TyndallManchester
Climate Change Research

Quantifying the implications of the Paris Agreement for Greater Manchester

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Setting City and Area Targets and Trajectories for Emission Reduction (SCATTER)

NB: All views contained with this report are attributable solely to the authors and do not necessarily reflect those of researchers within the wider Tyndall Centre.

1 Executive Summary

The Paris Agreement commits the global community to take action to: "*hold the increase in global average temperature to well below 2°C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5°C*". As part of the SCATTER project, this report translates the "well below 2°C" commitment enshrined in the Agreement into 1) a long-term carbon budget for Greater Manchester, 2) a sequence of five-year carbon budgets, and 3) a date of effective 'carbon neutrality' for the region. Building on the latest science and emissions data, the analysis quantifies the challenging mitigation agenda necessary for Greater Manchester to make a 'fair' contribution to a globally stable climate. This report does not address the still more challenging commitment to "*pursue efforts to limit the temperature increase to 1.5°C.*"

The development of post-2017 carbon budget ranges and carbon emissions pathways for Greater Manchester (GM) builds on detailed research (e.g. Anderson and Bows (1)), outside of the SCATTER project, transposing the 2°C temperature target and equity commitments set by the Paris Agreement to the UK level. The carbon budgets and carbon neutrality definitions in this report apply to carbon dioxide emissions from the energy system only.

Headline Conclusions

Based on our analysis, for Greater Manchester to make its 'fair' contribution towards the 2°C commitment enshrined in the Paris Agreement, Greater Manchester would need to:

1) Take prompt action to put Greater Manchester on a path to carbon neutrality in 2038.
GM's emissions in the short term are as important as our long term goal. Our proposed carbon neutrality date of 2038 corresponds with the beginning of GM's fifth recommended carbon budget[1]. It is not zero emissions but represents a very low level allowing for long term accounting uncertainty and year to year variation. Whilst a goal for 'carbon neutrality' gives a clear sense of the level of ambition and scale of carbon reduction needed, it is essential to understand that it is immediate near term action to significantly reduce our emissions that is required to ensure that GM can make its 'fair' contribution to international agreements on Climate Change.

***Carbon Neutrality** is here defined specifically for Greater Manchester and relates to the point beyond which GM's annual carbon dioxide emissions fall below a threshold level of 0.6MtCO_2 (i.e. over 97% lower than 1990 levels). The threshold year relates to the point at which less than 5% of the total carbon budget remains as residual emissions. The remaining residual emissions beyond this point, which equate to an annual average of less than 75 ktCO_2, still form part of the 2°C carbon budget and are anticipated to be very difficult to reduce. By 2100 they must be eliminated or thereafter compensated by a guaranteed uptake of carbon dioxide directly from the atmosphere.*

2) Hold cumulative carbon dioxide emissions at under 71 million tonnes (range of 45 to 104 MtCO_2)
Rising temperatures relate closely to the total quantity of carbon dioxide emitted – much of which remains in the atmosphere for many centuries to come. For the period from 2018 to 2038, inclusive, total emissions from GM should not exceed 67 million tonnes of carbon dioxide (67 MtCO_2), with the

[1] The total carbon budget derived for GM is sub-divided into five 5-year carbon budget periods, designed to coincide with those developed for the UK by the Committee on Climate Change. The emissions for these budget periods sum to 67MtCO_2, with 4MtCO_2 then remaining for the period 2039 to 2100.

remaining 4 $MtCO_2$ allocated to the period 2039-2100. This is well in excess of the UK government's target of an 80% reduction by 2050 due to differences in probabilities on exceeding the 2°C temperature threshold (further explanation on page 4) and the equity steer enshrined in the Paris Climate Agreement. The UK targets are currently not downscaled to local regions by the CCC and there do not yet exist detailed pathways that demonstrate how such reductions can be achieved at this scale. The recommended carbon budgets for GM are illustrated in Figure 1 along with the UK's legislated budgets apportioned to the GM level. The carbon budgets recommended should be reviewed on a five yearly basis to reflect the most up to date science, any changes in global agreements on climate mitigation and progress on the successful deployment at scale of negative emissions technologies.

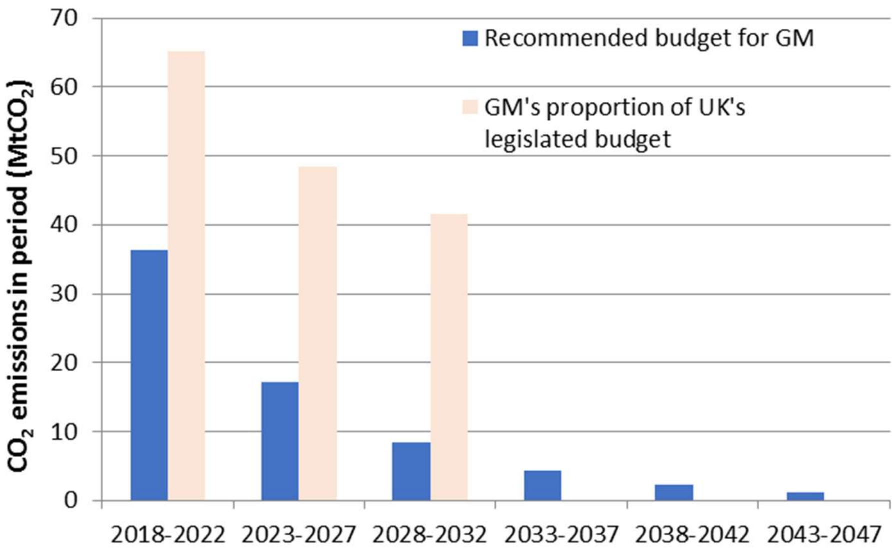

Figure 1: Recommended carbon budgets for Greater Manchester from 2018 to 2047

3) Initiate an immediate programme of mitigation delivering an annual average of 15% cuts in emissions

Our analysis finds that GM needs to achieve annual emissions reductions rates of between 10% and 20% in order to remain within its fair 2°C carbon budget. The 15% annual average reduction in emissions combines both national and local action. Achieving these levels of reduction in GM, will require a combination of local action and working to influence and collaborate at other scales. The estimates by BEIS indicate that between 2015 and 2016, UK CO_2 emissions have decreased by 5.4%, driven by a change in the fuel mix for electricity generation (2). The recommended pathway, 15% per annum reductions, represents similar annual rates of reduction as that achieved by GM in 2014 (13.9%) which was also primarily driven by a change in the fuel mix for electricity (2) . Since 2012, the power sector has been the driving force in emissions reductions with its emissions cut by over a half. In 2015, 31% of the GM emissions were attributed to electricity use with gas contributing about 31% and transport 34%. Under our current patterns of demand, complete decarbonisation of the electricity grid due to changes in national policies would result in a 31% reduction in emissions from 2015 levels. Therefore, national level action on grid decarbonisation is important and should be called for and supported by GM. However, actions beyond electricity supply and actions at a local level are needed if significant and rapid reductions in emissions are to be achieved. **A comprehensive programme of mitigation needs to begin immediately; any delay in starting, or pursuing a rate below the rates proposed here would require even more mitigation in the early 2020s.**

4) Manchester citizens' CO_2 emissions from flights should hold steady to 2030 and then reduce to zero by 2075

Flights from Manchester Airport are a major source of CO_2 emissions. We have included aviation in the national emissions budget, not the GM emissions budget, but propose tracking GM residents' consumption of flights for consistency with the other modelling assumptions. The above conclusions, 1 to 3, are dependent on no growth in CO_2 from UK aviation between now and 2030, with emissions subsequently reducing year on year to zero by 2075. This mitigation pathway is far less steep than for all other sectors. If these assumptions are not met and aviation emissions instead follow the Department for Transport (DfT) 2017 Baseline Central Forecast, then reductions of ~20% p.a. would be required in the GM carbon budget to meet the overall Paris Agreement objective.

5) Have greater engagement with other global carbon target setting cities to share knowledge

Many cities and regions around the world are committed to ambitious carbon emissions reduction targets including the achievement of carbon neutrality. There is generally a lack of a publicly available explanation of how global goals have been apportioned to city regions for setting reduction targets. Meanwhile, there are several global initiatives which seek to facilitate action on climate change at a local level. They share research and resources through various networks to provide mutual support for their goals. The cities in the carbon neutral alliance (17 cities) are targeting either deep decarbonisation or carbon neutrality. As other cities around the world seek to achieve mitigation levels in line with the Paris Agreement commitments, we suggest that Greater Manchester should share and exchange knowledge with a broad range of cities in order to develop best practice and promote learning from implementation experiences.

Why are the recommended GM carbon budgets different to the UK's legislated carbon budgets?

There are a number of analytical reasons that these emissions budgets are substantially smaller than those adopted by successive UK Governments. Current UK budgets correlate with an expected probability of exceeding 2°C of more than 56%. Although not explicit within the wording of the Paris Agreement, we interpret "…keep well below 2°C" as relating to carbon budgets with less than 33% chance of exceeding 2°C. The scenario set informing the UK targets also assumes substantial uptake of speculative negative emission technologies (NETs, see Box 1, p11), reducing the necessary levels of 'real' mitigation. Ours do not, however, we do regard development of NETs as representing the Paris Agreement's intention to "...pursue efforts to limit the temperature increase to 1.5°C." Finally, we believe that current UK budgets under-represent the equity steer of the Paris Agreement by setting a UK path that delays annual global emissions parity until 2050, despite our historic responsibility. We provide a greater proportional allocation to the poorer parts of the world and account for cement production at the global level to reduce the risk of conflict with the UN Sustainable Development Goals.

Brief overview of the carbon budgeting method

(following the method of Anderson & Bows (1))

Step1: Intergovernmental Panel on Climate Change global carbon budgets taken as the starting point as detailed in AR5 synthesis report.

Step 2: A deduction is made as a 'global overhead' for process emissions arising from cement production as cement is assumed to be a necessity for development (3). We also assume that there is no net deforestation at a global level (post 2017) so none of the global carbon budget is allocated to this source. This will require significant global effort to reduce deforestation and increase reforestation and afforestation.

Step 3: An allocation is made to non-OECD (industrialising) nations leaving a remainder for the richer OECD members[2].

Step 4: The UK is apportioned a share of the OECD budget to provide a national carbon budget range. The apportionment is made according to two regimes, i) population and ii) "grandfathering" of recent emissions (2010 to 2015).

Step 5: Assumptions and estimates are made about the level of future emissions from aviation, shipping and military transport for the UK. These emissions are then deducted from the national budgets as a 'national overhead' to derive final UK energy only carbon budgets.

Step 6: Greater Manchester is then apportioned part of the energy only UK carbon budget based on three different regimes to give a small range of budgets: population, grandfathering and Gross Value Added (GVA).

Step 7: Illustrative emission pathways are developed which are in line with those budgets. Within this range of budgets a 'recommended carbon budget' for Greater Manchester is proposed as the mean of the budget range.

This analysis indicates a carbon budget range for GM of 45 to 104 $MtCO_2$, for the period from 2018 onwards. The size of these budgets indicate that if GM is to make its 'fair' contribution to delivering on the Paris 2°C temperature commitment then it needs to begin an immediate and rapid programme of decarbonisation. **To give a sense of the scale of the challenge, at current (2015) CO_2 emission levels[3], GM would use its entire budget within 4 to 8 years.**

Emissions from Land Use, Land Use Change and Forestry (LULUCF)

Whilst LULUCF emissions have been removed from the recommended GM carbon budget, CO_2-only emissions from this sector should be tracked and aligned with GM's carbon neutrality ambition. Local actions in this sector can also have wider benefits in terms of improving natural capital. We recommend:

1. LULUCF achieves absolute zero CO_2 emissions, on an annual basis, by 2038 aligned with the year of carbon neutrality.
2. Post 2038 the *rate* of LULUCF emission reductions/sequestration continues to increase, reaching a maximum rate by around 2045. Thereafter, the sector continues to provide a stable level of annual sequestration across the century.
3. GM's emissions from LULUCF achieves net zero cumulative CO_2 emissions for the period 2018 to 2100

Emissions from aviation

Whilst aviation and shipping emissions have been removed from the UK carbon budget before an allocation has been made to GM, it is important that emissions from flights taken by GM citizens are monitored. If aviation emissions were to increase at a UK level then the available 2°C compatible budget for the city-region would be reduced. This is an area over which the city region can have influence with both a financial stake in the airport, and influence over the development and promotion

[2] The OECD: non-OECD classification is sufficiently close to both "non-Annex 1" and "non-Annex B" climate policy groupings to be comparable and is more widely understood.
[3] Based on GM's 2015 CO_2 emissions (excluding aviation, shipping, process CO_2 emissions from cement production and those from LULUCF).

of virtual engagement tools. For consistency with the assumptions in this report, GM should play its part in ensuring that the emissions from UK aviation follow a static path to 2030 and then steadily decline to zero by 2075.

