Reducing air pollution, congestion and CO_2 emissions from transport across Cambridgeshire

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2019 POLICY CHALLENGES COLLABORATION
Cambridgeshire County Council and
Cambridge University Science and Policy Exchange (CUSPE)

The Policy Challenges are a collaboration between CUSPE, the Cambridge University Science and Policy Exchange society, and Cambridgeshire County Council. It offers a unique opportunity for volunteer early-career researchers at the University of Cambridge to use their analytical skills to benefit the local community and engage with the practicalities of the evidence/policy interface.

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EXECUTIVE SUMMARY

Air pollution was linked to 64,000 deaths in the UK in 2015. In Cambridgeshire, air pollution from transport is at levels deemed unsafe by the government. Transport also produces 45% of carbon emissions in Cambridgeshire. In July 2019, the hottest day in UK history was recorded in the botanical gardens of Cambridge. The number of these extreme events is set to increase due to climate change, caused by increasing levels of greenhouse gas emissions.

This report aims to identify the policies with the highest capacity to reduce greenhouse gas emissions from transport, improve air quality and reduce congestion within Cambridgeshire. We estimate the baseline emissions likely to be produced between now and 2050 with no further local policy intervention in Cambridgeshire. Using case studies from cities around the world, we model the effect of various policies in Cambridgeshire. We combine these results to develop three possible scenarios to reduce emissions.

KEY FINDINGS

Success stories from cities in the UK and abroad have shown that: (1) local policy can stimulate the uptake of new technologies to combat air pollution and emissions; (2) modal shift away from cars reduces congestion, air pollution and emissions; and (3) Clean Air Zones and charging schemes stimulate fleet renewal, uptake of electric vehicles, combat congestion and improve air quality.

Informed by case studies, our modeling shows:

- In the baseline scenario, emissions remain at unsustainable levels by 2050.
- Acting quickly results in larger emissions savings.
- Policies that shift travel away from cars to walking, cycling and public transport yield emissions savings more quickly than vehicle electrification.
- Buses have a larger benefit when they are ‘green’ and busy.
- Air quality improves as diesel vehicles become less popular. This can be accelerated by promoting hybrid and electric vehicles.

CONCLUSIONS

Enacting ambitious policies can have a significant impact on emissions in Cambridgeshire. The earlier these are implemented, the higher the emissions savings. **We recommend two targets.** Firstly, a **minimum goal** that **60% of travel in 2030 (currently at 40% in 2019) ought to be on buses, cycling and walking**. This target includes an upgrade to the bus fleet, and is similar to targets that have been adopted by Manchester and London. To limit emissions from remaining passenger cars we recommend a second target that **at least 60% of new car sales in 2030 must be electric**. This can be stimulated at a local policy level by providing incentives for electric vehicle owners, similar to Dundee and Amsterdam. **If both of these targets were met, annual CO_2 emissions in 2050 would be 62% less than 2019 levels.** Further action would still be necessary to reduce emissions to levels in line with the Council's declaration of a climate emergency.

In order to meet these targets, policies need to prioritize sustainable modes of travel over private cars. These targets reduce emissions, congestion and air pollution, with positive effects on public health, the natural environment, and the climate.

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1. Introduction

1.1. Background

The Greater Cambridge Partnership (GCP) has proposed numerous policies to improve public transport, increase cycling and support the uptake of low emission vehicles. Many of these policies have been considered in past work by the GCP and local authorities in the LTP3,[1] Clean Air Zone Reports,[2] Air Quality Action Plan,[3] and Strategic Bus Review.[4]

This project aims to identify the policies with the highest capacity to reduce the dependence upon private vehicle use, promote technological improvements, improve air quality and reduce the emissions of CO_2.

1.2. Motivation

The Committee for Climate Change's (CCC) most recent report published in May 2019 recommends an ambitious target of carbon neutrality by 2050.[5] In line with this report, MPs declared a national environment and climate emergency.[6] Many local authorities across the UK, including Cambridge City Council, have followed suit and declared a climate emergency following the CCCs findings.[7] In July 2019, the hottest day in UK's history was recorded at 38.7°C, a recording that was made in the Botanical Gardens of Cambridge.[8] In Cambridgeshire, GHG emissions from transport amounted to 32% of all emissions in 2005, rising to 45% in 2017, while per capita transport emissions for all districts remain above the national average.[9] Clear and well-designed policies tackling climate change are necessary to meet these targets.

Air pollution has been classified as the biggest environmental risk to public health in Europe, and is particularly threatening to infants, children and the elderly[10]. According to the European Environmental Agency, 90% of city dwellers in the EU are exposed to concentrations of pollutants harmful to health. The Central Government mandates targets for air pollution that align with the National Air Quality Objectives (NAQO).[11] These require nitrogen oxides (NO_x) and particulate matter (PM_{10}) concentrations to remain below 40 µg/m^3. NO_x emissions can be toxic and penetrate deep into the lungs, increasing the risk of premature death.[12] Although PM_{10} concentrations within Cambridgeshire are below the national limits, NO_x emissions still do not meet the standards in many areas throughout the county, such as Long Road and Parker Street in Cambridge. With a projected 24% increase in population by 2035 in the county[13], measures must be put in place to ensure improvements in air quality.

[1] Cambridgeshire Local Transport Plan 2011-2031
[2] Cambridge Clean Air Zone feasibility study (2018)
[3] Cambridge City Council Air Quality Action Plan 2018 - 2023 (2018)
[4] Systra, CPCA Strategic Bus Review (2019)
[5] The Committee for Climate Change, "*Net Zero: the UK's contribution to stopping global warming*" (2019)
[6] https://www.bbc.com/news/uk-politics-48126677 Accessed: 08/08/2019
[7] https://www.cambridge.gov.uk/news/2019/02/22/cambridge-city-council-declares-climate-emergency Accessed: 08/08/2019
[8] https://www.theguardian.com/uk-news/2019/jul/29/met-office-confirms-new-uk-record-temperature-of-387c Accessed: 08/08/2019
[9] National Statistics, UK local authority and regional carbon dioxide emissions national statistics: 2005 to 2017
[10] https://www.eea.europa.eu/themes/air/air-quality-index Accessed: 05/08/2019
[11] https://uk-air.defra.gov.uk/air-pollution/uk-eu-limits Accessed: 08/08/2019
[12] http://www.icopal-noxite.co.uk/nox-problem/nox-pollution.aspx Accessed: 08/08/2019
[13] https://cambridgeshireinsight.org.uk/ Accessed: 08/08/2019

1.3. Report outline

- **Section 2** describes the model developed to predict CO_2 emissions and air quality in Cambridgeshire up to 2050. This includes the current emissions data and expected growth, as well as impacts of implemented policies.
- **Section 3** details the policies being considered by the GCP, such as clean air zones and congestion charging. We present case studies where these policies have been successful in cities around the UK and abroad. Guided by the case studies, these policies are integrated into the model to project emissions in Cambridgeshire to 2050.
- **Section 4** combines the effects of multiple policies and outlines three ambitious scenarios to save emissions.
- **Section 5** presents further policy ideas that are not yet under consideration by the GCP. These could shed light on new ways to tackle transport challenges that are in line with the GCP's principles and goals.
- **Section 6** concludes with an overall summary of our findings and some recommendations.

2. Projection of emissions and air quality

CO_2 and air pollutant emissions are modelled to provide a quantitative assessment of technology trends and the potential savings from policy options. In order to assess the impact of future developments in technology and policy on emissions, a baseline emissions trajectory is developed. This estimates the annual emissions to 2050 that would be produced under a business-as-usual scenario with limited local policy intervention. This baseline therefore includes population growth and expected technical efficiency improvements that would occur without further stimulus from local government. More ambitious policy intervention, guided by case studies of cities around the world, can then be quantitatively compared to this baseline trajectory. The model methodology and baseline assumptions are detailed in Appendix A.

2.1 Baseline CO_2 emissions

The figure below shows the baseline CO_2 emissions between 2011 and 2050 split by local authority (A) and vehicle source (B). Urban districts such as Cambridge have lower per capita emissions than more rural districts such as Huntingdonshire. This is due to a higher share of cycling and public transport trips, and a lower reliance on individual passenger vehicles. For example, the number of registered vehicles per capita in Cambridge is 0.3 compared with 0.58 in Huntingdonshire and South Cambridgeshire.

The majority of CO_2 emissions in the Cambridgeshire region are produced by passenger cars. This continues to be the case in 2050, even with an electrification of the vehicle fleet in later years. Emissions from both light and heavy duty goods vehicles remain relatively constant, technical improvements in internal combustion engines are offset by the need to service a growing population.

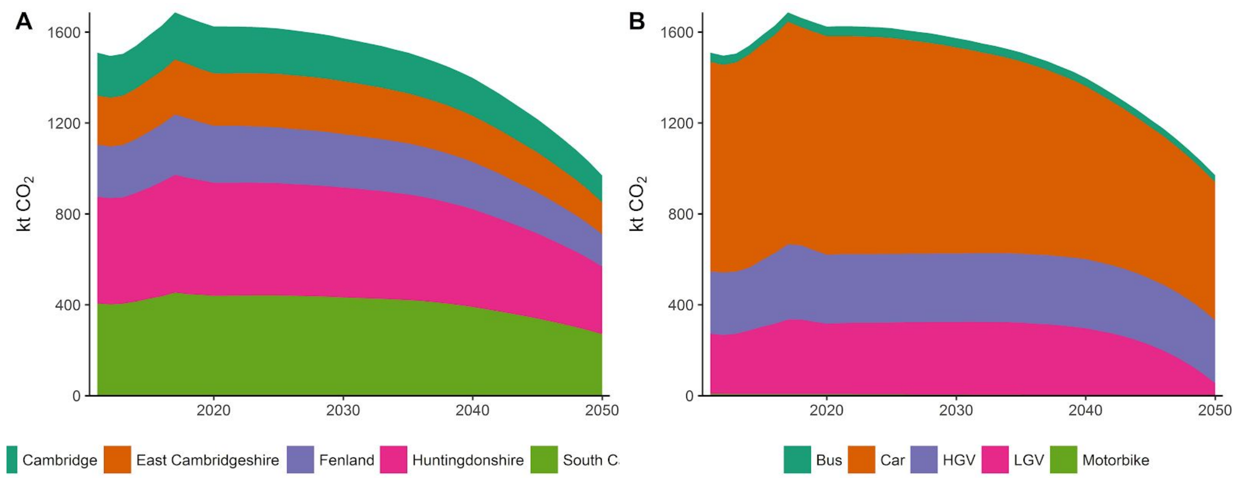

Figure 1. Annual emissions from transport in Cambridgeshire by (A) local authority and (B) source

2.2 Baseline air quality

The air pollutant emissions of new cars in the EU has been regulated by the European commission since 1992.[14] Every year, new vehicles need to undergo tests to ensure their emissions remain

[14] EU and European Commission, Regulation (EC) No. 443/2009 of the European Parliament and of the Council of 23 April 2009 "*Setting Emission Performance Standards for New Passenger Cars as Part of the Community's Integrated Approach to Reduce CO2 Emissions from Light-duty Vehicles*", Official Journal of the European Union, pp. 1-15, 2009

within legal limits. These limits have progressively become more stringent moving from the original 'Euro I' standards to the latest 'Euro VI' which have been effective since 2015. Unfortunately, the air pollution emissions from vehicles in real world driving has been found to differ considerably from the laboratory test conditions used for vehicle 'type-approval' (testing).

The emissions factors used in this report reflect the latest data on real world emissions of vehicles from remote sensing data[15]. The share of vehicles from each Euro emissions class is determined from MOT test data[16] for Cambridgeshire. Using this data, **we estimate that the average car in Cambridgeshire in 2019 produces 0.67 gNO_x/km**. This is similar to the legally required limit for Euro II diesel vehicles which were discontinued from 1996.

