

Developing a low carbon energy system for Greater Manchester: identifying challenges, risks and opportunities

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Summary

This project has developed an illustrative energy scenario pathway which aspires to deliver net zero carbon dioxide (CO₂) emissions from the energy system by 2050 for Greater Manchester (GM). Current and future energy use in the domestic, commercial, industry and transport sectors and the potential for low carbon energy supply options, have been evaluated to inform the development of the pathway. The illustrative pathway was developed in order to prompt and support stakeholders in discussing the challenges, risks and opportunities for delivering a net zero CO₂ emissions energy system for GM. Key findings identified from the stakeholder input is detailed below:

1) Whilst there is potential for local energy supply, decarbonising the centralised national energy system is essential for Greater Manchester to achieve net zero CO₂ emissions from its energy use

Greater Manchester needs to 'import' energy from outside its territory to meet future demand even if it deploys all of its technically feasible potential for renewable energy supply. Decarbonising the energy system outside of GM is therefore essential to attain net zero emissions from GM's energy use.

2) Greater Manchester needs a clear strategic plan for the development of a low carbon energy system which is co-developed with stakeholders and identifies co-benefits.

There are opportunities from new devolved powers to GM for the development of low carbon energy system but social innovations and support from public and industry is essential along with the 'political will' for transitioning to a low carbon energy system. Transformation of the energy system offers potential co-benefits across health, skills and jobs, prosperity etc and stakeholders from across their fields could work together more to plan for and ensure the realisation of these benefits.

3) Operation of a more decentralised zero carbon electricity system is highly challenging

An increase in the proportion of low carbon technologies such as solar photovoltaics (PVs), wind power, heat pumps (HPs) and electric vehicles (EVs) brings new challenges to the low voltage network. Further work on understanding the spatial distribution of vulnerability and stresses would support effective planning in this area. In addition, high levels of decentralisation have implications for the future of the transmission system that need to be more fully understood.

4) A rapid roll out of EVs and PVs with battery storage could be possible as soon as early in the 2020s

Stakeholders suggested potential cost reduction of batteries could result in a rapid roll out of electric vehicles and photovoltaics. Consequently, an electricity based transport and heating system may develop faster than bioenergy or hydrogen based systems.

5) More comparative analysis of the 'best' option for decarbonising heat for GM is needed

Decarbonising heating was identified as a key challenge where a range of potential solutions are often discussed. It was recommended that a detailed assessment for establishing the most

effective technologies and approaches to decarbonise heating in GM is needed to support this area. In addition, it was argued that the regulation of new heat networks needs further development and consumers must be protected.

6) Building retrofitting and energy generation offer opportunities but there is significant inertia to be overcome

Stakeholders discussed the need to encourage and facilitate both energy generation and retrofitting efficiency measures in domestic and commercial buildings. In addition, access to funding, planning, building standards and post occupancy evaluation were all seen as potential routes to improving performance in this area.

7) External factors can influence Greater Manchester's low carbon energy system

Stakeholders identified a range of external factors that could influence the delivery of a low carbon energy system for GM such as changes in the geopolitical context, the impacts of climate change and the availability of financing - it was stressed such factors need to be considered in the development of a plan for GM's low carbon energy system.

8) Further research is essential to understand some of the future challenges

Stakeholders identified a number of areas that should be further explored to support the development of a low carbon energy system for GM:

1. Public attitudes towards and performance expectations of electric vehicles and the related impact on the electricity network.
2. Identifying and delivering the skills and training to ensure there is a suitable workforce to support the development, operation and management of a new low carbon energy system.
3. Further spatial information on the distribution of existing and potential future low carbon energy technologies to identify vulnerabilities, stresses and system interactions.

To appropriately understand the energy scenario pathway, it is important to be cognisant of the following principal assumptions:

1. The scenario pathway developed is a simplistic illustration of a plausible energy system which has net zero CO₂ emissions by 2050 in order to stimulate discussions on the challenges for achieving a decarbonised energy system.
2. All the energy supplied in 2050 is from low carbon sources with net zero emissions (bio-energy) from its operation. The analysis excludes life cycle emissions or any associated non-CO₂ emissions.
3. Aviation and shipping sectors are not included in this analysis.
4. The potential installed capacity for heat and electricity in the scenario from 2020 to 2050 is constrained by the technical resource capacity identified in the GM Spatial Energy Plan report.
5. All the electricity generated within the GM spatial boundary is consumed within its boundaries and any additional electricity required is 'imported' from the National Grid to meet demand.

1. Introduction

Greater Manchester Combined Authority¹ (GMCA) has adopted an ambitious carbon reduction target of 48% by 2020 compared to 1990 levels with a goal to cut emission levels to below eighty to ninety-five percent, or two metric tons per capita, by 2050. The Tyndall Centre for Climate Change Research at the University of Manchester (UoM), in collaboration with GMCA's Low Carbon Hub², explored various challenges and risks associated with realising a low carbon energy system for GM under the *Resilient Nation* project. The project was funded by the Engineering and Physical Sciences Research Council (EPSRC) as part of its goal to increase the UK competitiveness through energy security and efficient provision of clean energy through a safe and reliable infrastructure. The aim of the project was to provide an assessment of existing and potential future energy systems in the context of climate mitigation and adaptation with consideration of other delivery risks. As part of the project an illustrative energy scenario pathway to deliver net zero CO₂ emissions by 2050 was developed for GM. This pathway was then used to stimulate discussions in a stakeholder workshop to identify challenges, risks and trade-offs associated with achieving a decarbonised energy system.

2. Methodology for the 2050 energy scenario

The illustrative energy scenario is premised on assumptions about a 'desirable future' where energy supply sources are renewable and end-use sectors (transport, domestic, industrial & commercial) use energy efficiently. From the desired end point energy demand (in this case energy in GWh in 2050), the low carbon energy pathway from the baseline (2014/16)³ was developed with two interim points of 2020 and 2030. The aim of this approach was to explore how the 2050 system might be realized from the present within the technical and resource constraints identified by the GM Spatial Energy Plan Report (1). The scenario pathway framework is based on the previous work by Kuriakose⁴ (2).

The starting point for the scenario is based on the most up to date data from the Department of Business, Energy and Industrial Strategy (BEIS) (3) at subnational level and the Department for Transport (DfT) vehicle statistics database (4). The scenario period from the baseline until 2020 is characterised by current trends in deployment for all the technologies with the aim of reflecting a 'realistic' change in the energy system in the very near term. Quantitative information based on various projects currently in development, historic (2010-2014) annual deployment rates of technologies, datasets published by Transport for Greater Manchester (TfGM), DfT and BEIS were used to inform these 'current trend' profiles. From 2020 to 2030, decarbonisation of the energy system gets further momentum with an accelerated deployment of low carbon technologies. In the pathway scenario, by 2030, it is assumed that policy makers have formulated and implemented long term decarbonisation policies learning from the experiences of initial developments in the 2020s. Beyond 2030, issues regarding implementing

¹ GMCA is made up of the ten GM councils who work with other local services to improve the city-region.