Discussion with Manchester Airport Group, Manchester Metropolitan University and Anthesis has identified a method for tracking emissions associated with GM citizens' flights. Carbon emissions from aviation are monitored at the national level and can be allocated to the residents of city-regions using the CAA Passenger Survey data. This is a transparent and straightforward process that will allow a city-region to track trends in flying. Alternative methods, alongside a discussion of the limitations of this approach are discussed in more detail in Appendix B.

GM's non-CO_2 emissions could be compensated with biological sequestration

GM has very low non-CO_2 emissions which nonetheless should be reduced as much as possible. The cumulative non-CO_2 emissions within the GM boundary could be compensated by sequestration from Land Use, Land Use Change and Forestry (LULUCF) activities. Given the absence of robust non-CO_2 emissions data at local level, we recommend quantified pathways and budgets should be developed once these datasets are available.

Offsetting

Ambition for 'carbon neutrality' is often accompanied by commitments on 'carbon offsetting'. Carbon offsetting refers to the purchase of a tradeable unit, representing emissions rights or emissions reductions, to balance the climate impact of an organisation, activity or individual. Although they can be stored and traded like a commodity, they are not material things; offset credits are not literally "tonnes of carbon" but stand in for them and are better regarded as intangible assets or financial instruments. To act as an offset, units must be cancelled to represent a reduction and prevent further trading.

In this report, the term 'offset' refers to the purchase and cancellation of tradeable units representing emissions reductions or sequestration outside the boundary of Greater Manchester to compensate for 'residual' carbon emissions. All carbon offset arrangements are open to criticism as being ineffective at reducing emissions. 'Carbon neutrality' achieved this way is an accounting procedure rather than a physical status. These procedures and the context under which they operate are liable to change through time, for better or worse. In light of this, we would not recommend entering into offset relationships. If GMCA identify financial resources and the necessity to pursue this path then they should i) only consider regulated systems and purchases, ii) revisit the available tradeable units at the time of purchase to consider which are the most robust and reliable, iii) recognise that this will be a controversial approach potentially drawing criticism, and public and professional cynicism.

The scale of the challenge

It is acknowledged that our recommended budget and associated pathway will be challenging to achieve and represents a much greater level of ambition than is embedded in current national policy. However it also represents an opportunity to demonstrate the potential for joined-up decision-making across devolved powers, and the development of political and societal will to take action that is genuinely in line with the Paris Agreement. Such a commitment, and the actions needed to achieve it, would certainly place Greater Manchester amongst the leading 'green cities' of the world.

2 Introduction

2.1 The Paris Agreement and a carbon budgeting approach

The UNFCCC Paris Agreement on climate change commits the global community to take action to "*hold the increase in global average temperature to well below 2°C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5°C*". This report translates the "well below 2°C" commitment enshrined in the Agreement into 1) a long-term carbon budget for Greater Manchester, 2) a sequence of recommended five-year carbon budgets, and 3) a date of effective carbon neutrality for the region. Building on the latest science and emissions data, the analysis quantifies the challenging mitigation agenda necessary if Greater Manchester wishes to make its fair contribution to a globally stable climate. Taking seriously the equity framing of the Agreement, the conclusions of this report are premised on industrial nations demonstrating leadership towards a post-fossil fuel society.

The analysis typically adopts more optimistic assumptions that, if anything, underplay the scale and timeframe of mitigation. Consequently, the recommendations made here should be viewed as the minimum required for GM to make a timely transition to prosperous and decarbonised future. The carbon budgets presented and definition of carbon neutrality apply to carbon dioxide emissions from the energy system only. This report does not address the still more challenging commitment to "*pursue efforts to limit the temperature increase to 1.5°C.*" However, this issue is considered in Box 1 'Negative emission technologies and 1.5 and 2°C scenarios'.

The most recent assessment report (AR5) of Working Group I (WGI) of the International Panel on Climate Change (IPCC) made clear that CO_2 emissions are the principal driver of long-term warming[4]. Although all greenhouse gas (GHG) emissions and other forcing agents affect the rate and magnitude of climate change, the long term warming is mainly driven by carbon dioxide (CO_2) emissions (4). Therefore, the cumulative CO_2 emissions from all anthropogenic sources must be limited to a specific amount to maintain warming to "well below 2°C". It is this cumulative quantity of CO_2 that is known as the carbon budget (5,6). Additionally, carbon budgets, as adopted by the IPCC synthesis report, relate to CO_2-only emissions, as the physical or chemical properties of each GHGs vary with different life-times causing warming in different ways (Appendix A) and have large uncertainties in their accounting (7). As such, the carbon budgets developed for the SCATTER project are based on CO_2-only emissions.

2.2 Context

The UK Climate Change Act 2008 has enshrined a commitment to at least an 80 percent reduction in greenhouse gas emissions by 2050 from 1990 levels, with five yearly carbon budgets to act as stepping stones (8). Meanwhile, Greater Manchester Combined Authority[5] (GMCA) has adopted its own target of a 48% reduction in carbon emissions 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[6] (9). By

[4] This is due to the near-linear relationship between cumulative CO_2 emissions and temperature is the result of various feedback processes and logarithmic relationship between atmospheric CO_2 concentrations and radiative forcing, as well as the changes in the airborne fraction of CO_2 emissions (5,6).
[5] GMCA is made up of the ten GM councils who work with other local services to improve the city-region.
[6] It is worth noting that, based on UN estimates of global population, if all citizens were to emit 2 tonnes each in 2050, total emission would be over 18 billion tonnes of CO_2 ($18GtCO_2$). This is a global reduction of around 50% compared with

2015, excluding international and domestic aviation emissions associated with Manchester Airport, GM had achieved a 39% reduction in CO_2 emissions compared to 1990 (9,10). Whilst GM may meet its emissions reduction target for 2020, further and much more ambitious decarbonisation is essential if it is to deliver its fair contribution to the Paris Agreement's commitment of "well below 2°C".

2.3 Translating the 2°C objective to a fair carbon budget range for Greater Manchester

The development of post-2017 carbon budget ranges and carbon emissions pathways for Greater Manchester (GM) builds on detailed research, outside of the SCATTER project, transposing the 2°C temperature target and equity commitments set by the Paris Agreement to the UK level. Following the method of Anderson and Bows (1), the global carbon budgets published in the IPCC AR5 synthesis report (4) are taken as a starting point. A deduction is made as a "global overhead" for process emissions arising from cement production (100 $GtCO_2$) (11). An allocation is then made to non-OECD industrialising nations leaving a remainder for the richer OECD members[7]. Six non-OECD scenarios are generated for fossil fuels based only on assumptions about how quickly non-OECD countries may peak their emissions as detailed by Anderson and Broderick (3). This approach of considering the non-OECD nations first, is guided by the stipulation of equity within the Paris Agreement (and its earlier forebears, from Kyoto onwards). The OECD budget is then apportioned to the UK to provide a national carbon budget range. The apportionment is done according to population and "grandfathering" of recent emissions (2010 to 2015). Emission budgets for aviation, shipping and military transport for the UK are estimated separately and deducted from the national budgets when deriving the final UK carbon budgets. The UK budgets are subsequently apportioned to Greater Manchester (GM) based on three regimes: population, grandfathering and Gross Value Added (GVA). Illustrative emission pathways are developed in line with these budgets. The proposed budgets and pathways provide a sufficiently broad envelope of outcomes to inform the development of a 'recommended carbon budget' and associated pathway for Greater Manchester.

In the period 2010-2015 the UK has reduced emissions substantially more than the OECD average (21% vs 1% reductions respectively) (12), and this is reflected in a lower future allocation based on the grandfathering regime. The rationale for this regime is that the UK has already taken action on some of the larger sources of emissions and so requires less of the share of future emissions, although it should be noted that the recent substantial reduction in coal fired power generation occurred after the period 2010-2015. However, this may not be regarded as "fair" by some people and is less intuitive than a simple population based measure. Neither approach is privileged in the Paris Agreement which adopts individual determination of future emissions targets.

Building on the above approach, CO_2 only targets and five yearly CO_2 emissions budgets for GM consistent with a "likely" chance of holding the temperature rise to "well below 2°C" are estimated.[8] This analysis is based on territorial accounting, and does not take account of the balance of GM's

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2017 emissions and would fall far short of what is necessary to deliver on the Paris 2°C commitment and would put the 1.5°C target well beyond reach.

[7] The OECD non-OECD classification is sufficiently close to both "non-Annex 1" and "non-Annex B" climate policy groupings to be comparable and is more widely understood.

[8] The IPCC guidance notes provide taxonomy of 'likelihood scales", used here to transpose the qualitative language of the Paris Agreement into quantitative uncertainties. https://www.ipcc.ch/pdf/supporting-material/uncertainty-guidance-note.pdf

emissions associated with its imports and exports. Non-CO_2 emissions cannot be incorporated with CO_2 in a cumulative emission budget because of their different physical effects on the climate.

2.4 How have other cities have set targets?

Many cities and regions around the world are committed to ambitious carbon emissions reduction targets including the achievement of carbon neutrality. There are several global initiatives such as the Compact of Mayors[9], the Compact of States and Regions[10], Energy Cities[11], C40 Cities[12] and Carbon Neutral Cities Alliance[13] which seek to facilitate action on climate change action at a local level. These initiatives share research and resources through various networks to provide mutual support for their goals. The cities in the carbon neutral alliance (17 cities) are targeting either deep decarbonisation or carbon neutrality. The targets set by these cities vary in the range of greenhouse gases included, the level of reduction, the timeframe (ranging from 2020 to 2050) and the sectors included. Some examples of carbon targets for other city regions are provided below by way of context for the analysis presented in this report and the SCATTER project.

Copenhagen: Copenhagen City Council adopted a Climate Plan in 2012 to make the city the first carbon neutral capital in the world by 2025. The goal is to achieve zero carbon dioxide emissions from all energy sectors by 2025. Additionally, the Climate Plan has specific targets for each sector compared to a 2010 baseline. The carbon neutrality goal set by Copenhagen includes emissions from the city's energy system and the activities of utility companies owned by the city elsewhere. Excess renewable energy generation from their utilities is assumed to displace coal power generation when consumed by customers outside the city (13). As other parts of Denmark decarbonise, the carbon intensity of the displaced energy consumption will decrease, in turn reducing the degree to which the city could compensate for its carbon emissions in this way.

Adelaide: The Government of South Australia and Adelaide City Council (ACC) have announced their intention to make Adelaide the world's first carbon neutral city before 2020. ACC defines carbon neutrality as net GHG emissions associated with operational activities within the city region to be zero or else offset by sequestering emissions outside the ACC boundary. The offsets would be required to comply with the Australian government rules and methodologies and accredited under the National Carbon Offsets Standard (NCOS). The NCOS standard provides guidance on how to measure, reduce, offset, report and audit emissions to enhance the credibility of claims of carbon neutrality (14). In addition to offsetting, they envisage a 50% emissions reduction by 2020 compared to 2007 and 65% by 2025. ACC have also provided a long term strategy out to 2050 including moving towards a 100% renewable transport and electricity system, an energy efficient built-environment and utilising carbon sequestration (14). It is not specified in the plans if or how the reduction rates are related to global carbon budgets.

Berlin: The City of Berlin set a target of 85% reduction in carbon dioxide emissions by 2050 compared to 1990 levels with interim targets of 40% reduction by 2020 and 60% by 2030. The target

[9] https://www.globalcovenantofmayors.org/
[10] http://www.iclei.org/
[11] http://www.energy-cities.eu/
[12] http://www.c40.org/
[13] https://www.usdn.org/public/page/13/CNCA

is presented as underpinning a reasonable contribution by the city to achieving the global temperature target of limiting warming to below 2°C (15), however we have not been able to identify a publicly available source that explains the process of developing this target based on the global carbon budgets that relate to such a global temperature commitment.