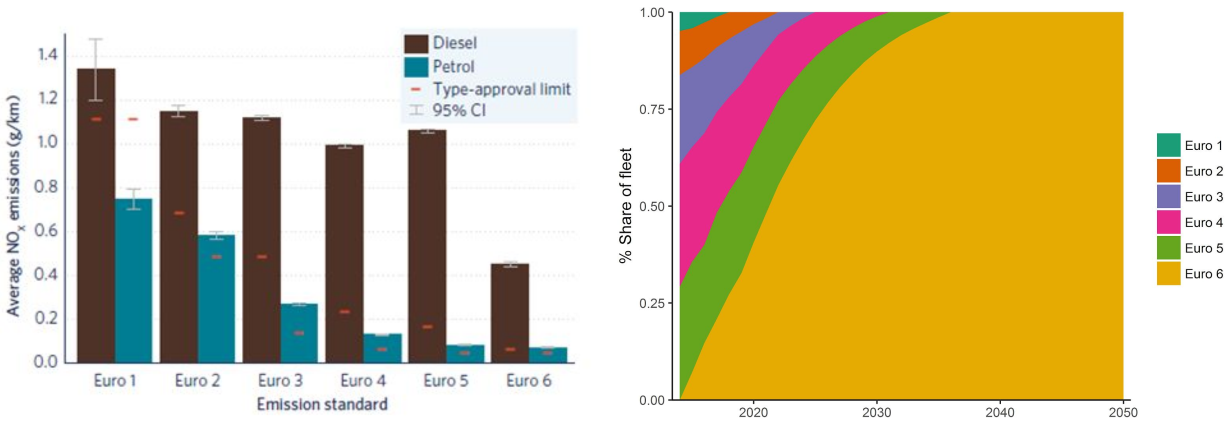

Figure 2. Average NO_x emissions factors (g/km) by Euro standard (left) from *Bernard et al. (2018)*[14] and the % share of the Cambridgeshire car fleet by Euro standard 2016-2050 (right).

As vehicles age and are removed from the fleet, the average air pollution levels of vehicles will slowly improve. However, **in our baseline scenario we estimate the average vehicle will still emit 0.45 gNO_x/km in 2030** which is still well above Euro IV legal levels (Euro IV vehicles were discontinued in 2005). **Short term action is urgently needed to promote modes of transport that do not produce emissions such as cycling and walking. In the medium term, efforts can help to stimulate the uptake of electric vehicles that do not produce tailpipe emissions.**

For buses, remote sensing data from Muncrief et al.[17] for buses in London is used to estimate real world emissions of Euro IV-VI standard vehicles. Estimates of the share of buses from each Euro standard in Cambridgeshire is not publicly available; CAZ report appendices[18] suggest there are no Euro III buses in circulation. However, in Stagecoach East's annual report the company suggests "*92% of our vehicles meet Euro* III *standards*" suggesting at least 8% don't. Using the CAZ report data **we estimate the average bus in Cambridgeshire produces 5.07 gNO_x/km** under real world driving conditions. **This is above the Euro III limit for buses** set by the European Commission.

Real world data shows that Euro IV and V vehicles produce 4 times more NO_x emissions than Euro VI vehicles. Short term, these older vehicles should be replaced with cleaner hybrid and battery electric vehicles.

Throughout this report we compare policies in terms of cumulative emissions rather than the effect they would have on annual emissions in 2050. This is a difficult concept, but is the

[15] Left hand figure from Bernard, "*Determination of real-world emissions from passenger vehicles using remote sensing data*", ICTT (2018)
[16] DVLA Anonymised MOT test data 2005-2017.
[17] From TRUE bus data: https://www.trueinitiative.org/media/597544/true-london-bus-fact-sheet.pdf
[18] Cambridge Clean Air Zone feasibility study (2018)

best basis for comparing the merits of different policies to one another. This accounts for the fact that some policies can be enacted now, and can therefore save emissions immediately, while others are dependent on future technology trends. Cumulative emissions show you the effect policies will have over time.

3. Key policies under consideration

This chapter focuses on the four key policies under consideration by the GCP: technological improvements, modal shift, clean air zones, and demand management levers. The following policies have been identified from the GCP 2019 Choices for Better Journeys[19] survey, as well as the Council's local transport plan.[20] Each policy is investigated in two ways: (1) Case studies that identify the successful implementation of these policies in other cities. (2) Model analysis to identify the potential benefits of implementing the policy in full in Cambridgeshire.

3.1 Promoting modal shift and behavioural change

The most efficient way to improve congestion, air quality, and pollution is to encourage a move away from the private car towards more sustainable modes of travel such as public transport, cycling and walking (referred to as modal shift). More than 50% of trips made by car in Cambridgeshire are less than 5 miles.[21] These are journeys that can be easily shifted to public transport or cycling. Policies from local authorities are necessary to encourage this behavioral change by making sustainable modes of transport the natural choice for all.

Case studies

London[22]

The latest London Mayor's transport strategy sets an ambition for 80% of all travel to be made by foot, bicycle or using public transport by 2041. The aim is to have: no pollution from buses by 2037, no pollution from all new road vehicles by 2040, and no pollution from London's transport system by 2050.

In London, when distances are too far for walking or cycling, public transport is more efficient than a car. Therefore, it is important to design stations, stops and streets to facilitate these modes over a private car. Technology and signs will play a vital role in making planning a journey easier. Bus experiences will be improved for the disabled through driver training, and an increase in wheelchair spaces on board. Additionally, more stations will be made step-free, and accessible thereby eliminating steps between the platform and the street. Money will be spent on expanding already existing trains to reduce crowding. The city will be designed with a priority for people to have: public spaces, cycle parking and storage, places for walking and cycling, and user friendly public transport. Action Plans to support the strategy include:

- **Walking action plan:** To make walking part of all of one's journey; thereby making London the world's most walkable city. The target is to increase the number of daily walking trips by more than a million by 2024.
- **Vision Zero action plan:** To make streets safe for walking and cycling. The aim is to eliminate all deaths and serious injuries on London's transport system.

[19] https://www.greatercambridge.org.uk/cityaccess/choices-for-better-journeys/ Accessed: 08/08/2019
[20] Cambridgeshire Local Transport Plan 2011-2031
[21] Leigh, "*Response to the Strategic Outline Business Case for the Cambridgeshire Autonomous Metro*", Smarter Cambridge Transport (2019)
[22] Mayor's Transport Strategy (2018)

- **Cycling action plan:** To make cycling part of the Londoner's everyday travel. The aim is to make cycling in London an accessible and inclusive way of getting around.

Leicester[23]

Leicester has a dense population of 520000, with an expected growth of 25% in the demand for housing by 2026. The compact road system shares the same challenges of congestion, noise and air pollution that are present in many other urban areas. There is an integrated website for journey planning using different modes of transport. The area has a fair amount of bus routes around the city centre, which means it is possible to travel between two non-central regions without having to go through the city centre first. This helps cut down on journey time and prices.

- Bus transport is being improved through the building of dedicated bus corridors, bus lanes, improvement of junctions and a new bus station.
- Creation of a safer route for pedestrians and cyclists, through off-road cycling paths and narrower roads reducing traffic.
- Flexible weekly and period fares for unlimited travel across all operators, making bus travel easier and more affordable. Topping up can be done on most buses and on more than 200 outlets located across Leicestershire.
- Park & Ride users also benefit from reduced bus fares (£4 for up to five people), and further discounts for frequent users.
- The council offers free cycling training courses for adults and schools. One-off small grants are also available to fund projects that will support and encourage more people to cycle.

Manchester[24]

"Greater Manchester (GM) has a vision for 2040 of world-class connections that support long-term, sustainable economic growth and access to opportunity for all." **By 2040 it aims to have 50% of all journeys made on foot, by bike or public transport.** This means one million more journeys need to be made sustainably. Currently 39% of journeys within the region are made through sustainable modes, while 61% are by car. The Bus Services Act of 2017 gave Mayoral authorities like GM powers to improve and reform the bus market by bus franchising. The local authority also has plans for:

- Improving cycle lanes, and building 1000 miles of new bike routes. This network will benefit 2.7 million people, connecting every community in Greater Manchester and offering an alternative to individual cars.
- Improving the walking network by having more high-quality footpaths and improving road crossings.
- Working with businesses to promote cycle to work schemes.
- Promoting and supporting bike rental, car share, and car club schemes.
- Giving advice and support to businesses to upgrade their vehicle fleet and encourage greener staff travel.

Oxford[25]

Oxford City Council offers free cycling training for children, and bike pumps are available for public use in the city. The Council website promotes cycling as a health benefit, as well as the most effective mode of travel for short journeys of 2 - 5 miles. Cycle hire is available through three main providers of dockless bikes. A map of council-managed cycle racks is available online, which makes

[23] https://www.leicester.gov.uk/your-council/city-mayor-peter-soulsby/my-vision/connecting-leicester/ Accessed: 10/08/2019
[24] Greater Manchester Transport Strategy 2040, Draft Delivery Plan 2020-2025 (2019)
[25] https://www.oxfordshire.gov.uk/residents/roads-and-transport/connecting-oxfordshire Accessed: 10/08/2019

it easier to plan journeys by bike in the city. There are improved bike parking facilities and shelters at two P&R locations, which are promoted as a way to keep fit while reducing one's carbon emissions.

The council supports the development of not-for-profit community transport groups, through small start-up grants and training. Community minibuses and voluntary car schemes help make the public transport network more accessible, linking local villages with other transport hubs. The city has a Dedicated Active and Healthy Travel Steering Group, and is presently undertaking a consultation on active travel.

Nottingham[26,27,28,29,30,31]

Nottingham City Council aims to be carbon neutral by 2028, having already met their 26% reduction in CO_2 emissions target for 2020, and are on track to achieve a 20% low-carbon energy generation by then.

In Nottingham, cycling has increased 43% since 2010. This can be attributed to continuous improvements in cycling infrastructure, including:

- Segregated cycling lanes
- Secure and free cycling parking facilities across the city
- Free cycling tours
- Free "Dr Bike" check-ups
- Community cycling centres and other regular events.

Segregated bike lanes in particular were an important factor that made people feel safer when cycling, according to a consultation conducted in 2017. The city council also offers a cyclist awareness course, aimed at taxi, bus and lorry drivers. The course, which is funded by the Department for Transport (DfT), has been well received, improved the perception of cyclists by professional drivers, and has encouraged them to cycle more when not at work.

Nottingham City Council offers online local travel guides by bus and by tram, encouraging visitors and locals alike to explore the city by public transport. **The city has the largest fleet of double-deck biogas buses in the world. This biogas is methane produced from food and farm waste which are cleaner and emit 84% less CO_2 in comparison with diesel V buses.** With the arrival of these biogas buses, Nottingham has been able to remove the oldest buses in their fleet, and by the end of 2019 there will be no bus on the road that was built prior to 2010. The council reports that there are no electric buses available that do the mileage required on a single charge, and that, considered across its lifetime, the bio-gas bus emissions are lower. There is integrated ticketing in place, with season, pay-as-you-go and concessionary options, as well as student discounts. The biggest bus operator in the city is locally owned, which helps ensure that local interests are met. **Segregated bus lanes, bus-only routes and traffic light priority help ensure that buses are reliable.** Projects are being implemented to ensure a range of "*Bus Rapid Transit*" features are in place, such as the creation of expressways, full inbound bus priority in the city, and outbound priority on key locations.

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[26] https://www.intelligenttransport.com/transport-news/75379/nottingham-carbon-neutral-transport/ Accessed: 10/08/2019
[27] https://www.transportnottingham.com/professional-drivers-pedal-a-mile-in-someone-elses-shoes/ Accessed: 10/08/2019
[28] https://www.transportnottingham.com/ten-reasons-why-buses-in-nottingham-are-the-best/ Accessed: 10/08/2019
[29] https://www.transportnottingham.com/charlotte-perkins-living-life-on-the-bus/ Accessed: 10/08/2019
[30] https://www.transportnottingham.com/david-thompson-bus-hiking/ Accessed: 10/08/2019
[31] https://www.transportnottingham.com/explore-the-city-by-tram/ Accessed: 10/08/2019

Trams are also an important feature of Nottingham's transport network. With over 32 km of track, each tram can carry as many passengers as 170 cars. **Two-thirds of the largest employers in the city are within 800 metres of a tram stop.** The tram also connects key destinations such as the city centre, universities and medical centres. An integrated network of trams and buses is in place, and period tickets are valid on all modes.

Nottingham actively promotes and encourages the use of their public transport network. A quote from the Council's website: "*Nottingham's extensive bus network is so brilliant that you do not need to stress about driving into the city and finding parking. In fact, **you may no longer need a car at all** – especially when travelling into the city centre!*". The council pitches the reliability of the bus network through case studies, and provide local travel guides by bus and by tram.

Amsterdam[32,33]

Amsterdam is aiming to increase the uptake of public transport by providing multiple choices. New metro routes and tram lines are being built to improve connectivity and reliability within the city while improving traffic flow. Improving accessibility at all stations will provide further choices for groups with disabilities.