² The Low Carbon Hub is Greater Manchester's partnership-led body charged with retro-fitting homes and workplaces, developing more low-carbon skills, building renewable energy capacity and energy efficiency and supporting the low carbon business sector.

³ The year with the most up to date data available for each of the categories is used as baseline.

⁴ Jaise Kuriakose, lead researcher on the project

new systems are clear, with technologies and policy learning continuing to improve and almost complete decarbonisation is achieved by 2050 (2).

2.1 Renewable Electricity Supply

The renewable electricity generation capacity towards 2020 is based on the current trends in deployment for all the technologies registered for Feed in Tariff (FiTs) and BEIS statistics (3). The installed capacity for solar photovoltaic, wind and hydro by 2020 is increased by 20% per annum whereas for bioenergy technologies the increase is 5% per annum (based on historic uptake rates). The capacity increase for combined heat and power (CHP) is based on the GMCA's dataset of the likely projects that are under consideration to be implemented before 2020 by local authorities or other non-commercial developments⁵. The annual electricity generation for each technology is estimated based on the capacity factors at a regional level published by BEIS (5). The annual grid emission factor up to 2020 is estimated based on the National Grid's Future Energy Scenario Gone Green scenario dataset⁶ (6) and it is assumed that the emission factor for the grid will be reduced to zero by 2050. The carbon emissions saving from CHP is estimated based on the Chartered Institution of Building Services Engineers (CIBSE) guidelines for CHP emission factors (7). The scenario assumes the existing Carrington combined cycle gas turbine (CCGT) power plant has a lifetime of 25 years and will cease its operation before 2050.

2.2 Renewable Heat Supply

The renewable heat generation capacity towards 2020 is based on the current trends in deployment for all the technologies registered on the Renewable Heat Incentive (RHI) database for domestic and non-domestic (8). The installed capacity for solar thermal, biomass and heat pumps (HPs) by 2020 is increased by 30% per annum. This includes the GM smart energy project by the New Energy Development Organisation (NEDO) installing 600 new HPs in Wigan and Leigh (9). The annual heat generation for each technology is based on the regional average load factors from RHI statistics (8) applied to installed heat capacity for GM. The associated annual CO₂ emissions saving is estimated using a simple approach which assumes that renewable heat replaces heat produced by gas boilers. About 5% of all postcodes in GM, mainly in the regions of green space and agricultural land, are not connected to the gas network (1). Properties located in the above regions are assumed to use renewable heat supply.

2.3 Smart grid and smart metering

The distribution network operator (DNO) for the northwest region, Electricity North West (ENWL) is implementing various smart grid projects across the region. The scenario assumes that the smart grid projects will provide a network efficiency gain of 2% by 2018, with a further increase to 3% by 2020, by replacing network assets such as transformers and the installation of new Distribution Management System (DMS) by 2020⁷.

⁵ Commercial CHP projects are excluded due to lack of sufficient datasets

⁶ consistent with the UK's 2020 emissions reduction target of 34% compared to 1990

⁷ Personal communication with Sarah Davies based on discussions with ENWL

The scenario assumes all domestic properties will have smart meters (gas and electricity) by 2020 in line with existing national policy (10). Currently, about 1% of GM properties have smart meters for either gas or electricity installed. The Energy Demand Research Project (EDRP) managed by Ofgem suggests 3% savings on annual energy consumption from smart meters (11). The scenario assumes smart electricity meters will provide energy savings of 2% per annum whereas smart gas meters provide 1% every year. The savings from the smart heat meters is lower compared to the electricity meters due to domestic retrofit energy savings accounted for elsewhere in the scenario.

2.4 Retrofitting existing buildings

The Affordable Warmth scheme has implemented several retrofit projects for domestic properties across Greater Manchester. The Toasty Report (12) by GMCA shows that in 2014 approximately 3600 measures were implemented in domestic properties which provided carbon savings of approximately 2940 tCO₂ per annum. The scenario assumes a modest uptake of a third of similar measures every year out to 2020 due to lack of sufficient current policy measures that can accelerate domestic retrofit programmes. Beyond 2020, the scenario assumes new policy measures will be implemented that can fast-track retrofitting programmes. The carbon savings from public buildings is a combination of efficiency measures implemented for both electricity and heating. The emissions saving are estimated based on the local authority level datasets for gas and electricity use on public buildings. The scenario assumes 3% savings on gas use and 1% savings on electricity use per annum to 2020. Similar to domestic, after 2020 new policy measures further improve energy conservation from public buildings, reducing overall energy demand.

2.5 Transport

The transport energy and emissions are based on the current trends in annual average car emissions published by the Society of Motor Manufacturers & Traders (SMMT) every year (13), vehicle numbers and total kilometres travelled, uptake rates for the Ultra-low emission vehicles⁸ (ULEVs) in GM, published by Department for Transport (4) and the expansion of the metro network (14). The average car emissions in the UK during 2014 was 156.6 gCO₂/km (13) and the scenario assumes a car fleet efficiency improvement of 0.75% per annum to 2020. The average emissions from new cars registered in the UK by 2016 was 120.1 gCO₂/km and the EU's 2021 emissions target is to achieve 95 gCO₂/km for new cars (13). The emissions saving from the uptake of electric vehicles are based on the mileage (kWh/km) of Nissan Leaf (15), current trends in the market uptake of electric vehicles and the electricity grid emissions factor. Due to the metro link expansion, it is assumed that commuters in the three local authorities of Trafford, Manchester and Stockport⁹ switch 25% of their total annual journey km from cars to metro.

2.6 Other measures

All the local authorities in GM are replacing conventional lamps with LEDs for street lights.

⁸ Refers to fully electric, plug-in hybrid and hydrogen fuel-cell vehicles

⁹ New metro lines since the baseline year are the Manchester Airport, second city crossing and the proposed Trafford Park line,

The scenario assumes approximately 78% of all the street lights across GM will have LED lamps providing 35% savings on electricity use by 2020. Siemens is replacing 52,000 traffic lights across GM to LEDs which will provide an estimated 30% savings on electricity. Additionally, by planting 3 million new trees across GM by 2020 as part of the Manchester City of Trees initiative (16), sequestration of 14 ktCO₂¹⁰ is assumed (17). The detailed assumptions for the illustrative scenario pathway from 2020 to 2050 are shown in Table 1. The scenario outputs are illustrated in Figures 1 to 3.

