NIHR | Public Health Intervention Responsive Studies Teams

PHRESH

Project NIHR166658: Evaluation of the Zero Emission Bus Regional Area (ZEBRA) scheme: the introduction of zero-emission buses in Oxford, UK

Study Protocol

Evaluation Title	Evaluation of the Zero Emission Bus Regional Area (ZEBRA) scheme: the introduction of zero-emission buses in Oxford, UK
Local Authority	Oxfordshire County Council
Local Authority Contributors	Oxford City Council, Cherwell District Council, Vale of the White Horse District Council, South Oxfordshire District Council
Study Period	1st May 2024 –31st October 2025 (18 months)
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Contents

1. Amendment history

Date	Protocol version no.	Author of changes	Details of changes made
18/09/2024	2	SEB	p1, p30: Updated study dates
18/09/2024	2	SEB	P10, Table 2: Updated traffic intervention dates
18/09/2024	2	SEB	p23 and p24: data collection start date updated to 1st Dec 2015
18/09/2024	2	SEB	p26: corrected type (20250->2050)
18/09/2024	2	SEB	P25, Table 5: Corrected table reference
23/09/2024	2	JH	P8, Table 1: Updated phrasing of financial contributions to the ZEBRA project and included related references
21/10/2024	2	SEB	p23-24: Additional detailed information provided regarding Audiomoth data capture and deployment procedures.
6/11/2024	2	JH	P24, New Audiomoth map inserted depicting intervention and control data capture locations.
7/11/2024	3	SEB	p13, 14 updated details for PPI member representation
7/11/2024	3	SEB	p14 updated details for PPI input to draft protocol
7/11/2024	3	SEB	p23. Inclusion of District Council sites for air quality data collection
7/11/2024	3	SEB	p23 Updated methods for bias adjustment of NO2 diffusion tube data.
7/11/2024	3	SEB	p28 updated data-sharing details

2. Plain English Summary

What is the problem?

The transport sector makes a big contribution to air and noise pollution. Air pollution is a problem for public health as it can lead to childhood asthma, and lung cancer, emergency hospital visits and early death in adults. Noise pollution can affect hearing, worsen chronic conditions such as heart disease and affects mental health. Replacing older diesel vehicles with electric ones is a way to drastically reduce or remove harmful air pollution and reduce noise pollution. Replacing diesel buses with electric buses may affect bus drivers, bus users and people who live along bus routes. There is not much research on how switching to electric buses impacts the health of people living and travelling in the cities.

In Oxford, similar to many cities, air pollution is a public health concern, with levels that are harmful to human health. The national and local government and local bus companies have given money to replace 159 diesel buses with electric ones by November 2024. These buses are used along 34 routes serving Oxford and surrounding communities. The aim is to improve

air and noise quality as well as reduce traffic levels and congestion in the city. The buses also have updated features that include new branding and promotion, new road safety features, bus stop announcements and display screens and more wheelchair space.

What will we do?

This study aims to use a mix of research methods to understand if replacing diesel buses with electric buses in Oxford changes air pollution and noise pollution, and see how this changes the health, travel behaviours and any wider impacts on people living in, travelling to, or visiting Oxford.

How will we do it?

We will investigate how introducing electric buses has influenced levels of nitrogen dioxide. Nitrogen dioxide is one of the main gases that contributes to air pollution. We will measure nitrogen dioxide using monitors across the city that have been there for 10 years so that we can look at how the levels of nitrogen dioxide have changed over time. We will then explore how any changes in air pollution influence the health of children and adults in the city. We will look at the effect on asthma in children and adults, and lung cancer, emergency hospital visits and early deaths in adults. We will also measure levels of noise pollution along key city centre bus routes using small recording devices attached to lampposts for a two-month period both before and after the electric buses are introduced. We will assess costs of the scheme and explore monetary benefits, including health and social savings arising from reduced air and noise pollution among those living in the city region.

We will also speak with key people within the bus companies and local authority to learn more about how the scheme is rolled out. This includes any other challenges that the bus companies or local authority faced when replacing the diesel buses. We will speak with people living in, travelling to, and visiting Oxford by organising focus groups and speaking to people at bus stops. We will ask them how they think the scheme has impacted air and noise pollution as well as wider impacts on the city, travel, the local economy.

The findings from this study will be useful for setting up long-term monitoring of the ZEBRA scheme and sharing the lessons with other cities that receive funding in the future to replace diesel buses with electric vehicles.

We have worked with staff at Oxfordshire County Council and Oxford City Council as well as bus providers and members of the public (including bus users) to develop the research and will continue to work with them throughout the project

What will we do with the results?

We will share our findings with local authority partners and bus operators to help shape future delivery of the ZEBRA scheme. We will also share our finding with public groups who have taken part in the research through a range of creative outputs and activities.