Over time, journeys in Amsterdam have shifted from short, local trips to longer commuter journeys that include rail traffic. The public transport system has not kept up with these changes, the tram network is both too slow and too costly for longer journeys. Growth is inevitable in the city, with 5,000 new homes being built annually until 2025, meaning the issues with public transport will only get worse. Currently, there is heavy congestion throughout the city centre, with 40 - 60% of that traffic being through traffic. **Measures are being put in place to improve traffic flow, relocate heavy traffic to the outskirts of the city and reduce through traffic which will also help improve air quality.** As Amsterdam grows, accessibility remains of the utmost importance. It is not enough to combat traffic, but choices need to be given to people to shift away from the private car. **Soon people will no longer be able to claim individual parking spots. The role of cars is changing in the city, as they are no longer meant to be owned, but rather used collectively.**

To achieve this shift from the private car and combat congestion people going into the city centre will be provided with choices beyond driving their cars. First, a speed limit of 30 km/h in many areas will be enforced. On important routes traffic flow will be improved in and out of the city centre and will be controlled through measures such as:

- building better cycle routes, cycle crossings, and high-quality pedestrian areas.
- linking the city through completely connected cycle routes and improved public transport connections.
- ensuring fast, efficient routes in and out of the city for cars, building more P+R facilities on the outskirts of the city.

In an attempt to combat traffic and air pollution, Amsterdam is thinking out of the box. Rather than installing charges or clean air zones, the city has taken the two worst areas for air quality and temporarily removed parking spaces, adjusted the timings on traffic lights, and reduced the chances to turn off at intersections. If these types of interventions are successful at encouraging people to shift away from driving their cars, policies like this will be rolled out across the city.

32 https://www.amsterdam.nl/en/policy/policy-traffic/ Accessed: 08/08/2019
33 https://www.amsterdam.nl/en/policy/policy-traffic/public-transport/ Accessed: 08/08/2019

Known as the most bicycle-friendly city in the world, and with over one million bikes circling the streets, the city is investing in new cycle paths and parking.[34] Amsterdam is the most iconic example of a cycling city, where cycling is the city's fastest-growing mode of transport. Certain parts of Amsterdam's city centre congestion has reached a point where it is impossible to accommodate cyclists, drivers and pedestrians at the same time. In these situations which mode of transport will be given priority?

The city has chosen to prioritise cyclists by improving their experiences on the road. Bicycle traffic flow will be optimized through an overhaul of the existing cycle paths to make them wider, smoother, faster, and more easily recognizable. These new cycle paths will include new cycle routes, interconnectivity, and further room on popular routes to encourage cycling uptake. Amsterdam is also introducing new cycle parking regulations by cracking down on illegal parking and encouraging better cycling habits. Providing more parking will also prevent blocking of pavements and entrances to shops thereby improving walking for pedestrians. The goal is to improve bicycle parking satisfaction scores which are collected via surveys regularly.

Major projects are underway and aim to provide cyclists with more space through: expanding cycle parking at stations, more cycle bridges and ferry lines, connecting new residential areas, and a new cycling route in Amsterdam's inner ring, where trams and cycles will take priority over cars. This prioritization will be accomplished by prohibiting through traffic, and lowering the car speed limit to 30 km/h.

The infographic below summarizes the key policies involved in promoting modal shift and behavioral change, as identified from the case studies above.

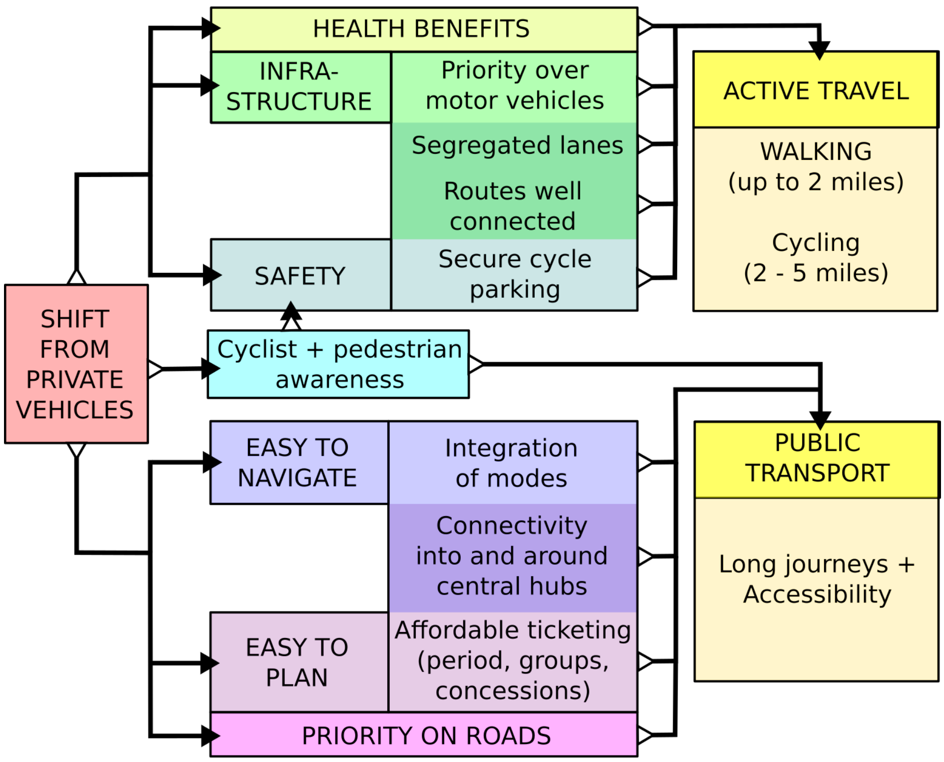

Figure 3. summary of key measures implemented/planned across different locations to promote modal shifts away from private vehicles.

[34] https://www.amsterdam.nl/en/policy/policy-traffic/policy-cycling/ Accessed: 08/08/2019

Model results - Cleaner buses are needed

Shifting travel from passenger cars to bicycles and walking has a large effect on reducing emissions. Longer distance trips and journeys for people with mobility difficulties can be shifted to public transport such as buses. Currently, all buses operating in Cambridgeshire have a diesel powertrain. Additionally, statistics from the Department for Transport show that outside of London, the average number of passengers on a bus at any one time is just 9.4. To obtain significant CO_2 emissions reductions from buses two things must be achieved: **the vehicle fleet has to be renewed, with more efficient vehicles such as hybrids and electric buses, and the number of passengers onboard a bus at any given time must increase.** The latter could be achieved as public transport becomes more appealing than individual vehicles.

The figure below shows the cumulative emissions savings from shifting 20% of travel from passenger cars to buses, assuming 5 years to introduce the policy. In the first instance, buses are renewed at the baseline rate and the occupancy remains at 2019 levels. This saves 8% of cumulative emissions to 2050. Increasing the share of hybrid and electric buses in the fleet to 70% and 10% respectively by 2030 and 10% and 90% respectively by 2050, saves 11% of emissions. Additionally, if the occupancy of buses is further boosted by 50% from 2019 levels, a further 1% of CO_2 emissions can be saved. In comparison, shifting the passenger car travel to cycling or walking saves 13% of cumulative emissions.

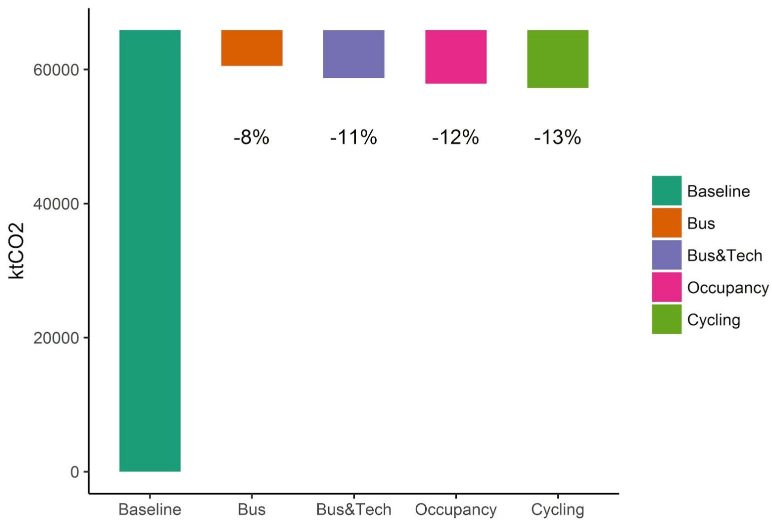

Figure 4. Cumulative emissions from transport in Cambridgeshire under different scenarios: Baseline, shifting travel from cars to buses (Bus), additionally improving the technical efficiency of buses (Bus & Tech), additionally increasing the average occupancy of buses by 50% (Occupancy) and shifting travel from cars to cycling (Cycling).

Summary

We estimate that cycling, walking and public transport travel in Cambridgeshire currently accounts for approximately 40% of travel (passenger kilometers). In order to promote sustainable transport and modal shift, it is important to plan new infrastructure that make pedestrians and cyclists the priority. When pedestrians and cyclists are provided with secure and well connected infrastructure, more short journeys tend to be made by these modes, as is clearly seen in the cases of Nottingham and Amsterdam. Good cycle parking facilities are also important, as well as good interconnectivity of the different modes. Affordable, easy to navigate and reliable public transport helps to steer people away from individual cars. Locally-run transport schemes can play an important part in connecting smaller communities to the main transport network. As was seen from the model, the emissions savings from shifting to public transport from cars can be maximised by increasing the uptake of more efficient buses and ensuring they have high occupancy.

3.2 Technological improvements and EV uptake

In addition to reducing the number of road vehicles, it is also important to shift towards less polluting engines. The uptake of EVs is only going to increase with the DfT focusing on passenger cars in its *Road to Zero'* strategy. The DfT expects[35]:

- 50 - 70% of all new car sales to be ultra-low emission vehicles by 2030.
- A complete ban on sales of diesel and petrol cars by 2040.

The International Energy Agency's (IEA) Global Electric Vehicle Outlook[36] has revealed the prerequisites to successful EV deployment:

- Publicly available charging infrastructure (1 per 10 cars)
- Access to home charging
- Access to workplace charging
- Vehicle range

These prerequisites have appeared in all the cities with successful EV uptake in recent years.

Case studies

London[37,38,39]

London is focusing on an Electric Revolution through prioritising charging infrastructure, with a focus on rapid charging points. The number of EVs and electric taxis on London streets in 2019 is over 30000, which makes up approximately 1% of the London fleet. The city also boasts the largest electric bus fleet in Europe. There are more than 3000 public charging points in Greater London, which provide 1 charging point per 4 - 8 EVs. London's electric revolution aims to optimize installation of charging points while avoiding underused or outdated points based on scenarios that estimate the growth of EVs over the next five years. Through the "Go Ultra Low City" partnership, London Boroughs have been able to install more than 1100 overnight residential charging points and more are on the way.

Nottingham[40,41]

In 2019, **Nottingham City Council is opening the first ultra-low-emission vehicles (ULEV) service centre to be run by a local authority**. ULEVs are defined as electric vehicles as well as other low emission vehicles (with emissions below 75gCO2/km). The centre will offer MOTs and servicing to customers, as well as maintenance for the government's growing fleet. The council sees this centre as an opportunity to expand into a rapid growing and currently under-served

[35] The Road to Zero Next steps towards cleaner road transport and delivering our Industrial Strategy (2018)
[36] International Energy Agency Global EV Outlook (2019)
[37] Department for Transport Table VEH 0132 (2019)
[38] https://www.drivingelectric.com/news/1049/ev-charging-stations-best-and-worst-uk-cities-charging-your-car Accessed: 08/08/2019
[39] https://www.london.gov.uk/press-releases/mayoral/mayor-sets-out-londons-electric-vehicle-future Accessed: 08/08/2019
[40] https://www.transportnottingham.com/ulev-service-centre-gets-the-go-ahead/ Acessed: 10/08/2019
[41] https://www.transportnottingham.com/driving/electric-taxis/ Acessed: 10/08/2019

market. They aim to become a hub for EVs in the East Midlands, as they would be able to provide maintenance services for other local authorities and business, as well as extend their services to members of the public.

There are grants available to aid with the installation of workplace EV charging stations. The council also runs ultra-low experience events, to inform fleet owners about the different models, infrastructure, costs of ownership and maintenance of a low emission fleet. They encourage the transition through detailed presentations, expert advice and up to £25k infrastructure grants to Nottingham business.

From 2025, all new taxis registered must be ultra-low vehicles. In order to promote this shift, the council bought three electric Hackney carriages, which can be hired for up to three days by taxi drivers who wish to "try before you buy". A deposit of £100 is taken at the time of hire, and is fully refundable if the vehicle is returned in good condition. Participants are encouraged to use the public charging network, and a complimentary £50 charge point card is provided to participants. The council also offers financial support for vehicle licence fees and MOT, insurance, charging allowance, among others. Hackney taxi drivers can apply for these benefits through an online form where funding is awarded under De Minimis State Aid rules.