Oslo: Oslo's city government has announced its intention of halving its carbon emissions by 2020 from 1990 levels, and becoming completely carbon neutral by 2030 (95% by 2030 compared to 1990 levels). The majority of the city's electricity consumption is already supplied from hydro power stations and its heating is mainly electric. Hence the target is mainly focused on decarbonising the transport sector, which represents more than 60% of the city's emissions, and development of a carbon capture and storage facility at its waste to energy plant at Klemetsrud. The Oil-Free project intends to phase out fossil fuels for heating following a ban on oil heating from 2020 (16). The city also intends to purchase carbon credits to offset any residual emissions from both within and outwith the EU(17). We were not able to identify a publicly available source that explains the process of developing the targets or a definition of carbon neutrality in the context of the 95% target.

New York City: The City of New York has committed to reduce its greenhouse gas emissions to 80% by 2050, compared to 2005 levels across all sectors using existing technologies (a target it refers to as 80x50). In 2017, the city announced its intention to align its 80x50 strategies with the Paris Agreement goal of limiting global temperature rise to 1.5°C. The city also committed to develop guidance on a path to carbon neutrality including a shared definition of carbon neutrality with C40 and other cities. This was made, at least partly, in response to President Trump's announcement of his intention to withdraw the United States from the Paris Agreement (18). New York's strategy states that it intends to pursue carbon sequestration and carbon offsets to account for residual GHG emissions after all "technically feasible" emissions reductions are achieved in order to achieve carbon neutrality (18). New York states that it has based its 1.5°C alignment on the Arup report 'Deadline 2020' (19) for C40 cities, which modelled a pathway for C40 cities to reduce emissions in line with the Paris Climate Agreement. The pathway suggested that most cities need to peak their emissions by 2020 and by 2030 average GHG emissions across all C40 cities need to be 3 tonnes per person per year or less. However, this pathway requires substantial negative emissions technology deployment (see Box 1) such that net global emissions are negative by 2050. We were not able to identify a publicly available source that gave a detailed explanation of the process of developing the 1.5°C alignment of New York City from the C40 pathway.

As cities around the world seek to achieve mitigation levels in line with the Paris Agreement commitments, we suggest that Greater Manchester should share and exchange knowledge with a broad range of cities in order to develop best practice and promote learning from implementation experiences.

Box1: Negative emission technologies & 1.5 and 2°C scenarios

Virtually all of the 2°C scenarios within the IPCC's database include negative emissions technologies removing several hundred billion tonnes of carbon dioxide directly from the atmosphere across, and beyond, the century (20). However, there is wide recognition that the efficacy and global rollout of such technologies are highly speculative, with a non-trivial risk of failing to deliver at, or even approaching, the scales typically assumed in the models (21).

Whilst the authors of this report are supportive of funding further research, development and, potentially, deployment of NETs, the assumption that they will significantly extend the carbon budgets is a serious moral hazard (20). Ultimately, if there is genuine action to mitigate emissions in line with a "likely" chance of staying below 2°C, and NETs do prove to be a viable and scalable option, then, in theory at least, an opportunity arises for holding the temperature rise to 1.5°C. By contrast, if action to mitigate for 2°C is undermined by the prospect of NETs, and such technologies subsequently prove not to be scalable, then we will have bequeathed a 3°C, 4°C or higher legacy. As is clear from the 2°C scenarios submitted to the IPCC, the inclusion of carbon capture and storage (CCS) and biomass energy with carbon capture and storage (BECCS) include considerably more fossil fuel combustion than those without them. It is evident, that mitigation advice to government is already being influenced by assumptions about NETs, and indeed the rapid uptake of CCS, neither of which shows any sign of approaching the scales of rollout in the models.

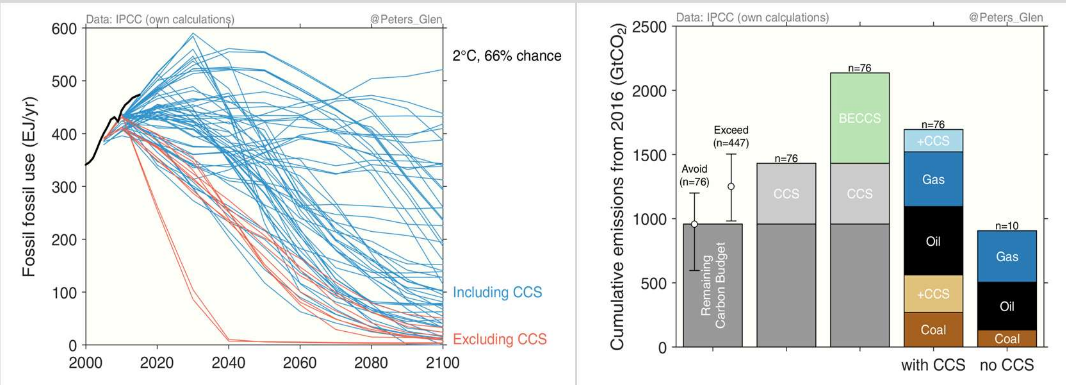

Figure 2a. (left) Emissions pathways based on the IPCC scenarios for a 66-100% chance of staying below 2°C, illustrate how the inclusion of fossil fuel combustion with CCS and BECCS (BECCS being the NET of choice in models and reliant on successful CCS technology) result in much more fossil fuel use. Figure 2b. (right) demonstrates the total 2°C carbon budget from 2016 (left hand bar). The adjacent bar shows additional emissions released during fossil fuel combustion and subsequently captured by CCS. The middle bar demonstrates further fossil fuel emissions assumed but compensated by BECCS. The final two bars demonstrate the median modelled use of fossil fuels with and without CCS (and BECCS)

If the huge uptake of very uncertain NETs were the exception amongst mitigation scenarios, it would be of value. However, evoking global-scale NETs as a viable substitute to actual and much more challenging mitigation is the norm. Reinforcing this endemic bias for less onerous mitigation is the exclusion of uncertain carbon-cycle feedbacks anticipated, on average, to reduce available carbon budget space.

This ubiquitous preference for uncertainty that favours less onerous mitigation is dangerously weighting policy towards technocratic-only responses whilst at the same time closing down more challenging debates over deeper social-economic and lifestyles change. A measured approach would be to develop most scenarios without either NETs or positive carbon cycle feedbacks, with such uncertain parameters informing only the fringes of the analysis and providing the more extreme boundaries of possible scenarios.

2.5 Allocating a carbon budget for aviation, shipping and military transport

These sources of emissions are typically considered at a national level and relate to emissions from aircraft and ships, not the stationery infrastructure that supports them. Although there are a number of potential approaches for allocating emissions regionally, there are limitations to each (a discussion is provided in Appendix B). For aviation we propose a two stage process i) to allocate a national emissions budget to aviation prior to determining the GM budget, and then ii) monitoring regional emissions with an indicative measure for consistency but not including them within the GM carbon budget. For shipping, a similar approach is taken at the national level but a regional monitoring metric has not been established. This is of less concern as its expected share of future emissions is substantially lower than for aviation. Manchester Airport emissions that relate to ground transport and buildings will be reflected elsewhere in the GM inventory, outside of the aviation figure i.e. road transport and stationary energy. A small amount are included in GM's Scope 1 inventory reporting to the Compact of Mayors to reflect aircraft that take off and land within GM on the same trip. The detail of this is still to be confirmed however was believed to be wholly immaterial by Manchester Airports Group (<1% of total GM scope 1 emissions).

2.5.1 National aviation pathway

The Department for Transport (DfT) forecasts aviation emissions based on future growth in air passengers and aircraft movements. Under the Baseline Central Demand forecast, with no new London runways, annual UK CO_2 emissions are forecast to be 37 Mt by 2050 (22). An emissions pathway premised on this forecast out to 2050 followed by a linear reduction to zero emissions by 2075, including military transport, equates to total emissions of 1742 $MtCO_2$ for 2018-2075 (Figure 3).

We find that this DfT forecast takes too much of the UK's Paris compatible carbon budgets to allow achievable decarbonisation paths in other sectors. Consequently for SCATTER, we assume emissions from aviation, including military aircraft, are static out to 2030 followed by a linear reduction to full decarbonisation of the sector by 2075. The cumulative emissions budget (2018 onwards) for this path is estimated to be 1262 $MtCO_2$ (Figure 2). The pathway for aviation decarbonisation presented here has carbon emissions 500 $MtCO_2$ lower than the DfT forecast. If the DfT forecast is followed then our central estimate of the GM share of UK emissions would be 25% lower at 53 $MtCO_2$, necessitating ~20% per annum decarbonisation rates. If GM is committed to climate action in accordance with the Paris Agreement, then the lower assumption on UK aviation emissions growth is appropriate.

Although our method does not include this source in the regional budget, consistency with this pathway should be validated through monitoring of an aviation emissions indicator. Approaches for such accounting, and monitoring of, aviation emissions at a GM level are discussed in Appendix B. Following discussion with Manchester Airports Group, Manchester Metropolitan University and Anthesis we propose that national emissions are allocated to a city-region according to passengers' residence details recorded in the CAA passenger survey data. This data set provides an indication of the number of journeys made by GM residents from all airports around the UK, based on passenger residence by postcode, not only Manchester Airport. Latest data available, for 2015 – 2016, show total UK aviation emissions 36 $MtCO_2$ (33 $MtCO_2$ international, 1.5 $MtCO_2$ domestic, 1.5 $MtCO_2$ military). The portion allocated to GM residents flying from Manchester airport is 0.76 $MtCO_2$ and 0.07 $MtCO_2$ flying from other UK airports.

2.5.2 National shipping pathway

CO_2 emissions in this category arise from ships transporting goods to the UK, trade around the UK, coastal passenger shipping and naval shipping. The NAEI dataset for international shipping emissions for the UK (based on UK bunker fuel sales) underestimate actual emissions as ships are typically fuelled elsewhere on route (23). Walsh et al (24) indicates an underestimate of 52% in 2015 and 55%

in 2012 for the UK international shipping emissions. The revised shipping emissions data for the UK (based on Walsh et al (24)) is used in this analysis.

Walsh et al (24) assessed the emissions reduction and cumulative emissions from UK shipping that is necessary to meet 2°C goal under three scenarios. The cumulative shipping emissions under the scenario 'big world' are estimated to be 323 $MtCO_2$ from 2010 to 2050. The mitigation under this scenario is primarily attributed to reduction in speed from container ships. The scenario considers extended trade partners outside Europe which may be relevant to the anticipated 'Brexit' trade impact. Since the scenario period extends only up to 2050, an assumption is made that by 2075, the shipping sector will decarbonise completely. Similar reduction rates are assumed for naval shipping. In the case of coastal shipping, complete decarbonisation by 2050 is assumed as the shorter travelling distances are amenable to electrification and other low carbon technologies. The cumulative emissions budget (2018-onwards) for the UK shipping under these assumptions, including coastal and naval, is estimated to be 275 $MtCO_2$ (Figure 3). The Committee on Climate Change (CCC) central forecast from its review of shipping emissions is included here for comparison (23). The cumulative CO_2 emissions budget from aviation, shipping and military aircraft is then deducted from the UK budget to derive the final national budgets for apportioning to local regions.

