Oxford Zero Emission Bus Regional Areas Scheme (ZEBRA) Evaluation

Public Health Intervention Responsive Studies Teams (PHIRST)

- Commissioned by National Institute for Health and Care Research (NIHR).
- Link academic teams with local government organisations.
- Provide timely and accessible evaluations of public health interventions.
- Evaluations co-designed with local authorities and relevant partners.
- PHIRST PHRESH, consortium of three universities in the West Midlands (Birmingham, Warwick and Keele).

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Executive Summary

Key findings

- Electrification of urban bus fleets reduced both air and noise pollution.
    - In Oxford this transition has cut roadside nitrogen dioxide (NO_2) by up to 24%*, and lowered peak traffic noise by an average of 5.1 dB, comparable to moving three times further away from a road.

- Electrifying bus fleets can improve people's city experience. In Oxford, people reported less exhaust smoke and diesel fumes, creating a cleaner, more pleasant streetscape. Bus passengers noted better ride quality, improved accessibility, and a sense of civic pride – feeling that their city cares for them, but this had limited impact on their bus use due to wider impacts such as cost, reliability and route connectivity.

- Electrifying bus fleets can help to achieve clean air targets, improve public health, and accelerate progress towards net-zero transport - however existing challenges such as traffic congestion limit the potential to increase bus usage.

*Provisional findings based on analysis of roadside Automatic Monitoring Data at Oxford High Street and Oxford Centre-St Aldates to calculate annual average NO_2 change from 2023 to 2024. All data available at https://www.oxonair.uk/data

Key findings (continued)

- Oxford's compact layout and dense urban bus network made it an ideal setting for rapid ZEBRA scheme implementation. Success depended on strong collaboration between bus operators and local authorities, underpinned by a shared vision for improved public transport services.

- Local transport authorities, bus operators and suppliers should prioritise collective planning, co-operation and partnership to overcome practical and logistical challenges to scheme implementation.

- Public communications play a vital role in the public impact of bus electrification schemes. Customising bus fleets with a consistent brand identity can raise awareness of scheme benefits.

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Policy Implications

- To maximise gaseous pollution benefits of battery electric buses, local transport authorities should prioritise bus routes serving communities most affected by air and noise pollution and consider complementary measures which make bus travel more affordable, reliable and convenient.

- Timely installation of charging infrastructure, and provision of comprehensive staff training should be given equal importance to fleet procurement to enable effective and timely scheme rollout.

- When designing vehicle livery and marketing materials a full range of sustainability considerations – should be addressed. These measures can strengthen public awareness, reinforcing the environmental credibility of sustainable transport initiatives.

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Background

Zero Emission Bus Regional Area (ZEBRA) scheme

- Department for Transport (DfT) scheme to reduce carbon emissions from public transport.
- Funding for local transport authorities (LTAs) to introduce 'Zero-Emission' buses and relevant infrastructure (from 2021).
- Monitoring, evaluation and impact assessment
    - Process evaluation (Jacobs, 2022)
    - National evaluation (in progress).

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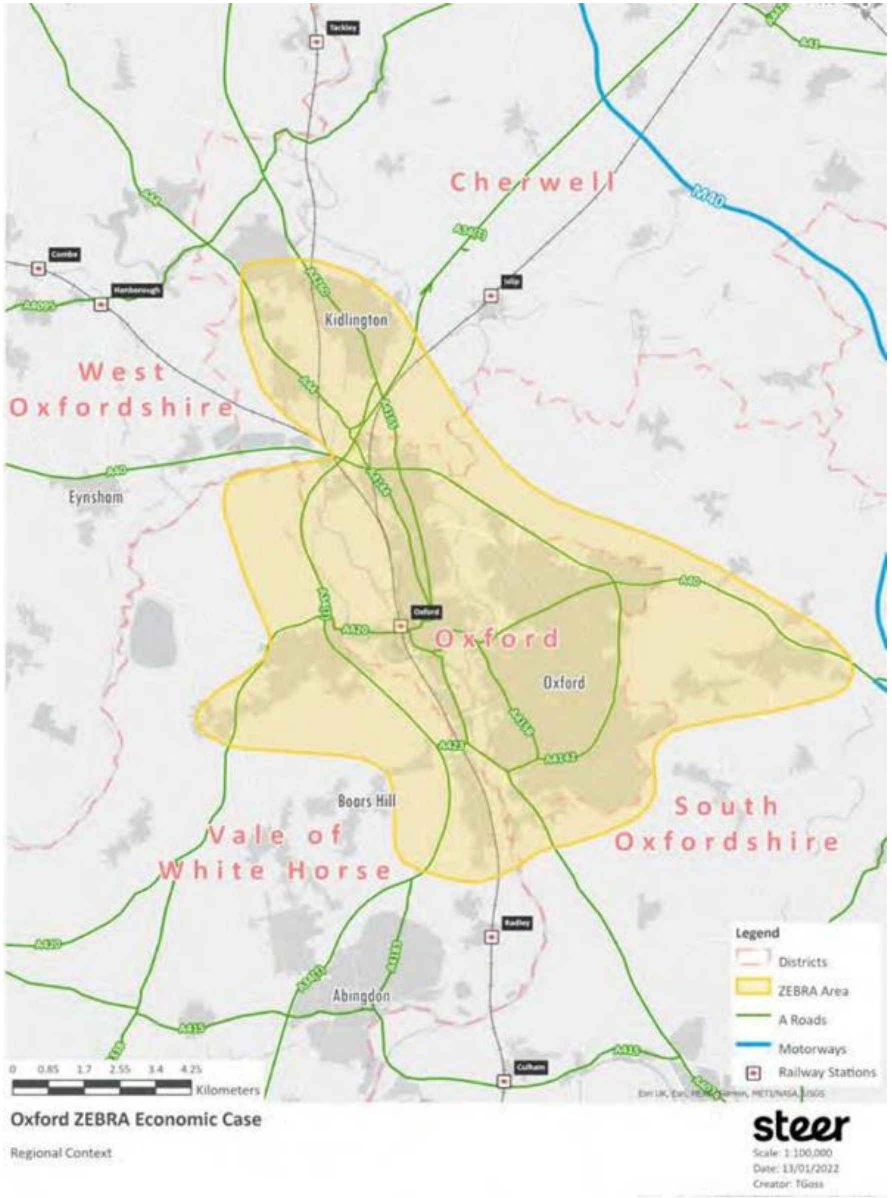
Jacobs. (2022). ZEBRA programme monitoring and evaluation. Pre-implementation process evaluation report. Available at: https://assets.publishing.service.gov.uk/media/646f21e17dd6e70012a9b36a/zebra-pre-implementation-report.pdf

ZEBRA scheme – Aims

- To support the government's commitment to decarbonisation and to reduce the transport sector's contribution to CO_2 emissions.
- To support the initial roll-out of 4,000 zero-emission buses.
- To support bus manufacturers in the development of zero-emission bus technology.
- To support partnership working between Local Transport Authorities, bus operators, and other local stakeholders as set out in the National Bus Strategy.
- To understand better the challenges of introducing zero-emission buses and supporting infrastructure to inform future government support for zero-emission buses.

ZEBRA defined area for Oxford

- Rationale:
  - Core Oxfordshire bus network
  - ‘Smartzone’ integrated ticketing area
  - High proportion of short bus trips
  - Higher than national average bus usage
  - Need for COVID-19 recovery
  - Includes Air Quality Management Area



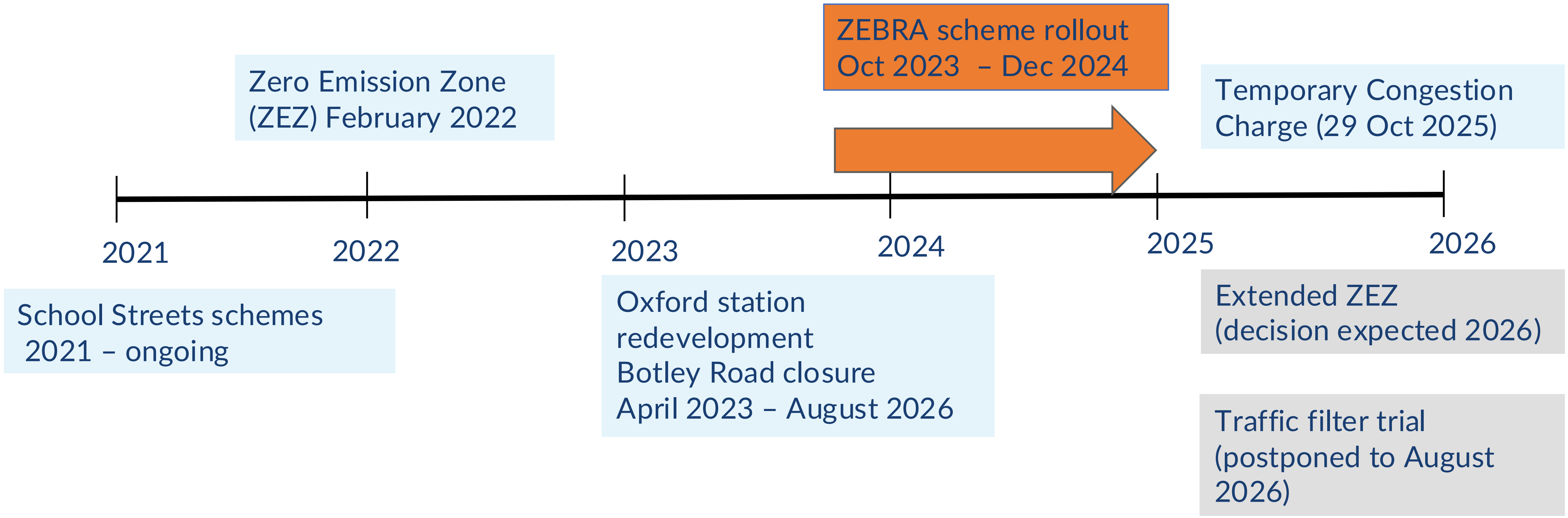
Source: Oxfordshire County Council Zero Emission Bus Regional Area Business Case (2022)

ZEBRA scheme in Oxford

- 159 battery electric buses (by end 2024)
- 34 bus routes
  - 49% bus services
  - 69% daily bus mileage
  - 65% hourly bus flows (major routes)
- Key amenities and services:
  - Transport
  - Healthcare
  - Major employers
  - Education
  - Tourism

Source: Oxford Bus Company (2025)

Transport interventions (Oxford)



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Evaluation Aims

Evaluation aims

Effectiveness:	(1) To assess the direct health benefits of the ZEBRA scheme, including impacts of air and noise pollution changes across the defined area. (2) To understand the impact of the ZEBRA scheme on the travel preferences and behaviours of residents, commuters and visitors. (3) To identify and explore (where feasible) the wider indirect impacts of the ZEBRA scheme, such as economic, social and technical implications, including unintended consequences.
Feasibility and Acceptability:	(4) To understand experiences of ZEBRA scheme implementation, including feasibility and acceptability of full adoption. (5) To explore the costs of the scheme from both Local Authority and societal perspectives and consider the feasibility of a longer-term economic evaluation.
Evaluation Design:	(6) To support relevant research skills and infrastructure development within Oxfordshire County Council to enable long-term ZEBRA scheme monitoring and evaluation.