Dundee[42,43]

Dundee has placed itself at the forefront of the Scottish Government's plans to phase out petrol and diesel vehicles by 2032. It is Scotland's only "Go Ultra Low City", having secured funding to become a model city for the uptake of EVs. Currently, 40% of the public sector car and van fleets are electric, as well as 15% of the taxi fleet. As benefits to EV users, the city offers free public charging, and free parking while charging and after. The key to Dundee's success consists of a focus on fleets, infrastructure, workplace charging, local incentives, and stakeholder engagement.

Amsterdam[44,45,46]

The city plans to ban all diesel and petrol cars by 2030. Currently, 10% of Amsterdam's fleet is made up of EVs. With 3000 public charging points, and more on the way, there is 1 charging point per 2 - 3 EVs encouraging the growth of the market in the city. The share of EVs is only expected to rise further as the city approaches 2030. Freight traffic must meet Euro 6 standards by 2022, and emission-free vehicles will be used for all public transport south of Amsterdam Central Station by that year. After another three years, the emission-free area will be expanded, affecting taxis, mopeds, scooters, buses, coaches and boats. By 2030, all vehicles producing emissions will no longer be allowed in the inner city. This ban will affect approximately 4000 cars in the city. The city will need 16000 to 23000 car charging stations by 2025 to make the project a success, a significant rise from the numbers available today. In order to make the transition easier, subsidies and exemption schemes will be made available in order for people to be able to purchase 'clean' vehicles. Once a clean vehicle is purchased certain privileges are awarded, such as a parking permit, which is a huge asset in a city where 90% of the population do not have their own parking space.

[42] Department for Transport Table VEH 0132 (2019)
[43] https://www.dundeecity.gov.uk/news/article?article_ref=3284 Accessed: 08/08/2019
[44] https://www.iamsterdam.com/en/business/key-sectors/smart-mobility Accessed: 08/08/2019
[45] https://evbox.com/en/success-stories/amsterdam-city Accessed: 08/08/2019
[46] https://www.iamexpat.nl/expat-info/dutch-expat-news/amsterdam-plans-ban-all-electric-cars-2030 Accessed: 08/08/2019

Norway[47,48]

Norway has committed to an ambitious task of ending new petrol and diesel car sales by 2025, by having 100% Zero Emissions Vehicles (ZEVs) as well as buses. 2018 and 2019 have seen a surge in sales of EVs, with each month performing better than the last. Most recently, sales of pure electric cars surged 40 percent to 46,092 in 2018, and 58% of all new vehicles sold in March 2019 were EVs. This surge was met with a 28% drop in diesel sales, and a 17% drop in petrol, as well as a 20% drop in hybrids, as people shifted towards ZEVs. Norway provides many benefits to EV owners: free parking, reduced road tax and VAT exemption, access to bus lanes, and one public charging unit per 20 vehicles. These initiatives have propelled Norway to have the highest electric vehicle use per capita in the world. However, there are still barriers to uptake of EVs at a rapid pace, these include the lack of private charging infrastructure and long waiting times to obtain an EV.

Uptake of EVs across the US[49]

The US is the third largest EV market globally. Electric vehicle sales in the United States increased from approximately 200,000 in 2017 to more than 350,000 in 2018, with approximately 65% of these being fully battery electric vehicles (BEVs) and 35% plugin hybrid electric vehicles (PHEVs). The San Jose area had the highest electric vehicle market share at 21%, followed by other California cities. Overall, the share of new plug-in electric vehicles in the 50 most populous metropolitan areas was 2.7%, compared to 1.0% elsewhere in the US. California and the 9 other states that have adopted the Zero Emission Vehicles' Regulations are committed to increasing shares of electric vehicles through 2025, and implementing a wide array of policies, consumer incentives, infrastructure deployment, information campaigns, and various local measures. These states want to help to overcome electric vehicle adoption barriers related to higher upfront costs, functional electric range and range anxiety, and spread awareness of the benefits of electric vehicles.

The most important factors that have helped the continued uptake of EVs have been:

- Model availability, with the top five electric vehicle markets by volume, representing over 40% of all U.S. 2018 electric vehicle sales, each having at least 33 electric vehicle models available.
- Access to high occupancy vehicle lanes.
- Consumer incentives such as keeping upfront costs low.
- **Charging infrastructure, electric vehicle market shares are typically larger where there is greater availability of public regular, public fast, and workplace charging infrastructure. Markets with high electric vehicle uptake have at least 400 public charge points per million people.**

The table below summarizes the state of the electric vehicle market in the various cities and countries discussed in the case studies above.

Table 1. A quantitative comparison of the electric vehicle market of the different cities/countries and their electric vehicle uptake targets.

[47] https://www.reuters.com/article/us-norway-autos/norways-electric-cars-zip-to-new-record-almost-a-third-of-all- sales-idUSKCN1OW0YP Accessed: 08/08/2019
[48] https://www.weforum.org/agenda/2019/04/norway-electric-car-market-vehicle-sales/ Accessed: 08/08/2019
[49] The International Council on Clean Transport The surge of electric vehicles in United States cities (2019)

Country/City	EVs (% of fleet)	Charging Units (CU)	EVs/CU	Targets
London	1	3000	5 - 10	Focus on infrastructure
Dundee	0.7	150	2 - 3	100% ULEVs sales by 2032
Amsterdam	10	3000	7	100% ULEVs sales by 2030
Norway	7	10000	20	100% ULEV sales by 2025
California	2.5	13600	27	Increasing shares of EVs by 2025

Environmental Considerations[50,51,52,53]

Although EVs offer a straightforward solution for reducing emissions locally, it is important to consider their environmental impact. If the electricity used for charging still comes from carbon-intensive sources, it will still generate air pollution and emit GHGs, even if not locally. The production of the batteries to power EVs should also be taken into account. The carbon footprint from producing a battery increases with its capacity. In addition, batteries require minerals such as cobalt, copper and neodymium, which are limited or rare, often coming from conflict zones. Their extraction may be associated with human rights violations, deforestation, and contamination of water and soil. Recently, a study concluded that if the UK's vehicle fleet were entirely replaced by EVs by 2050, it would require almost twice as much as the global annual supply of cobalt. Even if the issues above were to be overlooked, locally it would not be long before managing the waste generated by the increasing amount of discarded batteries became a problem. Although often recycled, batteries produced today have a huge toxic potential to contaminate waterways, groundwater and soil, if not disposed of correctly. Unless facilities are in place to properly handle and recycle these items, they could pose a threat to the local environment and communities.

Model results - large CO_2 savings

The modelling in this report accounts for the CO_2 emissions required to produce both electric and traditional internal combustion engine vehicles. It also accounts for the emissions needed to produce electricity and refine fuels in order to compare vehicles on an 'apples-to-apples' basis. According to the International Council on Clean Transportation,[54] the average european vehicle in 2017 with an internal combustion engine emitted 258 gCO_2/km on a lifecycle basis. 36% of these emissions were not produced locally and originate from fuel refining and vehicle manufacture. In contrast to this, the average electric vehicle produced 129 gCO_2/km on a lifecycle basis and is predicted to reduce to 88 gCO_2/km by 2030 due to grid decarbonisation. Accounting for embodied

[50] https://www.nhm.ac.uk/press-office/press-releases/leading-scientists-set-out-resource-challenge-of-meeting-net-zer.html Accessed: 10/08/2019
[51] https://www.gov.uk/guidance/conflict-minerals Accessed: 10/08/2019
[52] https://www.azocleantech.com/article.aspx?ArticleID=132 Accessed: 10/08/2019
[53] https://www.theguardian.com/sustainable-business/2017/aug/10/electric-cars-big-battery-waste-problem-lithium-recycling Accessed: 10/08/2019
[54] ICCT 2019 European vehicle market statistics pocketbook 2018/19.

emissions in passenger cars makes a large difference to the baseline emissions trajectory as shown below.

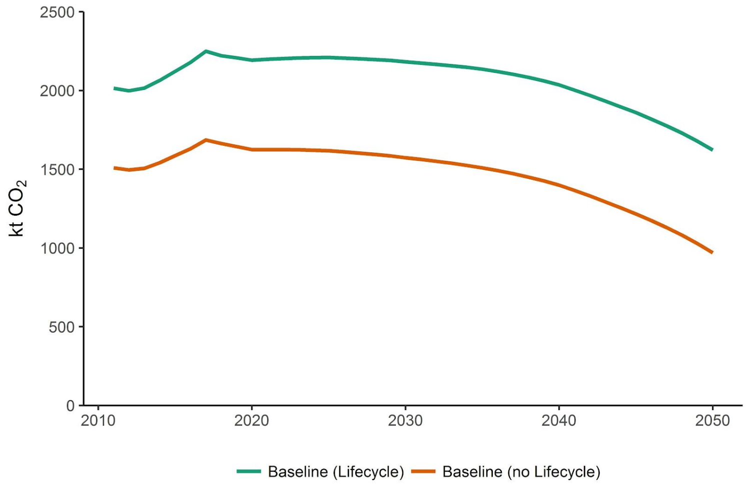

Figure 5. Annual emissions from transport in Cambridgeshire with/without embodied emissions of passenger cars.

Incentivising the use of EVs yields large CO_2 savings. Boosting EV sales can generate large CO_2 emissions savings in the UK. The carbon intensity of electricity is set to continue to improve in line with government policy meaning electric vehicles will continue to save emissions even after embodied emissions are accounted for. However, boosting sales can be helped by local policy making as well as national level policy.

The figure below shows the cumulative emissions savings over the period 2019 - 2050 period from reaching different shares of EVs in new car sales in 2030. In the baseline scenario, EVs make up 13% of new sales in 2030. Reaching 40% of sales by 2030 saves 12% of emissions compared to the baseline. Action needs to be taken quickly to boost this share to higher levels to gain even larger savings. If 100% of new passenger vehicles sold in 2030 were electric, this would save 27% of cumulative emissions. This is ambitious and the UK is currently behind on ambitions to reach this goal. However, it is not impossible with Norway aiming to reach this goal by 2025. Since cumulative emissions show you the effect policies will have over time, **the higher the target and the earlier it is achieved yields exponentially greater returns in carbon savings** in the long term.

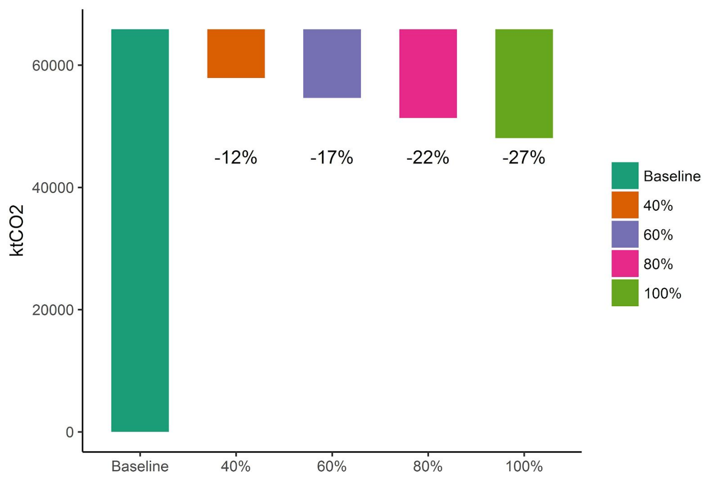

Figure 6. Cumulative emissions from transport in Cambridgeshire under different scenarios: Baseline and different shares of EV new car sales by 2030.

Summary

In summary, EVs have the potential to improve air quality and reduce emissions locally, when compared to their petrol and diesel counterparts. However, EVs do not solve the problem of congestion. Furthermore, if the demand for private vehicles remains the same, merely switching the fleet to EVs will have further environmental and social consequences. In comparison to the ambitious targets set by Amsterdam and Norway, the UK government's desire to phase out petrol and diesel cars by 2040 is not enough. The targets are also ambiguous and leave room for hybrid electric vehicles to be purchased past 2040. Additionally, the incentives and policies outlined are vague, especially in terms of the charging infrastructure necessary to support such a change[55]. Not to mention the uptake of EVs at such a rapid rate will lead to barriers similar to those encountered in Norway: lack of charging infrastructure especially private charging points, as well as waiting times of up to two years before an EV is received once it is purchased. Therefore, EVs are part of the solution when combined with an overall reduction in the number of vehicles on the roads, and a cultural change away from the individual car.

3.3 Clean Air Zones

A Clean Air Zone (CAZ) is an area where restriction measures on polluting vehicles are put in place, in order to improve the air quality of that area.[56] No vehicles are banned from entering the zone; however, the most polluting are requested to pay a daily charge to enter the zone. Currently, the only CAZs in effect in the UK are the ones in London, and are referred to as low emission zones (LEZ). CAZ and LEZ will be used interchangeably. Two other cities have been given the green light to implement a CAZ: Manchester and Leeds. All other cities within the UK are still in their planning phase.