Table 1: Scenario assumptions for the key energy technologies and energy consumption by end use in Greater Manchester out to 2050

	2015	2050	Assumptions
Population	2.75 million		Increase in energy due to growth in population and housing stock will offset by improvements in efficiency ¹¹ .
Housing stock	1.17 million		
Electricity demand	11.75 TWh	22.8 TWh	The electricity demand increases by 84% compared to 2015 due to high electrification of heat and transport. A third of the electricity will be generated within GM boundaries from renewable sources and the remaining electricity will be imported to GM boundary from the National Grid.
Grid carbon intensity	367 gCO ₂ /kWh	0 gCO ₂ /kWh	
Solar PV	96 MW	1500 MW	
Wind	1.2 MW	20 MW	
Bio-energy	74 MW	800 MW	
Heat demand	21.6 TWh	15.1 TWh	The heat demand decreases by 30% compared to 2015 due to efficiency improvements & deep retrofit. The annual average heat requirement for GM household in 2015 was 12,500 kWh (18). The heat will be supplied from a range of sources including HPs, biomass, industrial waste and solar thermal. High utilisation of district heating networks shifting from individual boilers at high density domestic/commercial centres.
Solar thermal		50% of households	
Heat pumps		50% of households will have either ASHP or GSHP or Hybrid HPs.	
District Heating:			
Transport	15.3 TWh	10.8 TWh	30% decrease in the end use energy from road transport compared to 2015 due to efficiency improvements (internal combustion engines (ICE) to electric/hydrogen fuel cell) and increasing use of public transport and car shares. Air transport is not considered in this analysis.
Biomass and waste	225 GWh	19500 GWh	The biomass resource potential (including agriculture/ forestry/ crops/ waste) for heating, transport and electricity under ‘energy focus’ scenario by Welfle et al (19) is 540 TWh of energy. Applying GM’s proportion of the UK final energy consumption (4%) to biomass resource potential would give 19.5 TWh.

¹⁰ Assuming plantation of 1/7th of trees each year from 2013 to 2020 and absorb 10% of carbon starting after 3rd year of plantation.

¹¹ The assumptions are made for a simplistic energy scenario to explore potential challenges in the stakeholder workshop

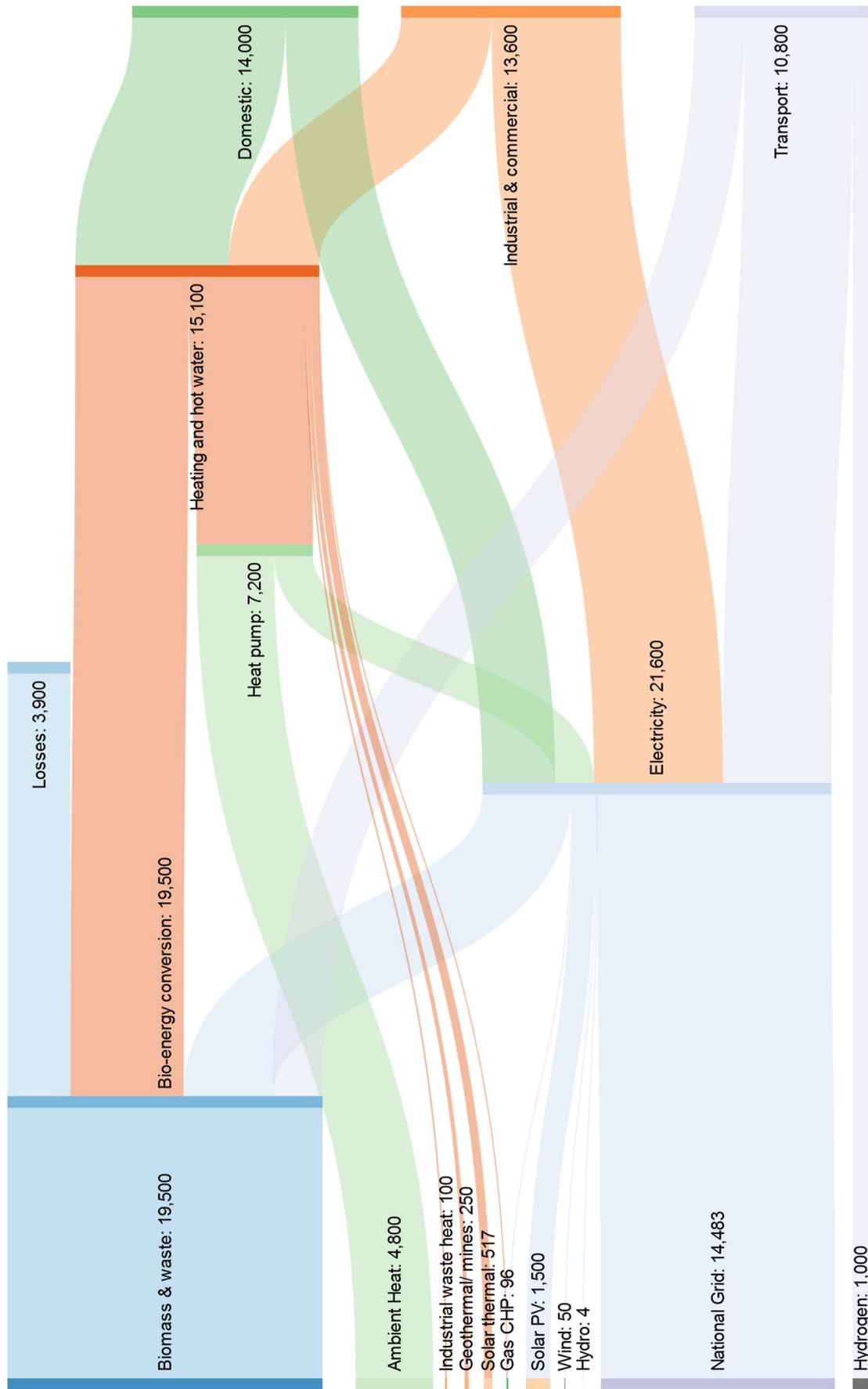


Figure 1: Sankey diagram for Greater Manchester's 2050 energy scenario (units in GWh)

