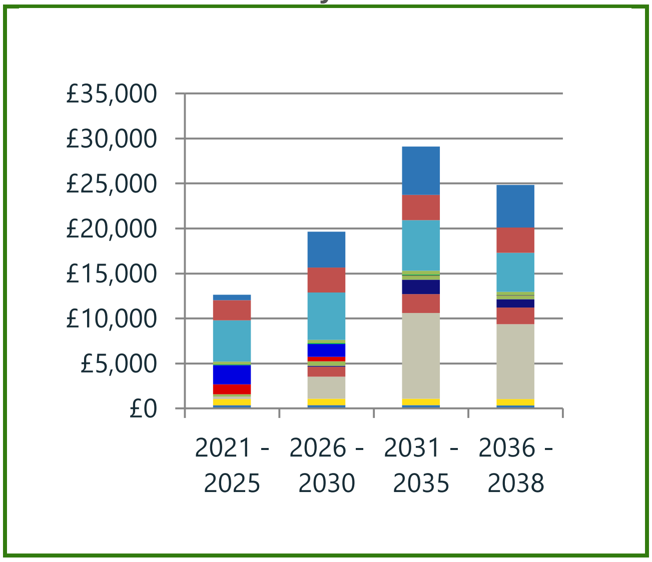
SYSTEM COST

Primary Scenario



£92 bn total

Secondary Scenario



£86 bn total

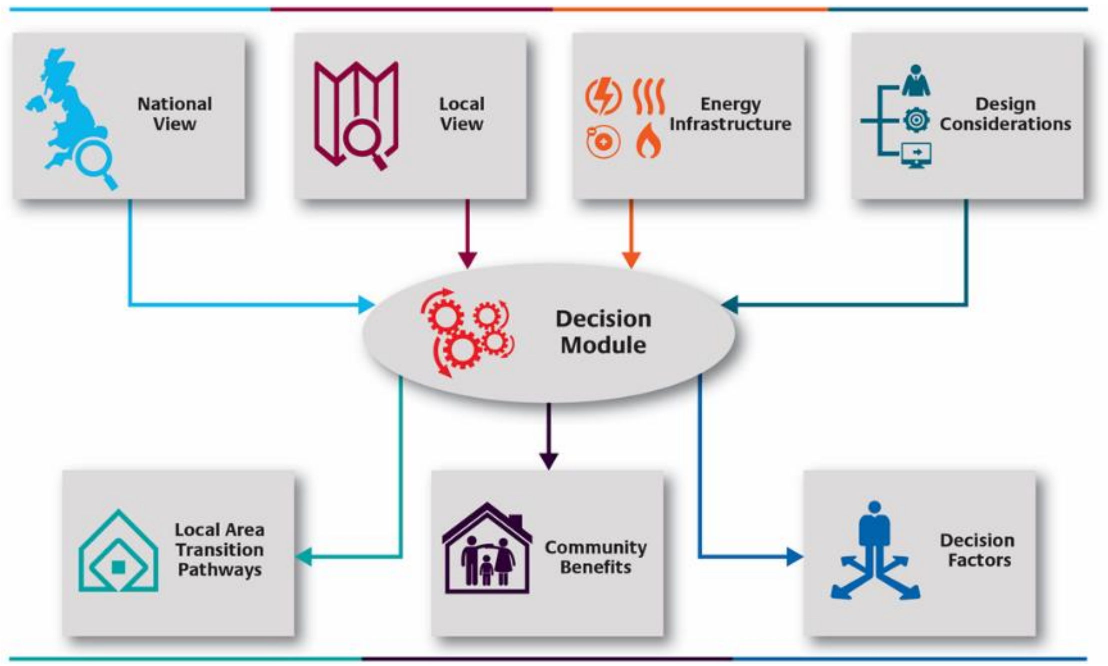
- Domestic Heating Systems & Insulation
- Domestic PV
- Electricity Import
- Electricity Network
- EV Chargers
- Gas Import
- Gas Network
- Heat Networks
- Hydrogen Import
- Hydrogen Network
- Non-Domestic Heating & Insulation
- Non-domestic Solar
- Oil Import
- Solar Ground Mounted

The modelling of the 4 future local energy scenarios for GM has been performed using the ESC-developed EnergyPath Networks. This tool seeks to develop a full range of decarbonisation options for the local area and then use an optimisation approach to identify the combination that best meets the carbon ambitions in a cost-effective way across the whole system.