3. Study Summary

This protocol outlines the approach and methods that will be used in the Public Health Intervention Responsive Studies Team (PHIRST) PHRESH evaluation of the Zero Emission Bus Regional Area (ZEBRA) scheme in the Oxford City area in Oxfordshire. The ZEBRA scheme administered by the Department for Transport (DfT) is a place-based scheme intended to support local transport authorities (LTAs) outside London, to work in partnership with bus operators and other stakeholders to deliver zero emission buses (ZEBs) and supporting infrastructure (DfT, 2021a). The ZEBRA scheme introduced in Oxfordshire is funded from national and local sources, including national and local government and commercial bus operator contributions. The PHIRST evaluation will adopt a multiple-methods

approach using quantitative and qualitative data sources to: (a) understand intended and unintended impacts of the ZEBRA scheme; (b) explore feasibility and acceptability among stakeholders and public groups, and (c) inform procedures for long-term monitoring and evaluation. The evaluation findings will enable Oxfordshire County Council (and relevant stakeholders) to determine contribution of the ZEBRA scheme to achieving intended public health benefits and progress towards key strategy targets, to identify emerging unintended consequences which may be mitigated and to establish suitable resources and infrastructure to enable effective long-term monitoring of ZEBRA and other place-based local transport interventions, beyond the timeline of the current evaluation.

4. Overview of the PHIRST Scheme

Funded by the National Institute for Health and Care Research (NIHR), Public Health Research (PHR) Programme the PHIRST programme provides timely and accessible evaluations of public health interventions to local authorities. This evaluation is delivered by the PHIRST PHRESH team, a consortium of three West Midlands Universities: University of Birmingham, University of Warwick and Keele University. The PHIRST PHRESH evaluation approach is centred on responsive collaboration, with co-production involving researchers, local government professionals and public representatives at every research stage.

5. Background and rationale

5.1. Overview of the intervention

In March 2021 the UK Government published 'Bus Back Better' the national bus strategy for England which set out a vision for transition towards a fully zero-emission bus (ZEB[1]) fleet across the country (DfT, 2021b). Since that time, two competitively awarded ZEBRA funding rounds have supported introduction of over 4000 ZEBs operating across Local Transport Authorities (LTAs) in England, including a successful Oxfordshire CC funding application supplemented by financial support from commercial operators Stagecoach and Go-Ahead Group and Oxford City Council (Table 1, DfT, 2024; OCC, 2022). At a national level the ZEBRA scheme aims to contribute to Government objectives for transport decarbonisation and enhancement of bus quality and provision. At a local level the ZEBRA Business Case was developed to support local strategic objectives to reduce traffic congestion and improve air quality, including by introduction of a Traffic Filter scheme intended to reduce car usage in Oxford City (by 10% by 2025). The scheme also aims to improve bus service reliability and support bus patronage, in accordance with the Oxfordshire Bus Service Improvement Plan (Oxfordshire CC, 2024a).

[1] A zero-emission bus is defined as one that has no combustion engine on board, has no tailpipe air pollutant emissions, and saves at least 30% greenhouse gas emissions compared to operation of a Euro VI diesel engine of equivalent passenger capacity. The buses will still contribute to non-tailpipe pollution and GHG/air pollutant emissions associated with energy production (Williams et al, 2022).

Table 1 Summary of ZEBRA funding awarded to support the Oxfordshire scheme

Scheme Name	Funding provider	Total Funding Received
Zero Emission Bus Regional Area' (ZEBRA)	Department for Transport	£32,800,000
ZEBRA Support Package	Stagecoach / Go-Ahead Group	£43,700,000
ZEBRA Support Package	Oxfordshire City Council	£6,000,000

ZEBRA funding was used by Oxfordshire County Council to support introduction of 159 ZEBs across 34 routes serving Oxford City and surrounding communities. Routes serving key city locations (including transport hubs, healthcare facilities employment and educational facilities) suitable for operation of battery electric buses were prioritised for the scheme. The ZEBRA fleet has been phased in from November 2023 with replacement of older diesel buses (including Euro V and Euro VI vehicles) across the selected routes, with 99 operational ZEBs by July 2024 and full implementation of all 159 buses expected by November 2024 (originally June 2024). The routes served at full implementation are expected to reflect, ~50% of daily bus flow and ~70% of daily bus mileage.

5.2. Intervention context

The geographical location of the initiative (referred to as the 'ZEBRA defined area') is the Oxford 'Smart Zone' joint bus ticketing area, covering all of Oxford City (Figure 1) and extending beyond the city boundary to the suburban communities of Kidlington (North), Cumnor (West) and Wheatley (East). The intervention area comprises a population of ~170,000 people (including ~35,000 students) (Oxfordshire CC, 2024b; ONS, 2020). In addition, Oxford is a key employment location for the wider region, with ~46,000 people commuting into the city daily for work prior to the COVID-19 pandemic (Oxfordshire CC, 2024a). Overall life expectancy of the area population is better than the national average, however there are major differences from the least to the most deprived areas in Oxford City of 13 years (men), and 9 years (women) (Oxford CC, 2024).