Developing our logic model

- Visual description of how an intervention works
- Clarifying assumptions and mechanisms of change
- Identifying key components that need to be delivered
- Highlighting contextual enablers and barriers
- Defining indicators at each stage

Inputs/Resources → Activities → Outputs → Outcomes → Impact

- Inform evaluation
  - *What do we need to understand at each stage to know whether the intervention is working as intended?*
  - *Why might the intervention not work as intended ?*

Logic Model development

- Logic model workshop held 21 June 2024 (17 attendees)

- Basic ‘straw’ model shared prior to workshop

- Model developed iteratively – dialogue with project team/stakeholders

- Simplified model used to initiate external discussions
    - Related academic projects
    - Key stakeholders: Department for Transport, Oxford University Hospitals NHS Foundation Trust, Oxford Health NHS Foundation Trust

Initial logic model – Developed Summer 2024

INPUTS

Financial
Business case
Funding (capital)
- Dept for Transport (DfT)
- OxfordshireCC
- Bus Operators (Stagecoach/Go-Ahead

Human Resources
OxfordshireCC staff
Bus drivers/operators

Partnerships
LAs – OxfordshireCC + District Councils
Bus User groups
Emergency services
Community engagement

Infrastructure
High voltage charging equipment
Power supply
- Generator
- National grid

Monitoring equipment

Legislative
DfT contract
Air Quality Targets
- Oxfordshire Strategy Legal Air Quality Objectives

ACTIVITIES

Procurement
- Bus fleet
- Operating equipment
- Monitoring equipment

Route and Timetable planning
- Boarding facilities
- Accessibility
- Maintenance schedule
- Safety planning

Staff training
- Drivers/operators
- Maintenance

Bus fleet deployment
- Route prioritisation
- Redeployment/sale (existing fleet)

Marketing & Promotion
- Branding
- Press release(s)
- Social media

Consultation
- Stakeholder
- Community

Legislative
- Health and safety protocols
- Risk assessments

OUTPUTS

Environmental
- Reduced tailpipe emissions
- Reduced on-board air pollution
- Reduced bus engine noise
- Change in road wear/potholes

Operational
- Increase in % zero emission bus fleet
- Changes to bus routes and timings

Bus patronage
- Improved passenger numbers
- Improved passenger diversity (e.g. concessionary pass status)

Social
- Increased public awareness Increased social preference for bus travel

Economic
- Increased bus ticket sales

OUTCOMES

Short term (weeks) Environmental
- Reduced gaseous pollution (ambient/indoor)
- Reduced noise pollution levels

Medium term (weeks - months) Operational
- Improved bus timetable reliability
- Changes to bus route provision

Behavioural
Modal shift
- Car to bus
- Car to active travel
- Bus to active travel
- Bus to e-scooter

Change in transport attitudes and preferences

Long term (months – years)
Increased bus fare revenue
Changes in road maintenance
Changes in bus fleet procurement

IMPACTS (Intended)

Environmental
- Improved carbon mitigation
- Reduced traffic congestion
- Reduced urban heat island effects (adaptation)

Operational
- Improved bus service efficiency

Behavioural
- Reduced car usage and car dependency
- Improved transport equity

Health and Social
- Reduced incidence of acute and chronic cardio-respiratory diseases (public, bus drivers)
- Reduced school absence
- Reduced transport KSIs (killed or serious injuries)
- Improved physical activity
- Improved educational attainment
- Reduced health and social inequalities

Economic
- Increased tourism
- Increased retail revenue
- Improved access to education and employment opportunities
- Improved civic pride
- Reduced NHS and social care expenditure

IMPACTS (Unintended)

Environmental
- Increased particulate pollution (non-exhaust emissions)
- Increased GHG emissions (e.g. fleet disposal/whole life-cycle emissions)
- Increased pollution outside city

Operational
- Reduced bus service provision
- Increased bus fares
- Reduced bus driver recruitment/retention
- Increased cost of whole fleet renewal/procurement

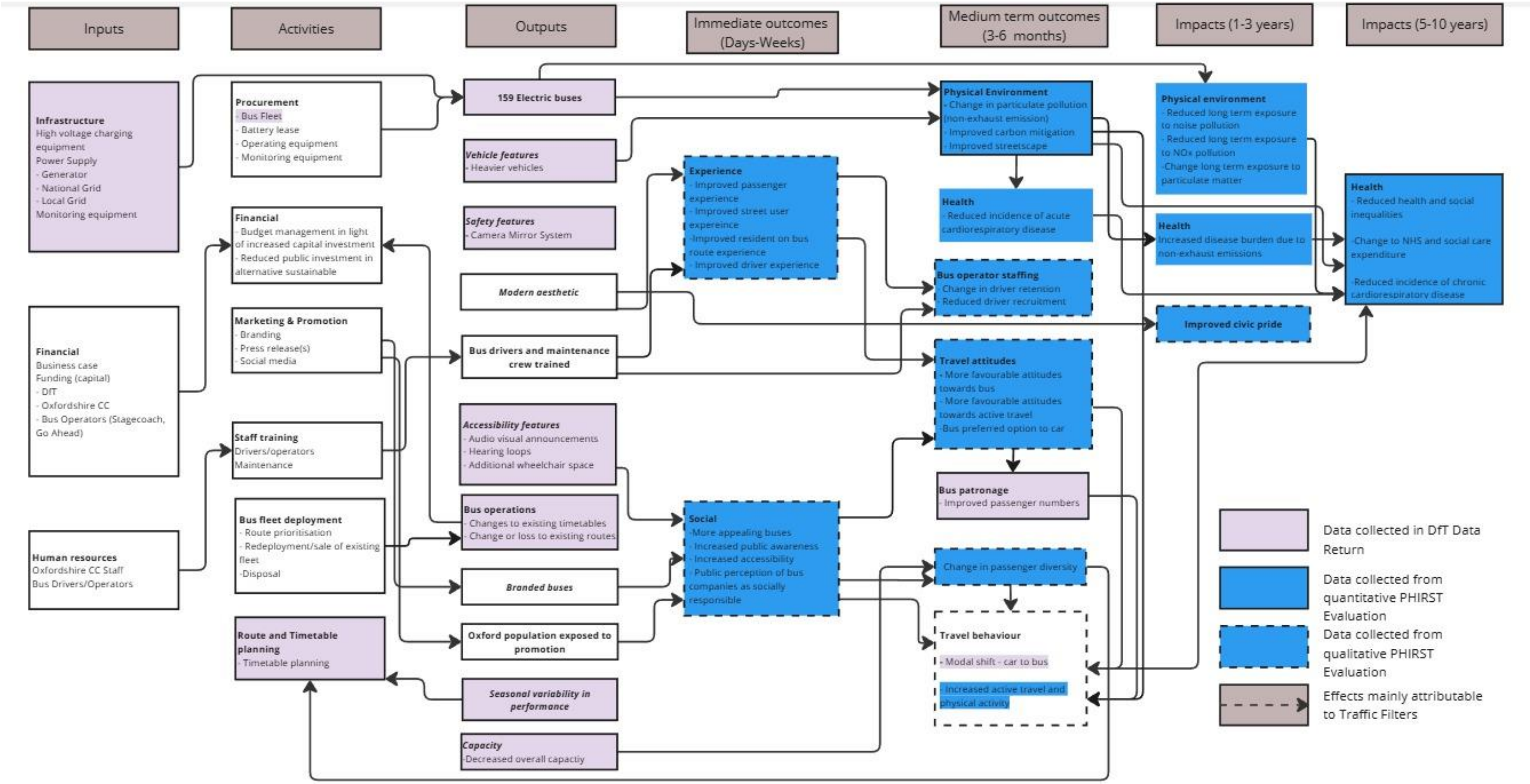
Behavioural
- Reduced bus service demand (due to modal shift to walking and cycling)
- Reduced bus usage among vulnerable groups (e.g. elderly)

Health Increased transport KSIs (number/severity)
- Increased disease burden due to non-exhaust emissions
- Increased health inequalities
- Health impacts of mineral extraction (Global South)
- Toxicity effects of battery disposal

Economic
- Reputational damage
- Reduced public investment in alternative sustainable transport modes

Contextual influences: National: net-zero targets, ban on sale of petrol/diesel vehicles, political administration, bus farestation redevelopment, pricing and franchising, cost of living, new technology (e.g. hydrogen). **Local**: schemes e.g. OxfordshireCC LTCP, LTNs, traffic filters, Workplace Parking Levy, ZEZ, Vision zero, utility changes, 20mph limits Oxford United stadium relocation, Oxford station redevelopment, NHS Green Plans, media, roadworks/construction, Arriva depot closures. **Other:** seasonality, climate change

Updated logic model – Autumn 2024



Contextual influences: **National:** net-zero targets, ban on sale of petrol/diesel vehicles, political administration, bus fare, bus fare cap raised to £3 (January 2025) station redevelopment, pricing and franchising, cost of living, new technology (e.g. hydrogen). **Local:** schemes, e.g. Oxfordshire CC LTCP, LTNs, traffic filters, Workplace Parking Levy, ZEZ, Vision Zero, utility changes, 20mph limits, Oxford United stadium relocation, Oxford Station redevelopment, NHS Green plans, media, roadworks/construction, Arriva depot closures, large financial risk to bus operators, bus operators commitment to corporate social responsibility. Political climate **other:** Seasonality, climate change.