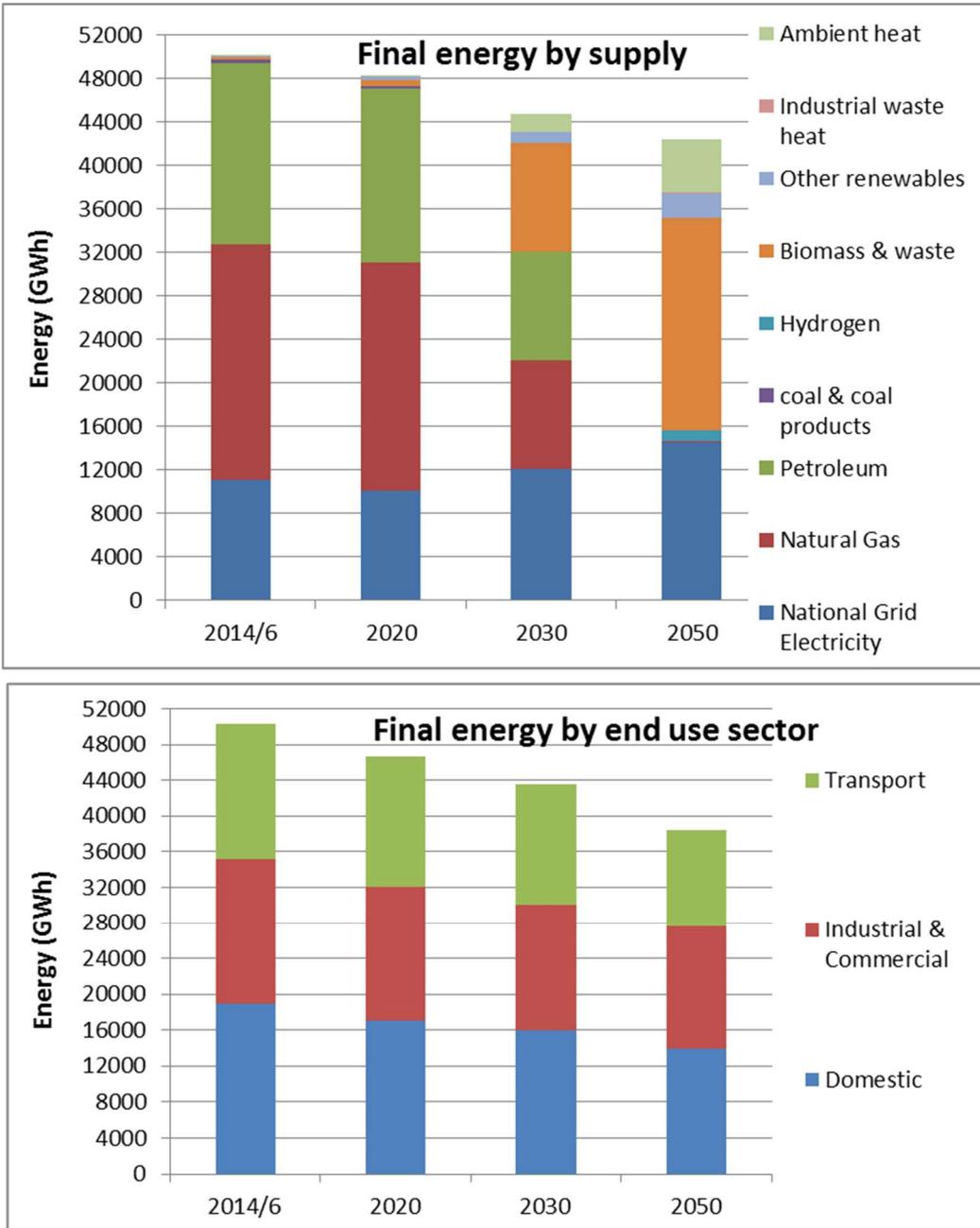


Figure 2: Final energy by supply and end use sector for Greater Manchester by 2050

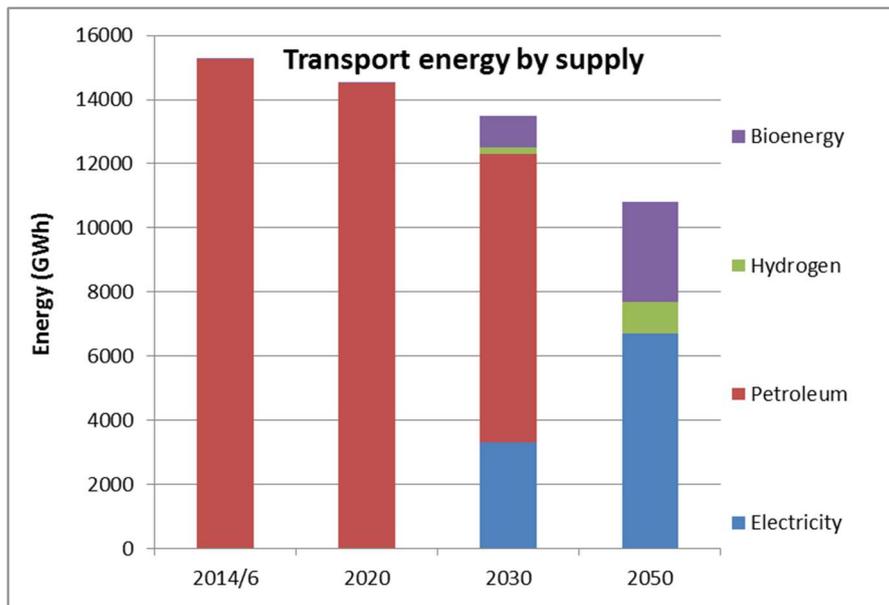
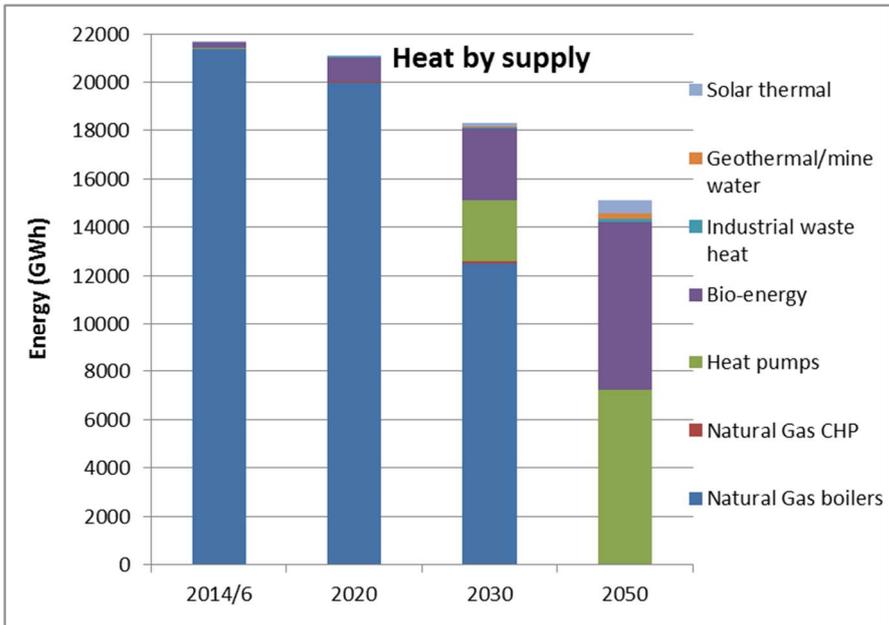
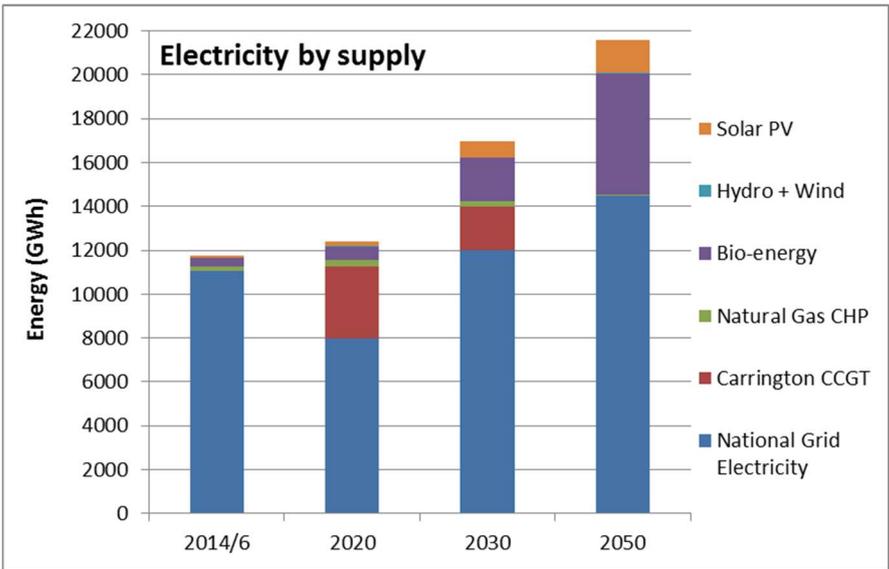