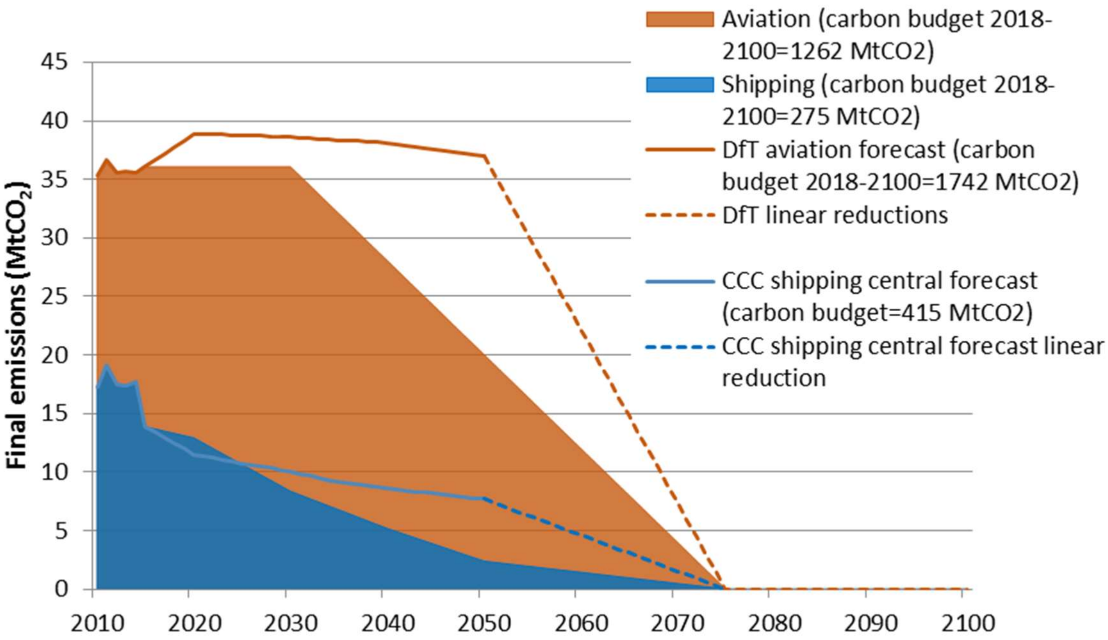

Figure 3: Cumulative CO_2 emission budgets for the UK from aviation and shipping (2018-2100)

2.6 Apportioning the UK budgets to Greater Manchester

Three apportionment regimes are used here to allocate the UK ("well below 2°C") energy-only CO_2 emissions budget (post-2017) to GM. These are outlined below and provide a sufficiently broad envelope of budgets to cover the outcomes from most apportionment regimes.
Grandfathering (GF) – The carbon budget for GM is estimated on the basis of recent GM emissions (10) (i.e. the mean from 2010-2015), compared to those of the UK (2) averaged over the same period. This proportion of GM to UK emissions is then applied to the UK post-2017 emissions budget to give a GM budget from and including 2018 out to 2100 and beyond.

Population (Pop) – The UK population (25) is compared to that of GM (26) from 2010 to 2015. The emissions budget (2018-2100) for GM is then apportioned from the UK budget based on its average proportion of population for the period 2010-2015.
Gross Value Added[14] (GVA) – The UK GVA (27) is compared to that of GM (27) from 2010 to 2015. The emissions budget (2018-2100) for GM is then apportioned from the UK budget based on its average proportion of GVA for the period 2010-2015.

Based on these apportionment regimes, the subsequent CO_2 emission budgets and illustrative mitigation rates are provided in Table 1. The recommended carbon budget for GM (final row in Table 1) is the mean of all budgets. This 71 $MtCO_2$ budget excludes the possibility of aligning GM to a good chance of limiting warming to 1.5°C and should be considered as the minimum mitigation effort necessary to avoid 2°C. It is also only valid provided aviation and shipping emissions are also reduced at the levels outlined by the allocations above. Any failure in these sectors would see the GM budget shrinking still further.

Table 1: Apportionment regime[15], CO_2 budgets and annual mitigation rates for Greater Manchester, 2018-2100

Apportionment regime (bracket term is GM's proportion of the UK)	**UK mid-value budget[16] ($MtCO_2$)**	**Greater Manchester mid value budget ($MtCO_2$)**	**Average annual mitigation rate (%)**
Grandfathered to GM from UK UK CO_2 based on population split of OECD **GF-Pop-** (3.3%)	2463	82	12.2%
Population split to GM from UK *UK CO_2 based on population split of OECD* **Pop-Pop** (4.2%)	2463	104	9.8%
GVA[17] split to GM from UK UK CO_2 based on population split of OECD **GVA-Pop** (3.6%)	2463	89	11.3%
Grandfathered to GM from UK UK CO_2 grandfathered from OECD **GF-GF** (3.3%)	1350	45	20.2%
Population split to GM from UK *UK CO_2 grandfathered from OECD* **Pop-GF** (4.2%)	1350	57	16.6%
GVA split to GM from UK *UK CO_2 grandfathered from OECD* **GVA-GF** (3.6%)	1350	49	18.9%
Recommended carbon budget for Greater Manchester		**71**	**14.8%**

[14] Income approach at current basic prices
[15] The UK mid-value budgets used here are taken from the report "Quantifying the implications of the Paris Agreement: what role for the UK's energy system?" Anderson (2017).
[16] Assumes a peak in non-OECD emissions between 2022 and 2023 (3).
[17] Using GVA as a proxy for apportioning the UK emissions to GM ignores the fact that its GVA/capita income is ~15% lower than that for the UK as a whole. Similarly when using the purchasing power standard (PPS), which is the economic aggregate divided by its purchasing power parities, GM residents has 15% lower economic capacity for action on climate mitigation. PPS is the technical term used by Eurostat for the common currency in which national accounts aggregates are expressed when adjusted for price level differences using PPPs.

2.7 Carbon neutrality and five yearly budgets for Greater Manchester

The 2014 Emissions Gap Report by UNEP (28) uses the term 'carbon neutrality' to refer to a situation where global anthropogenic carbon dioxide emissions from energy, industry, and land use / land cover change (LULC) are quantitatively balanced to be 'net zero' by carbon dioxide removals. Although the intention is to reduce all emissions of carbon dioxide from energy to zero, not all emissions can be mitigated to zero and there is the possibility of year to year variation in biological sequestration. This is particularly the case with non-CO_2 GHGs such as Methane (CH_4) and Nitrous Oxide (N_2O) associated with agriculture. Detailed analysis on the concept of carbon neutrality is presented in Appendix A.

Rather than assume zero emissions for every year to 2100, for practical purposes we propose that carbon neutrality be defined for Greater Manchester as the point beyond which GM's average annual carbon emissions fall to below 0.6MtCO_2/yr (i.e. over 97% lower than 1990 levels). The remaining residual emissions still form part of the 2°C carbon budget and so by 2100 must be eliminated or thereafter compensated by a guaranteed uptake of carbon dioxide directly from the atmosphere.

The family of emission pathways for GM premised on the carbon budgets shown in Table 1 as well as the emissions related to 'carbon neutrality' are illustrated in Figure 4a & 4b. The figure demonstrates how reducing emissions to zero may well extend beyond the project relevant carbon neutrality date. Emission pathways developed here are more ambitious compared to the pathway recommended by the Committee on Climate Change (CCC)[18]. A methodology for downscaling the UK's legislated carbon budgets to GM and the key differences between the UK legislated and Tyndall budgets are explained in Box 2.

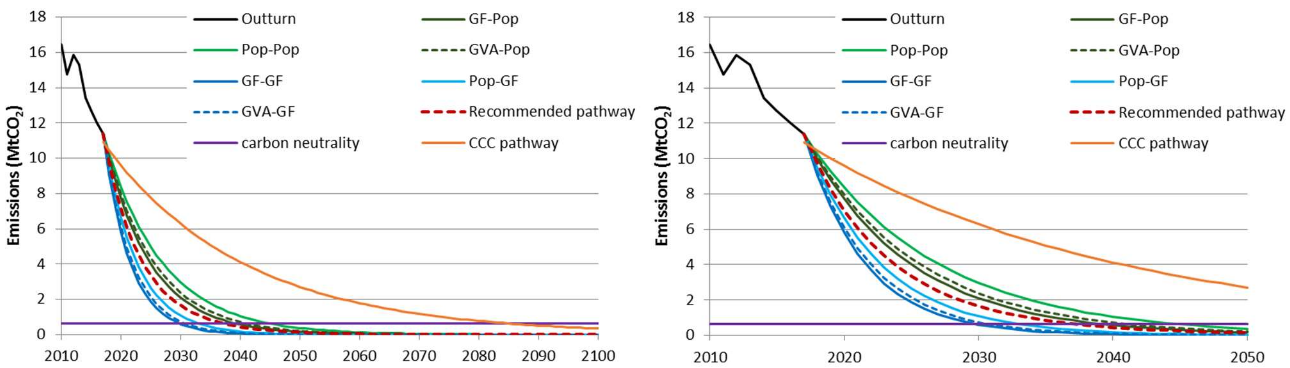

Figure 4a (left): Fossil fuel CO_2 only emissions pathways (**2010-2100**) for Greater Manchester premised on carbon budgets shown in Table 1. **Figure 4b (right)**: Fossil fuel CO_2 only emissions pathways (**2010-2050**) for Greater Manchester premised on carbon budgets shown in Table 1.

The recommended year for carbon neutrality on this basis is estimated as 2038. In order to provide guidance more in line with electoral cycles, the CCC five year budget framework is provided here to offer policy makers a clear sequence of stepping stones towards the goal of carbon neutrality that is consistent with the Paris Climate Agreement. The five yearly carbon budgets for GM up to 2047 are illustrated in Table 2, Figures 5 & 6.

[18] The CCC pathway shown in Figure 3 is based the interim budget up to 2022 and intended from fourth budget period onwards (31).

The recommended carbon budgets exclude emissions from LULUCF, aviation and shipping. Considering projected growth in aviation passenger demand and that some local authorities have a direct interest in the operations and management of their local airports (Greater Manchester authorities own a proportion of the Manchester Airport Group PLC) there is an opportunity for local authorities to reduce emissions from aviation (29). For GM to be consistent with Paris commitments, in addition to meeting periodic carbon budgets, it should present data illustrating Manchester's contribution to achieving the UK aviation path outlined above.

Table 2: Periodic carbon budgets from 2018 under various regimes for Greater Manchester

Carbon budget period		GF-Pop	Pop-Pop	GVA-Pop	GF-GF	Pop-GF	GVA-GF	Recommended GM CO_2 budget
	2018-2022	39	42	40	30	34	32	36
	2023-2027	20	25	22	10	14	11	17
	2028-2032	11	15	12	3	6	4	8
	2033-2037	6	9	7	1	2	1	4
	2038-2042	3	5	4	0	1	1	2
	2043-2047	2	3	2	0	0	0	1
	2048-2100	2	5	2	0	0	0	2
	Total CO_2	**82**	**104**	**89**	**45**	**57**	**49**	**71**

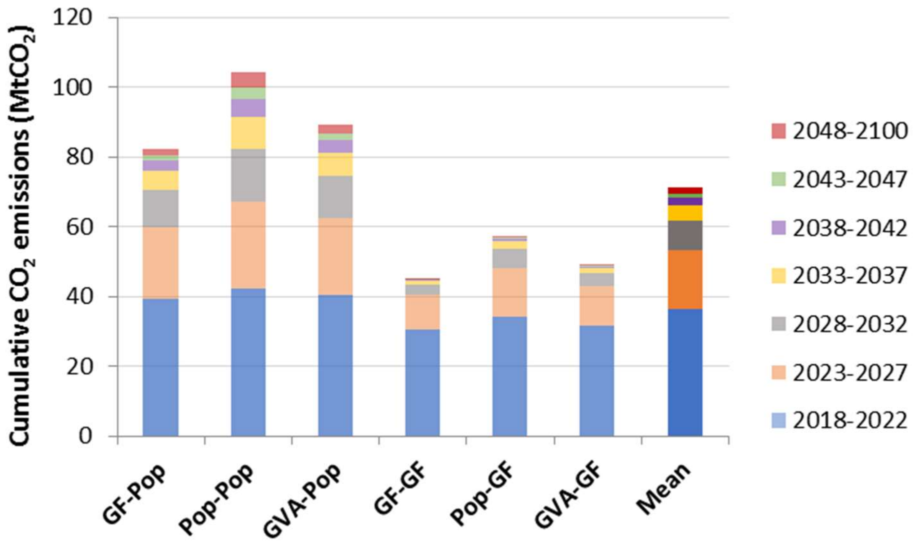

Figure 5: Periodic carbon budgets from 2018 under various regimes for Greater Manchester

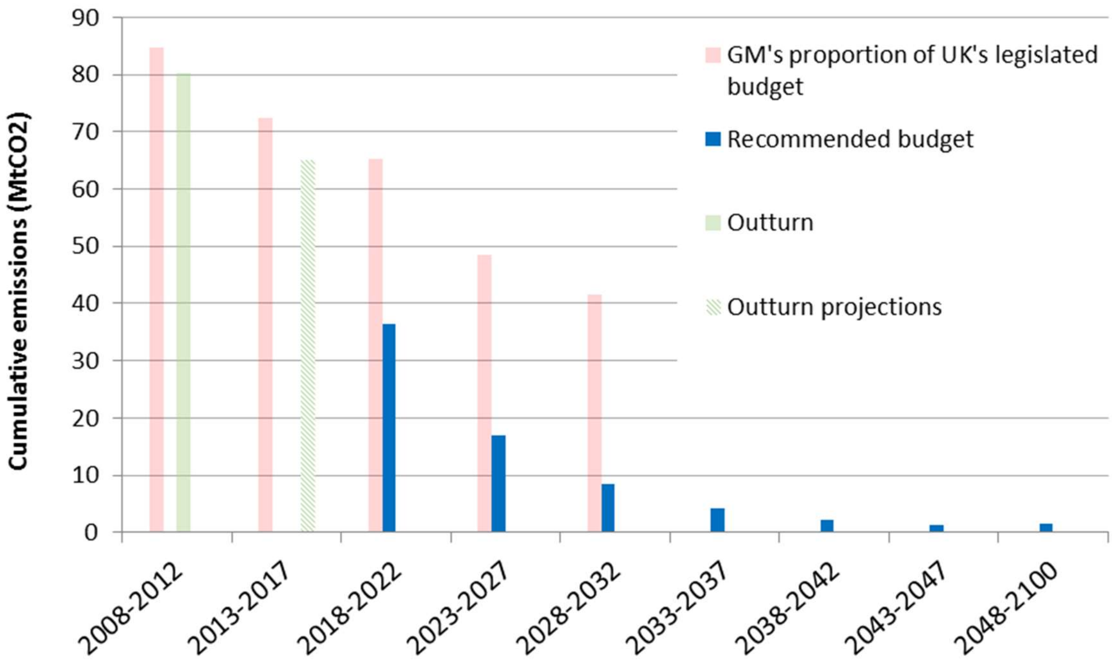

Figure 6: Periodic carbon budgets from 2008 and recommended budgets for Greater Manchester

Box 2: Why are the recommended GM carbon budgets different to the UK's legislated carbon budgets?