Case studies

London[57,58,59]

The main purpose of the LEZ is to reduce the emissions of air pollutants that are harmful to human health. The first LEZ was implemented in London in 2008, with an operating area covering most of Greater London. The zone targets the worst polluters, specifically heavy diesel vehicles, buses and coaches by imposing minimum emissions standards on them. The LEZ is in operation all year round without exclusions imposing daily charges of £200 on heavy vehicles if they do not meet a Euro IV minimum standard, and a daily charge of £100 on specialist vehicles if they do not meet a Euro III minimum standard.

Five years from the introduction of the LEZ quantitative results reveal:

- The LEZ encouraged fleet renewal, with registrations of non-compliant commercial vehicles within the LEZ decreasing by 20% above the natural replacement rate.
- Additional 10% and 20% drop in pre Euro III specialist and heavy vehicles in London.
- Small improvement in air quality within the LEZ compared to the neighbouring areas: The mean concentration of PM10 decreased by an average of 13% within the LEZ since it was

[55] Brand and Anable, "'Disruption' and 'continuity' in transport energy systems: the case of the ban on new conventional fossil fuel vehicles", ECEEE (2019)
[56] https://www.rac.co.uk/drive/advice/emissions/clean-air-zones/ Accessed: 08/08/2019
[57] https://tfl.gov.uk/modes/driving/low-emission-zone Accessed: 08/08/2019
[58] https://tfl.gov.uk/modes/driving/ultra-low-emission-zone Accessed: 08/08/2019
[59] Ellison et al., "*Five years of London's low emission zone: Effects on vehicle fleet composition and air quality*", Transportation Research (2013)

implemented. NO_x emissions have dropped steadily between 0.5% and 1.5% per year between 2008 and 2011.

What the LEZ does not do, is restrict or charge the travel of private vehicles through it.

In April 2019, a more restrictive Ultra Low Emission Zone (ULEZ) was created, comprising an area of about 21km² in Central London, which is due for expansion in 2021. This ULEZ targets the private cars that the LEZ does not. Petrol vehicles must meet at least Euro IV standards, and Diesel Euro VI or else are charge £12.50/day. Same charges are applied for vans and specialised vehicles, motorcycles and mopeds. Lorries, coaches and other large vehicles must meet Euro VI, or else are charged £100/day. If vehicles cross the boundary of both the LEZ and ULEZ they have to pay both charges. Due to its recent implementation, it is not yet possible to quantify its impact on fleet composition or air quality.

Manchester[60]

Greater Manchester (GM) has found that A Clean Air Zone is one possible action to bring down NO_x levels in the region. This will require the most polluting buses, coaches, HGVs, vans, taxis and private hire vehicles to pay a daily penalty to drive into the zone. Seven local authorities within Greater Manchester (GM) have been identified with NO_2 concentrations likely to exceed annual mean EU Limit Values of 40 µg/m³ beyond 2020. Upon instruction from the government GM has developed a Clean Air Plans which present the CAZ as one viable option amongst many to bring levels of NO_2 on local roads within legal limits as soon as possible. CAZs will be deployed across the whole of GM in two phases from 2021 and 2023, and will cover the whole of GM so that the air quality problem doesn't just shift to another location within GM. There will be a potential extra ULEZ for the most polluting vehicles, including cars, within the inner ring road from 2021.

The CAZ will be in operation all year round. They will not include cars (other than private hire vehicles), motorcycles or mopeds. GM has found that the greatest benefit will come from cleaning up commercial and passenger transport vehicles because they are in operation in town and in city centres much more frequently. To avoid a charge HGVs, buses and coaches must have Euro VI engines or pay £100/day as of 2021. Petrol and Diesel taxis and private hire vehicles must have Euro IV and above engines or pay or pay £7.50/day as of 2021, while vans, minibuses, motorhomes and motorised horseboxes must have Euro VI engines or pay £7.50/day as of 2023. All ULEVs are exempt from a charge.

GM will use the revenue made from the CAZ to first cover its operating costs. Then, whatever remains will be used to improve public transport, cycling and walking. GM is applying for funding from the government to help people and businesses upgrade to cleaner vehicles. A summary of the different funds GM is setting up, and the vehicles affected by the CAZ in GM can be found in Appendix C.

Leeds[61]

Leeds is the other of the two cities outside of London to have had its plans for a CAZ approved by the government. The CAZ will cover most of Leeds' city centre, and will come into effect as of the 6th of January 2020. To start off with private cars, and light good vehicles will not be charged. Taxi and private hire vehicles will have to pay a £12.50/day charge, or £50 per week if they are licensed in Leeds. Buses, coaches and HGVs will be charged 50£/day. This will affect the 500 taxis and more than 4,000 private hire vehicles in Leeds with a fleet composition of: 86% diesel, 6% petrol and the rest electric hybrid and gas/biofuel.

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[60] https://cleanairgm.com/clean-air-plan?cookies=true Accessed: 08/08/2019
[61] https://cleanairleeds.co.uk/final-proposals-leeds-clean-air-charging-zone-revealed Accessed: 08/08/2019

Oxford[62]

Oxford's LEZ aims to encourage the uptake of cleaner vehicles, in order to reduce pollution and improve air quality. It was first implemented in 2014, but its restrictions extend only to buses and coaches. All buses in the LEZ must meet at least Euro V standards. Buses are also required to turn off their engines when parked for periods longer than a minute.

The city council is proposing the phased introduction of a zero-emission zone (ZEZ) in the city centre from 2020, in order to reduce the concentration of toxic gases such as NO_x. The ZEZ would fully restrict the circulation of vehicles, allowing only those "*which emit less than 75g of CO_2/km from the tailpipe and capable of at least 10 miles of zero emission driving*". These include pure and range-extended electric, hydrogen fuel cell, and certain plug-in hybrid vehicles. Concessions and exemptions are proposed for residents and blue badge holders.

The initial ZEZ would mainly cover the centre of town. It has not yet been decided whether this would be a full time or part time restriction. Loading and parking in the core of the city centre may be prohibited during busy daytime hours for any vehicles that do not meet the zero-emission standards. The area may be extended, according to the reception and results of the initial measures. By 2022 any new taxis would be required to be zero-emission, and 2035 is set as the latest date to transition to zero emission buses.

The table below summarizes implemented, and under consideration CAZs in the various cities discussed in the case studies above.

Table 2. A quantitative comparison of CAZs and their benefits in the various cities

Country/City	Began	Private Cars (PC) Affected	PC Charges (£/day)	LGV Charges (£/day)	HGV Charges (£/day)	Benefits: Uptake of LEVs?
London LEZ	2008	No	--	100	200	Yes
London ULEZ	2019	Yes	12.5	12.5	100	Unknown
Manchester LEZ	2021-2023	No	--	7.5	100	Unknown
Manchester ULEZ	2021?	Yes	Unknown			
Leeds	2020	No	--	12.5	50	Unknown
Oxford	2020	Yes	Charging schemes under consideration for 2023			Unknown

[62] https://www.oxford.gov.uk/info/20216/air_quality_management/1306/oxford_zero_emission_zone_zez_frequently_asked_questions Accessed: 10/08/2019

The Cambridge CAZ study[63]

No modelling was done on the impacts of a CAZ in Cambridge as The City Council ran its own feasibility study. This study assesses the benefits of introducing one or more CAZ in Cambridge to limit the levels of air pollution (especially NO_x). A brief summary is described here. The various factors considered in the feasibility study were location, charging classes, effects on residents etc. Different charging classes (A, B, C, and D) and restrictions on vehicle access were proposed considering four main themes: impact on emissions, environmental benefits, implementation costs and implementation risks. The charge for assessment purposes has been set at the same level as the London ULEZ: £100/day for HGVs and buses, and £12.50 per day for taxis. Results showed that air quality in Cambridge will not improve from 2017 levels without intervention. The most effective CAZ was one that charges private vehicles and requires them to be minimum Euro VI for diesel, and Euro IV for petrol. HGVs, buses and coaches need to meet a minimum Euro VI requirement, and taxis, private hire vehicles and LGVs have the same restrictions as private vehicles.

In short, the benefits to residents and the environment from upgrading vehicles, in the form of reduced levels of NO_x, CO_2 and particulate matter, in addition to the financial benefits through reduced fuel costs, outweigh the costs of upgrading, implementing and operating the CAZ.

Summary

CAZs can be effective in improving air quality and promoting fleet renewal, as well as providing a source of income which can be used to improve public transport, cycling and walking infrastructure. Their impact on air quality depends on the vehicles affected, and the area the zone covers, since the problem can shift to outside the CAZ. Greater Manchester will attempt to circumvent the problem of air quality shifting to different localities outside the CAZ, by converting all of GM into a CAZ. The only comprehensive data available currently from a CAZ is that of London, where there was an effective reduction in the number of dirtier cars, and a faster than average fleet renewal to cleaner vehicles, as well as improvements to air quality from a NO_x and particulate matter perspective.

3.4 Congestion Charging and Strategic Closures

The main purpose of introducing such demand management levers as congestion charges (CC) and strategic closures is to reduce congestion. By way of pricing, or closures transport at peak hours reduces and is redistributed in both space and time. These levers also help improve air quality in the areas where they are applied.

Case studies

Durham[64,65]

Durham has implemented a CC referred to as the Road User Charge Zone that is in operation for two purposes: to reduce traffic congestion and pollution, and improve air quality in the area. This zone was introduced in October 2002, and covers the peninsula, Durham Market Place, Durham Chorister School, Durham University colleges and a variety of shops and businesses. Additionally, it hopes to encourage those with more flexibility to drive ‘out-of-hours’

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[63] Cambridge Clean Air Zone feasibility study (2018)
[64] https://www.durham.gov.uk/article/3437/Durham-Road-User-Charge-Zone-congestion-charge Accessed: 08/08/2019
[65] https://web.archive.org/web/20071007090419/http:/www.durham.gov.uk/durhamcc/pressrel.nsf/vweb/0E6AA A7F1E29973880256DB1002FFB5B?opendocument Accessed: 08/08/2019

when feasible. Thus, creating safer and more attractive streets for everyone. The zone is in operation Monday to Saturday from 10.00 am to 4.00 pm excluding bank holidays. The boundaries of the zone are clearly defined, and any vehicle crossing the zone must pay a daily charge of £2, unless exempt from the charge. Unpaid charges might result in a £50 penalty.

Prior to the introduction of the CC:

- Around 3,000 vehicles/day used the sole access road into the City center Peninsula.
- The narrow street was built centuries ago to cater for nothing bigger than a horse and cart, was also used by up to 17,000 pedestrians a day.
- Conflict between the two was causing traffic congestion, environmental problems, road safety hazards, and detracting from the experience of the World Heritage Site.

Benefits of the CC:

- **1 week later: The volume of traffic entering the peninsula fell by 90%.**
- **1 year later: Traffic reductions steadied at 85%. Pedestrian activity increased by 10%. Heavy and light goods vehicle activity during the restricted period has fallen by 50%. Public perception is positive, 70% of interviewees think the CC is a good idea. 83% of businesses on the peninsula have not been affected by the CC.**

London[66,67]

The London Congestion Charge was introduced with the goal of reducing traffic at peak times. It came into effect in February 2003, and it operates between 7:00 am - 18:00 pm weekdays and excludes weekends, public holidays, and Christmas and New Year's days. All vehicles crossing the 21 km^2 boundary identical to that of the ULEZ must pay 10.5 £/day if they are registered with autopay which is set up by Transport for London (TfL), unregistered users must pay 11.5 £/day on the day or in advance, and if paying the day after the charge rises to 14 £/day. In London, if a vehicle crosses the LEZ, ULEZ, and CC in one day it must pay all three charges.

Benefits of the congestion charging scheme were immediate: before the charge 180,000 vehicles would cross the charging zone everyday. Once the charge was implemented the vehicles crossing dropped to 120,000 which is a **30% reduction in congestion daily.**

Stockholm[67]

Stockholm implemented a six month congestion charge trial. Results revealed a similar reduction in congestion levels and cars entering the congestion zone as in London.

Milan[67]

Milan placed its congestion zone under suspension for 50 days to investigate the impacts. Milan's zone exempts bi-fuel, hybrid, and electric vehicles from the daily charge. Once the charge was suspended, there was a 17% reduction in exempt fuels entering the zone, as well as a 13% increase in cars rated Euro 0 to III, i.e those with the highest charge rate. This shows that congestion charging doesn't only affect traffic flows, but also the uptake of LEVs.