Figure 3: Electricity, Heat and Transport by supply for Greater Manchester out to 2050

3.0 Stakeholder Workshop

The illustrative scenario was used as a prompt for discussion in the stakeholder workshop to facilitate conversations on whether the assumptions in the scenario pathway were realistic, the associated challenges and constraints for various technologies and how energy system transformation could be delivered in Greater Manchester. The objective of the workshop was to identify challenges, risks and trade-offs associated with achieving a decarbonised energy system. The workshop also explored system interactions, research gaps and opportunities. The workshop took place on 22nd March, 2017 and was attended by participants from organisations listed in Appendix 1. The workshop was recorded using a digital recorder and transcripts were obtained to support the development of this summary report.

The participants were divided into three groups, reflecting the key energy sectors of electricity, heat and transport. A general overview of the workshop procedure and the illustrative scenario for the discussions was presented. Each group was given time to consider the key challenges within the sector and actions that had the potential to deliver rapid emissions reduction. They were also asked to identify some of the risks associated with achieving a decarbonised energy system and suggest key policy instruments or opportunities to make the system more resilient and overcome the challenges identified. The term resilience means to ‘bounce back’ and implies the ability of the system to return to its original condition after an event disrupting its state (20). Each of the three groups also examined potential external influences that could impact the future energy system. Finally, the groups explored research questions and system interactions to support a resilient energy system for Greater Manchester.

The output from the stakeholder workshop is outlined in sections 3.1 to 3.4. Initially, a critique of the scenario pathway by stakeholders is presented. This is followed by discussions on: key challenges from each of the three sectors; a group activity on ‘Tipping Points’; external factors impacting resilience of the energy system and finally, key future research areas.

3.1 Scenario Pathway

The majority of the stakeholders felt that the illustrative scenario pathway was too optimistic with regard to assumptions on: large reductions in end use energy demand from transport and zero natural gas, high levels of public transport and the diversity of supply sources by 2050. They also perceived that such rapid change by 2050 was unrealistic considering the relatively small changes that have happened over the last 30 years.

Some stakeholders considered transport as the most challenging sector to decarbonise and therefore other sectors such as domestic or industry were thought to need to reduce their emissions at a faster rate. Additionally, some participants pointed out that large scale use of hydrogen in the scenario was optimistic because they believe other transport scenarios have scaled down its contribution to the transport system. This is largely due to the lagging nature of hydrogen technology development compared to EVs, as well as safety concerns on the use of hydrogen.

3.2 Key challenges from the sectors

3.2.1 Vision, leadership and co-ordination

Stakeholders discussed the importance of addressing the wider sustainability issues and its co-benefits beyond the energy and climate change focus. Participants highlighted devolution as a major opportunity for a strategic plan focusing on the type of devolutionary powers that can support local ‘political will’ to deliver a low carbon energy system for GM. It was also suggested that an overarching vision for GM addressing wider sustainability issues at a regional level could help to support and drive changes at national level.

The stakeholders raised concerns over the lack of co-ordination between sectors and disjointed value chains operating in silos meaning that the co-benefits of interventions are not fully understood or realised. For instance, domestic insulation can bring savings to both the customer (utility bills) and to social or private landlord (maintenance). In addition, the NHS may have savings on hospital admissions through fewer cases of ill health. Participants suggested bringing together these usually disparate forms of expertise to more fully understand and account for these co-benefits. An example of local leadership on this approach through co-operation of key relevant actors on the benefits of measures that reduce carbon and air pollutions on health and therefore demands on the NHS was given. Additionally, participants noted the need for a new form of Green Deal financing outside of the public sector to address some of the above challenges.

3.2.2 Energy demand and policy measures

Participants indicated that the changing demography of GM with a growing population that has higher life expectancy may lead to changes in energy demand in future. Any increase in demand and variation in diurnal demand profiles may have implications to the heat and electricity networks such as inadequate capacity of substations.

Stakeholders advocated that adequate policies both at national and local level incentivising the deployment of renewable technologies are essential. They highlighted that national policies are pivotal, because a self-sustaining GM was not feasible meaning that electricity ‘imports’ from the National Grid will still be needed to meet future demand. Integration of low carbon technologies such as PVs, EVs, Storage and Demand Side Management (DSM) were also seen as essential for reducing the demand for National Grid ‘imports’. At the same time, integrating low carbon technologies through implementation of smart grids may bring other challenges to the electricity grid network operators such as increasing cyber-attacks. One of the participants expressed *“If terrorists could hack and dump fifty megawatts worth of battery storage into a local area at any given time, are we frying the local network?”*

Stakeholders stressed the need to consider how GM level policies could be delivered ‘on the ground’ and engage stakeholders extensively in assessing this. Support from the public and actors across the energy system were seen as essential for radical and rapid changes in the energy system to be achieved.