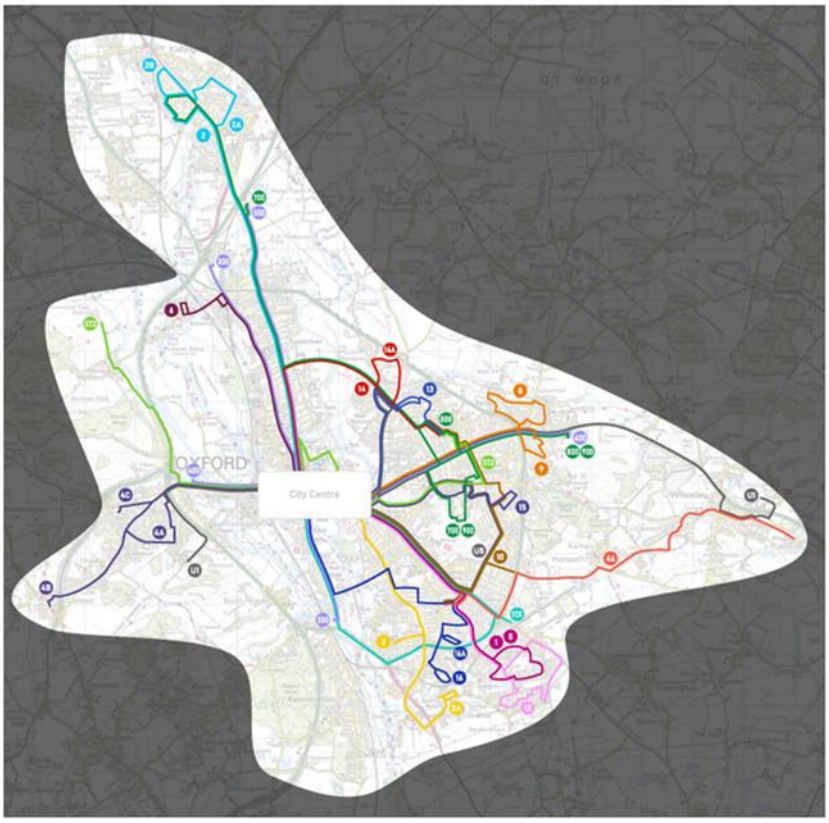

Figure 1 An overview of the Oxford 'Smart Zone' bus ticketing area showing 34 ZEB routes.

5.3. The problem being addressed

Oxford is a medieval city with limited river crossings and well documented challenges of traffic congestion as far back as the late 18th century (Oxford Clarion, 2024). In recent years average bus speeds have reduced to ~10 mph on key radial routes serving the city centre (OCC, 2024a). The city area also has recognised poor air quality primarily due to gaseous nitrogen dioxide (NO_2) pollution which is strongly linked to transport sources in urban areas. According to Oxford's most recent air pollution source apportionment study, the transport sector continues to be the largest contributor (68%) to emissions of nitrogen oxides (NO and NO_2), followed by domestic combustion (19%), industry combustion (12%) and waste, agriculture and solvents (<1%) in the city (Ricardo, 2020).

Oxford City Council declared the whole city an Air Quality Management Area (AQMA) in 2010, resulting in legislative requirements for measures to be introduced to achieve NO_2 compliance with legal limit values. A key early measure was the 2014 implementation of a bus-based central Low Emission Zone (LEZ) (further extended in December 2021) requiring all operating buses to meet a minimum engine emissions standard of Euro VI[2] (OCC, 2021a; Singh et al., 2022). In addition to the updated LEZ, Oxford City and County Councils more recently introduced a Zero Emissions Zone (ZEZ) in the city centre (from February 2022) where only fully battery or fuel cell vehicles may enter, and which is expected to be expanded to cover the whole city area by 2035 (Oxfordshire CC, 2024c).

The city's current Air Quality Action Plan sets out further actions to deliver in 2021-2025 to improve NO_2 levels in the city (Oxford CC, 2021). This plan seeks to go further than the UK legal annual limit value of NO_2 of 40 μgm^3, by adoption of a more stringent local mean NO_2 target of 30 μgm^3 to be achieved by 2025; recognising that health harms exist below current legal objectives. Since 2021 there has been an average reduction of 18% of NO_2 across the

[2] Euro VI buses have a NOx emissions limit of 80 mg/km compared to Euro V diesel buses with a limit of 180mg/km.

city and in 2023 no exceedance of any UK legal limits (annual or hourly mean) were measured, reflecting the impact of existing measures in the context of nationally declining NO_2 emissions attributable to cleaner vehicle fleets and changing travel patterns post-COVID-19 pandemic.

Consequently ZEBRA is one of several interlinked transport schemes implemented or planned for delivery in the Oxford area, which are intended to address the interlinked challenges of traffic congestion and poor air quality as outlined in Table 2. In recent years there has been increasing public interest in these measures, including organised campaigning both in favour and against traffic reduction in the city area (Oxfordshire CC, 2024d, Oxford Clarion, 2024).