In 2008, the Committee on Climate Change (CCC) developed two sets of budgets, the 'intended' (which would be adopted following a global deal on emissions reduction) and the 'interim' (for the period before a global deal was reached). The budget proposals were designed in such a way that a proportion could be met by purchasing EUAs (pollution permits within the EU Emissions Trading Scheme) and offset credits, as well as by national decarbonisation (30,31). Both the 'intended' and 'interim' budgets are premised on the assumption that emissions of between 20-24 $GtCO_2$ by 2050 would represent an appropriate contribution by the UK towards global efforts (30). The CCC recommended that the UK's legislated five yearly carbon budgets to third budget period (2022) are based on the interim budget and the intended budget thereafter (31).

The GHG budgets developed by the CCC, and thus far adopted by the UK government, are here downscaled to Greater Manchester using a similar approach to that explained in Section 2.2. The emissions from domestic aviation and shipping, LULUCF, cement process emissions as well as non-CO_2 emissions, are removed for compatibility with the recommended carbon budgets presented in our analysis. The final UK CO_2 only budgets are then apportioned to GM using the regime of grandfathering. A comparison of legislated carbon budgets with our recommended budgets and annual reduction rates are illustrated in Table 3, Figure 4 and Figure 6.

The GM budgets, based on the CCC approach, require an 80% reduction in emissions by 2050 and 51% by 2030 which is broadly consistent with UK targets. However, it is worth noting that the CCC's 80% target does include aviation and shipping, and, as they note, if these sectors do not significantly reduce their emissions then the 80% reduction (for other sectors) will likely need to be tightened significantly. The CCC pathway (for a >56% chance of exceeding 2°C) follows an annual average reduction rate of 4.2% compared to 15% for the pathway recommended in this report (for <33% chance of exceeding 2°C). The CCC carbon budgets imply no action is required by GM until the end of third carbon budget period in 2022 assuming no further increase in emissions from 2015 levels.

Table 3: UK's legislated carbon budgets apportioned to GM level excluding LULUCF, aviation and shipping (32,33)

	Budget 1 (2008-2012)	**Budget 2 (2013-2017)**	**Budget 3 (2018-2022)**	**Budget 4 (2023-2027)**	**Budget 5 (2028-2032)**
Legislated UK GHG budgets in $MtCO_2e$	3018	2782	2544	1950	1725
UK carbon budgets excluding non-CO_2, LULUCF, cement process emissions ($MtCO_2$)	2505	2256	2030	1507	1297
UK carbon budgets (CO_2 only) apportioned to GM ($MtCO_2$)	85	72	65	49	42
Recommended carbon budgets for GM ($MtCO_2$)			36	17	8

There are a number of analytical reasons that our recommended emissions budgets are substantially smaller than those legislated by successive UK governments. Current UK budgets have an expected probability of exceeding 2°C of more than 56% (i.e. a *"likely"* chance of *exceeding* 2°C). According to the CCC the 'interim budget was premised on a 63% chance of exceeding 2°C and the 'intended' on an improved 56% chance of exceeding 2°C. However, these probabilities related to a global carbon budget range available prior to the publication of the IPCC's fifth assessment report, where the range of global carbon budgets for different temperatures was revised downwards. It is our understanding that the CCC's advice has not been substantially changed since its original conception and, consequently, the UK government's existing carbon budgets are for an even higher chance of exceeding 2°C than was originally reported (i.e. greater than a 56% and 63% chance of ***exceeding*** 2°C). By contrast, our analysis uses the IPCC's 'advice to authors' as a framework for transposing the wording of the Paris Agreement, *"…keep well below 2°C"* into a *"likely"* chance (66% to 100%) of ***not exceeding*** 2°C". This offers a much better probability of the UK delivering on its fair contribution to the Paris 2°C commitment (i.e. a smaller carbon budget) than that posited by the CCC and adopted by government (i.e. a larger carbon budget). The CCC global budgets are much larger than the budgets shown in IPCC AR5 synthesis report (34). The CCC budgets are based on global cumulative emissions of 1341 $GtCO_2$ post 2011[19] (30) compared to IPCC AR5 budget of 1010 $GtCO_2$ for a 66%-100% chance of not exceeding 2°C (4).

The CCC's scenarios assume a substantial uptake of speculative negative emission technologies (NETs), reducing the necessary levels of 'real' mitigation. Our analysis makes no allowance for NETs substituting for 'real' 2°C mitigation. It does however; suggest research and development of NETs to provide a theoretical possibility of delivering on Paris Article 2's *"...pursue efforts to limit the temperature increase to 1.5°C."*. Our analysis takes explicit account of the clear equity steer within the Paris Agreement, with its apportionment of the global 2°C budget to the UK premised on the early stabilisation and subsequent reduction in inequality in 'cumulative emissions' between citizens in wealthier and poorer nations. The CCC's budget allocation to the UK sees already high levels of inequality in individual cumulative emissions rise significantly for the coming three decades (until 2050). Put simply, our analysis apportions a much greater share of the 2°C carbon budget to the poorer nations than the CCC; this is a major factor in

[19] Based on the CCC trajectory with global emissions peaking in 2016 and subsequent reductions at 4% per annum.

explaining the difference between the CCC and our analysis. Our analysis notes how high levels of cement use, for which there are no major substitutes at scale, are essential for the development of poorer nations. Consequently, process emissions from cement are taken as a 'global overhead', rather than held solely as the responsibility of those poor nations striving to develop. This approach removes around 100GtCO_2 from the global 2°C carbon budget. The CCC approach holds poorer developing nations solely responsible for their process cement emissions, reducing significantly the fossil fuels they are able to use in progressing their development. A similar equity-based approach is taken with regards to deforestation, though the associated assumption in this analysis is that global forest restoration, reforestation and afforestation will broadly match the emissions from deforestation.

2.8 Allocating a carbon budget for the LULUCF sector

Land Use, Land Use Change and Forestry (LULUCF) consist of both emissions and removals of CO_2 from land and forests. Compared to the various energy sectors LULUCF is unusual in that it measures not just carbon releases (e.g. deforestation), but also carbon removals (e.g. carbon uptake in soils, plant growth etc). The uncertainty range for LULUCF in 2015 is estimated as $\pm$86%, whereas for fossil fuels (energy sectors) it is within the range of $\pm$5%, both with a 95% confidence interval. The LULUCF uncertainties are exacerbated by further reservations over other non-CO_2 GHGs. The main uncertainties arise both from natural variability in vegetation and soils (changes in soil carbon density), and incomplete knowledge about the extent of activities and the underlying processes affecting sinks and sources (35).

The CO_2-only emissions from LULUCF in 2015 were about 0.5% (~60 ktCO_2) of GM's total CO_2 emissions (10). The annual LULUCF emissions within the GM boundary are net positive, compared to those for England which are net negative (-5.5 MtCO_2) (2). We propose a GM regional budget for LULUCF CO_2-only emissions that is tracked separately to, but consistent with, the GM energy only five-year carbon budgets.

The carbon budgeting method for GM's LULUCF sector has been developed to ensure that across the century any early emissions from the sector will be fully compensated by later carbon sequestration. Moreover, the method has been designed to enable LULUCF emissions to reach zero by 2038, so as to align with GM's zero-emission commitment. Finally, post 2038, sequestration by LULUCF is set to compensate, at least in part, for GM's unavoidable non-CO2 greenhouse gas emissions. In brief:

1. LULUCF achieves absolute zero CO_2 emissions, on an annual basis, by 2038 consistent with the year of carbon neutrality.
2. Post 2038 the ***rate*** of LULUCF emission reductions continues to increase, reaching a maximum rate by around 2045. Thereafter the sector continues to provide a stable level of annual sequestration across the century.
3. GM's emissions from LULUCF achieves zero cumulative CO_2 emissions for the period 2018 to 2100

The above method is illustrated in Figure 7 along with five yearly carbon budgets in Figure 8. In this method the cumulative emissions from 2018 to 2038 (area A) is compensated with carbon removals from 2039 to 2100 (area B).

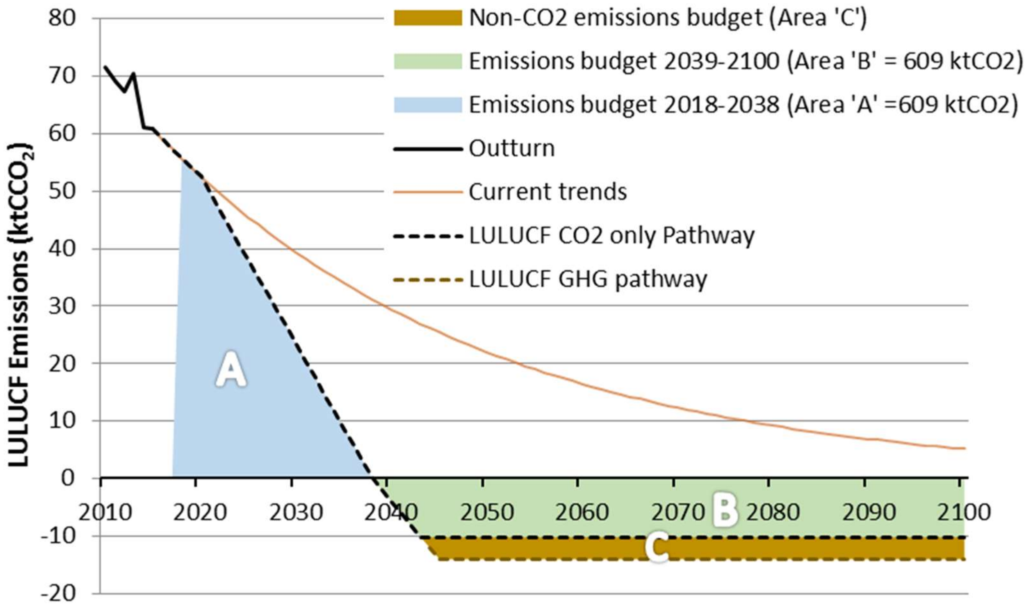

Figure 7: Cumulative emissions budget for LULUCF sector within Greater Manchester

The current trend in emissions reduction (a mean of 2.9% for 2010-2015) is also shown. An additional illustrative area C is provided for the non-CO_2 emissions which are explained in section 3. The five yearly carbon budgets for the LULUCF pathway are shown in Figure 8.