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Available to view online:
https://miro.com/welcomeonboard/QjQ4TEtUQ2g1SCt1SFE0bkwrT1I1aStpU3kzWENaU0RTZmRENTA2V25obnBRL25BZytVdHRvZlA5WENoNHVxME9kUjRhaURWTlJmK090eFFGVGFlTnpmNGppeFdadHpaeU8yNEtWL0dsWDZVdVRjQXY4RTdlY1BHOGZwL3U2ZmZzVXVvMm53MW9OWFg5bkJoVXZxdFhRPT0hdjE=?share_link_id=823047646710

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Evaluation Methods

Ethical approval granted by Science, Technology, Engineering and Mathematics Ethics Committee, University of Birmingham [ERN-3088]

Evaluation methods overview

Research aim	Quantitative methods	Qualitative methods
Effectiveness	Air quality monitors Noise sensors*	Key stakeholder interviews Resident and commuter focus groups Intercept interviews
Feasibility and Acceptability	Health and economic assessment	Key stakeholder interviews Resident and commuter focus groups
Evaluation design	Logic model development Methodological advances	

* University of Oxford Collaboration

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Methods – Air quality data

Methods - Air quality data

Data collection: 1 Jan 2022 – 30 Nov 2025

Automatic Monitoring data: (NO_2, $PM_{2.5}$,PM_{10})

- Oxford St Ebbes* (Urban Background): (NO_2, $PM_{2.5}$,PM_{10})
- Oxford Centre Roadside**: (NO_2)
- Oxford High Street* (Roadside): (NO_2, $PM_{2.5}$,PM_{10})

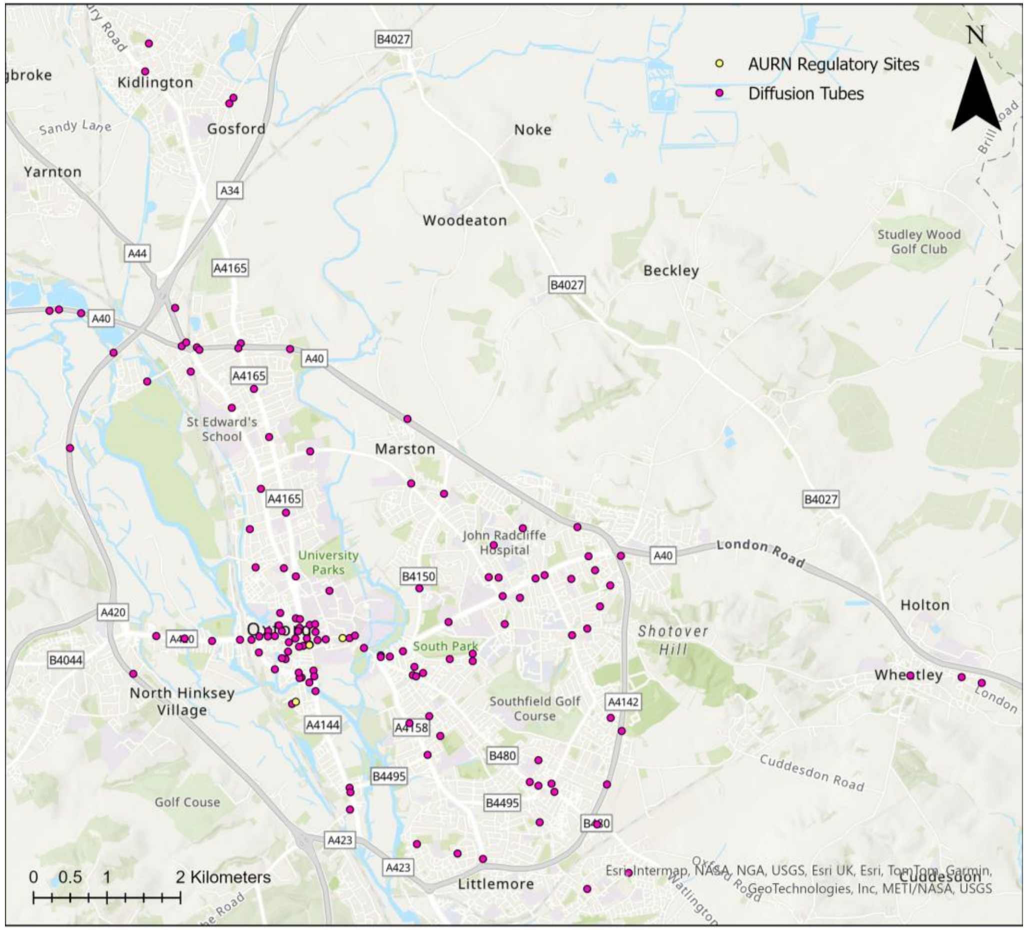
Diffusion tube data (NO_2)

~100 diffusion tubes deployed by

- Oxford City Council
- South Oxfordshire District Council
- Vale of the While Horse District Council
- Cherwell District Council

*Automatic Urban and Rural Network (AURN) site managed by Defra **Monitoring site managed by Oxford City Council

Data obtained from: https://www.oxonair.uk/data



Air quality monitoring locations across the ZEBRA defined area (2025). Yellow = AURN regulatory sites; Pink= diffusion tubes

Methods – Bus route classification

Updated to 2024 baseline

Number of scheduled buses by route:

- Route data (ZEBRA return)
- Timetable data (Bus Improvement Team)

Calculation of total traffic flow*

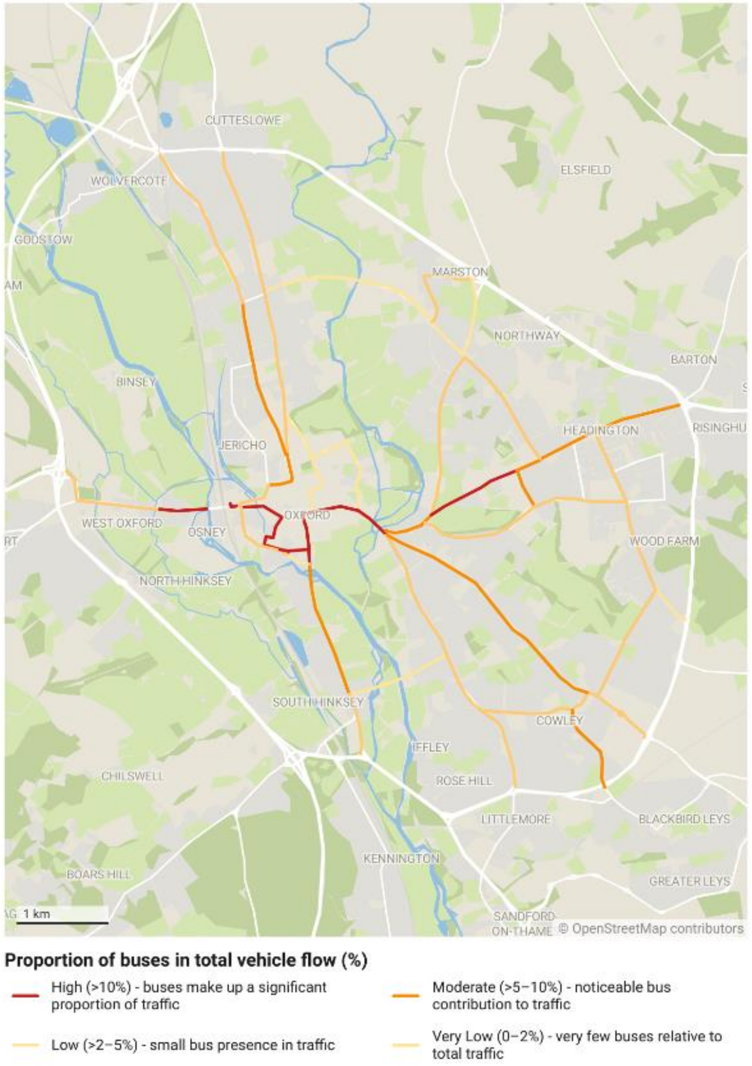
- Oxfordshire County Council Vivacity sensors
- Automated traffic counts and local authority datasets
- Annual Average Daily Traffic (AADT)

Classification of road segments by bus: traffic ratio (excluding coaches)

Traffic modelling data available but may not reflect changes (due to multiple interventions to reduce congestion in Oxford)

*Traffic data provided by Oxfordshire County Council

Oxford Bus Traffic Density: Proportion of Buses in Total Vehicle Flow (AADT 2023/2024)



Created with Datawrapper

Methods - Air quality data analysis

Study design: Interrupted time-series analysis

(1) City Centre

- Primary outcome: NO_2 concentrations
- Secondary outcomes: $PM_{2.5}$ / PM_{10} concentrations
- Data sources: Oxford St Ebbes (Urban background): (NO_2, $PM_{2.5}$, PM_{10}), Oxford Centre Roadside: (NO_2), Oxford High Street (Roadside): (NO_2, $PM_{2.5}$, PM_{10})
- Time resolution: daily/weekly/monthly
- Study period: 1 Jan 2022 – 30 Nov 2025*

(2) Whole city stratified analysis (high/medium/low bus flow routes)

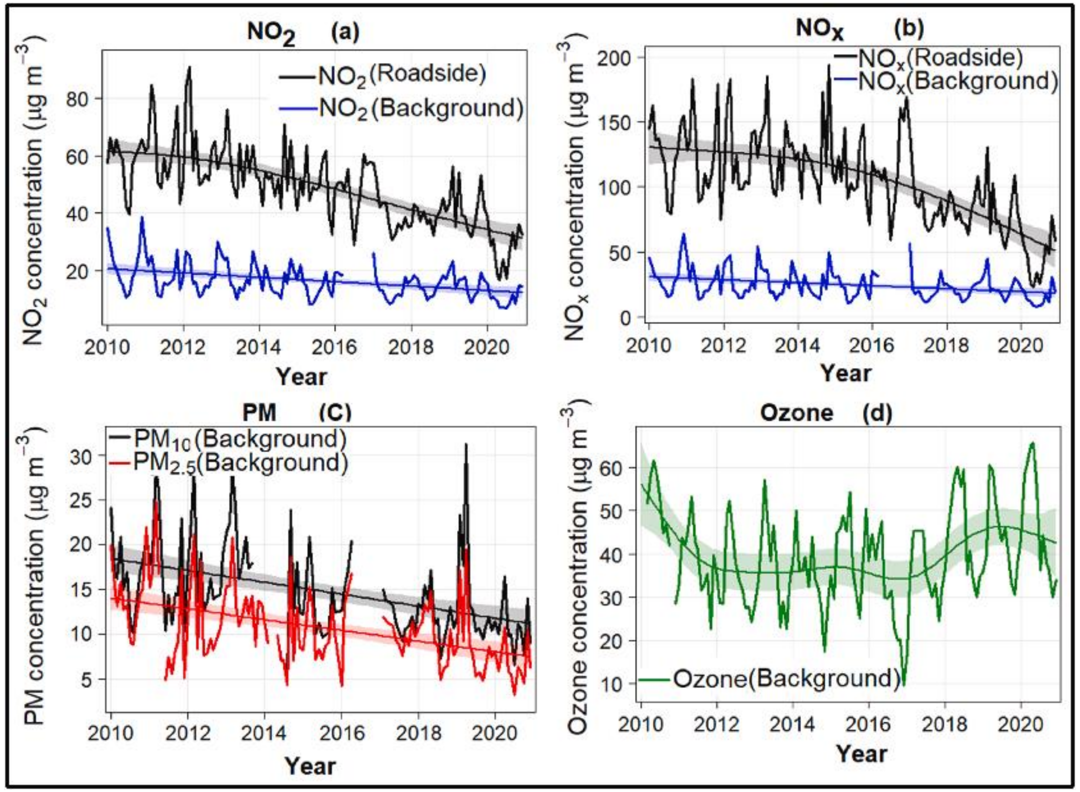
- Primary outcome: NO_2 concentrations
- Data source: Diffusion tubes
- Time resolution: monthly
- Study period: 1 Jan 2022 – 30 Nov 2025*
- Explore changes around intervention dates and comparisons between high/medium/low bus flow routes

*Air quality data analysis will be completed following ratification of 2025 air quality data expected in early 2026.