Table 2 Summary of Oxfordshire County Council transport interventions and introduction timescales

Intervention	**Introduction Implementation Date**
20 mph Speed Limits	2021-2022
School Streets	2021 – Ongoing
Zero Emission Zone	February 2022 (2026 extension)
Low Traffic Neighbourhoods	May 2022
Botley Road Closure[3]	April 2023 – ongoing
ZEBRA	January 2024 – November 2024
Traffic Filters	November 2024 (on hold)
Workplace Parking Levy	Winter 2027

5.4. Review of existing evidence

5.4.1. Health impacts of air pollution

Ambient air pollution is the biggest environmental hazard for human health in the UK contributing to an estimated 26,000-38,000 early deaths each year (CMO, 2022). The transport sector is one of the major contributors to both carbon emissions and air pollution and transport decarbonisation (achieved through behaviour change and advances in vehicle technology) plays a pivotal role in meeting net zero targets (Avenali et al., 2024; Moutet et al., 2024). Public transport is generally a more sustainable method of transportation with lower per capita emissions compared to private vehicle usage; however, diesel-fuelled buses contribute to carbon emissions and air pollution via NO_x emissions (Bakker and Konings, 2018).

Exhaust emissions, particularly from diesel combustion engines, contain a mixture of nitrogen dioxide, smoke-related particulate matter, carbon monoxide, gaseous aldehydes and toxic polycyclic hydrocarbons (Austin et al., 2019). Particulate matter and hydrocarbons can reach deep into the lungs when inhaled with the former reaching the bloodstream (Austin et al., 2019; Muzyka et al., 1998). This can have several detrimental health effects, including immediate short-term pulmonary impacts (Austin et al., 2019; Stevens et al., 2010). Longer term impacts, including on diesel bus drivers, includes increased risk of six types of cancer and malignant tumours after just three months of exposure whilst children are particularly vulnerable to emissions that can reduce lung function growth, capacity and forced expiratory flow and increase the likelihood of asthma development (Austin et al., 2019; Beaty and Shimshak, 2014; Cloughert and Kuzansky, 2008; Gauderman et al., 2005; Gendron-Carrier et al., 2018; Soll-Johanning et al., 1998).

[3] Closure of a major westbound route into Oxford City Centre for Oxford Station redevelopment

Improved emission standards (for diesel buses) have been shown to reduce emergency department visits for respiratory diseases among residents living on bus routes (Austin et al., 2019; Ngo, 2015). Furthermore children born to mothers living closest to bus routes with older (and theoretically more polluting) buses show reduced birth weights and gestational age compared to those living further away or on bus routes with newer, lower emitting buses (Austin et al., 2019; Ngo, 2017). Sunyer et al. (2015) also showed that primary school children experiencing traffic related air pollution exposure at schools located close to busy roads had impaired development for all cognitive measurements.

Bus fleet electrification is a key national and local policy mechanism to significantly reduce or remove harmful exhaust emissions from public transport (Avenali et al., 2024). Research suggests potentially major reductions in air pollution (including commuter exposure at bus stops) noise pollution and consequently significant potential health benefits (Avenali et al., 2024; Bae et al., 2022; Morales-Betancourt et al., 2023). In addition to reduced emissions, ZEBs may also contribute to reducing traffic congestion within the location they operate through modal shift from private vehicles to public transport and active travel (Avenali et al., 2024); however empirical real-world evidence is limited. Travel surveys suggest that willingness to use bus transportation is higher if it is electrified, even at higher fare costs (Avenali et al., 2024; Sunitiyoso et al., 2022; Lin and Tan, 2017; Tan and Lin, 2019).

5.4.2. Health impacts of noise pollution

Traffic noise pollution has been determined as the second worst environmental health effect after air pollution (Hanninen et al., 2014; Munzel et al., 2020; Vienneau et al., 2015; WHO, 2011; 2018). The World Health Organisation has published research and guidelines regarding traffic noise that determines that annually over 1.6 million healthy life years are lost in Europe as well as being a risk factor for other diseases (Munzel et al., 2020; WHO, 2011). The WHO guidelines are below those of the European Union for environmental noise pollution with a strongly recommended road traffic level of <53 dB (Munzel et al., 2020; WHO, 2018).

Research has shown that physical health effects of noise pollution include heart disease, hearing loss and the development of tinnitus and adverse birth outcomes (Dzhambov and Lercher, 2019; van Kempen et al., 2018; Lan et al., 2020; Nieuwenhuijsen et al., 2017; Sliwinska-Kowalska and Zaborowski, 2017). Night-time noise is also an important risk factor in the development of cardiovascular disease due to a reduction in sleep duration and quality, leading to an increase in stress hormone levels and vascular oxidative stress (Munzel et al., 2020; 2021). Noise pollution will also increase blood pressure and impact cognitive function of children, particularly for memory and learning aspects (Stansfeld and Clark, 2015; Munzel et al., 2021).