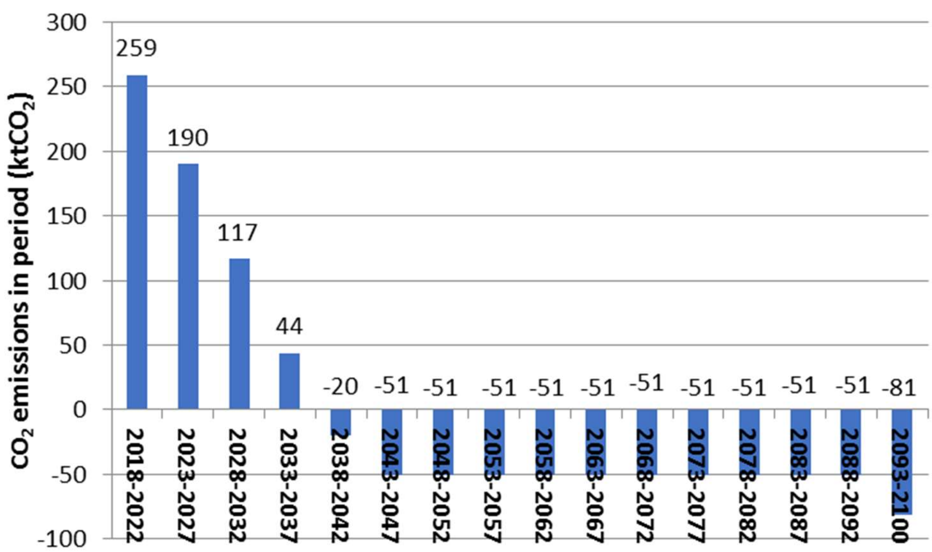

Figure 8: Five yearly carbon budgets for the LULUCF sector in Greater Manchester

3 Non-CO_2 emissions for Greater Manchester

BEIS LA emissions statistics do not provide non-CO_2 emissions data at the regional level. The accompanying GM scale emissions inventory developed by Anthesis Consulting, includes individual non-CO_2 gases at scopes 1 and 2 but not for the land use, agriculture and waste sectors (36). Although a small part of GM's economic activity, at a national level these sectors dominate non-CO_2 emissions and this therefore makes it difficult to determine the key source of non-CO_2 emissions at a GM scale. As reported in the GM scale emissions inventory, GM's total non-CO_2 emissions result mainly from fuel combustion.

An ‘emission budget’ approach is not used in this part of the analysis, as the physical or chemical properties of each GHG varies with different lifetimes causing warming in different ways. Furthermore, there are large uncertainties in non-CO_2 emissions accounting, as well as challenges in reducing annual emissions below a certain ‘emissions floor’.

Anderson and Bows (37) postulate a global non-CO_2 ‘emissions floor’ of 7.5 $GtCO_2e$ by 2050 assuming a global population of 9 billion (thereafter remaining stable) and the UK Committee on Climate Change (CCC) (30) suggests 6 $GtCO_2e$. While these studies do not reflect on how such reductions could be best achieved, Bows-Larkin et al (38) suggest it is difficult to envisage an absolute fall in non-CO_2 emissions below an ‘emissions floor’ of around 7 $GtCO_2e$ (by 2050) as a consequence of continued growth in global N_2O emissions. This increase in N_2O is linked to increased absolute fertiliser use deemed necessary to increase yields and thereby improve global food security. Maintaining such a significant emissions floor, increasingly dominated by N_2O, has implications for the rate and level of mitigation required of CO_2 and CH_4 if the Paris temperature commitments are to remain viable (38).

The landscape within the GM boundary is predominantly urban with little land used for agriculture. Therefore GM does not generate significant amounts of non-CO_2 agricultural emissions, nor those associated with specific industrial activities (e.g. adipic acid production).

Given the absence of robust non-CO_2 emissions data, we recommend the LULUCF pathway shown in Figure 7 should be adopted so as to include sequestration equivalent to area C in order to help compensate for any cumulative non-CO_2 emissions within the GM boundary. The pathway for non-CO_2 emissions is illustrative as the requisite data is not available. Once the non-CO_2 emission datasets are available quantified pathways and budgets should be developed.

4 Conclusion

Energy-only UK CO_2 emissions budgets are apportioned to Greater Manchester based on three regimes of Grandfathering, Population and GVA. Simple emission pathways corresponding to these three budgets are then derived. The pathways demonstrate that if GM is to make its 'fair' contribution to delivering on the Paris 2°C temperature commitment then it needs to begin an immediate and rapid programme of decarbonisation to remain within the necessary carbon budget range of 45 to 104 $MtCO_2$ (for the period from 2018 onwards). To give a sense of the scale of the challenge, at current (2015) CO_2 emission levels[20], GM will use its entire budget within 4 to 8 years. However, existing trends and policies have lead GM CO_2 emissions to reduce at an average rate of 7.5% per annum since 2012, halfway to the objective presented here.

To provide a smooth transition in line with the above budgets, average annual mitigation rates of CO_2 from energy need to be between 10% and 20% – beginning in 2018. Some of the annual mitigation rates for GM are slightly lower than those for the UK as a whole; this is because GM starts from lower per capita emissions (5.5 tCO_2, compared with the 7.0 tCO_2 for the UK[21]). The percentage reduction of emissions for the years 2020, 2030, 2040 and 2050 under each of the scenarios compared to 2015 are shown in Table 4. To put these reduction rates into context, GM needs to reduce its emissions by 66% in 2020 from 1990 levels compared to GM's current target of 48% reduction. The current targets are insufficient in meeting the IPCC carbon budgets or the CCC pathways as shown in Figure 4 which requires 54% reduction. Hence immediate near term action is essential and any reduction in the mitigation rate in the early years will require a significant increase in the rate in future years for the same budget to be met.

Table 4: Percentage reduction of emissions for the CO_2-only scenarios out to 2050 in relation to 2015

	GF-Pop	Pop-Pop	GVA-Pop	GF-GF	Pop-GF	GVA-GF	Recommended pathway	LULUCF
2020	39%	34%	38%	55%	48%	52%	44%	14%
2030	83%	77%	81%	95%	92%	94%	87%	62%
2040	95%	92%	94%	100%	99%	99%	96%	107%
2050	99%	97%	98%	100%	100%	100%	99%	117%

To achieve carbon neutrality in all the sectors, a separate regional LULUCF CO_2-only emissions budget of 609 $ktCO_2$ from 2018 to 2038 is provided. The LULUCF emissions should reach zero by 2038 with net sequestration thereafter to compensate the cumulative LULUCF emissions from 2018 to 2038 by the end of the century.

Turning to the non-CO_2 emissions and given the paucity of regional data from BEIS, in the GM scale emissions inventory GHGs are not split by gas for the land use, agriculture and waste sectors. For these sectors, only total CO_2e data are available. Given the absence of robust non-CO_2 emissions data, we recommend, the LULUCF pathway should further remove carbon and sequester additional cumulative emissions to compensate for any cumulative non-CO_2 emissions within the GM boundary.

[20] Based on GM's 2015 CO_2 emissions (excluding aviation, shipping, process CO_2 emissions from cement production and those from LULUCF).
[21] These values are for 2015 and exclude aviation, shipping, process CO_2 emissions from cement production and those from LULUCF.

Once the non-CO_2 emission datasets are available, quantified pathways and budgets should be developed.

In summary, we recommend GM initiate an immediate, rapid and deep reduction in its annual carbon dioxide emissions of, at the very least 10% p.a, towards carbon neutrality by 2038. At the same time GM must maintain ongoing progress in reducing its non-CO_2 emissions for several decades to come.

It is acknowledged that our recommended budget will be challenging to achieve and represents a much greater level of ambition than is embedded in current national policy. However it also represents an opportunity to demonstrate the potential for joined-up decision-making across devolved powers, and the development of political and societal will to take action that is genuinely in line with the Paris Agreement. Such a commitment, and the actions needed to achieve it, would certainly place Greater Manchester amongst the leading 'green cities' of the world.

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Appendix A: Options for Carbon Neutrality

A.1 Background

Greater Manchester's newly elected Mayor, Andy Burnham, announced his ambition to make GM one of the leading green cities in Europe by achieving 'carbon neutrality' as early as possible (39). Similarly, Manchester City Council, in its latest climate change strategy document, outlined a vision to become a 'zero carbon' city by 2050 (40). There is a proliferation of related terms in policy and research documents in the field, including *inter alia;* 'net-zero', 'climate neutrality', 'full decarbonisation', 'carbon offset', 'carbon balanced' and 'carbon compensated'. However, there are multiple definitions of these terms offered and they are, at times, used interchangeably (41). Likewise the terms greenhouse gas[22] (GHG) emissions, carbon (C) emissions and carbon dioxide (CO_2) emissions are also often used synonymously, particularly in high level and summary communications on these topics. Hence clear working definitions, alongside a clear articulation of emissions inventory boundaries, are essential in developing, evaluating and implementing pathways to achieve the goal of 'carbon neutrality' for Greater Manchester.

A.2 Terms in use

A.2.1 Zero carbon and zero emissions

These terms would indicate that there are no direct emissions of carbon dioxide (only) or GHGs respectively, from an organisation or individual's activities. This is a strict criterion to fulfil and depends upon the boundary established for reporting.

A.2.2 Carbon neutrality and net zero

Reducing carbon emissions and GHG emissions to zero will be very challenging for most economic sectors and some organisations will look to reductions beyond their direct reporting boundaries. The 2014 Emissions Gap Report by UNEP (28) uses the term 'carbon neutrality' to refer to a situation where global anthropogenic carbon dioxide emissions from energy, industry, and land use / land cover change (LULC) are quantitatively balanced to be 'net zero' by carbon dioxide removals. This approach could be extended to geographic or administrative areas which capture both emissions and removals within their boundaries. The idea of carbon neutrality has also been extended by organisations and individuals to include carbon offsetting relationships where the balance extends across organisational boundaries.

The British Standards Institute published the industry led specification PAS 2060 in 2010 and updated this in 2014. It outlines a consistent approach for a range of entities to transparently demonstrate claims to carbon neutrality. Within PAS 2060 "carbon neutral" is defined as "*a condition in which during a specified period there has been no net increase in the global emission of greenhouse gases to the atmosphere as a result of the greenhouse gas emissions associated with the subject during the same period*" (42). It identifies determination of boundaries and substantiation of the subject for which a claim of carbon neutrality is made as key steps, as well as the presentation of supporting evidence for transparency so that declarations by entities are readily available for verification of any claims. A commitment to the timescale for achieving carbon neutrality is also highlighted. When offsetting is used to achieve these claims, the entity must present a strategy outlining quantities,

[22] carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, per-fluorinated compounds and sulphur hexaflouride

sources, and type of credits to be purchased. General principles for the choice of credits are laid out, for instance that they should be additional, permanent and take account of leakage, although no specific guidance is offered as to how this is to be judged. Examples of schemes that adhere to these principles is presented in Table A-1, however, the schemes presented have received criticism for their interpretation of these norms in some cases.

A.2.3 Carbon Removal, also Carbon Dioxide Removal (CDR)

Carbon removal (also referred to as carbon dioxide removal or CDR) consists of a cluster of practices and approaches which remove and sequester CO_2 from the atmosphere. These are generally categorised as biological (also termed 'natural') and technological options examples of which are shown in Figure A-1 below (43,44). Bioenergy combined with carbon capture and storage (BECCS) combines both approaches.