Methods - Air quality data processing

Methodological considerations – seasonality/trend

- Air pollution concentrations have decreased in Oxford in recent years. Pollution is also influenced by weather and other external events
- Solution: Use of 'deweathering' and 'detrending' method using augmented synthetic control method (Shi et al, 2021) DOI: 10.1126/sciadv.abd6696
- Enable isolation of air quality impacts *attributable* to the local intervention
- Repeat time series analyses using crude and deweathered/detrended datasets



Time series of monthly mean ambient air pollutant concentrations in Oxford City from 2010 to 2020. The shaded lines represent the smooth fit line at the 95% confidence interval. (Singh et al, 2022) https://doi.org/10.1016/j.envpol.2021.118584

Methods – Audio data

Methods – Audio data collection

- Audiomoths* - Low-cost microphone + data-logger
- Capable of recording at sample rates up to 384kHz
  - Audible to ultrasonic
  - For this application set to 48 kHz (will detect 24 kHz noise)
- Records uncompressed WAV files to microSD card
- Powered by 3 x AA batteries
  - Deployed until power runs out
    - ~4 weeks in burst-logging mode
- Measures 58 x 48 x 15 mm
- Set to log for 5 mins 3x per hour (00, 20, 40)
  - Static deployment
- Continuous logging – where deployed on vehicles

*Audiomoth sensors provided by Oxfordshire County Council

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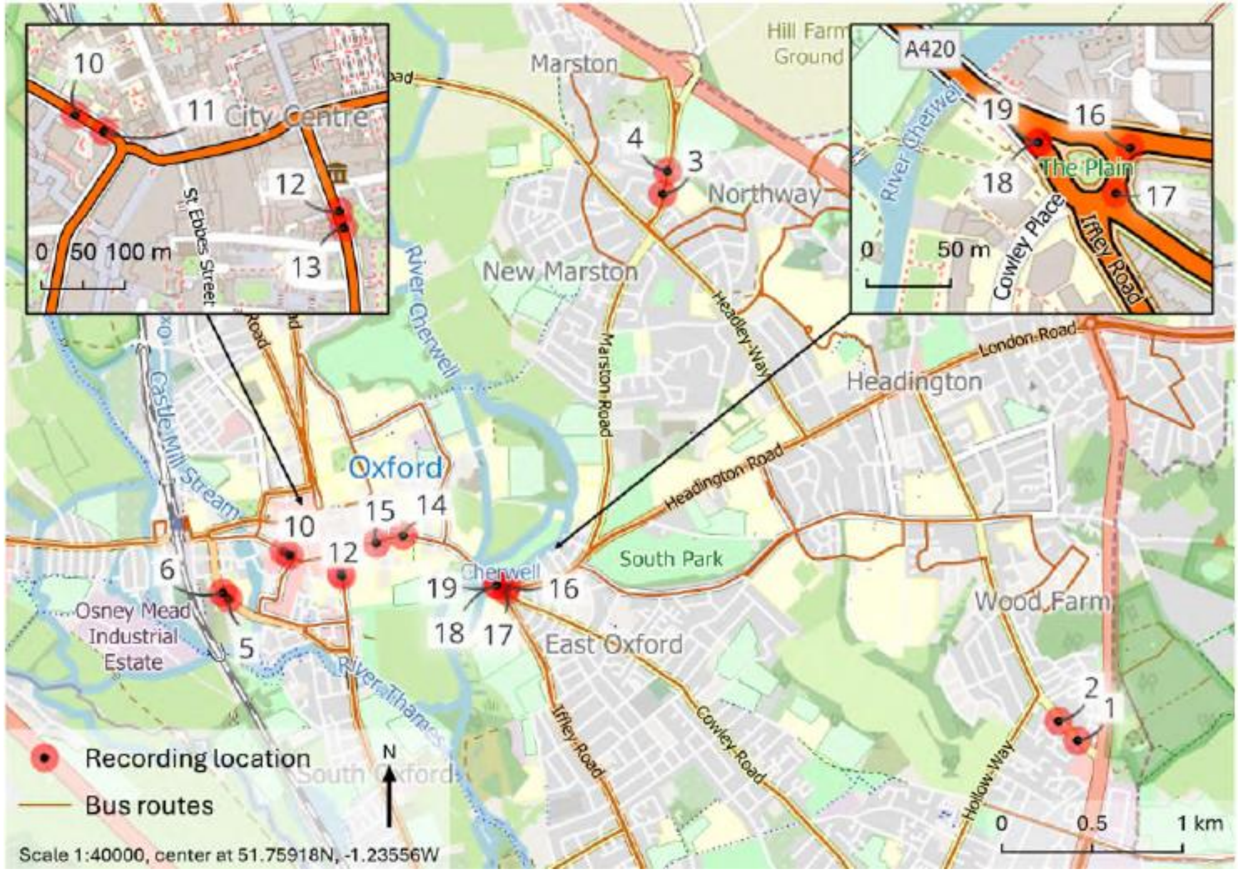
Methods - Audio data collection

Static roadside data collection

- 16x Audiomoths deployed around Oxford
  - 10x Core ZEBRA bus route (New Road / St Aldate's through to the Plain)
  - 6x 'control' locations
  - Mounted on street furniture (~3m height) away from acoustically reflective surfaces (collocated with VL traffic sensors)
- 2x deployments:
  - 25 January 2024 – 20 February 2024 (pre-intervention)
  - 24 January 2025 – 20 February 2025 (post-intervention)



Map of static Audiomoth locations. Black (Intervention sites). Blue (Control sites)
Detailed location information available upon request.

Methods - Audio data collection

Deployed on-board

- 4x buses measured: 2x electric, 2x diesel
    - One technical change (linear to dB logging) to provide protection against distortion
- Ethical approval for mounting + practical considerations ➔ fan/engine compartment

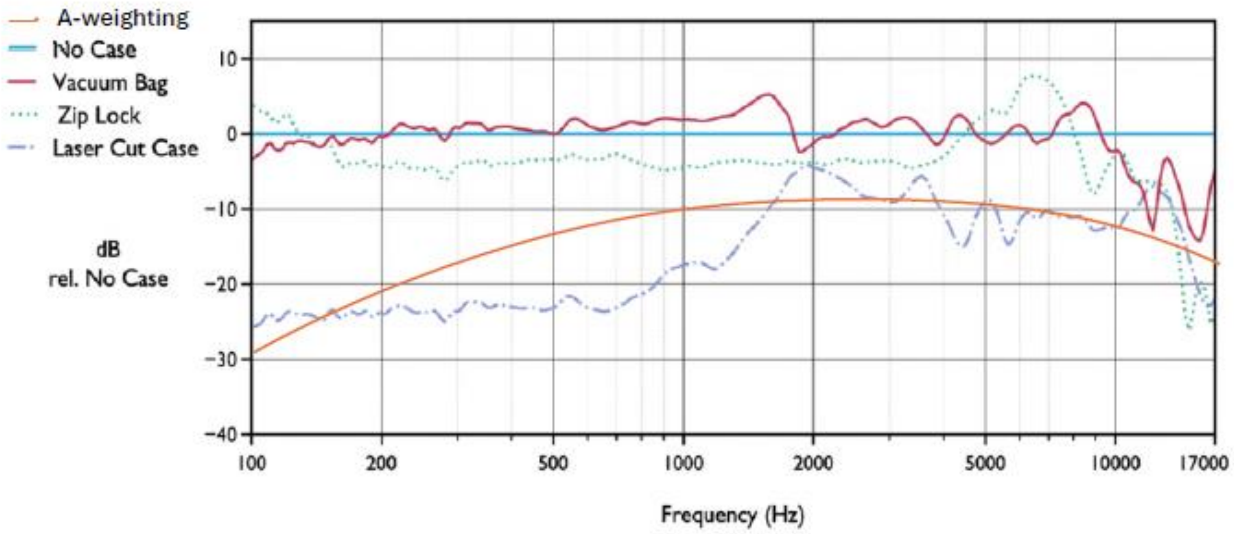
Electric

Diesel

Methods – Audio data analysis

Static deployment

- ~1,880 five-minute audio samples per device-deployment
    - ➔ 58,000 total samples
- Processing done in R
- Equivalent (A-weighted) continuous sound pressure level, L_{eq} or LA_{eq}
    - L_{10} is the level exceeded for 10% of the time (i.e. peak noise)
    - L_{90} similarly (quietest level)



Oxford tests showing case gives broadly same performance as the A-weighting filter (i.e. do not filter twice!)

Methods – Audio data analysis

Static deployment

- Noise Differential Sound Index - NDSI (measure of ratio of anthropogenic to biogenic noise intensity)
    - -1 for anthropogenic sources to 1 for biotic sources
    - Freq ranges 1-2 & 2-11 kHz examined
    - Previously used in LTN project
- Traffic Noise Index – TNI
    - Good correlation with perceived dissatisfaction from traffic noise

$$TNI = 4(L_{10} - L_{90}) + (L_{90} - 30)$$

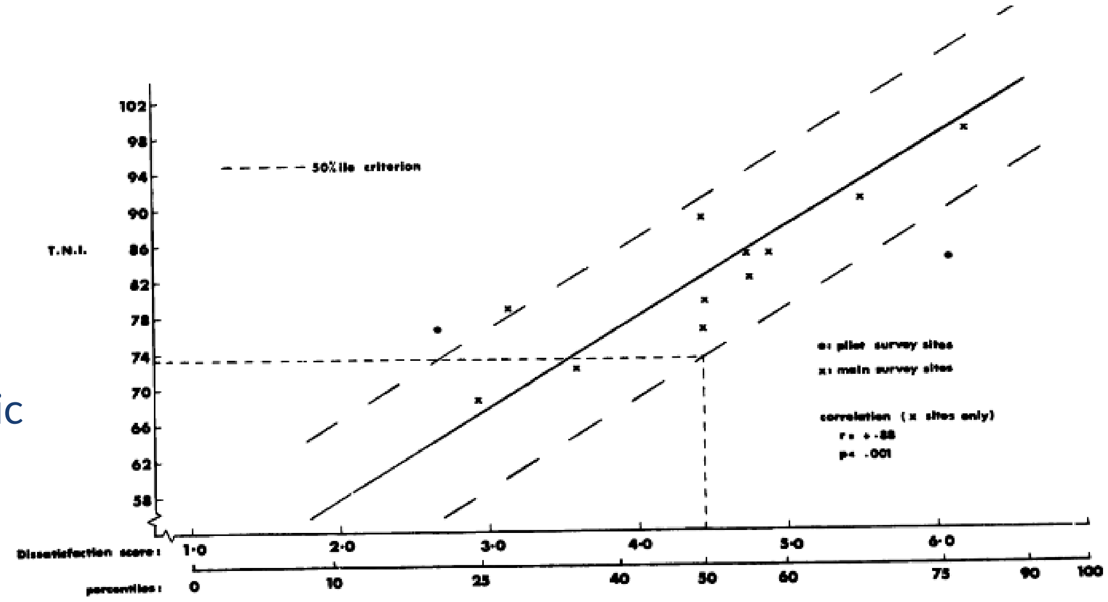


Fig. 3. Relationship between TNI and dissatisfaction with traffic noise.