EnergyPath Networks is a whole system optimisation analysis framework that aims to find cost effective future pathways for local energy systems to reach a carbon target whilst meeting other local constraints. EPN is spatially detailed, covers the whole energy system and all energy vectors, and projects change over periods of time. The focus is decarbonisation of energy used at a local level.

An overview of EPN is shown in the diagram to the below.

EnergyPath Networks Process Flow



At the core of EPN, a Decision Module compares decarbonisation pathways and selects the combination that meets the CO2 emissions target set for the local area at the lowest possible total cost to society.

A variety of local energy system pathways are possible to meet emissions targets. Running multiple EnergyPath Networks scenarios and doing sensitivity analyses reveals decarbonisation themes that are prevalent across all scenarios.

EPN uses optimisation techniques in the Decision Module to compare many combinations of options (tens of thousands) rather than relying on comparisons between a limited set of user-defined scenarios (although scenarios of different inputs are still typically used and the Decision Module then runs within each of these scenarios).

EnergyPath Networks is unique in combining several aspects of energy system planning in a single tool:

- Integration and trade-off between different methods of meeting heat demand – e.g. gas, solid/liquid fuels, electric power, hydrogen, district heating schemes, etc.
- Integration through the energy supply chain from installing, upgrading or decommissioning assets (production, conversion, distribution and storage) to upgrading building fabric and converting building heating systems
- Inclusion of existing and new build domestic and commercial buildings
- The spatial relationships between buildings and the networks that serve them, so that costs and benefits are correctly represented for the area being analysed
- Spatial granularity down to building level when the input data is of appropriate quality
- A modelled time frame of 2020 to 2040.

Taken together, the analyses enable informed, evidence-based decision-making and can be used to ensure long-term resilience in near-term decisions, mitigating the risks of stranded assets.

The approach to modelling these aspects of the energy system is described in detail over the following slides.

Domestic Buildings

The thermal efficiency of domestic buildings is related to the construction methods used, the level of any additional insulation that has been fitted and any modifications that have been undertaken since construction. The oldest buildings in the UK generally have poor thermal performance compared with modern buildings. In addition to building age, the type and size of a building also have a direct influence on thermal performance. For example large, detached buildings have a higher heat loss rate than purpose-built flats, due to their larger external surface area per m^2 of floorspace.

Buildings are categorised into five age bands in EnergyPath Networks, from pre-1914 to the present. These are broadly consistent with changes in building construction methods (as defined in building regulations) and so represent different levels of ‘as built’ thermal efficiency. The thermal efficiency of future new homes represents the minimum efficiency level required by current building regulations. There are ten modelled domestic building types. This allows approximately 60 different age and building type combinations which are used to define the thermal characteristics of existing and planned domestic buildings.

Once the current characteristics of a building have been defined, based on its age and type, the basic construction method can then be categorised. For example, the oldest buildings in the region can be expected to be constructed with solid walls. Buildings constructed between 1914 and 1979 are more likely to have been built with unfilled cavity walls. Buildings constructed from 1980 onwards are likely to have filled cavity walls. Where data (for example, Energy Performance Certificates) shows that they are likely to be present, thermal efficiency improvements that have been carried out since construction (such as filling cavity walls) are also included.

Where available, address level data is utilised in the EnergyPath Networks modelling to provide accurate building attributes. Missing building attributes, for example types of wall or windows are filled using rules based on English Housing Survey data.

Domestic Heating Systems

The definition of current (primary) heating systems is handled in a similar way to the definition of the building fabric. Information is used to identify the heating system as follows:

1. Xoserve data is first used to identify which buildings in the local area are not connected to the gas grid
2. Direct user input is used where the actual heating system in individual buildings is known (e.g. from Energy Performance Certificates), and from data provided by GM from Accelerating Retrofit[*] study
3. Defining logic rules based on the most likely heating system combinations within each archetype group.

Once the current thermal efficiency of a building has been defined, Ordnance Survey MasterMap and LIDAR data is used to establish its floor area and height. With this knowledge of a building's characteristics there is sufficient information to perform a Standard Assessment Procedure (SAP) calculation. SAP calculations are used to calculate the overall heat loss rate and thermal mass of domestic buildings in the study area.