3.2.3 Operational challenges for the electricity network

Stakeholders discussed the operational implications of a more self-sufficient energy system using high levels of distributed renewables for GM. They highlighted that it may bring other challenges such as the funding structure for the transmission system operator and the operational management of the distribution network. Currently the operational cost for the transmission network is recouped through consumers' energy bills. Hence, the implications of low carbon energy system need to be evaluated carefully. Additionally, the operational structure of the existing electricity grid network was thought to need review in light of anticipated changes such as the new roles for the network operators (DNOs) as distribution system operators (DSO).

3.2.4 Energy efficiency in buildings

The participants discussed the challenges for large scale energy related investment in buildings ranging from domestic dwellings to public estates. They highlighted the trade-off for decision makers between investments in energy efficiency measures and renewable energy technologies for both the domestic and commercial sector. Stakeholders suggested that a mechanism for enforcing planning regulations and building standards that focuses on reducing emissions through both efficiency and generation is essential. One suggested approach was compulsory post occupancy evaluations.

3.2.5 Zero carbon heating and bio-energy

Stakeholders recommended a detailed assessment for establishing the most effective strategy to decarbonise heating. For instance, decarbonisation can be achieved through electricity (e.g. heat pumps) or using heat networks or a mixture of alternative systems including the use of industrial waste heat. Additionally, it was argued that the regulatory side of heat networks needs further improvement to make it similar to that for the gas network and ensure rights for consumers, such as ability to change their supplier.

The participants indicated that a heating system dependent on large scale biomass resource may not be feasible due to competition for resource. Hence, GM's biomass resource capacity and its ability to meet the future energy requirement need to be assessed in detail including its impact on food production. Additionally, it was suggested that increasing use of lignocellulosic biomass for energy may introduce new challenges such as a surge in biomass waste production.

Stakeholders suggested that a review of the advantages and disadvantages of using biomass resource at industrial scale versus individual building scale is essential. Stakeholders regarded ideally biomass should be used at industrial scale with carbon capture and storage (CCS) to remove the CO₂ emissions. Burning biomass at industrial scale is argued to be cleaner compared to individual building scale (residential scale) due to advanced flue system but requires a district heating system to link between the buildings. However, the implications of biomass imports due to industrial scale bioenergy systems needs to be examined, such as challenges in identifying biomass resource supply across the world, the sustainability (social, economic and environmental) implications of the local area of production and the associated transport emissions. Large scale imports of biomass may not necessarily reduce emissions on a

global level - sustainably managed production is essential for delivering a genuinely low carbon energy system.

One of the stakeholders highlighted studies (21,22) that suggest production of additional bioenergy in an agricultural area can strengthen food production. This occurs by creating a more diverse economic case for farmers to invest in best practices for food and bioenergy production and a diverse environment for natural species, thereby increasing disease resistance to the plants. Stakeholders suggested similar schemes can be implemented in underutilised agricultural land areas immediately outside GM, to encourage best practices. This can then create new markets for bioenergy production.

3.2.6 Transport

The discussions on transport focused on societal changes in the future, such as how people might live or work and the role of transport within such society. For example, large scale use of virtual technologies with information and communication technologies (ICT) in the future may reduce transport demand for business purposes. Stakeholders recommended that GM should support businesses to use virtual technologies for reducing transport demand.

The stakeholders highlighted the opportunities from devolution on low carbon energy development. For instance, changes in rules and regulations for low carbon transport could influence the transport emissions in GM. Participants indicated that introducing measures similar to landfill tax, which influenced innovation that reduced waste, could potentially help in reducing emissions from transport sector. Additionally, it was suggested that there are many international case studies that could offer lessons and best practices when implementing such policies in GM (e.g. Norway which has high penetration of EVs).

Participants perceived that ‘range anxiety’ over EVs is a significant issue although most journeys in a day last about twenty-four miles. Range for EVs has been improving considerably, for example Nissan Leaf has improved its range by at least 50% between 2010 and 2017. Although not included in our pathway scenario, the role the aviation sector in supporting economic prosperity for GM was discussed – with differing opinions on the benefit of the sector to GM and the need to reduce emissions from this sector.

3.3 Group activity - ‘Tipping points’

As part of the stakeholder workshop an activity called ‘Tipping points’ was conducted to attempt to identify how early stakeholders believed substantial changes in the energy system properties could occur. A tipping point was defined as “a level of change in system properties beyond which a system reorganises, often abruptly, and does not return to the initial state, even if the drivers of the change are abated”(23). A poster with nine key subject areas was provided to the participants as outlined in Table 2 with an option to add other subject areas of interest, if they wished to do so. Participants were then asked to use coloured stickers to indicate the most likely time period for the tipping point to occur for the subject areas selected.

The group discussions covered a wide range of opinions, such as the definition of a tipping point, and the idea of ‘reverse tipping’, where changes in policy or other elements may reverse

trends in technology deployment. An example discussed by the stakeholders was, if solar photovoltaics (PV) become too expensive after considering the costs associated with the variability of solar, small scale PV deployment may have a ‘reverse tipping’. The key outputs and discussions from each of the tipping point subject areas are outlined in Table 2.

Table 2: Tipping points for various energy technologies

Subject Area	Stakeholder views
Solar PV+ battery	Early 2020s. Key challenge is the cost of the battery.
Electric Vehicles (EVs)	The majority of stakeholders were of the view that tipping point may occur in early 2030s. New finance models may assist in accelerating the deployment of EVs beyond 2030. Meanwhile industries that are closely working on EVs viewed that the tipping point could happen in early 2020's. An earlier than anticipated tipping point of EVs could lead to challenges for low voltage networks, such as overloading of the transformers and voltage variation. Autonomous Vehicles were presented as a disruptive technology resulting in a transport scenario with low ownership of personal transport. Stakeholders indicated that the cost and depreciation of EVs would be central in the future deployment rates.
Heat pumps	Late 2020s to early 2030s.
District Heating	There was no consensus on district heating as opinions vary from early 2020 to 2040.
Hydrogen infrastructure	Although there was no consensus the discussions suggested tipping point may occur from late 2030s onwards.
Deep retrofit + new build ¹²	Around 2030.
Combined Heat & Power (CHPs)	No tipping points were indicated for CHP.
Smart grid systems	Around 2030.
Civic energy system ¹³	Early 2020s.
Political will	This is an additional subject area discussed by stakeholders. Early 2020s.
Devolution	This is an additional subject area discussed by stakeholders. Early 2020s.