Methods – Audio data analysis

Static deployment

- Outlier exclusion
    - Median Absolute Deviation method
    - Exclude data >2.5 x standard deviation from median
    - ~2.2% of data excluded
    - Outliers identified as wind, street cleaning, scaffolding or street cleaning
    - Reduces L_{eq} by -1.5% (dB)

Methods – Qualitative data

Methods – Qualitative participant recruitment

Participants and recruitment:

- **Key stakeholders** with direct involvement in the delivery and rollout of the ZEBRA scheme, e.g. elected council members, bus operators, council officers.
  - Recruited via email inviting to participate in the study

- **Bus operator staff** from the two main bus operators in Oxford involved in the operational delivery of the scheme, e.g. bus drivers, engineers, operational staff, driver trainers.
  - Recruited via staff newsletters, posters at bus depots and direct approach from managers
  - In-person focus groups at bus operator depots during working hours
  - Separate focus groups for staff from each of the two bus operators

Methods – Qualitative participant recruitment

Participants and recruitment:

- **Sustainable transport advocacy group** members to represent a broad range of transport users by age, sociodemographic groups, rural locations and those living with disabilities.
  - Recruited via emails, newsletters and social media posts from key sustainable transport advocacy groups in Oxfordshire.

- **Residents and commuters in Oxford** with experience of travelling in Oxford, aged over 16 and with sufficient English proficiency to participate in a focus group/interview.
  - Recruited via Oxfordshire County Council Newsletters, posters in key community locations, in-person recruitment at community venues and events and social media.
  - Recruitment targeted at areas in more deprived areas of Oxford to ensure inclusion of residents affected by health inequalities

Methods – Qualitative data collection

Semi structured interviews *(Key stakeholders)*

- Conducted online, approximately 30-60 minutes.
- Followed a pre-prepared topic guide asking questions about experiences of the scheme rollout, acceptability of the scheme and initial impacts of the scheme.

Focus groups *(Bus operator staff; sustainable transport advocacy groups; residents and commuters)*

- Separate focus groups for each participant group.
- Duration of ~90-minute and participants re-imbursed £40 Love2Shop vouchers for taking part.
- 8 focus groups in-person at convenient locations in Oxford and a range of dates and times.
- One online focus group with residents and commuters.

Methods – Qualitative data collection

Intercept interviews *(Residents and commuters)*

- Bus users approached on while riding or waiting to board buses for 5-minute interviews
- Bus routes selected to serve a range of key locations in Oxford, including hospitals, university, park and ride sites and deprived communities.
- Permissions granted by bus operators to conduct interviews and drivers aware
- Researchers asked basic demographic details, about their journey and views on the impacts of the ZEBRA Scheme
- Researchers made field notes. Interviews **<u>were not</u>** audio recorded.

Methods – Qualitative data analysis

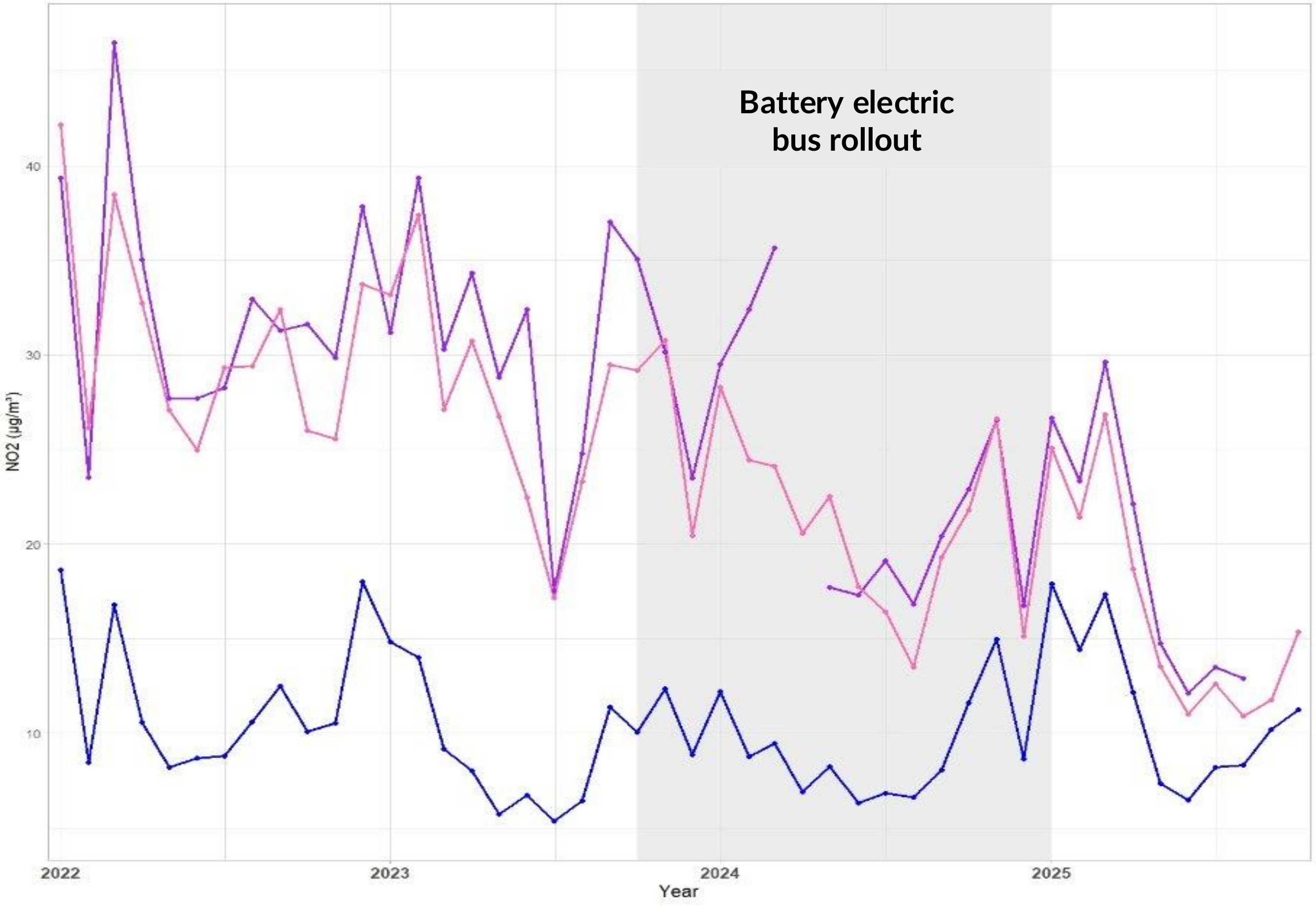
- Interviews and focus group audio recordings were transcribed and anonymised.
- Transcripts analysed using codebook thematic analysis. Key steps included:
    - Familiarisation with the data
    - Coding transcripts under core domains of the logic model
    - Inductive coding within each logic model domain.
    - Two researchers coded transcripts in duplicate to agree an initial coding framework
    - Remaining transcripts coded separately by one researcher.
- Researchers met to review and refine codes.
- Following coding, codes were examined and collated to themes which were reviewed and refined.
- Data analysed using Nvivo software to facilitate coding.

Results

Results - Air quality

Results - Air Quality (Provisional)

- On average, NO_2 levels reduced by 10% across the city in 2024 (from 2023).
- Reductions of up to 24% were observed in central areas of high bus traffic (Oxford High Street and St Aldates).
- Air quality data analysis (including $PM_{2.5}$ and PM_{10} concentrations) will be completed following ratification of 2025 data expected in early 2026.



Monthly average Nitrogen Dioxide (NO2) concentration by reference monitoring station // Purple: Oxford Centre (St Aldates) – Roadside. Pink: Oxford High Street – Roadside. Blue: Oxford St Ebbes – Urban Background. Data available at https://www.oxonair.uk/data

Results – Audio data

Results – Audio data

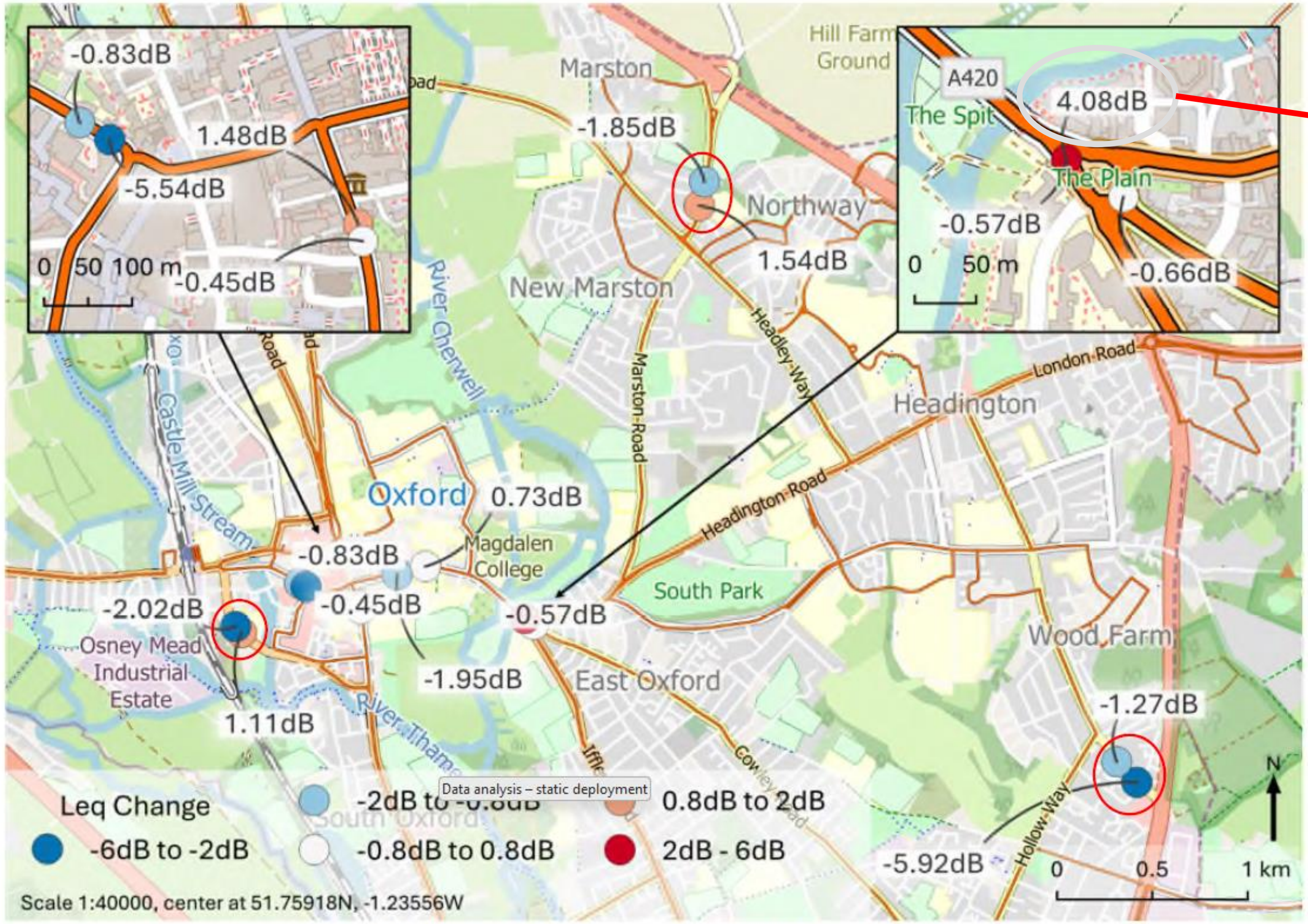


Figure 12; $\Delta L_{eq,T}$ by location, with control locations circled

Static deployment - L_{eq}

- Device has construction opposite in 2025
- Mixed picture, bus locations show ~0.5-1 dB reduction