Additionally, transportation noise has been identified as being detrimental for mental health and anxiety (Lan et al., 2020). Studies suggest that a 10 dB increase in traffic noise can cause a 9% higher likelihood of self-reported anxiety (Lan et al., 2020). This is hypothesised to be due to noise pollution increasing physiological arousal and stress hormone secretion; repeated stimulation of the endocrine system and nervous system which can then lead to increased anxiety (Babish 2002; Clark and Paunovic, 2018; Hahad et al., 2019; Lan et al., 2020; McEwen, 1998; Stansfeld and Clark, 2015). Transport noise has also been shown to be associated with an increased risk of dementia and Alzeheimer's disease and a higher depression risk (Cantuaria et al., 2021; Eze et al., 2020).

5.4.3. Potential negative effects of electric vehicles

Transition to ZEBs from diesel buses may also generate trade-offs including potential increases in non-exhaust emissions (NEEs) from brake, tyre, road wear and road dust resuspension and increased road maintenance costs due to heavier vehicle weights. There is limited understanding of these impacts of ZEBs in real-world settings, however an exploratory

study which compared Euro VI diesel and battery electric bus emissions operating on routes in London, suggested a potential decrease of 2-12% or increase of 12-50% depending on a combination of bus weight, regenerative brake performance and journey type (Tivey et al., 2023). There also remains uncertainty regarding suitable metrics which may be adopted to quantify and compare NEEs from ZEB sources.

5.5 Rationale for the evaluation

There is currently limited 'real-world' evidence regarding the wider public health impacts of 'zero-emission' public transport interventions. Existing evaluations are typically limited to considerations of implementation processes, or modelled benefits for reducing carbon or tailpipe air pollutant emissions and operational outcomes. DfT previously commissioned an interim process evaluation reporting findings from the pre-implementation phase of the ZEBRA scheme, exploring experiences of the funding application process, effectiveness of partnership working and successes and challenges of pre-implementation activities (DfT, 2023). In addition DfT require all LTA recipients of ZEBRA funding to set out plans for collection and reporting of monitoring data on the schemes in the respective business case, and require engagement with programme level monitoring and evaluation undertaken by a DfT contractor, including quarterly return of relevant monitoring data (DfT, 2023; DfT, 2021c; Atkins Jacobs, 2022).

To the best of our knowledge, evaluations that include full consideration of wider public health impacts, including unintended consequences are scarce. Hence, we plan to undertake a multi-methods evaluation of the process and outcomes of ZEB fleet introduction, including exploration of the experiences of a range of stakeholders and public groups, consideration for air and noise pollution impacts and arising health benefits and economic consequences. Better understanding of both processes and outcomes is essential to understand if the scheme is delivering intended benefits, to identify (and mitigate) unintended consequences and to inform scientifically robust long-term monitoring and evaluation, providing a framework for adoption in other settings.

6. Co-production and Public Partnerships

6.1. Approach to research co-production

The PHIRST PHRESH team have worked with the LA to co-develop the evaluation since the initial meeting at end May 2024. Meetings of the core Project Working Group (PWG) including the research team and Oxfordshire County Council officers (spanning transport, public health, iHub, press communications) have been held on a weekly basis through June 2024. Further members of the PWG will include relevant stakeholder representatives (e.g. Oxford City Council) and two PPI representatives, one from the PHRESH PHIRST panel and a local PPI member. It is expected the PWG will continue to meet on a weekly or fortnightly basis throughout the initial evaluation phase. A collaborative logic model development workshop was convened in-person on 21st June, including representation from Oxford Bus Company, a member of Oxon4Buses, two PHRESH co-applicants and additional OxfordshireCC officers, (see Appendix A).

6.2. Evaluability assessment process

The co-production method was used to develop the Evaluability Assessment (EA) which was submitted on 5 July 2024. The evaluability assessment provides a rapid and collaborative approach to clarifying evaluation objectives, how these will be achieved and how these can be translated into outcomes and impact. Steps involved in developing the EA included:

- Meeting with evaluation users
- Clarifying the intended evaluation purpose
- Exploring the programme reality with stakeholders
- Reaching agreement on activities or goals

- Exploring a range of alternative evaluation findings
- Agreeing on priorities and intended uses of the information generated.

Through these joint activities we have identified the need for the LA to understand wider impacts of the ZEBRA scheme, beyond those assessed by statutory DfT monitoring and evaluation, including both intended and unintended consequences. Key outcomes of interest identified included effectiveness of the scheme to:

1. Reduce levels of air and noise pollution experienced by bus users, commuters and residents, improve health and reduce health inequalities.

2. Influence perceptions and attitudes towards bus travel (among both bus users and non-users), and to understand how these changes influence choice of transport mode and therefore bus demand and modal shift to sustainable transport

3. Deliver wider social and economic benefits, through indirect impacts including reduced levels of traffic congestion, improved access to educational and employment opportunities, and attractiveness of Oxford City public realm for residents, commuters and visitors (including tourists).

The above needs were identified as aligning key LA strategies including Oxfordshire's Health and Wellbeing Strategy 2024-2030 (OCC, 2024e), response to the Director of Public Health's Report on Climate Change and Health (OCC,2023a), Local Transport and Connectivity Plan 2022-2050 (OCC, 2022), Bus Service Improvement Plan (OCC, 2024a) and Central Oxfordshire Travel Plan (OCC, 2023c). Key outcomes are relevant for local targets adopted the LA including the Oxfordshire Air Quality Strategy (OCC, 2023a) and commitment to achieving net-zero by 2030 through Pathways to a Zero Carbon Oxfordshire (Environmental Change Institute, 2021).