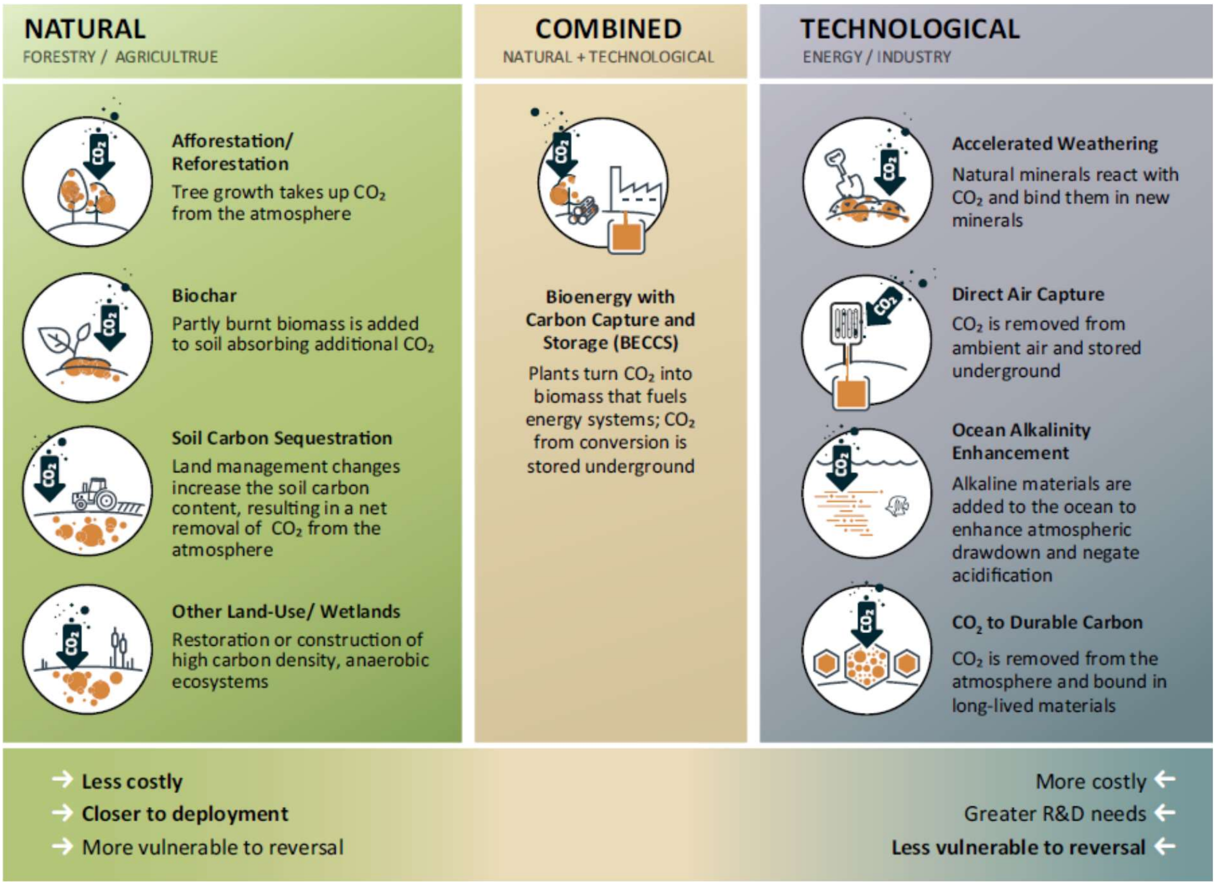

Figure A-1: Types of carbon removal and Negative Emission Technologies (NETs), from UNEP 2017 (43)

A.2.4 Net zero GHG emissions, emissions metrics and climate neutrality

Net zero GHGs takes carbon neutrality further by considering other GHG emissions that may be reported in an inventory and relating them with a "metric". Each GHG causes warming in different ways, directly by altering the atmosphere's energy balance, and indirectly by altering other chemical or physical processes, and have different atmospheric lifetimes after emission. Therefore, volumes, masses or amounts cannot simply be summed to compare to their warming effect through time. Metrics are multiplying factors that relate the warming effect of non-CO_2 GHGs to that of CO_2 to enable them to be summed on a common basis. Global Warming Potential (GWP) is the most widely used and sums a particular physical effect of GHGs, radiative forcing, through a defined time period, typically 100 years. It does not relate emissions to a temperature response or other aspects of climate change e.g. sea level rise, maximum seasonal temperature. Depending on the gas and time period in question it can over or under estimate the climate impact of a release of GHG emissions relative to CO_2. Climate neutrality is synonymous with net zero GHGs, relying on a metric to quantify an inventory of multiple GHG emissions and then balancing this with removals or reductions within a boundary or outside of it through offsetting.

A.2.5 Carbon offsetting and carbon compensation

These terms are used synonymously to denote the use of tradeable units representing emissions rights or emissions reductions outside of an organisation's or individual's reporting boundary, in place of direct emissions reductions. The diversity of units, credits, permits and allowances under different schemes, is discussed in the following section. Though all are denominated in CO_2 or CO_2 equivalent, as per the original source of emissions, the units are not material things; they are not literally "tonnes of carbon" but stand in for them. The units are created by one party and cancelled by another to represent a transfer of reduction effort. The purchase and cancellation of a unit should lead to an additional reduction in emissions, over and above what would have happened without the transfer.

A.2.6 Decarbonisation

The concept of 'decarbonisation' is generally applied only for energy and industrial processes, not other activities such as agriculture which lead to the release of other GHGs (3). It represents zero unabated carbon dioxide emissions from energy and industrial process. Unabated emissions are those that enter the atmosphere and are not subsequently sequestered (or stored) by an end-of-pipe technology e.g. amine scrubbers for carbon capture.

A.3 Options for Carbon Offsetting

As noted above, carbon offsetting is the purchase of a tradeable unit, representing emissions rights or emissions reductions, to balance the climate impact of emissions from an organisation, activity or individual. The main feature of these units is that they are denominated in CO_2 or CO_2 equivalent, as per the original source of emissions. Although they can be stored and traded like a commodity, they are not material things; they are not literally "tonnes of carbon" but stand in for them and are better regarded as intangible assets or financial instruments. To act as an offset, units must be cancelled to represent a reduction and prevent further trading.

There are two major implications of this i) it matters how the calculation and accounting systems are established and ii) even for the most robust regulated units there is not direct equivalence between original measured emissions and offsets. As such, all offset purchases are vulnerable to criticism as being unreliable and ineffective. The terms of creation, quantification and the procedures for monitoring, reporting and verification are typically set by an independent body, and vary substantially. Technical objections to carbon offsetting are based mainly on these terms. There can also be political objections as the creation of units can also coincide with a regulatory penalty and therefore represents a transfer of wealth.

Units must also be uniquely accounted for in a registry of some sort, to unequivocally identify their owner and status when cancelled. Without this record there can be deliberate fraud and accidental "double counting" whereby two organisations claim neutrality on the basis of the same project activity or units.

Examples of tradeable units and their regulatory schemes can be separated into "baseline and credit" and "cap and trade". There is also a distinction between units created on the so-called "voluntary market" where private institutions, foundations or charities regulate the production of units, and those created by national governments, regional legislatures (e.g. EU) and supranational bodies (e.g. UNFCCC).

Baseline and credit units are created by defining a boundary around a project and estimating a counterfactual time series of emissions in the absence of the project, a "business as usual" baseline. Actual emissions are then monitored and the difference between the baseline and actual is determined to be an emissions reduction. There are many decisions that determine the validity and consequence of creating and cancelling the units. The units in these schemes are referred to as credits.

Cap and trade systems set a limit on the total number of units available to the participating or regulated parties. At the end of defined periods, regulated parties must own as many units as they have produced emissions or pay a fine to the regulator. The units in these schemes are referred to as allowances. Voluntary purchase and cancellation of these units can therefore be seen as an offset; the total emissions arising from the participating parties should be lowered as the cap has effectively become tighter. However, the effect is dependent on the cap being a strict limited in the first place and the initial allocation not including "hot air".

Table A-1: Types of Carbon Offset Units

	Baseline and Credit **Units are credits**	**Cap and Trade** **Units are allowances**
Regulated system	Certified Emissions Reductions (CER) from the UNFCCC Clean Development Mechanism (CDM).	European Union Allowances (EUA) from the EU Emissions Trading Scheme (ETS).
Voluntary, independent system	Verified Emissions Reductions (VER) under the independent Verified Carbon Standard (VCS). Voluntary Emissions Reductions (VER) is a generic term for credits generated by a variety of independent, unregulated schemes.	Carbon Financial Instruments (CFI) on the now defunct Chicago Climate Exchange (CCX).

The UNFCCC's Clean Development Mechanism (CDM) is the most advanced baseline and credit scheme used for international offsetting with the largest number of projects, credits and transactions. However, it has drawn criticism in the past that many credits are not additional to "business as usual" and project certification has been lax. The system is due to close in 2020 and be replaced by a new market mechanism under the Paris Agreement, details of which are yet to be confirmed. Criticism has also been levelled at voluntary credit schemes due to their lack of transparency and rigour, and at the EU ETS for the high level of the cap relative to current emissions.

A.4 Recommendations

Given that the goal announced by the Mayor is expressed as 'carbon neutrality' (rather than say, 'zero emissions'), the approach developing the SCATTER recommended budgets and pathways for GM will be to apply the goal of neutrality to CO_2 rather than all GHGs. For CO_2 producing activities, the aim will be to reduce all emissions of carbon dioxide to zero, however, LULUCF carbon dioxide emissions that cannot be rapidly mitigated may be 'balanced' within the GMCA LULUCF inventory boundary through increased carbon removal in later periods e.g. through afforestation[23], reforestation[24] and restoration of anaerobic ecosystems (wetlands and peatlands). The year of carbon neutrality is therefore defined as 97% reduction in energy-related CO2 compared to 1990 levels.

For other GHGs all feasible options should be explored with the goal of reducing these to as low a level as possible. Whilst mitigation measures can be sought in all sectors, there are some processes from which GHGs cannot be eradicated, for example the use of natural and artificial fertilisers in agriculture, and we should identify and acknowledge these.

As noted in Figure A-1, biological carbon sequestration is vulnerable to reversal, e.g. due to trees dying or being lost to fire or development. If carbon neutrality is achieved through biological carbon removal then the impermanence of such reductions must be acknowledged and continuous records of carbon stocks and flows must be kept. Potential losses from biological carbon stocks should also be acknowledged. An early task must therefore be to identify the annual potential and ultimate extent of biological carbon removal within the GM boundary, and contingency for losses. The date determined for carbon neutrality has a bearing on the extent of residual CO_2 and potential for carbon removal due to ongoing changes in land use, ecosystems and climate.

For SCATTER, the term 'offset' will refer to the purchase and cancellation of tradeable units representing emissions reductions or sequestration outside the boundary of Greater Manchester to compensate for residual carbon emissions. All carbon offset arrangements are open to criticism as being ineffective at reducing emissions. As described above, material quantities of emissions are not exchanged and as such 'carbon neutrality' achieved this way is an accounting procedure, not a physical status. These procedures and the context under which they operate are liable to change through time, for better or worse. In light of this, we would not recommend entering into offset relationships.

If GMCA identify financial resources and the necessity to pursue this path then they should i) only consider regulated systems and purchases, ii) revisit the available tradeable units at the time of purchase to consider which are the most robust and reliable, iii) recognise that this will be a controversial approach potentially drawing criticism, and public and professional cynicism.

[23] Afforestation refers to growing forests on bare or cultivated land which has not been forested in recent history (50 years or more) (51).
[24] Reforestation refers to re-growing forests in areas where recently deforested (51).

Appendix B – Allocating Aviation Emissions to a Regional Level

Manchester Airport is the third largest in the UK by passenger traffic and aircraft movements (45) and is seen by many as a key part of growth and prosperity for Greater Manchester (GM). It is important to understand the scale emissions of the full range of activities at the airport, including the movement of aircraft, within the context GM carbon budget. Quantifying and allocating emissions should be done to verify consistency of action in this sector with the share of the UK carbon budget allocated to GM.

There are a number of categorisations of emissions associated with aviation activity. Emissions from airport buildings and ground support vehicles[25] are included within local authority level data currently available from BEIS (10). Emissions from aircraft can be separated into those produced during the landing and take-off cycle (LTO) and those emitted during the cruise phase that constitutes the majority of the distance travelled. A distinction is also made between international aviation and domestic aviation. Domestic aviation is included in current UK carbon budgets. However, whilst international aviation emissions are quantified nationally, and considered by the Committee on Climate Change (CCC) in target setting, they are formally excluded from UK carbon budgets and our Nationally Determined Contribution to the Paris Agreement.

B.1 Existing sources of aviation emissions data

The National Atmospheric Emissions Inventory (NAEI) provides emission estimates annually for the UK and all devolved administrations. These estimates are calculated by a civil aviation emissions model, the inputs of which are the number of aircraft movements (data from the UK Civil Aviation Authority (CAA)) and estimates of fuel consumption for component phases. Finally, the total estimate of fuel consumed from this model is compared with DUKES aviation bunker fuel consumption data[26] (46).