Results – Audio data

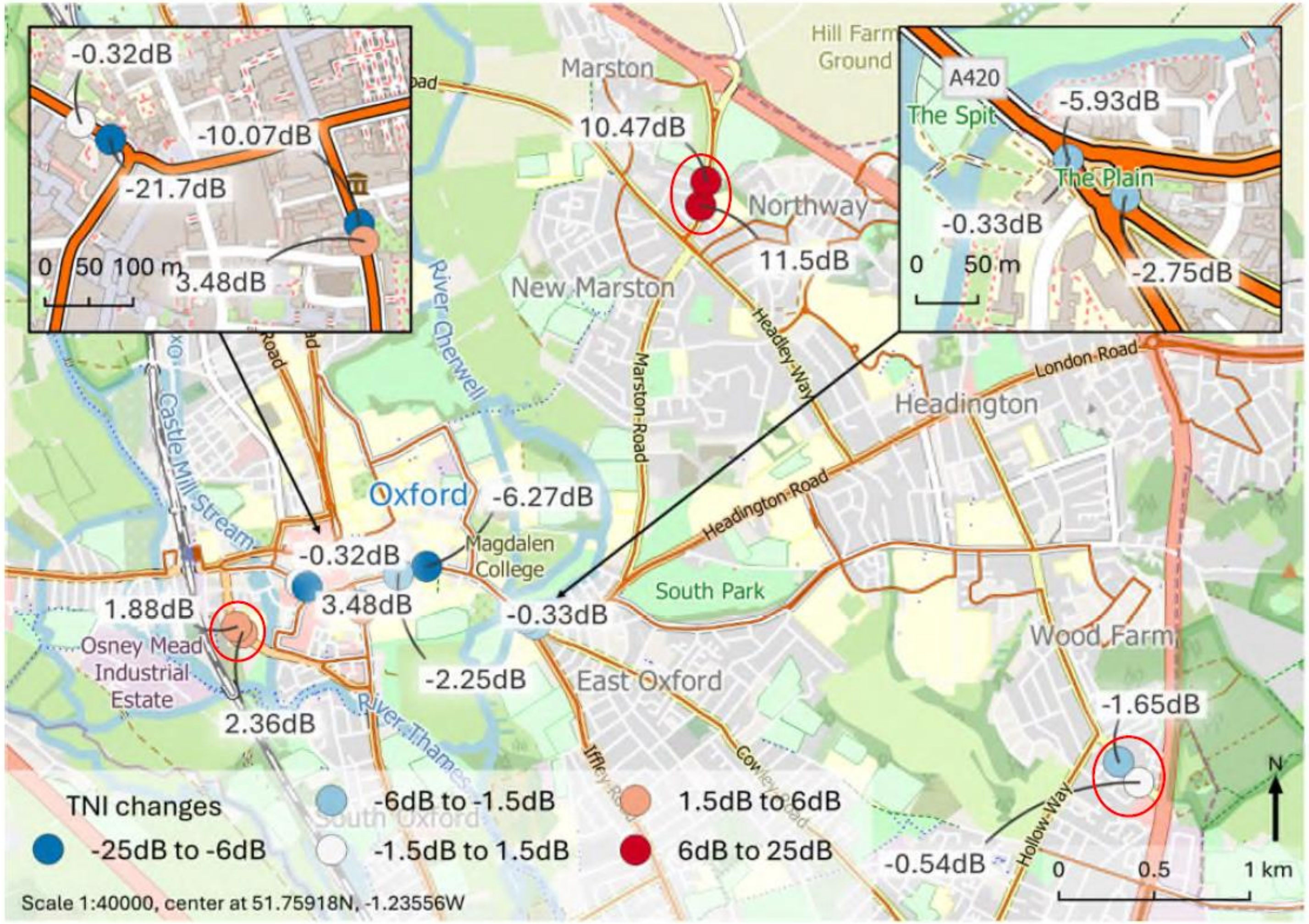
Static deployment - $L_{10/50/90}$

- Control locations only see small changes in L_{10} (peak noise), L_{50} (median), and L_{90} (quietest noise)
- Intervention locations see large reduction in L_{10} (peak noise gets much quieter)
- Intervention locations also see some reduction in L_{90} (quietest noise gets quieter)
- L_{50} variable
- ➔ Intervention has reduced peak noise substantially

Results – Audio data

Static deployment – Traffic Noise Index

- Very clear results in Traffic Noise Index
- Bus locations show 0.3-6 dB drop
  - Average 5.1 dB drop
- Control locations:
  - Oxpens 2 dB rise
  - Hollow way 1 dB fall
  - Marston 10 dB rise
  - **Average 7.0 dB rise**

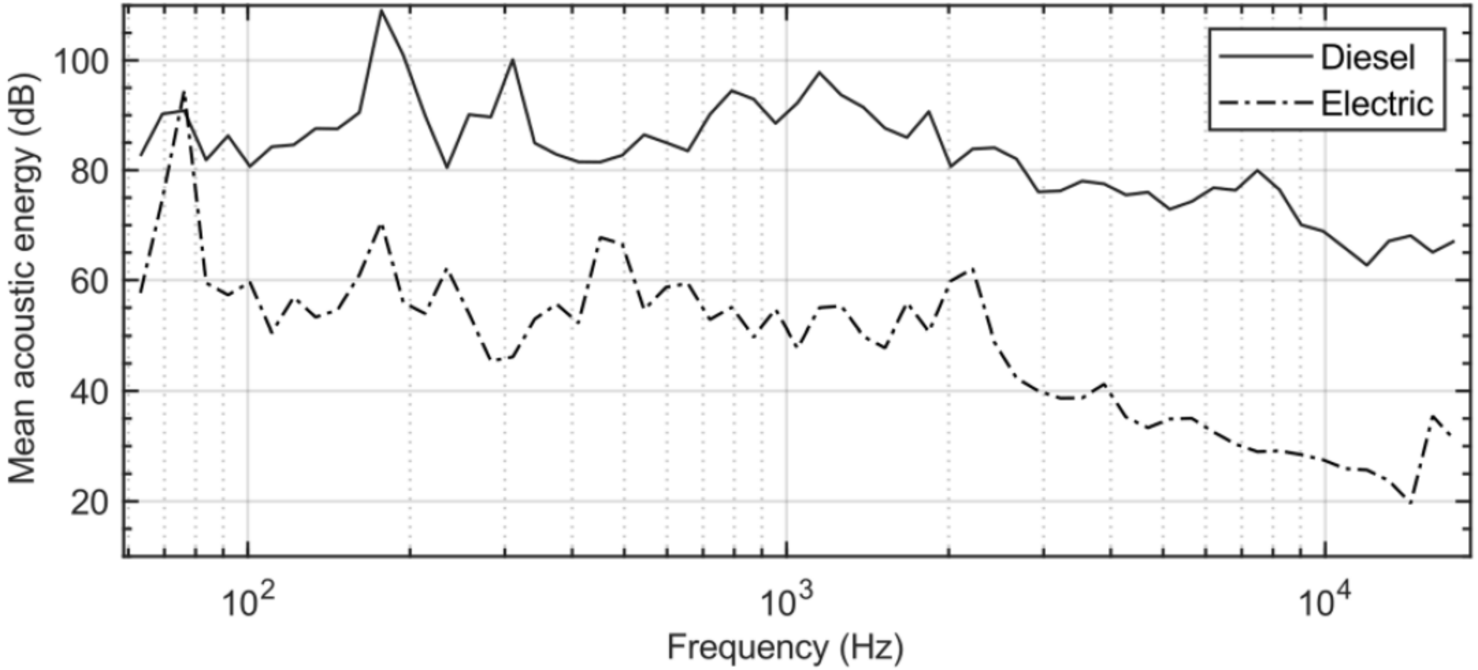


Traffic Noise Index changes by location (dB), with control locations circled

Results – Audio data

On-board measurements - frequency

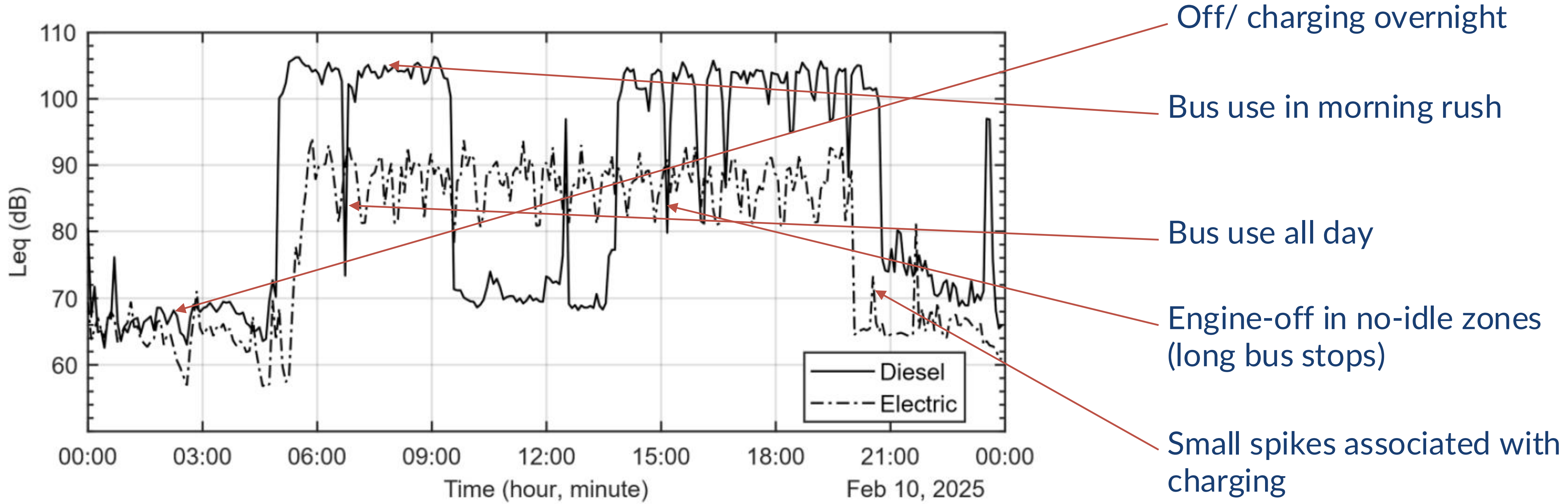
- 20-30 dB reduction in onboard noise from electric bus
- Consistent across frequency range
  - One E-bus peak ~85 Hz – fan (we think)



Results – Audio data

On-board measurements - diurnal

- ~15 dB higher diesel noise consistently (except when off)
  - 32 times the acoustic dose



$L_{eq,5min}$ over time, diesel and electric buses

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Results - Audio data

- Significant changes observed at roadside locations (intervention vs control) using traffic noise index
- On-board results show 20-30 dB reduction in onboard noise from electric bus

Conclusions - Audio data

- 20 Audiomoths successfully deployed to measure noise impact of ZEBRA intervention
- Substantial reductions in TNI seen for intervention locations
- L_{eq} and $L_{10/50/90}$ show reductions in overall noise too
- NDSI not appropriate in urban environments
- Other things matter too (wind, construction etc)
- The transition from diesel to electric buses in Oxford has had a meaningful and measurable impact on reducing traffic-related noise in central areas

Results – Qualitative data

Results – Qualitative data

- **10 interviews with key stakeholders** (3 bus operator employees; 4 elected council members; 3 council officers)

- **9 focus groups (Total 65 participants)**
    - 2 focus groups with 18 bus operator employees (6 drivers, 2 driver, trainers, 4 engineers and 6 operational staff).
    - 1 focus group with 10 members of sustainable transport advocacy groups.
    - 6 focus groups with 37 resident and commuters in Oxford.