[66] https://tfl.gov.uk/modes/driving/congestion-charge Accessed: 08/08/2019
[67] Morton et al., "*Exploring the effect of local transport policies on the adoption of low emission vehicles: Evidence from the London Congestion Charge and Hybrid Electric Vehicles*", Transport Policy (2017)

Madrid[68,69]

The Madrid Central Low Emission Zone began operating in November 2018 as part of the 'Plan A for Air Quality and Climate Change'. In April 2019 a new measure was introduced that made it mandatory for Spanish vehicles to have a sticker to be able to circulate and park in the municipal area of Madrid. The difference in the Madrid CAZ is that vehicles are not charged for entry, but rather they are not allowed entry within the boundaries of the zone. To enter Central Madrid permanent, temporary, or daily authorization is required, and by 2025 vehicles without the correct sticker will no longer be granted access. Exceptions for some roads are made so that traffic passing through the city center is eliminated. Exceptions are also made so that residents, people with reduced mobility and security and emergency services can access Central Madrid with their vehicles. However, residents purchasing new vehicles must meet Euro III and IV standards for petrol and diesel cars respectively. Additionally, low emissions vehicles are granted varying degrees of entry and parking privileges within Central Madrid as long as they have the correct labels.

Benefits: Within one month of launching the program, traffic dropped by 24%, nitrogen oxide (NO_x) levels dropped by 38% to their lowest levels since 2012, and CO_2 emissions fell by 14%. At the same time, the drop in congestion increased bus speeds.

Madrid Central is considered by some studies as Europe's most successful CAZ. Recently, plans were presented by the new local government to revoke the CAZ. Public pressure and protests ensured the CAZ remained in place, with a judge ruling that the public health of the city was more important than the individual right to travel by car.

The table below summarizes the charging zones and strategic closures implemented in the various cities discussed in the case studies above.

Table 3. A quantitative comparison of congestion charges and strategic closures, and their benefits in the various cities

Country/City	CC	Closure	Congestion Reductions	Other Benefits
Durham	Yes	No	85%	--
London	Yes	No	30%	--
Stockholm	Yes	No	30%	--
Milan	Yes	No	Unknown	Uptake of LEVs
Madrid	No	Yes	24%	NO_x dropped 38% CO_2 fell 14% Bus speeds increased

[68] https://urbanaccessregulations.eu/countries-mainmenu-147/spain/madrid-access-restriction Accessed: 08/08/2019
[69] https://www.theverge.com/2019/7/1/20677089/madrid-congestion-pricing-emissions-reversal-pollution Accessed: 08/08/2019

Summary

Congestion charging and strategic closures that provide exemptions to LEVs are capable of reducing congestion and improving air quality. These demand management levers encourage people to rethink traveling at peak times, and to consider switching to more sustainable modes of transport. Similarly to a CAZ, congestion charging also provides a revenue stream for the local council. After operating costs are accounted for, the remaining profit from these charges can be put into improvements to public transport, cycling and walking infrastructure.

4. A multiple policy approach

4.1 Act fast

Climate change is caused by a growing quantity of greenhouse gases in the atmosphere, which cumulatively produce a warming effect. In the baseline scenario, 65 $MtCO_2$ are produced from the transport sector in Cambridgeshire between 2019 and 2050. **In order to reduce the effect of these accumulated emissions, it is necessary to act quickly, since emissions savings accrue over time.**

The figure below shows the cumulative emissions savings over the period of 2019 - 2050, targeting a 20% shift of travel from private cars to cycling. The results vary by the year this target is achieved. If a strong policy is introduced today in 2019 that shifts 20% of travel from cars to bicycles by 2020, 14% of the cumulative emissions from the baseline can be saved. If instead policies are put in place now but only yield the desired results in 2040, then only 9% of cumulative emissions are saved. Enacting policy as quickly as possible therefore has significant effects on reducing emissions.

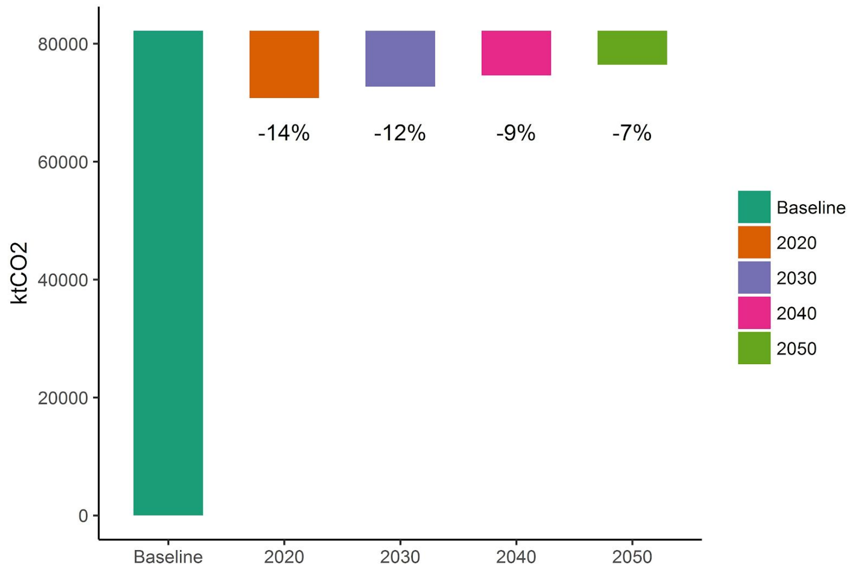


Figure 7. Cumulative emissions from transport in Cambridgeshire under different scenarios: Baseline and the effect of shifting 20% of travel from car to cycling by the year this target is achieved.

4.2 Multiple future scenarios

The figure below shows multiple scenarios of carbon emissions from transport in Cambridgeshire. We firstly model ambitious changes in the modes of travel (Mode Shift). In this scenario, policies move 20% of travel from passenger cars to buses (50%), cycling (25%) and walking (25%) by 2030 through incentives similar to those outlined by cities like Manchester and Nottingham. This results in 60% of travel being conducted by sustainable modes by 2030. **A benefit of this scenario is that it can save emissions relatively quickly, and is not reliant on uncertain technological developments. This set of policies saves a cumulative total of 6.2 million tonnes of CO_2 between 2019-2050, a 9% reduction compared to the baseline**.

Next, a scenario involving highly ambitious targets for electric vehicle deployment is modelled. Here, EVs make up 60% of new car sales, and 30% of the fleet of buses are battery electric by 2030. This is inline with the ambitious targets announced by the UK government for 50 - 70% of new car sales to be ULEVs by 2030. The success of this policy will require adopting ambitious incentives and increased rollout of charging infrastructure as seen in cities like Amsterdam, and countries like Norway. **This set of policies saves a cumulative total of 11.8 million tonnes of CO_2 between 2019-2050, an 18% reduction compared to the baseline.**

Finally, the effects of both the modal shift and EV uptake policies detailed above are combined in our final and most ambitious scenario. **This set of policies saves a cumulative total of 16.5 million tonnes of CO_2 between 2019-2050, a 25% reduction compared to the baseline.**

The importance of cumulative emissions as a measure of comparing policies is apparent here. Looking purely at annual emissions (Figure A) the second and third scenarios yield similar annual emissions reductions in 2050 (57% for scenario 2 and 62% for scenario 3). However, over time scenario 3 has a greater potential to save cumulative emissions (Figure B) since modal share policies can be enacted immediately. **Therefore scenario 3 yields the most savings with a 62% reduction in annual emissions in 2050 compared 2019 levels, and a 25% reduction in cumulative emissions over the 2019 - 2050 period.**

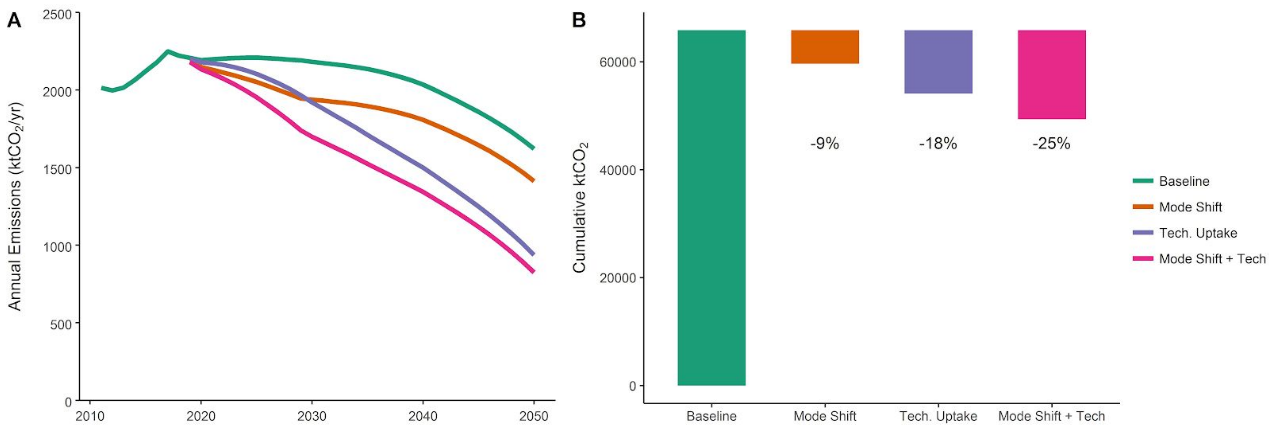


Figure 8. Annual emissions (**A**) and cumulative emissions (**B**) from transport in Cambridgeshire under different scenarios: Baseline, a 20% shift away from cars (Mode shift), a 60% share of EV sales in 2030 (Technology Uptake) and a combination of both mode shift and EV adoption (Mode Shift + Tech).

Summary

These results show that a combination of modal shift and EV uptake can save 25% of cumulative emissions compared to the baseline scenario, and help to offset the increased population and travel in the Cambridgeshire area. However, to meet a net zero target necessary to avert catastrophe, an even higher level of ambition is needed.

CAZs, congestion charging, and strategic closures were outlined in the above case studies, and have been successful at improving air quality, reducing congestion and emissions in cities such as London, Oxford, Durham, Madrid and more. Feasibility studies have been performed on their applicability within Cambridgeshire already, and they will be needed on top of modal shift and technology improvements to help Cambridgeshire meet its 2050 ambitions. In the next chapter we outline some innovative policies that have been successful elsewhere, as possible options to help Cambridgeshire meet its targets.

5. Other policy ideas

In this Chapter other policy ideas that are in line with the GCP's principles are presented. They have been implemented successfully elsewhere, and can be applicable to the GCP area. These were harder to quantify, and as such were not included in the model. Nevertheless, their impacts are discussed from a qualitative perspective. In the last section we discuss ways in which new policies can be framed to highlight their positive impact on people's lives.

5.1 Further case studies

The following policies have been identified as innovative ideas that are being implemented in other cities as part of their plans to make travel through public transport, cycling and walking the natural choice for people.

The case for coachways[70,71]

Coaches are some of the most efficient form of surface transportation: a full coach can remove a mile of car traffic from motorways. In 1997, Dr Alan Storkey proposed a way to make the coach system faster and more appealing to travellers. The key elements are:

1. Move coach terminals out of city centres to motorway junctions, where they could become hubs for interchanging services. Shuttle links (bus, train, tube) would transfer customers from these hubs into city centres. The hubs would also need good cycle parking facilities.
2. Increase the frequency of coach services, from current levels of pre-booked / hourly slots to a few times an hour. This would make the service more appealing, and has been successful for instance in the London to Oxford route.
3. Give coaches priority on the roads. To start with this could simply be to allow coaches to use the hard shoulder of the motorway when other lanes are blocked. As the system grows, dedicated coach lanes could be introduced. Combined with road pricing, it would lead to a migration from private to public transport, lowering emissions, improving air quality, and reducing traffic.

[70] http://www.alanstorkey.com/category/carstocoaches/ Accessed: 10/08/2019
[71] https://coachwaysuk.wordpress.com/2010/12/10/presentation-to-parliamentary-group/ Accessed: 10/08/2019

An express coach passenger's carbon footprint is estimated at 20 gCO_2/km, while for petrol and diesel cars that is over 100 gCO_2/km/passenger. Factoring in the embodied CO_2 footprint from manufacturing, express coaches have the potential to lower CO_2 emissions by 90% in comparison to individual cars. Coach networks also offer a cheap solution to orbital integration of railway lines, encouraging multimodal travel.

Past studies have concluded that orbital coach networks could significantly improve traffic flow, for example, a 2003 Government Office of the South East commissioned study concluded that a hub-and-spoke network would be the best alternative to alleviate congestion on London's orbital motorway (M25), in combination with increased frequency of service, better quality vehicles and stations, fair pricing, and priority measures for coaches on the roads. The project, however, did not get approved by the Dft. The model used by the DfT at the time put a price on wasted time of car drivers during their working day at £26.43 per hour, whereas for a coach or bus passenger that was down to £20.22. Therefore, the coach network would have ranked as less efficient, as it would likely cause an increase in private vehicle traffic congestion.