Through this evaluation the LA also seek to understand the broader efficacy of a package of planned intervention measures (e.g., traffic filters, zero-emissions zone, workplace parking levy) and we identified opportunities for establishing data collection procedures and analytical approaches which may be adopted for monitoring and evaluation beyond the timescale of the PHIRST evaluation.

6.3. Approach to public involvement and engagement

The PHIRST PHRESH team are committed to ensuring public voices are included throughout the full cycle of each evaluation, from inception, through delivery, completion and dissemination. The PHIRST PHRESH team have an established Public Advisory Committee (PAC) coordinated by the Programme Manager with support and guidance provided by the PPI Co-Investigator Lead. In addition to the PHRESH PAC PPI group, we are supporting Oxfordshire County Council to provide access to existing local community and public representative groups to advise on and assist with evaluation design and delivery. Key groups identified for PPI input include:

- *Oxon4Buses:* an informal association of bus users in Oxfordshire with an aim to increase bus usage throughout the county.
- *Oxfordshire Community Research Network:* a network which aims to address local issues and concerns that affect wellbeing, by involving community members in collaboration with local councils, academic institutions and health services.
- *Oxford Inclusive Transport & Movement Focus Group:* a group coordinated by Oxford City Council to ensure those with disabilities or who are visually impaired can safely access town centres and highways.

In addition one local PPI representative from the local community will provide representation at the PWG meetings, to enable continuity of PPI input and provide a mechanism for interaction with local groups.

6.4. Public and patient input to evaluation protocol

PHRESH PAC PPI representatives were consulted regarding the proposed research aims, questions and methods for this study which were refined in response to their feedback. The main amendments resulting from these interactions were:

- The inclusion of particulate ($PM_{2.5}$) data capture in Oxford City Centre to provide insights into potential changes in non-tailpipe bus emissions sources
- The inclusion of emergency admissions for acute asthma in health impact assessment
- The inclusion of an option for focus group participants to select an online or telephone interview if they are unable or unwilling to participate in a focus group
- The inclusion of focus groups located in low socioeconomic communities with targeted recruitment approaches.
- To inform the development of the qualitative topic guides to explore additional potential impacts beyond those identified by the research team, including psychological, financial, inequalities and access.
- The capture of a wide range of impacts, including emerging unintended consequences which may inform data capture in future long-term evaluation.

The PHRESH PAC PPI representatives were supportive of the proposed approaches in the protocol to speak to bus user advocacy groups that represent a broad range of bus users including those living with disabilities, to compensate for participants time with vouchers, and to use a sampling approach for qualitative data collection that includes participants with a broad range of demographic characteristics.

7. Evaluation Aims, Objectives and Research Questions

7.1. Evaluation aims

Building on insights provided by interactions with Oxfordshire County Council, relevant stakeholders and PPI members and literature review process, the overarching aim of this evaluation is to understand how the ZEBRA scheme has been implemented and to investigate the public health impacts (both intended and unintended), with findings used to inform appropriate study methods for long-term evaluation.

The evaluation aims are therefore:

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.

4. To understand experiences of ZEBRA scheme implementation, including barriers and enablers to full adoption.

5. To explore the costs of the scheme from both LA and societal perspectives, and consider the feasibility of a longer-term economic evaluation

6. To support relevant research skills and infrastructure development within OCC to enable long-term ZEBRA scheme monitoring and evaluation.

7.2. Research questions

To address these aims we have defined the following research questions outlined with the respective evaluation themes in Table 3.

Table 3 Evaluation themes, aims and research questions

Evaluation Theme	Aim / Sub-aim	Research Question (s)
Effectiveness	1. To assess the direct health benefits of the ZEBRA scheme, including impacts of air and noise pollution changes across the defined area	*What is the impact of the ZEBRA scheme on air pollutant concentrations?* *What are the health impacts of attributable air quality changes?* *What is the impact of the ZEBRA scheme on noise pollution?*
	2. To understand the impact of the ZEBRA scheme on the travel preferences and behaviours of residents, commuters and visitors.	*What is the impact of the ZEBRA scheme on residents, commuters and visitors travel choice of travel mode?* *What is the impact of the ZEBRA scheme on residents, commuters and visitors wider travel patterns?*
	3. To identify and explore (where feasible) the wider indirect impacts of the ZEBRA scheme, including economic, social and technical implications, including unintended consequences.	*What are the impacts of the ZEBRA scheme beyond the area of intended action?* *Which external influences are relevant to understanding scheme impacts?* *What information sources are required to understand these wider impacts and which stakeholders should be involved in future investigation?*
Feasibility & Implementation	4. To understand experiences of ZEBRA scheme implementation, including barriers and enablers to full adoption.	*Has the ZEBRA scheme been implemented as planned?* *What are the experiences of stakeholders involved in planning and delivery of the ZEBRA scheme?* *Which processes have worked well in scheme implementation, and which need to improve?*
Evaluation Design	5. To explore resources and costs of the ZEBRA scheme from both LA and societal perspectives, and consider the feasibility of a longer-term economic evaluation	*What is the scope of costs (resource use) and benefits (outcomes, effects) of the ZEBRA scheme?* *Which information sources are available to inform a future cost-consequence analysis?*
	6. To support relevant research skills and infrastructure development to enable long-term ZEBRA scheme monitoring and evaluation	*What are the most appropriate research methods to adopt for long-term evaluation?* *What are the key remaining uncertainties and how can these be addressed?*