- **47 intercept interviews with bus users**

Results – Qualitative data

Demographic data for public participants			
	n (%)		
	Sustainable transport advocacy groups (1 Focus group)	Resident and commuters (6 Focus groups)	Resident, commuters and visitors (Intercept interviews)
	n=10	n=37	n=47*
Gender			
Male	6 (60%)	11 (30%)	13 (27%)
Female	4 (40%)	25 (68%)	30 (63%)
Other		1 (3%)	2 (4%)
Age			
16-24	0 (0%)	1 (3%)	13 (27%)
25-44	0 (0%)	14 (38%)	21 (44%)
45-64	2 (20%)	9 (24%)	5 (10%)
Over 65	8 (80%)	13 (35%)	6 (13%)
Ethnicity			
Asian or Asian British	0 (0%)	7 (19%)	6 (13%)
Black, Black British, Caribbean or African	0 (0%)	2 (5%)	8 (17%)
Mixed or multiple ethnic groups	0 (0%)	1 (3%)	0 (0%)
White	10 (100%)	25 (68%)	26 (54%)
Prefer not to say	0 (0%)	0 (0%)	2 (4%)
Other	0 (0%)	0 (0%)	3 (6%)

***Demographic data missing for 3 participants**

- Recruitment strategies for resident and commuter focus groups, e.g. in-person recruitment at community venues and events widened demographic profile of participants.
- Intercept interviews on board buses recruited a greater diversity of participants, that was more representative of Oxford City population compared to the focus groups.
- Compared to the characteristics of Oxford population there was over-representation of people aged over 65 and white ethnicities in focus groups with sustainable transport advocacy groups and resident commuters

Results – Qualitative data

Theme 1: Experiences of the environment

Improved air quality

- Described noticeable improvements in air quality – less exhaust smoke, pollution, heat and diesel fumes.
  - **'They tend to just glide along the road rather than belching out lots of diesel smoke' [Resident/Commuter]**

- Stakeholders reference Air Quality Reports published that demonstrate impact.

- Frustrations expressed that congestion limits potential impact of buses on air quality (but at least battery electric vehicles are not contributing to pollution when stuck in traffic).

Results – Qualitative data

Theme 1: Experiences of the environment

Reduced noise pollution

- Residents on bus routes describe fewer noise disturbances, enjoying a more peaceful home environment.
    - **‘Even when you’re sitting in the evening watching TV, they stop nearly opposite my house, then you’d know straight away that they’re going past. But now we don’t notice them half as much.’ [Resident/Commuter]**

- Reduced noise contributed to lower stress levels of road users.

- Safety concerns mentioned due to quietness of buses and pedestrian safety, particularly for people with hearing and sight loss.

Results – Qualitative data

Theme 1: Experiences of the environment

Improved urban and natural environment

- Transformative impact of electric buses on the city centre streetscape and high frequency routes due to collective impacts of air and noise.
  - **'It just feels a lot less offensive city centre experience in the city.' [Resident/Commuter]**

- Contributed to a more pleasant, enjoyable atmosphere, reduced sensory overstimulation and an improved social experience.

- Cyclist and pedestrians report more pleasant experience.
  - **'If you are cycling and you're sharing the road with a bus there's no comparison between being behind one of these new electric vehicles compared to a horrible smelly old diesel.' [Key Stakeholder]**

Results – Qualitative data

Theme 2: Positive perceptions and experiences of electric bus fleet

Overall improvement to travel experience

- Pleasant experience to travel on electric buses leading to preference for diesel and disappointment when travelling in diesel bus.
    - **'You will occasionally get diesel buses on a local, drivers now will complain if they don't have an electric vehicle.'[Bus operator Staff]**

- Drivers pleased to be able to offer improved ride quality and report improved passenger satisfaction and fewer negative passenger interactions.

- Notably, some intercept interview participants noticed no difference in passenger experience during the transition from diesel to electric buses.

Results – Qualitative data

Theme 2: Positive perceptions and experiences of upgraded bus fleet

Improved travel experience due to electric vehicles

- Some improved travel experience due to electric features, e.g. quieter engine, reduced vibration and smoother acceleration and deceleration leading to smoother and more pleasant journeys.

- Cumulative impact of reduced vibrations and more responsive driving described as enhancing driver wellbeing.

- Surprise among drivers of suddenness of acceleration and deceleration and safety concerns among passengers.

Results – Qualitative data

Theme 2: Positive perceptions and experiences of upgraded bus fleet

Improved travel experience due to upgraded bus fleet

- Features include upgraded technology, modern appearance, comfortable seating and cleaner, fresher interior (including smell), and a focus on driver comfort.
- Positive perceptions of enhanced accessibility features and those with direct experience of travelling with wheelchairs and prams welcomed additional space. Although on some buses, the layout meant it was difficult to manoeuvre prams and wheelchairs into the allocated spaces.

Results – Qualitative data

Theme 3: Wider transport influences on travel behaviour

Mixed perceptions on modal-shift

- Some participants improved travel experience encouraged them to use the bus more.
    - **'I remember going on a bus more recently, maybe in the last year, and being like oh this is actually really convenient, actually a nice experience, so I'll probably do this more.' [Resident/Commuter]**

- Others describe more prominent influences on travel decisions, e.g. cost, reliability, connectivity, ticketing and journey times and mode of travel is secondary consideration.
    - **'I think there's some of the points you mentioned that are wider issues beyond the electric buses that would need addressing before those benefits come into play, and that might be things like we've mentioned the reliability, the cost, those things I feel like some of those elements need to be addressed first.' [Resident/Commuter]**

- Bus operators note no change in bus patronage, acknowledging the delayed implementation of bus journey time improvement measures.

Results – Qualitative data

Theme 4: Perceived impacts on health

Physical health impacts

- Improved symptoms of existing health conditions, including asthma, chronic obstructive pulmonary disease and eye irritation. Previous noise from diesel buses had aggravated tinnitus.

- Also experienced by drivers, who report improvements in physical health after long shifts.
  - **‘As a driver one major, major benefit when you sit in the cab for nine hours with an electric bus, you get out of it far less fatigued, because at every set of traffic lights in a diesel bus, at everything, the bus is vibrating at you.’[Bus Operator Staff]**

Mental health and wellbeing

- Contributed to lower levels of irritation and stress and improved mood due to lower noise.
  - **‘I feel less angry, because genuinely sometimes you’d be there and you’re just dropping off and then a bus will turn up and sit there, and it’s the kind of thing where you want to get up and throw a shoe out the window…and you just don’t have that anymore.’ [Resident/Commuter]**

- Residents on bus routes report less noise disturbance at night, leading to improved sleep and wellbeing.

Results – Qualitative data

Theme 4: Perceived impacts on health

Hypothesised benefits on long-term health

- Long-term health impacts based on evidence, expert opinion or general understanding of health impacts rather than direct experience.

- Stakeholders described benefits to population respiratory health with potential to reduce prevalence and severity of child asthma.

- Stakeholders described potential to reduce health inequalities because routes in deprived areas converted predominantly to electric.
  - **‘Certainly, some of the corridors where it’s having a dramatic impact on air quality and noise pollution are some of the more deprived areas in the east of the city.’ [Key Stakeholder]**

Results – Qualitative data

Theme 5: Wider and unintended impacts

Unintended impact on existing road and building infrastructure

- Impact of heavier vehicles on road surface degradation was prominently discussed. Concern often speculative, and difficulty in attributing road degradation to only the electric buses.
  - **'I think there is a perception of greater road damage, I don't know again true that is. But it seems to be now that any time there was a problem with the road anywhere it... you go on social media and it's just 20 people blaming electric buses, even if electric buses have never gone down there.' [Key stakeholder]**

- Bus drivers note quicker rate of degradation when a problem appears.

- Emerging incidents of road degradation and damage to road surfaces, water drains and resident homes on lower classification roads, while can't be attributed to electric buses, they 'can't have helped'.

- Accelerated rate of surface degradation in bus depots reported by one operator.

Results – Qualitative data

Theme 5: Wider and unintended impacts

Wider environmental impacts

- Concern among residents and commuters about wider environmental impacts. Note that particulate pollution from brake and tyre wear may be worse due to heavier vehicles.

- Residents and commuters not aware of energy source for vehicles and concern that emissions are being displaced.
    - **I know with a lot of electric vehicles that's one of the concerns, is yes in the city there's less pollution, but at the production site is it creating more waste, creating more other kinds of pollution, and what is the impact on the surrounding communities there.' [Resident/Commuter]**

- Concern about lifecycle impacts of buses, including battery production and recycling.

Results – Qualitative data

Theme 5: Wider and unintended impacts

Impacts on wider transport system

- Displacement of existing high quality diesel buses confer benefits to other towns and cities in the county and country, although lack of awareness about this.

- Wider influence on transport policy including sense of confidence in council and bus operators to implement innovative schemes and acceptability of policies to improve priority for buses, including the temporary congestion charge.
    - **'Giving buses priority has certainly become easier, because it's electric buses are seen as something that's generating positively to the environment. Whereas putting priority into a smelly diesel go past, even though it's still much better for the environment than ten cars is, of course there is perception that's not the case.' [Key Stakeholder]**

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Results - Feasibility and acceptability of implementation

Results – Qualitative data

Contextual features influence the implementation of battery electric vehicles

Existing local transport context

- An existing intensive bus network and city-centre ticketing boundary, supplied by two main operators limited the use of inter-urban routes, less suitable for electrification.
- High levels of bus patronage in Oxford and good level of service.
- Existing traffic congestion impacts bus reliability and profitability therefore reducing congestion is a priority.