3.4 External factors impacting the low carbon energy system

The external factors that were identified as having potential to significantly impact the delivery of a low carbon energy system included climate change, oil prices, energy security, Brexit, Scottish independence and large corporate non state actors influencing the energy transition. Other factors include cost of technology, availability of finance, extreme weather events (e.g. flooding of road and rail) and vulnerability of modern communication systems.

There was a general consensus among stakeholders on the need for planning energy system resilience¹³ to overcome the above factors. For example, an increase in cooling demand reduces the distribution network capacity which can raise the risk for network failure. A decrease in gas demand (electrification of heat or warmer temperatures) may have implications on the gas network operation.

¹² A deep energy retrofit is a whole-building analysis and construction process that uses "integrative design" to achieve much larger energy savings than conventional energy retrofits.

¹³ Civic energy system has an expanded role for civil society in delivering electricity supply to other members of society

Stakeholders discussed the importance of potentially competing policy goals (e.g. growth, development, immigration) and warned that changes to the prominence and framing of these had the potential to create instability in terms of national and international action on climate change. The strength and stability of commitment to climate change action at national and international levels was felt to be an important external factor impacting action at a GM level. Therefore it was suggested that plans should consider resilience to changes in priorities and support from outside GM.

Stakeholders suggested that the planning and development of technologies and systems needs to be realistic in terms of its availability when deploying widely. Hence, to accelerate the deployment of low carbon technologies requires a focus on workable mechanisms rather than relying on promised technology breakthroughs. Relying on uncertain future technologies risks there being little effect in reducing emissions and there are existing established technologies that can be deployed.

3.5 Knowledge Gaps

Stakeholders identified a number of ‘knowledge gap’ areas that should be explored to support development of a largely decarbonised energy system by 2050.

3.5.1 Consumer preferences on EV charging

Consumer behaviour is a key area to explore in the roll out of electric vehicles. For example, the user may expect their EV to be fully charged before leaving to go to work from home. However, that may affect the low voltage distribution network capacity in some areas when clusters of electric vehicles are charging at same time. Therefore strategic actions may be required at an earlier stage for those locations to manage any increase in electricity demand on the network. The proposed actions could be smart grid solutions, such as demand management and managed smart charging, which can bring confidence to customers. Further research in this area is identified as vital for the operational resilience of electricity system.

3.5.2 Knowledge and skills

Enabling sufficient knowledge and skills is identified as key for enhancing the resilience of the energy system. Adequate skills and training for efficient and successful delivery of low carbon infrastructure are required. However, care must be taken that such skill expansion should be in tandem with technology development to avoid deployment being delayed or people being trained but not finding relevant employment opportunities. Stakeholders used the example of heat pump deployment in the UK to illustrate this issue when at the early stages of implementation there were few adequately trained people for design and installation or a certain level of certification scheme.

3.5.3 Spatial information on GM’s low carbon energy

The stakeholders identified that spatial mapping of low carbon technologies under development and their implications is a key knowledge gap. Such new maps can provide indication on the location of clusters where EVs might be charged on domestic driveways or to

establish the availability of south facing roofs across GM. A similar map for the potential heat networks across GM has been already produced. The 'MappingGM' portal could be used to develop such datasets. MappingGM (24) is a visualising spatial information portal which has a series of maps on physical infrastructure, planning, housing, environmental, social, economic and demographic data across GM. Electricity North West has already mapped the distribution network infrastructure and areas of network vulnerability. Understanding the vulnerability hotspots under future changes with EV charging and Solar PV will be useful for planning storage locations and upgrading work.

The GM spatial framework (1) identified four technologies that have opportunities for carbon reduction at local level: solar PV, solar thermal, biomass, heat network, heat pumps. However, stakeholders believed there is lack of clarity on the realistically feasible capacity for those technologies and the physical interactivity between them such as how they might conflict with each other. For example, heat pumps powering the district heating system.

3.6 Conclusion

The Resilient Nation project developed an illustrative energy scenario for GM achieving net zero carbon dioxide emissions by 2050. Based on the findings from the stakeholder workshop, the project identified a range of challenges, risks and opportunities that need to be considered in planning for a low carbon energy system for GM.

The development of and response to the illustrative energy scenario demonstrated that achieving net zero carbon dioxide emissions will be very challenging. When considering the technical potential of renewable energy in Greater Manchester, it is evident that the potential generation from renewables is not sufficient to satisfy demand. Hence, additional energy (electricity & heat) needs to be 'imported' to Greater Manchester from the national grid. The stakeholder discussions highlighted the opportunities from devolution for achieving a low carbon energy system and net zero emissions. However, given the importance of 'imported' energy it is essential that action at a GM level is supported by national level policies and action. Social innovations and public support, beyond political, will also be seen as vital for transitioning to a low carbon energy system.

Stakeholders discussed the operational challenges for the electricity distribution network when deploying high levels of solar, wind, EVs and HPs on the network and these challenges require further analysis and assessment. Although several options are available for decarbonising heat, a detailed comparative assessment of these options was felt to be essential to establish an effective strategy. Bioenergy has significant potential in decarbonising the energy system but further work is needed to evaluate the sustainability implications across the supply chain, locally and internationally, of different bioenergy feedstock, technology and scale options. For transport, challenges were identified in relation to social acceptance and performance expectations.

In the group activity on 'tipping point' stakeholders suggested the mass roll out of solar PV with storage and electric vehicles could happen as soon as early 2020s if potential cost reduction of batteries are realised. Significant decarbonisation of the electricity system was seen as possible by early 2030s, supported by smart grid development. However, technologies

such as heat pumps, district heating, bioenergy and hydrogen based systems were thought to be likely to take longer to be deployed at a wide scale with timescales of beyond 2030, unless policy development on this area is advanced quickly.

Stakeholders identified a range of external factors that could influence the delivery of a low carbon energy system for GM, such as changes in the geopolitical context, the impacts of climate change and the availability of financing, which it was stressed needed to be considered in the development of a plan for GM's low carbon energy system.

Finally, stakeholders identified three key knowledge gaps for further research:

1. Public attitudes towards and performance expectations of electric vehicles and the related impact on the electricity network.
2. Identifying and delivering the skills and training to ensure there is a suitable workforce to support the development, operation and management of a new low carbon energy system.
3. Further spatial information on the distribution of existing and potential future low carbon energy technologies to identify vulnerabilities, stresses and system interactions.