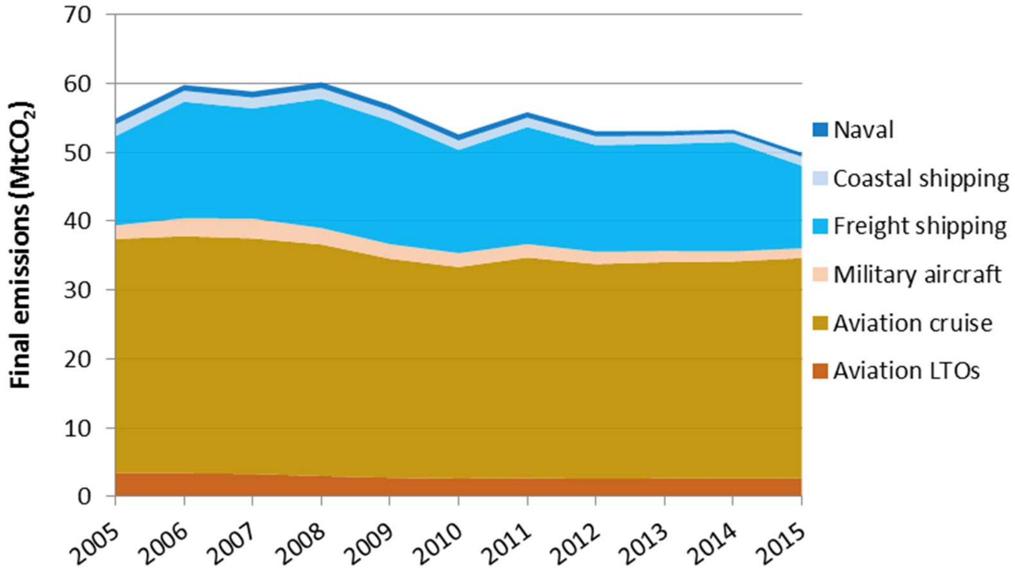

Figure B-1: Final UK carbon dioxide emissions from aviation, shipping and military transport from 2005 to 2015.

[25] Within the 'other transport' category

[26] The aviation bunker fuel (aviation spirit and turbine fuel) consumption covers domestic, international and military use. The military aviation fuel used is provided by the MOD.

CAA aircraft movement data are broken down by type, airport, domestic or international and next/last port of call from which sector length have been calculated. The EMEP-EEA Emission Inventory Guidebook (47) provides fuel consumption and emission factors (including non-GHGs (NOx, HC and CO)[27]) for number of aircraft types and modes. Each aircraft type in the CAA is then assigned to a generic type (46). LTO emissions are aircraft emissions while operating on the ground and in the air over the UK, up to an altitude of 1000m[28] and as such do not include emissions from ground support vehicles. Individual airport studies of time spent in each part of the LTO cycle are combined with emissions factors for appropriate engine thrust setting to inform the final estimate (46). The total contributions for all aircraft movements in the year are then summed to annual emissions. The cruise emissions are calculated only for aircraft departures from the UK airports and thereby allocated to departure airport, which gives the total fuel consumption compatible with recorded deliveries of aviation fuel. This is to prevent double accounting of international aviation emissions[29] (46).

B.2 Allocating emissions regionally

The different sources of emissions from aviation can be combined and allocated on a hybrid producer-consumer basis (29). LTO emissions (5) are allocated to regional airports in proportion to the total number of air transport movements[30] (13). Cruise phase emissions are then estimated using a top down approach allocating emissions to regions according to the origin of passengers recorded in the CAA Passenger Survey. For example if two passengers (Alice and Bob) were on the same flight from Manchester to Heathrow, but Alice lived in Preston and Bob lived in Oldham, only Bob's cruise emissions would be allocated to GM whilst the whole of the aircraft's landing cycle would be allocated to Manchester. For context, about 8% of UK air transport movements are through Manchester Airport, and of the passengers surveyed in 2015, 31% were from GM region.
In current national and international climate policy a distinction is also made between domestic and international journeys. An alternative consumer only apportionment, based on the residence of passengers taking flights can also be considered.

Four options, incorporating these different classifications, are therefore:

1. Hybrid domestic aviation emissions - The UK LTO and cruise emissions from domestic flights (5) are attributed to the GM region
2. Domestic flights plus all LTO emissions - All LTO emissions from international and domestic aviation are attributed to the GM region using the percentage of UK air transport movements that occur at Manchester Airport (1). Cruise phase emissions from domestic flights (5) are allocated in proportion to terminating passengers from the GM region.
3. Full hybrid approach - All LTO emissions from international and domestic aviation are attributed to the GM region using the percentage of UK air transport movements that occur at

[27] Methane emissions are negligible in the cruise mode.
[28] The various modes of operation under LTO cycle are Taxi-out, Hold, Take-off Roll (start of roll to wheels-off), Initial-climb (wheels-off to 450 m altitude), Climb-out (450 m to 1000 m altitude), Approach (from 1000 m altitude), Landing-roll, Taxi-in, Auxiliary Power Unit (APU) use after arrival and APU use prior to departure.
[29] Flights between the UK and overseas territories are classified as domestic. International flights with an intermediate stop within the UK are considered international in the CAA aircraft movement data. They are classified as having a domestic leg and an international leg by NAEI.
[30] Air transport movements are landings or take-offs of aircraft engaged on the transport of passengers, cargo or mail on commercial terms

Manchester Airport (1). Cruise phase emissions from domestic and international flights (5) are allocated in proportion to terminating passengers from the GM region.

4. Consumer approximation – the full CAA Passenger Survey dataset provides an indication of the number of journeys made by GM residents from all airports around the UK, based on passenger residence by postcode, not only Manchester Airport. The aggregate NAEI emissions data can then be allocated on the assumption that the mean emissions of a journey made by a GM resident are the same as the national average. Data have been supplied by Manchester Airport Group but because of their commercial source have not been validated by the Tyndall Centre or Anthesis.

A breakdown of emissions between sources, for each option, is presented in Figure B-2.

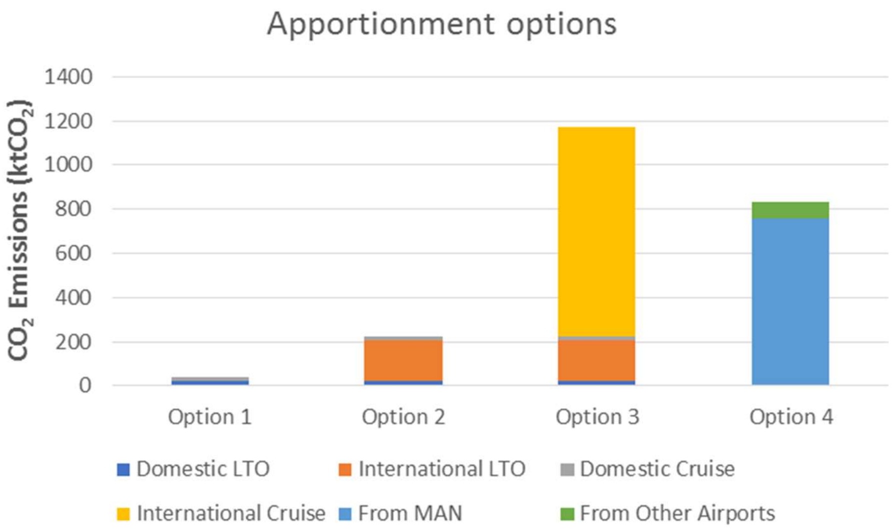

Figure B.2: Comparison of options for aviation accounting based on 2015 NAEI and CAA data.

Emissions allocated with Option 1 are of a similar scale to "Transport Other" emissions for Manchester in 2015; 36.5 $ktCO_2$ from a GM total 66.5 $ktCO_2$, although other sources included in this category are not further disaggregated. This option doesn't account for emissions from Manchester residents who fly to domestic destinations out of other UK airports. As a small number of airports (Blackpool, Liverpool, Leeds and Doncaster) are likely to represent the bulk of alternative departures this could be corrected with additional analysis of the same datasets. This calculation also assumes that the proportion of passengers originating inside GM is the same for those flying to domestic destinations as for international destinations; this should be validated empirically with further surveys. However, whilst option 1 is the most robust of those presented, more than 90% of UK aviation emissions are associated with international rather than domestic travel.

Option 2 includes LTO emissions of all flights allocated to Greater Manchester on the basis of the Airport's ability to influence this source with changes to operational practice (48). This approach doesn't distinguish between freight and passenger flights although freight emissions are comparatively small accounting for 2.8% of total UK aviation emissions (cruise and LTO) in 2005 (29). Similarly, a small portion of Manchester Airport's activity is associated with freight movements. The recent trends in freight suggest that an increasing proportion of freight tonnage is carried in the hold of passenger aircraft (78%) and that freight aircraft size is increasing together leading to a decline in total freight air transport movements (22).

However, the main weakness of this approach is that any reduction in GM emissions due to technical or operational improvements at Manchester Airport, over and above the UK sector as a whole, would not be visible in the regional carbon accounts in its present structure. It is anticipated that the battery technology development can influence in the ground operations such as electrification of ground handling vehicles (49) and potential hybrid-electric propulsion aircrafts may reduce LTO emissions in the future (50). Further detail would be required from the NAEI model to reveal this.

Option 3 uses the same data sets as Option 2 but allocates all cruise emissions on the basis of the publically available CAA passenger survey data. This means that approximately one third of emissions from flights out of Manchester airport are allocated to GM. To be effective this method would require a model of cruise phase emissions related to aircraft type and destination. The simple top-down approach doesn't capture the specific detail of flights (short haul/long haul) to or from Manchester Airport. Cruise phase emissions are assumed in this case to be uniformly distributed, which while tolerable for domestic flights could be significant for the international cruise phase. Publicly available CAA data shows Manchester to have more international flights from outside the EU relative to Liverpool where the majority of flights are within the EU. Similarly, this method doesn't capture flights to international destinations taken by GM residents out of other airports. Of the North West residents in the 2016 CAA passenger survey, 76% were recorded at Manchester Airport, however, this was not an exhaustive study of all UK airports. This weakness could be remedied with access to more detailed CAA survey data and further analysis but this would require substantial resources.

Option 4 arises from discussions between Manchester Airports Group (MAG), Manchester Metropolitan University, Anthesis and Tyndall Manchester. MAG has access to the full CAA survey dataset and this has enabled them to produce more representative estimates of aviation emissions associated with residents of GM than outlined above by distributing total UK aviation emissions according to residency of passengers identified in the survey. This data would be available on a commercial basis from CAA and is a promising option for tracking aviation emissions through time. However, we note that there still remain some weaknesses with the approach in the context of SCATTER deployment. This method assumes that all passenger journeys have equivalent emissions, at the UK national average. This could be substantially inaccurate for airports with a greater or lesser share of long-haul flights or city-regions with a greater or lesser consumption of long-haul flights. This could be ameliorated to some extent by adopting a domestic-international division as per Options 1-3. Similarly, freight is allocated evenly amongst passengers but this has the potential to cause misrepresentation in only a few limited cases (e.g. East Midlands Airport). Given that we propose to use this metric to monitor consistency with a broader set of assumptions, rather than inventory reporting, these limitations are acceptable.

B.3 Conclusion

Carbon emissions from aviation can be allocated to the residents of city-regions using the CAA Passenger Survey, NAEI and BEIS DUKES bunker fuel datasets in a number of ways. A simple consumer approximation, based on the full CAA Passenger Survey dataset, is a transparent and straightforward process that will allow a city-region to track broad trends in aviation emissions. Although we propose that this source of emissions is not included in city-region inventories, for reasons of accuracy and influence, it is important that they are tracked to maintain consistency with the top level assumptions in the budget downscaling method.

Revision 1

Paragraph 1 of Section A4 carried the original text as below. This was revised on 21/12/18 to clarify the temporal distinction related to LULUCF CO_2 emissions.

Given that the goal announced by the Mayor is expressed as 'carbon neutrality' (rather than say, 'zero emissions'), the approach developing the SCATTER recommended budgets and pathways for GM will be to apply the goal of neutrality to CO_2 rather than all GHGs. For CO_2 producing activities, the aim will be to reduce all emissions of carbon dioxide to zero, however, should there be any remaining residual carbon dioxide emissions that cannot be mitigated they may be 'balanced' within the GMCA inventory boundary through increased carbon removal e.g. through afforestation[1], reforestation[2] and restoration of anaerobic ecosystems (wetlands and peatlands). The year of carbon neutrality is therefore defined as 97% reduction compared to 1990 levels.

[1] Afforestation refers to growing forests on bare or cultivated land which has not been forested in recent history (50 years or more) (51).
[2] Reforestation refers to re-growing forests in areas where recently deforested (51).