Social, political and geographical context were conducive to acceptability

- A young, well-educated population that are receptive to net-zero policies.
- Perceptions of Oxford as an innovative city and at the forefront of development.
- Local authority and elected members supportive and ambitious to deliver schemes to maximise best use of space within city centre.

Maximising impacts of bus electrification

- Business case included agreement to improve bus journey times by 10% to maximise bus efficiency, service and re-investment into bus improvements, as a key mechanism of securing financial investment from bus operators.

Results – Qualitative data

Collaborative working across stakeholder groups

Stakeholders had a collective vision underpinned by differing priorities

- Stakeholders described working towards an overarching collective vision of increased bus patronage.
- Stakeholders from local authority described ambitions to improve public realm and air quality and bus operators prioritised bus network improvements.

Collaborative approach to funding

- Finding the right funding opportunity was important bids to previous funds had been withdrawn due to their unsuitability to the Oxford context.
- Requirement for additional funding from commercial bus operators and Oxfordshire County Council.
- Business case needed to ensure funding proposal was commercially viable, balancing operational feasibility with financial sustainability.

Results – Qualitative data

Collaborative working between multiple stakeholders

Buy-in required from stakeholders across multiple levels to sustain strong relationships

- Scheme required collaborative working between national and local governments and competing commercial bus operators.
    - **"I think we're very grateful that the ZEBRA scheme, facilitating the level of investment that a city like Oxford using its vehicles, because it's brought all partners together really to be able to invest in replacing the bus fleet." [Key stakeholder]**

- Features of strong relationships included ability to have regular, open and honest conversations as an essential factor for implementation, although, one stakeholder describe the delay of bus journey improvement time measures were placing strain on these relationships.

- Collective buy-in also described strongly within one bus operator, with staff embracing the shift to electric vehicles.

Results – Qualitative data

Bus operation planning

Implementation requires ongoing planning and monitoring to respond to changes over time

- Reduced battery ranges (influenced by routes, weather and traffic conditions), influence bus timetables, driver shift patterns and rotas, where plans were refined over many stages to maximise the efficiency.

- Difference described between bus operators in the degree of planning which led to difference experiences of the smoothness of rollout, e.g. initially there were some breakdowns as buses didn't have enough charge.

Results – Qualitative data

Bus operation planning

Depot infrastructure and electricity supply

- Both operators faced challenges when electrifying depots, including legal, health and safety, and operational challenges.
  - **“We had a couple of challenges, the biggest one at that stage was around vehicle movements, where we were putting a lot more vehicles onto a site than we previously had, and obviously chargers take up room.” [Key stakeholder]**
- The bus depot location was fortunate as they were able to plug into a charging superhub of renewable energy developed on outskirts of Oxford to provide high voltage power supply.

Vehicle procurement

- Selection of vehicle manufacturer was commercial decision for each operator. One operator used tender process, stipulating need to provide training to their engineers for sustainability, other selected based on long-standing relationships.
  - **“If [bus manufacturer] collapses tomorrow… or if they struggle to recruit engineers, or different people run [bus manufacturer] than run it today, doesn’t matter, because our guys are trained up to a level where they can look after the vehicles, and that’s important really.” [Key stakeholder]**

- Choice of vehicle manufacturer impacted scheme implementation, with one operator experiencing technical faults and vehicle recalls.

Results – Qualitative data

Bus operation planning

Upskilling staff to adapt to new roles

- Engineers, drivers and operational staff required training to adapt to differences in vehicles e.g. heavier vehicles, different fault types.

- Mixed views among drivers whether they had received sufficient training. One operator described a 6-month gap between training and vehicle implementation, which impacted drivers implementing course learning.

- There was apprehension among drivers, which dissipated after rollout, and among some engineers due to the lower number of anticipated defects on electric vehicles with potential impacts on job security.

- Participants highlighted the importance of training operational staff early to assist drivers during rollout.

Implications for policy and practice

Implications for policy and practice

Introduction of electric **buses delivers environmental benefits** and **improved passenger experience.** To maximise scheme benefits local transport authorities should:

- Prioritise routes serving communities most affected by air and noise pollution
- Consider complementary measures which make bus travel mode affordable, reliable and convenient

Implications for policy and practice – local context

- **Consider features of the existing bus network and the local transport context when designing and planning schemes**
  - The number of bus operators delivering services on bus routes within the implementation zone will impact on the feasibility of delivery.
  - Consider utilising features of existing bus network to design and draw boundaries on service implementation e.g existing ticketing zones.
  - Consider the suitability of existing bus routes for electrification based on features including distance, topography and passenger demand.
- **Consider using wider transport policy packages to maximise buy-in and the positive effects of bus electrification**
  - Explore embedding fleet electrification alongside additional policy measures to achieve local ambitions, e.g. traffic reduction.
  - Embed additional policy measures into legal agreements to ensure delivery and to facilitate commitment and buy-in from stakeholders.

Implications for policy and practice – working together

- **Ensure buy-in from multiple stakeholders and maintain strong working relationships**
  - Identify common vision of scheme for all stakeholders involved and ensure there is awareness among stakeholders of differences in underlying priorities.
  - Maintain regular, open and honest communication between all partners about implementation progress including challenges to maintain strong relationships.
  - Identify additional opportunities to collaborate, including marketing and promotion.
- **Identify funding opportunities and ensure they are suitable for local needs**
  - Assess potential funding opportunities from national and local government and assess their suitability for the local context.
  - Explore collaboration between multiple stakeholders to obtain and maintain financial buy-in from all who stand to benefit from the scheme.

Implications for policy and practice – bus operation

- **Ensure adequate planning across multiple business operations and continual monitoring and evaluation to respond to changes over time**
  - Conduct monitoring at key times during implementation, including business case, vehicle model selection and within local operation with continued monitoring during different seasons and as battery ages.
  - Utilise available real-world data and make conservative estimates for vehicle capabilities during initial rollout to ensure adequate battery rate and smooth transition.
  - Utilise updated monitoring to maximise efficiency of buses and explore their use on additional routes.
  - Consider innovative solutions to timetable and driver rotas to make most efficient use of electric vehicles.

Implications for policy and practice – bus operation

- **Consider the suitability of existing depot sites for installing charging infrastructure and obtaining and adequate power supply**
  - Assess suitability of existing depot sites for electrification beyond initial impressions, e.g. open, flat land, to include legal considerations (e.g. land ownership, depot boundaries) and availability of adequate energy supply.
  - Consider identifying new depot sites within the options appraisal.
  - Consult with energy companies to assess and mitigate risks to energy supply.
  - Utilise additional specialist expertise to inform the depot electrification.

Implications for policy and practice – bus operation

- **Provide high quality staff training across roles within bus operators to improve buy-in ahead of significant role changes**
  - Ensure driver training includes in-service elements and occurs close to implementation and offers ongoing support for drivers following implementation.
  - Ensure operational control staff are trained ahead of vehicle rollout to enable them to support drivers during the initial stages of implementation.
  - Provide opportunities for staff to learn from each other as rollout progresses.
  - Assess ability to train staff with limited vehicle numbers, trainers and requirements to take drivers out of service.
  - If required, communicate early and clearly with staff members and trade unions in relation to role changes.
  - Monitor changes in staff workloads resulting from implementation and recruit additional staff accordingly.

Capacity building and evaluation design

Skills and Infrastructure Development (local)

- Air quality modelling to quantify health benefits of net-zero scenarios including battery electric bus transition.
- Support for Community Engagement Officer to develop research skills in primary data collection (intercept interviews, focus groups).
- Provisional findings provided to inform Oxfordshire County Council Air Quality Strategy 2025-2030.
- Provision of local air quality data for Oxford University Hospitals NHS Foundation Trust to support Green Plan reporting.

Monitoring and evaluation

- The evaluation has informed design of future evalautions including: (a) baseline data and (b) methodology and wider contextual considerations.

- Research has been coordinated with the naitonal ZEBRA evaluation (Steer) including a recommendation to include air quality data in mandatory evaluation returns for local authorities .

- Joint bid developed with Oxfordshire County Council for the Local Authority Innovation Monitoring and Evaluation (DSIT Regulators Pioneers Fund) .

- Additional commissioned work:
  - Development of an Air Quality Lifecourse Assessment Tool for Oxfordshire.
  - Scoping future research to quantify air and noise benefits of rail electrification.

Monitoring and Evaluation

Recommendations for primary data collection to understand medium (3-6 months) to long-term (1-10 year) outcomes for the ZEBRA scheme

	Indicator(s)	Data source(s)	Data provider(s)
Health	Morbidity: disease incidence, hospital admissions, consultations, prescriptions Mortality: all-cause/cause-specific	Hospital Episode Statistics (HES) Primary care consultations Census data	NHS Digital Clinical Practice Research Datalink (CPRD) Office for National Statistics (ONS)
	Road casualties: killed/serious injuries	Casualty reports Road safety statistics	Local authority DfT
	Physical activity: pedestrian/cycle counts	Roadside sensors	Local authority
	Occupational health: key groups (i.e. bus drivers, highway workers)	Bus and Coach driver statistics	Bus operators DfT
	Highway condition	Road surface quality	Local authority National Highways

Monitoring and Evaluation

Recommendations for primary data collection to understand medium (3-6 months) to long-term (1-10 year) outcomes for the ZEBRA scheme

	Indicator(s)	Data source(s)	Data provider(s)
Environment	Air and noise quality: NO_2, $PM_{2.5}$, PM_{10}, Ozone. Traffic noise index (dB)	Automatic monitoring, diffusion tubes Noise measurements	Defra Local authority Research institutions
	Carbon dioxide: whole-life cycle emissions	Energy consumption Recycling and disposal	Bus operators
	Meteorological: Temperature, humidity	Weather records	Met Office
	Traffic congestion	Traffic activity data	Local authority DfT
	Highway condition	Road surface quality	Local authority National Highways

Monitoring and Evaluation

Recommendations for primary data collection to understand medium (3-6 months) to long-term (1-10 year) outcomes for the ZEBRA scheme

	Indicator(s)	Data source(s)	Data provider(s)
Productivity	Retail sector activity	Footfall Expenditure Shop vacancies	Local authority Surveys
	Bus usage	ZEBRA quarterly data returns	DfT
Place-shaping	City streetscape	Focus groups, interviews	Local authority Research institutions
	Travel preferences	Focus groups, interviews	Local authority Research institutions
Connectivity and Inclusivity	Bus journey times	ZEBRA quarterly data returns	DfT
	Bus breakdowns/repairs	ZEBRA quarterly data returns	DfT
	Bus accessibility	Focus groups, interviews	Local authority Research institutions

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Paul Mullins

Katie Parnell

Sasha Redhead

Jason Taylor

Dr Foyeke Tolani

Oxford City Council

Pedro Abreu

Ealing Council

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Public Collaborators

Peter Richardson

Karen Keates

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Oxford Bus Company

Stagecoach

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