8. Study Design and Methods

8.1. Evaluation framework

Our evaluation is based on the MRC guidance for evaluation and process evaluation of complex interventions and is structured to assess mechanisms of impact (effectiveness), environmental, health and economic outcomes, feasibility, implementation and to inform ongoing evaluation design (Figure 2). This framework informs our four evaluation themes: effectiveness, feasibility and implementation, and evaluation design.

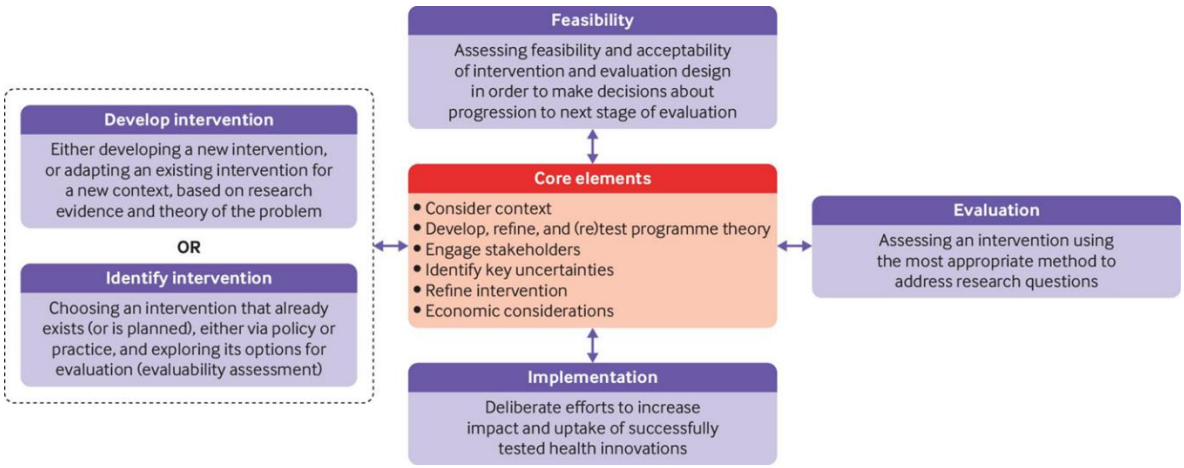

Figure 2 Evaluation framework adapted from Skivington K et al, 2021.

The evaluation study design has been developed through interactions with the LA partner(s), stakeholders and PPI representatives with consideration given to pre- and post-intervention data availability, implementation timescales and methodological considerations. A key methodological consideration is the need to adopt suitable methods to isolate impacts of the ZEBRA scheme in the context of a broad range of contextual factors and concurrently delivered transport interventions. We will draw upon the MRC framework to explore these contextual influences, including how they interact with intervention delivery and outcomes and to inform the most appropriate methods for long-term evaluation.

8.2. Evaluation structure

We will adopt a multi-methods approach to address the evaluation research questions. The evaluation activities will be organised and reported across four interlinked workstreams including relevant qualitative and/or quantitative methods (Table 3)

Table 4 Evaluation workstream structure and summary methods

Workstream	Topic	Methods
Workstream 1:	Effectiveness of the ZEBRA scheme (intended impacts)	Quantitative/Qualitative
Workstream 2	Feasibility and acceptability of ZEBRA scheme	Qualitative
Workstream 3:	Wider impacts of the ZEBRA scheme (intended/unintended)	Qualitative /Quantitative
Workstream 4:	Long-term monitoring and evaluation of the ZEBRA scheme	Quantitative/Qualitative

8.3. Qualitative study design

The qualitative element of the study will collect data using semi-structured interviews, focus groups and intercept interviews in two phases. Phase 1 (Autumn 2024) will assess the feasibility and acceptability of the ZEBRA scheme implementation (Workstream 2), utilising semi-structured interviews with key stakeholders involved in implementing the scheme and focus groups with a group of bus users and bus operator staff.

We will hold an interim workshop with key project stakeholders to present initial findings from Phase 1. During the meeting, we will update the logic model underpinning the ZEBRA scheme. The results and interpretations from Phase 1 will be used to inform Phase 2 (spring -summer 2025). This could include informing the topic guides, target participant groups, recruitment strategies or data collection procedures.