The case for coachways was presented again to the Parliamentary Group on Climate Change in 2010, and although well received no further action seem to have taken place. Dr Storkey has an updated study from 2017 published on his personal website[64].

Although their original proposal is for an ambitious nation-wide network, it is possible to infer how benefits could be achieved locally by implementing some of these ideas. For example, a coach journey from Cambridge to Oxford takes 3h35min at £15 return, in comparison with almost 3h and £57.40 by rail. The same journey clocks just over 2h directly by car at present, which may be longer when including parking restrictions on both ends and the likely need to use a P&R. Coach services run every 30min during the day, and late until midnight, also connecting smaller towns in the route.

Milton Keynes is one of the towns served by the Oxford-Cambridge route. The town opened a new coachway in 2010, located by Junction 14 of the M1, aiming to create a new transport hub and alleviate congestion locally. The coachway has a number of facilities such as cycle racks, toilets, parking and EV charging points. In addition to the aforementioned route, there are buses and coaches linking different parts of town, university buses to Cranfield and Bedford, and many National Express routes. Unfortunately, at present there are no studies available on the impact of this new coachway to reducing congestion.

Amsterdam - better integration and prioritization[72,73]

By 2020, the Amsterdam Metropolitan Area and the Dutch government will invest an additional €10 billion to improve connectivity throughout the region. The goal is to have more journeys made by public transport than by car. For this to be possible reliability, frequency and speed of services will be optimized so that public transport is an attractive alternative to the car. Both public transport and rail will be increased in frequency during peak times, and journey times will be shortened so that the focus is on the speed of getting to the required destination. So that reliability and speed are not jeopardized the city is prioritizing by mode depending on the area:

- Cyclists and pedestrians will be given priority on narrow streets such as the historical city centre. Cars will only be allowed in as 'guests' and will be kept separate from the different modes of public transport.

[72] https://www.amsterdam.nl/en/policy/policy-traffic/public-transport/ Accessed: 08/08/2019
[73] https://www.amsterdam.nl/en/policy/policy-traffic Accessed: 08/08/2019

- Whenever possible, busy pedestrian streets will be closed to traffic for safety.
- When journey times are long, and are inaccessible by metro, buses and trams will have priority over the car.
- Cars will only be given space on wide roads that can accommodate them, and that do not have any air or noise pollution problems.

This prioritization scheme has shown that it works. Areas have been closed to vehicles, and traffic redirected while other areas have been converted into one-way streets. Results have revealed an increase in walking and cycling without a negative impact on motorists.

Amsterdam is working hard on interconnectivity as the city continues to grow. The number of on-street parking is diminishing, and new apartments won't be granted on-street parking permits. The city is focusing on improving P+R facilities, optimizing already available parking lots, and increasing underground parking. As on-street parking diminishes more space will be made for cyclists and pedestrians. The network of interconnected pedestrian routes in the city centre is under expansion. To accomplish this, motorised traffic will be restricted or prohibited in certain areas, and more room will be allocated to pavements and pedestrian areas.
These sets of improvements to walking, cycling and public transport and restrictions to private cars will give individuals the opportunity to complete a journey using multiple modes of transport without jeopardizing flexibility or speed.

Sao Paulo - workplace incentives for public transport uptake

Integrated bus ticketing makes it easier for the individual passenger to navigate the public transport network, as the fares become simpler to understand. Bus franchising is also a good option to ensure that routes and timetables meet the needs of the local community. In London, bus usage has been increasing since the franchising system was implemented.

Going further away from the UK, other interesting examples are found on means to promote public transport. The case in Sao Paulo, although dependent on franchising, combines integrated ticketing with workplace incentives for workers commute by bus, underground or overground. Under Brazilian legislation, employees can choose to "sacrifice" a small percentage of their salary in exchange for public transport vouchers. This is particularly helpful to workers in lower incomes, for whom public transport fares may be too expensive; or for those who need more than one bus / mode in their commute.

The public transport vouchers are saved in a magnetic card akin to London's Oyster. To opt-in and obtain this benefit, the employee has to inform their employer which modes they require to take in their commute. The employer then calculates the amount needed for the commute, deduces 6% of the employee's salary, and tops up the correct value each month on the employee's card.

Sao Paulo also tries to encourage multi-modal travel through a number of concessions and discounts. Being one of the largest cities in the world, long journeys and congested traffic are commonplace. The solution found by the city was to offer "unified" public transport fares. Similarly to London, a single magnetic card can be topped up and used for buses, underground, and some local trains. However, in Sao Paulo, people are allowed to board up to four buses within three hours using the same single fare. Alternatively, it is also possible to take up to three buses and one rail journey, paying a discounted combined fare which is cheaper than two single fares. These time allowances for modal combinations are also possible under the salary sacrifice scheme described above, and under the reduced fares existent for students. In a city where two thirds of public transport journeys require at least two buses or bus + rail, this type of benefit is a considerable incentive. The unified ticketing system was implemented in 2006. In 2007, the modal split in the city was 30% walking, 28% bus, 28% private car, 10% rail and 4% other modes.

5.2 Publicising policies

Public perception is key when policies are established by a local authority. When policies on climate change are framed from a public health perspective they can have a positive impact on public opinion. The case presented earlier from Madrid is a clear example of a community prioritising public health over removing restrictions on private vehicles.

In essence, the main benefit of an efficient and clean transport network is the improved wellbeing of the communities that are built around it. 90% of city dwellers are exposed to unsafe concentrations of pollutants that are also detrimental to the environment. Reducing pollutant emissions, improves air quality, and is the most accurate way to achieve this goal. Reducing emissions of these greenhouse and toxic gases is the most accurate way to achieve this goal. it is essential to keep in mind, and always promote, the health benefits for both individuals and communities from having cleaner air, safer, and less congested streets.

Active modes of transport have great health benefits. A network that is designed to ensure the uptake of walking and cycling is easy and safe will also promote a more healthy lifestyle, and make it easier for individuals to increase their daily amount of physical exercise, tackling public health issues such as sedentarism, obesity, diabetes and cardiovascular disease[74]. A more active routine may also improve mental health and social integration.[75]

While financial incentives can help, promoting a consistent, long-lasting behavioural shift away from individualised, polluting and passive travel, towards more active, healthy, clean and active modes of transport, requires educating people on the benefits of such a lifestyle, as well as redesign of public streets that shift away from prioritizing the car.

This section concludes with a last case, the Healthy Streets Approach from London.[76] The vision for London is to have less cars on the street, reduce danger on the roads, increase walking and cycling which improve health and air quality for the elderly, young children, disabled citizens, and low income people.

People still drive in London because the streets and public spaces are not designed to allow more people to walk or cycle. Public transport is overcrowded, unreliable, and inaccessible to all. Currently, there are 8.7 million people living in London, this number is on the rise and expected to reach 10.8 million by 2041. This growth is expected to be accompanied by an increased pressure on London's already congested public transport system and streets. If improvements aren't made, projections show that 70% of trips will be crowded during morning rush hour on the London Underground. In London today 27 million trips are made daily, but only 60% of these trips are made on foot, by bike or by public transport. By 2041, 33 million trips will be made every day, and the aim is to see 80% of them made by walking, cycling or by public transport. Through "*the **Healthy Streets Approach** to prioritize human health and experience in planning the city, the Mayor wants to change London's transport mix so the city works better for everyone.*" At the heart of the strategy:

[74] Celis-Morales et al., "Association between active commuting and incident cardiovascular disease, cancer, and mortality: prospective cohort study", BMJ (2017)
[75] Public Health England "*Working Together to Promote Active Travel: A Briefing for Local Authorities*" (2016)
[76] London Mayor's Transport Strategy (2018)

- **Healthy streets and healthy people:**[77] designing streets that people enjoy using because there are less cars and more people walking or cycling. Improve public transport by integrating stops or stations with footpaths or cycling paths. Ensuring new homes and jobs are well connected to stations, and cycling and walking paths. Therefore, as London continues to grow car numbers do not. Driving to work is equivalent to 1 minute of activity, taking public transport is equivalent to 7 - 8 minutes, while walking and cycling are equivalent to 17 minutes and 22 minutes respectively. By 2041 the Mayor's aim is to get all Londoners to do at least 20 minutes of active travel every day to help them stay healthy. To achieve this:
    - Local streets and areas will be nice places for people to walk, cycle, use public transport and to spend time.
    - Streets will be easier for disabled people to use. Pavements will be wider and have fewer obstacles along them.
    - There will be interconnected cycle paths that encourage the uptake of cycling as well as walking.
    - Additionally, there will be areas with no traffic, such as the closure of Oxford Street that will promote alternative modes of travel.
    - The mayor is also aiming to increase road safety to ensure no one is killed by a bus by 2030. Ensuring traffic moves slower, and increasing safety standards for buses will reassure people and encourage them to walk even more.

[77] Mayor's Transport Strategy (2018)

6. Conclusion and Recommendations

Cambridgeshire recently declared a climate emergency, in line with the recommendations of the UK Committee on Climate Change for the country to reach net-zero emissions by 2050. Acting to reduce greenhouse gas emissions has the joint benefit of tackling the problem of air pollution. Reducing emissions should not be seen as a burden on the public, but as an opportunity to improve public health, through cleaner air and the promotion and uptake of active modes of travel. These would imply fewer vehicles, reduced congestion, as well as safer and quieter roads. Coupled with an efficient and clean public transport network for longer journeys, and the uptake of new technologies, the aim of "reducing emissions" clearly becomes one that will greatly improve the health and wellbeing of our local communities.

We investigated policies from various cities around the world that combat air pollution and emissions, and have concluded that:

- Prioritizing buses, cyclists and pedestrians stimulates a shift away from the private car;
- Access to charging infrastructure and financial incentives can be effective at stimulating the uptake of electric vehicles;
- Clean Air Zones and charging schemes stimulate fleet renewal, uptake of electric vehicles, combat congestion and improve air quality.

Using insights from these case studies, we recommend two **minimum targets** for Cambridgeshire:

Firstly, **a goal that 60% of travel in 2030 ought to be on buses, cycling and walking (currently at 40% in 2019).** This target includes an upgrade to the bus fleet currently operating in Cambridge. Similar targets have already been adopted by Manchester and London. With infrastructure in place to support further uptake of active travel, this should be an achievable goal. In order to limit emissions from remaining passenger cars, **we recommend a second target that at least 60% of new car sales in 2030 must be electric.** This is in line with government ambitions, but must be stimulated at a local policy level by providing incentives for electric vehicle owners, similar to Dundee and Amsterdam.

If both of these targets were met, annual CO_2 emissions in 2050 would be 62% less than 2019 levels. Since greenhouse gas emissions accumulate in the atmosphere, acting quickly is essential. **A policy enacted now saves more cumulative emissions than if delayed.** Our two recommended targets give cumulative emissions reductions that are 25% less than business-as-usual. **These achievable targets ought to be a minimum ambition, and more will be necessary to reach net zero emissions in line with climate emergency declarations.**

Appendix A

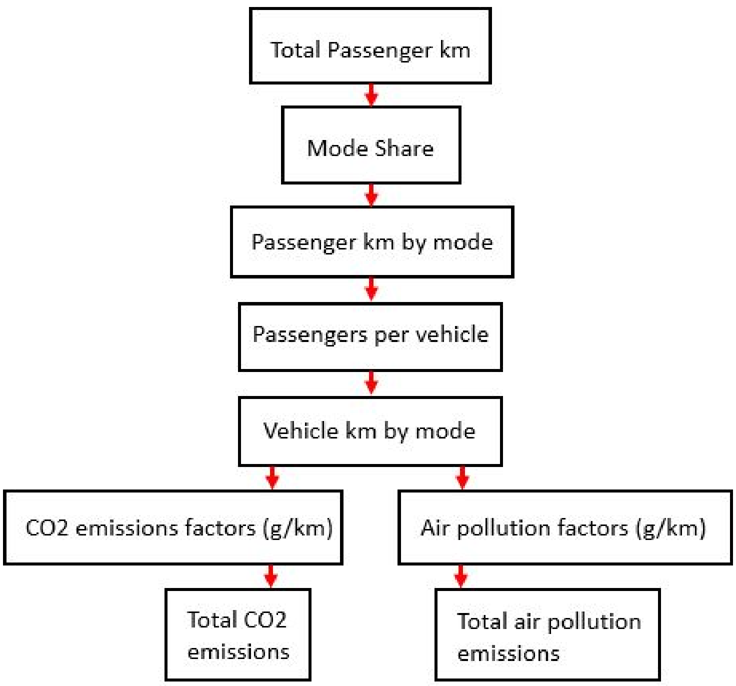
Data and methods

This section explains the methods and assumptions used to develop the model. A baseline scenario of emissions in Cambridgeshire is built to determine the historical annual emissions (from 2011) and the predicted emissions with no local policy action. This model calculates the vehicle kilometers (vkm) of each mode of transport split by local authority, mode, powertrain technology and emissions class (shown in the table below).