EnergyPath Networks utilises these SAP results, as well as detailed retrofit and heating system cost data, to group buildings into similar archetypes. EnergyPlus is used to calculate dynamic energy profiles for heat and power demand for each group, for the current and all potential future pathways. These pathways include potential to install varying levels of fabric retrofit and different future heating systems in multiple combinations. Restrictions are applied so that inappropriate combinations are not considered, so for example loft insulation cannot be fitted to a mid-floor flat. EnergyPath Networks also filters out heating systems and storage combinations that cannot be sized to a large enough power within a home to meet a predefined target comfort temperature and hot water requirements based on the EnergyPlus analysis.

Three primary elements are defined in each heating system combination:

1. The main heating system
2. A secondary heating system which can provide additional heat or hot water
3. Thermal storage – either not present or a hot water tank.

For each domestic building the modelling assumes that the heating system will be replaced once between now and 2038. This assumes that heating systems are replaced at their end of life (generally around 15-20 years). On each of these occasions there is an opportunity to change to an alternative heating system and perform some level of building fabric retrofit. Different heating systems reach end of life at different times, but there would need to be some coordination of the change if transitioning to a district heat or community system. Three different levels of retrofit (thermal performance enhancement) are considered, ranging from do-nothing, to basic measures to a full retrofit. In addition, each heating system option can be combined with advanced heating

[*] Study conducted by Parity Projects on housing stock of Greater Manchester https://democracy.greatermanchester-ca.gov.uk/documents/s13523/

controls and each level of retrofit. Options will be excluded if a new heating system technology is unable to provide sufficient power to meet heat demand in a building with a given level of retrofit. These combinations mean that for each building there can be as many as 126 different future pathways which must be considered.

Non-Domestic Buildings

Non-domestic (commercial and industrial) building stock is more diverse than domestic stock. There are a wide variety of construction methods and few robust data sets are available defining the design of any particular building, its heating system or thermal performance. Due to these limitations, an energy benchmarking approach is used to establish the energy demand of the non-domestic stock.

Different building types are given an appropriate energy use profile per unit of floor area. The building type represents how the building is used (e.g. industry, retail, offices, school) and is sourced from a variety of datasets including OS Address Base and Energy Performance Certificates.

Benchmarks are defined for electricity (direct electric, ground source heat pump and air source heat pump), gas, hydrogen, oil and heat demand in 30-minute time periods for different characteristic heat days. Benchmarks are defined for current and future use to represent changing energy use over time.

The footprint floor area and height for each building is derived from the OS MasterMap and LIDAR data. The building height is then used to establish the number of storeys, from which the total building floor area is estimated. Using an energy benchmark (derived from CIBSE and CARB2 data) appropriate to the particular use class, the half hour building energy demand for gas, electricity and heat is calculated for each of the characteristic days.

For both domestic and non-domestic pathway options, EnergyPath Networks includes costs of replacing all technologies at their end of life. At these points technologies can be replaced with a lower carbon system or like-for-like. For example, even in a scenario without a local carbon target, costs will be incurred when boilers and windows are replaced with analogous technologies.

Electricity Network Infrastructure

In order to assess potential options for future changes to energy systems, knowledge of current electricity, gas and heat network routes and capacities is required. From this the costs of increasing network capacities in different parts of the local area, as well as extending existing networks to serve new areas, can be calculated.

The road network is used in EnergyPath Networks as a proxy to calculate energy network lengths. Substation capacities are established using DNO data and steady-state load flow modelling of networks. For example, EnergyPath Networks will find the load at which a Low Voltage (LV) feeder will require reinforcement and the costs associated with doing so. The cost of operating and maintaining the networks varies with network capacity and is modelled using a cost-per-unit length, broken down by network asset and capacity.

The EnergyPath Networks method does not replicate the detailed network planning and analyses performed by network operators. Rather, the energy networks are simplified to a level of complexity sufficient for numerical optimisation and decision-making. The method is used to model the impact of proposed changes to building heat and energy demand on the energy networks that serve them, for example increased or reduced capacity. The costs of these impacts can then be estimated and the effects of different options on different networks can be compared. Only network reinforcements required inside the study area are explicitly considered as options in EPN.

The local Distribution Network Operator (DNO) Electricity North West Limited (ENWL) provided the following data for the current electricity network:

1. Locations and nameplate capacities of the HV (33kV to 11kV) and LV (11kV to 400V) substations.
2. Estimated upgrade costs of network assets.