Findings from this workshop will be fed into on-going work at the GM level through the SCATTER project, which is a collaboration between Anthesis Consulting, Greater Manchester Combined Authority and Tyndall Manchester and funded by the Department for Business Energy and Industrial Strategy to support the delivery of more sustainable future energy systems. We would like to thank all the participants who generously shared their experience and expertise. This report does not necessarily reflect the views of all those who participated in the workshops.

References

1. Energy Systems Catapult. Greater Manchester Spatial Energy Plan [Internet]. Birmingham; 2016. Available from: https://es.catapult.org.uk/wp-content/uploads/2016/05/Compressed_GMCA_Spatial_Energy_Plan_2016_11_07-LATEST-ilovepdf-compressed.pdf
2. Kuriakose J. The Resilience of Low Carbon Electricity Provision to Climate Change Impacts: The Role of Smart Grids [Internet]. University of Manchester; 2016. Available from: https://www.research.manchester.ac.uk/portal/files/54585637/FULL_TEXT.PDF
3. Department for Business E and IS. Digest of United Kingdom Energy Statistics (DUKES) [Internet]. Digest of UK Energy Statistics (DUKES). 2017 [cited 2017 Jan 23]. Available from: <https://www.gov.uk/government/organisations/department-for-business-energy-and-industrial-strategy/about/statistics>
4. Department for Transport. Vehicles statistics [Internet]. Department for Transport. 2016 [cited 2016 Jun 15]. Available from: <https://www.gov.uk/government/collections/vehicles-statistics>
5. DECC Regional Renewable Statistics [Internet]. DECC. [cited 2016 Jan 10]. Available from: <https://www.gov.uk/government/statistics/regional-renewable-statistics>
6. National Grid. National Grid - Future Energy Scenarios [Internet]. [cited 2017 May 18]. Available from: <http://fes.nationalgrid.com/>
7. Woods PS. CHP and District Heating - how efficient are these technologies? In: CIBSE Technical Symposium, DeMontfort University [Internet]. Leicester: CIBSE; 2011. p. 1–17. Available from: <http://www.cibse.org/knowledge/cibse-technical-symposium-2011/chp-and-district-heating-how-efficient-are-these-t>
8. Department for Energy and Climate Change. Renewable Heat Incentive statistics [Internet]. DECC. 2016 [cited 2016 Jun 15]. Available from: <https://www.gov.uk/government/collections/renewable-heat-incentive-statistics>
9. GM Smart Energy [Internet]. [cited 2017 May 18]. Available from: <http://www.gsmartenergy.co.uk/>
10. DECC. Smart Metering Implementation Programme -Third annual report on the roll-out of Smart meters [Internet]. Department of Energy and Climate Change. London; 2014. Available from: <https://www.gov.uk/government/publications/third-annual-progress-report-on-the-roll-out-of-smart-meters>
11. Raw G, Ross D. Energy Demand Research Project: Final Analysis [Internet]. Ofgem. St. Albans; 2011. Available from: <http://www.ofgem.gov.uk/Sustainability/EDRP/Pages/EDRP.aspx>
12. Gandhi T. Greater Manchester Green Deal Communities Programme [Internet]. Greater Manchester Low Carbon Hub. 2016 [cited 2017 Oct 16]. Available from: <http://gmlch.onthepatform.org.uk/article/greater-manchester-green-deal-communities-programme-exceeds-targets>
13. The Society of Motor Manufacturers & Traders. New Car CO2 Report 2016 [Internet]. London; 2016. Available from: <http://www.smmmt.co.uk/wp-content/uploads/sites/2/SMMT-New-Car-Co2-Report-2016.pdf>
14. Transport for Greater Manchester. Greater Manchester Transport Strategy 2040 [Internet]. Manchester; 2017. Available from: <http://www.tfgm.com/2040/Pages/strategy/index.html>
15. Nissan leaf. Nissan Leaf Range chart [Internet]. 2011. Available from: <http://www.mynissanleaf.com/viewtopic.php?p=101293#p101293>

16. Oglesby Trust. A Woodland Potential Study [Internet]. Manchester; 2014. Available from: <http://www.oglesbycharitabletrust.co.uk/media/6832/Final-GMWPS-May15.pdf>
17. Urban forestry network [Internet]. Available from: <http://urbanforestrynetwork.org/benefits/air-quality.htm>
18. National Heat Map [Internet]. [cited 2017 May 18]. Available from: <http://nationalheatmap.cse.org.uk/>
19. Welfle A, Gilbert P, Thornley P. Securing a bioenergy future without imports. Energy Policy [Internet]. 2014 Jan [cited 2014 Mar 2]; Available from: <http://www.sciencedirect.com/science/article/pii/S0301421513012093>
20. Hosseini S, Barker K, Ramirez-Marquez JE. A review of definitions and measures of system resilience. Reliab Eng Syst Saf [Internet]. 2016 Jan;145:47–61. Available from: <http://www.sciencedirect.com/science/article/pii/S0951832015002483>
21. Osseweijer P, Watson H, Johnson F, Batistella M, Cortez L, Lynd L. Bioenergy and sustainability: Bridging the gaps. In: Souza GM, Victoria RL, Joly CA, Verdade LM, editors. SCOPE briefing [Internet]. 1st ed. Sao Paulo: Scientific Committee on Problems of the Environment (SCOPE); 2015. p. 4. Available from: <https://naturalsciences.ch/service/publications/75155-bioenergy-and-sustainability-bridging-the-gaps>
22. Kline KL, Msangi S, Dale VH, Woods J, Souza GM, Osseweijer P, et al. Reconciling food security and bioenergy: priorities for action. GCB Bioenergy [Internet]. 2017 Mar 1 [cited 2017 Oct 19];9(3):557–76. Available from: <http://doi.wiley.com/10.1111/gcbb.12366>
23. IPCC. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. In: Core Writing Team, Pachauri RK, Meyer LA (eds) IPCC, Geneva, Switzerland, 151 p. [Internet]. Geneva; 2014. Available from: <http://ar5-syr.ipcc.ch/>
24. MappingGM [Internet]. [cited 2017 May 9]. Available from: <https://mappinggm.org.uk/>

Appendix A

List of organisations represented at the stakeholder workshop

1. University of Manchester
2. Greater Manchester Combined Authority
3. Greater Manchester Public Health Network
4. Association for Public Service Excellence
5. Transport for Greater Manchester
6. Be Thinking Group
7. British Gas
8. Quantum Strategy and Technology
9. Procure Plus
10. Stockport Council
11. Arup
12. Anthesis Consulting
13. Energy Systems Catapult
14. EA Technology
15. Salford University
16. Electricity Northwest