Geographical	Modal	Technology	Air Quality
Cambridge	Car	Petrol	Euro 1
East Cambridgeshire	Motorbike	Diesel	Euro 2
Fenland	Bus	Hybrid	Euro 3
Huntingdonshire	LGV	EV	Euro 4
Peterborough	HGV		Euro 5
South Cambridgeshire	Cycling		Euro 6
	Walking		

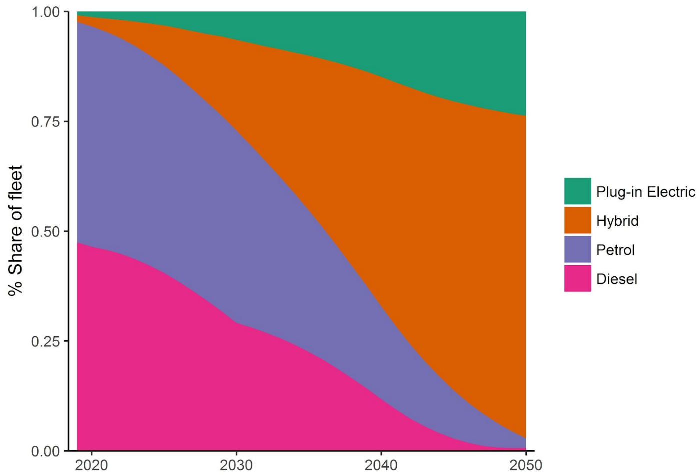
The baseline scenario assumes that the modal share and load factor (number of passengers per vehicle) remains constant at 2018 levels. Vehicle kilometers are then used with detailed emissions factors (grams of pollutant per kilometer) to determine the total annual emissions for each mode and technology.

The baseline projections are then altered using two 'tools'. The first tool modifies the modal shares of each mode. This increases the travel (pkm) in a certain mode (e.g. cycling) and reduces the travel in another, user-defined mode (e.g. cars). The load factor of each mode can also be modified. Together this modal share tool changes the vkm of each mode in response to a policy. This feeds forwards to CO_2 emissions and air quality in order to assess the impact of each proposed policy.



The second tool in the model changes the share of new sales of electric vehicles from a baseline scenario. This feeds into a stock model, which calculates the turnover of vehicles as they age and calculates how a change in new sales affects the total number of vehicles in the stock every year. The share of each vehicle powertrain in the stock is used with specific emissions factors for CO_2 and air pollutants to determine the total emissions rate.

The choice of electric vehicle (EV) sales scenario makes a very large difference on the stock of EVs and therefore the baseline emissions. We have also assumed new sales of diesel vehicles continue their downward trajectory in line with recent trends post dieselgate.



Modelling methodology

Vehicle Travel

Car vehicle kilometres for Cambridgeshire from 2005-2018 are obtained from the Department of Transport.[78] LGV, HGV and Motorcycle vehicle kilometres for the East of England[79] from 2005-2018 are scaled for Cambridgeshire using total vehicle kilometres for Cambridgeshire.[80] Vehicle kilometers are projected to 2050 using forecasts from the Road Trac Forecasts 2018, which gives car, LGV and HGV vehicle kilometers for the East of England to 2050.[81]

Car, LGV, HGV and Motorcycle vehicle kilometres have been approximated at the district level within Cambridgeshire based on the number of car registrations within that district.[82] Car registrations are assumed to remain proportional to population and have been projected to 2050 using population predictions from Cambridgeshire insights.[83]

Bus vehicle kilometres have been predicted using mode shares of trips to work estimated from the 2011 census and scaling this with car vehicle kilometres.[84] This gives a breakdown of bus kilometres at a district level, which is important as bus kilometres are more variable across districts.

[78] Department for Transport, Table TRA8905 Car vehicle traffic (vehicle kilometers) by local authority
[79] Department for Transport, Table TRA0106 Road traffic by vehicle type and region
[80] Department for Transport, Table TRA8906 Motor vehicle traffic (vehicle kilometers) by local authority
[81] Department for Transport (2018), Road Trac Forecast, Reference Scenario 1
[82] Department for Transport, All vehicles (VEH01) VEH0105: Licensed vehicles by body type and local authority: United Kingdom
[83] https://cambridgeshireinsight.org.uk/population/ Accessed: 08/08/2019
[84] Systra, CPCA Strategic Bus Review (2019)

Passenger Kilometres

Passenger kilometres for cars and buses are obtained by scaling the vehicle kilometres by an average load factor which is the average occupancy within the vehicle. For cars the load factor is 1.6[85] and for buses it is 9.6.[86]

Vehicle Fuel Efficiency

- **Cars:** The types of passenger cars in Cambridgeshire and the fuel efficiency of petrol, diesel and hybrid cars is obtained using MOT and VCA data as well as real world fuel consumption estimates.[87] It is assumed that fuel efficiency improves by 28% for petrol cars, 19% for diesel cars and 19% for hybrid cars between 2015 and 2050.[88] The fuel efficiency of electric vehicles is calculated using an average miles/kWh value from the VCA28 [89]combined with the energy intensity of the grid.
- **Buses:** Bus fuel efficiency is report by Stagecoach.[90] It is assumed that fuel efficiency improves by 12% between 2015 and 2050.
- **LGVs:** Fuel efficiency comes from the UK Inventory report[91]. LGVs are assumed to have the same rate of fuel efficiency improvement as cars.
- **HGVs:** Fuel efficiency comes from the UK Inventory report. It is assumed that fuel efficiency improves by 12% and 21% for rigid and articulated HGVs respectively between 2015 and 2050.
- **Motorcycles** Fuel efficiency comes from the UK Inventory report.[92] All improvements in vehicle fuel efficiency come from the DfT Road Trac Forecast 2018.[93]

Emissions Intensities

It is well known that official fuel economy and emissions statistics of passenger cars are not representative of real world driving due to flexibilities in EU testing procedures (Kadijk2012, Stewart2015). For this reason real world emissions data is used where possible in this report. Fuel economy data by vehicle model for passengers cars is sourced from over 200,000 driver reported estimates (Craglia & Cullen 2019). NO_x emissions from passenger cars by EURO emissions class is sourced from over 700,000 remote sensing measurements in the UK (Bernard et al. 2018). NO_x emissions intensities for EURO IV-VI buses are sourced from (TRUE2018) which used remote sensing in London.

Baseline Forecasts

Mode Technology Shares

- **Cars:** The UK government has made a commitment that 50-70% of new cars sales are ULEVs by 2030[94] and has banned sales of diesel and petrol cars by 2040.[95] However, there

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[85] Department for Transport, Table NTS0905 Car/van occupancy and lone drive rate by trip purpose
[86] Department for Transport, Table BUS0304 Average bus occupancy on local bus services by metropolitan area status and country
[87] UK Informative Inventory report 1990-2017.pdf
[88] Department for Transport (2018), Road Traffic Forecasts
[89] Vehicle Certification Agency, Car and Van Fuel Consumption Database
[90] Stagecoach East Annual Report 2016-17
[91] UK Informative Inventory report 1990-2017.pdf
[92] UK Informative Inventory report 1990-2017.pdf
[93] Department for Transport (2018), Road Traffic Forecasts
[94] Department for Transport, The Road to Zero: Next steps towards cleaner road transport and delivering our Industrial Strategy (July 2018)

is remaining ambiguity over the definition of an ULEV, and this target allows sales of hybrid electric vehicles after 2040. A recent study modelled the effects of UK government policy on EV shares of new vehicle sales, and how the EV share of the total car and van fleets evolve to 2050.[96] The baseline scenario selected from this study bans the sale of ICE vehicles from 2040 but allows sales of HEVs.

- **Buses:** EU lawmakers have agreed that at least 25% of new buses will need to be hybrid or electric by 2025, and at least a third by 2030.[97] Based on these figures, in 2025 it is assumed that buses are 5% hybrid and electric in 2025, 15% in 2030 and 60% in 2050. The split between hybrid and electric buses is assumed to be equal.
- **LGVs:** The UK Government has set a target for up to 40% of total LGV sales being EV at 2030 has banned the sale of ICE LGVs by 2040. The LGVs fleet powertrain shares are assumed to follow the same trend as cars until 2040, where new vehicle sales are 100% EV.
- **HGVs:** HGVs are 100% diesel until 2040, where shares of electric HGVs rise linearly up to a 10% EV share at 2050.[98]
- **Motorcycles:** Fleet powertrain shares are assumed to increase linearly to 100% EV in 2050.

Electricity Emissions

The baseline projection uses a Department for Business, Energy and Industrial Strategy electricity emissions projection to 2050 for the carbon intensity of electricity required by EVs.[99]

Appendix B

Differences between our model methodology and that of BEIS.

Our model (without lifecycle emissions) gives CO2 emissions that are 13% lower than the BEIS estimates for 2014. This is most likely due to differences in the emissions caused by cars which make up the majority of emissions, we therefore focus our attention on this.

The BEIS model uses the network of UK roads split into three types, A roads, motorways and minor roads. Vehicle traffic estimates for different types of roads are used with speed dependent emissions factors to determine CO2 emissions. Each type of vehicle is modelled to emit a certain level of CO2 emissions when travelling at a certain speed. An average speed is estimated for the three types of road.

Our (relatively simple) model uses publicly available data from the Department for Transport (DfT) on total vehicle kilometres travelled by mode and local authority. This is calculated by the DfT using traffic counts and types of roads in each local authority but is presented as an aggregate for all roads. We cannot therefore account for the type of road a vehicle is driven on. If Cambridgeshire has a higher than average share of travel on minor roads (where vehicles are typically less efficient) this would increase the BEIS CO2 estimates relative to ours. Similarly, if Cambridgeshire has a higher than average amount of congestion this could increase the BEIS data but it's unclear whether the BEIS model is that detailed.

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[95] GOV.UK, Air quality plan for nitrogen dioxide No 2 in UK 2017 (26 July 2017)
[96] Brand and Anable, "'*Disruption' and `continuity' in transport energy systems: the case of the ban on new conventional fossil fuel vehicles*", ECEEE (2019)
[97] https://www.edie.net/news/11/Europe-agrees-sales-targets-for-clean-buses-in-cities/ Accessed: 08/08/2019
[98] Kluschke et al., '*Market diffusion of alternative fuels and powertrains in heavy-duty vehicles: A literature review*' (2019)
[99] Department for Business, Energy and Industrial Strategy 2019, Electricity emissions factors to 2100.

The emissions factors used by BEIS are more detailed than those used in our model because they vary by the speed of the vehicle. However, the emissions factors used in our model also have some strengths compared to the BEIS numbers. Real world emissions differ from type approval emissions (the values on the specs sheet that are tested in unrepresentative laboratory conditions). This is partly accounted for in the BEIS model using factors estimated by Nziachristos et al. 2014. However, these are slightly out of date and are not sales weighted. Our model uses the most up to date data available[100] and therefore addresses these issues.

Secondly, the BEIS model uses emissions factors for national average types of vehicles (i.e. the UK average diesel car). Our model uses MOT data to determine the local vehicle stock in Cambridgeshire in much higher detail. This shows vehicles in Cambridge are newer than the national average.

The BEIS model does not account for embodied emissions but this is not the source of the difference as we can 'turn off' lifecycle emissions.

Appendix C

Case Studies Supplementary Information

Manchester Clean Air Zone [101]

The funds GM is setting up will support the vehicles affected by the implementation of the CAZ:
Clean Freight Fund: 26% of the HGV fleet in GM will be affected by the CAZ in 2021. 48% of vans, minibuses, motorhomes and motorized horseboxes in GMwill have to pay a daily charge to the CAZ in 2023. GM is requesting £59 million from the government to help these affected vehicles to upgrade.
Clean Bus Fund: 58% of buses in GM will be affected by the CAZ and will have to pay a daily charge in 2021. GM is requesting £29 million from the government to help registered buses to upgrade.
Clean Taxi Fund: 69% of taxis, and 36% of private hire vehicles in GM will be affected by the CAZ in 2021. GM is requesting £28 million from the government to help affected vehicles registered in GM to upgrade. If vehicles are registered outside of GM they will not be eligible for financial support.

[100] Craglia & Cullen (2019), "Do technical improvements lead to real efficiency gains? Disaggregating changes in transport energy intensity". *Energy Policy (Under Review)*
[101] https://cleanairgm.com/clean-air-plan Accessed: 08/08/2019