EnergyPath Networks synthesises feeders from each LV substation to its nearest HV substation, following the shortest path along the road network. Customer connections are then derived based on nearest substation and peak load constraints for each feeder. Non-domestic buildings with high demands are assumed to connect directly to the HV network. Network feeder capacities are then calculated based on the current load on each feeder and a headroom allowance. Voltage drop and thermal limits are considered when establishing asset capacity requirements. EnergyPath Networks performs steady state load flow modelling for electricity and heat networks using the Siemens tool PSS®SINCAL.

Once all the building data has been analysed and the buildings located, it is possible to identify their nearest roads, which shows where the buildings are most likely to be connected to energy networks. In this way the total load and the load profile for each energy network can be calculated at different scales from individual building level, through local networks up to aggregate values for the whole study area. This allows an understanding of different energy load scenarios in different parts of the local area and the energy flows between those locations. In addition, an understanding of network lengths and required capacities can be established.

Gas Network Infrastructure

Gas networks are modelled differently within EPN, with capacity increases deemed not to be required in the same way that the electrification of heat and EV rollout would require. Because of this, EPN has the option within each analysis area to either decommission, repurpose for hydrogen, or retain the existing gas infrastructure. To assist with this modelling, data from Cadent has been used including:

1. Gas high pressure entry points to the region.
2. Material of each pipe.

The pipe material is especially useful to be able to determine the costs of repurposing the gas network to hydrogen, and to be able to accurately tell how much of the network has already been converted to a suitable polyurethane.

Analysis Areas

Due to the complexity of the optimisation within EnergyPath Networks (for buildings, networks and generation technologies) the total problem cannot be solved at individual building or network asset level. To do this would require quadrillions of permutations Each of the 10 authorities of Greater Manchester are divided into a number of spatial analysis areas, of between 7 and 10 per authority. Decisions are made at this level based on aggregating similar buildings and network assets within each area.

The analysis areas are necessary within the EnergyPath Networks model but do not correspond directly to local districts, wards or neighbourhoods. However, each local authority has provided a preferred naming scheme for these areas to assist the local engagement of the individual Local Area Energy Plans.

Within each analysis area, different components of the system are aggregated. Aggregation of buildings is performed based on energy demand and cost of retrofitting insulation and new heating systems. This way, similar buildings within an individual analysis area will all follow the same pathway. Similarly, decisions on network build and reinforcement are made at an aggregated level. If the electricity loads in one analysis area increase, such that the aggregated capacity of the low voltage feeders is exceeded, then reinforcement of all low voltage feeders within that area will be assumed to be required. The same applies for all other aspects of the energy networks such as low voltage substations, high voltage feeders and substations and heat network capacity.

Since the network options are aggregated, it is important that the boundaries between analysis areas do not cut across the electricity network. It would not be realistic to reinforce the ‘downstream’ end of an electricity feeder without considering the impact of the loads on those components further upstream in that network.

To ensure consistency in the analysis of electricity network options, the study area was divided by considering each high voltage substation within the local area and all of the electricity network downstream of each substation to give the analysis areas discussed above. Some simplifications to create continuous areas were applied.

Once the analysis areas had been defined, energy network links between them were defined. This allows transmission of heat, gas and electricity across the analysis area boundaries.

Local Energy System Design Considerations

Options which are not considered technically feasible are excluded from EnergyPath Networks – for example, fitting loft insulation into a mid-floor flat or cavity wall insulation to a building which has solid walls.

There are other options which, whilst they may be possible, are not practical in a real-world environment. For example, the use of ground source heat pumps in areas of dense terraced housing: a lack of space means that cheaper ground loop systems cannot be fitted, whilst there is insufficient access for the equipment required to create vertical boreholes. In addition, the heat demand for a row of terraced houses may cause excessive ground cooling in winter leading to inefficient heat pump operation and a need for additional top-up heat from an alternative source.

Consumer preferences also influence suitability of certain options. The installation of domestic hot water tanks for heat storage is a good example. Many low-carbon heat technologies, such as air source heat pumps, work at a lower output power than conventional gas boilers, and this can require the use of heat storage in order to be able to meet peak demand for heat on cold days. However, many households have removed old hot water tanks and fitted combi-boilers to provide hot water on demand. This allowed the space previously occupied by the hot water tank to be repurposed for other uses, which householders find valuable, such as additional household storage.

For example, the English Housing Survey shows that 54% of homes had a combi-boiler in 2016 with this figure rising by around 2% a year since 2001. These consumers often place a high value on the space that has been made available by doing this and are unlikely to embrace heat solutions that require large amounts of domestic space to be sacrificed. A proxy for the value that consumers place on space in their homes is property market values normalised by floor area. With median house price costs in England and Wales in 2017 varying from £32,000 (within County Durham) to £2,900,000 (within Westminster) it is clear that the options for using space for domestic heat storage are likely to be heavily dependent on local factors.

Data Sources Annex

The data sources annex summarises the consistent baseline data used by the ESC used to develop the ten GM district LAEPs upon which this report is based.

BUILDINGS

Domestic

- **Ordnance Survey AddressBase Premium, MasterMap Topography, Highways**
  - Shows location, footprint and classification of buildings, plus road layout for network modelling.
  - Latest data obtained December 2020 for buildings and roads.
- **GMCA Accelerating Retrofit Domestic Buildings Dataset**
  - Detailed attributes of all domestic properties in GM produced by Parity Projects, using EPCs and filling gaps with other data.
- **Energy Performance Certificates (EPCs)***
  - ESC-built address matching algorithm to match housing attributes from EPCs
  - Informs building-level attributes – e.g. current heating system, levels of insulation.
- **Listed Buildings** – Historic England† as a potential constraint on retrofit

Non-Domestic

- **Ordnance Survey MasterMap Topography**
  - Provides status and classification of building (e.g. office, retail).
  - Informs building size and height.
- **OpenStreetMap** has not been chosen due to inconsistent national coverage compared with Ordnance Survey.
- **Non-domestic Energy Performance Certificates (EPC) and Display Energy Certificates (DEC)** to provide further building attributes and demands.
- **GMCA Public Sector Decarbonisation Scheme (PSDS)** to provide further demand data for significant public sector buildings and funded interventions in specific buildings
- **GMCA "Go Neutral"** provides further demand data for public buildings.
- Energy benchmarks (kWh/m^2) developed in conjunction with Arup

Future Building Stock

- **GMCA Existing Land Supply Sites**
  - For domestic, number given split by house/apartment, with planned construction date.
  - For non-domestic, type given (office, retail, industry/warehouse) with planned construction date.

- **GMCA Spatial Framework Allocation Sites**
  - Usage as above.
  - In total over 3,000 sites provided

* https://epc.opendatacommunities.org/
Note: details of Green Homes Grant (GHG) and Local Authority Delivery (LAD) projects provided separately by Local Authorities where relevant

† https://historicengland.org.uk/listing/the-list/data-downloads/

Networks

- Relationships & NDAs with Electricity North West (ENWL) & Cadent
- **ENWL** (Electricity Distribution Network Operator)
    - Substation locations and capacities (for 11kV-400V upwards)
    - Typical component costs, combined in packages to generate reinforcement costs for different network assets.
- **Cadent** (Gas Distribution Network Operator)
    - Mapping of pipes including material, size and pressure.

Local Generation

- **Renewable Energy Planning Database***
    - Current planned and operational renewable energy installations (above 150kw)
- **Feed-in-tariff install reports**†
    - Current levels of domestic PV by postcode
- **GMCA "Unlocking Clean Energy in Greater Manchester" project**
    - Details of various solar PV, hydro-electric generation, battery storage and electric vehicle (EV) charging projects.
- **ENWL Embedded Capacity Register**‡
    - Identify registered generation assets within the region.

Electric Vehicles

- **Zap-Map**§
    - Location and speed of public chargepoints.
    - **National Chargepoint Registry (NCR)**** has not been used since its data is included within Zap-Map's national database.
- **Future domestic EV uptake**
    - ESC in-house analysis on the expected uptake of EVs on the network.
- **GMCA Transport for Greater Manchester (TfGM) list of potential EV charging sites**
    - Work carried out by Arup to determine 60+ locations, number of connections and charge speed across GM.

* https://www.gov.uk/government/publications/renewable-energy-planning-database-monthly-extract
† https://www.ofgem.gov.uk/publications-and-updates/feed-tariff-installation-report-31-december-2020
‡ https://www.enwl.co.uk/get-connected/network-information/embedded-capacity-register
§ https://www.zap-map.com/
** https://www.gov.uk/guidance/find-and-use-data-on-public-electric-vehicle-chargepoints