Phase 2 will reassess the feasibility and acceptability over time (Workstream 2) and explore the intended and unintended impacts of the scheme following implementation (Workstream 1 and 3). We propose that during Phase 2, as far as possible, we will conduct semi-structured interviews and focus groups with the same participant groups as Phase 1. We will conduct additional focus groups with residents and commuters in Oxford and intercept interviews with bus users along key travel routes. For all participant groups, semi-structured interviews will be offered if they are unable to attend focus group sessions.

8.3.1. Study Participants

Phase 1: During Phase 1, semi-structured interview participants will be key stakeholders that have direct experience of implementing the ZEBRA scheme within their professional role. Implementation activities could include, but are not limited to, procurement of equipment, route and timetable planning, staff training, deployment of buses, redeployment of diesel buses, marketing and promotion of ZEBRA scheme. Examples of eligible stakeholders include operations managers, controllers and schedulers from the bus operators deploying ZEBRA buses, bus manufacturers, central ZEBRA administrators, Communications Officers at OCC, Traffic Filter Scheme Lead, Sustainable Transport Manager at Oxfordshire County Council and elected council members.

Additionally, during Phase 1 we will conduct focus groups with two participant groups (1) bus operator staff; and (2) bus user advocacy groups. Firstly, bus operator staff members will be employed by one of the two bus operators in Oxford and will have been involved in delivering the ZEBRA scheme. Participants are likely to include bus drivers, bus mechanics, training providers and trade union representatives but we will seek further advice from each of the bus operators about the composition of the focus groups. Secondly, participants from bus user advocacy groups will be members of, or part of the network of the local Oxon4Buses group, an independent representative of bus passengers in Oxford or Oxford Inclusive Transport and Movement Focus Group. They represent a broad range of bus users by age, sociodemographic groups, rural locations and those living with disabilities. Semi-structured interviews will be offered if participants are unable to attend, or do not wish to participate in focus groups.

Phase 2: During Phase 2, we will conduct semi-structured interviews with key stakeholders involved in implementing the ZEBRA scheme. In the first instance, the same participants from Phase 1 will be invited to participate in Phase 2. Findings and interpretations from Phase 1 will inform any additional key stakeholder or participant groups for Phase 2 who will be invited to participate. Depending on findings from Phase 1, we may repeat focus groups with bus operator staff and bus user advocacy group or invite individuals within these groups to participate in semi-structured interviews.

We will conduct additional focus groups with residents and commuters in Oxford. Participants will be those with experience of travelling within Oxford. These can include but are not limited to residents, commuters travelling to workplaces in Oxford, students at the Universities. There will be no inclusion criteria based on travel patterns, but participants must have been resident in or travelling regularly to Oxford for ≥12 months as they will be able to recognise the impact of the scheme. Participants will be included if they are over 16 and have sufficient English proficiency to adequately participate.

We will also conduct intercept interviews at key travel locations in Oxford. Intercept interview participants will be included if they are aged over 16, travelling alone or in pairs and speak sufficient English. We will include residents in Oxford as well as those visiting the city.

8.3.2. Sampling and Participant Recruitment

For both study phases, the sample size will remain flexible based on information power and pragmatic considerations. Information power indicates that the more information the sample holds relevant for the study, the lower the required sample size (Malterud et al., 2016). Table 1 provides sample size estimates to facilitate resource planning, yet we will re-assess this throughout the study based on the five items that impact on information power (Study aim; sample specificity; Use of established theory; quality of dialogue and analysis strategy).

Table 5 sample size estimates to facilitate resource planning

Phase 1 (autumn 2024)	
Semi-structured interviews	8-10 interviews
Focus groups	3 focus groups
Phase 2 (spring-summer 2025)	
Semi-structured interviews	8-10 interviews
Focus groups	6-8 focus groups
Intercept interviews	20 intercept interviews

Phase 1:

Interviews: For the semi-structured interviews with key stakeholders, we will obtain contact details of key stakeholders from Oxfordshire County Council. We will utilise snowball sampling to identify any additional key stakeholders, asking participants to identify further key stakeholders with experience of implementing the ZEBRA scheme. We will invite all identified stakeholders via email. The invite will outline the purpose of the study, the reason they have been invited and include a participant information sheet. Participants will be given the opportunity to ask any questions prior to completing online informed consent, which will be emailed to participants prior to the interview. Interviews will be scheduled at a convenient date and time for both the participant and the researcher. The interview will take place face to face, online or via telephone, depending on participant preference. An email reminder will be sent to all participants the day before the interview.

Focus groups: We will recruit bus operator staff to participate in focus groups by utilising key contacts at each bus operator to facilitate recruitment. The precise methods of recruiting participants are likely to include emails to staff mailing lists, posters in depots or email to key staff and direct invitations, but we will be guided by key contacts as to the most appropriate

method of recruitment and these are likely to be different between the bus operators. We will purposively sample participants according to their job roles to ensure that the final sample includes participants from a diversity of job roles within the bus operators. We will recruit focus group participants from bus user advocacy group Oxon4Buses and Oxford Inclusive Transport and Movement Focus Group. Participants may be members of these groups or respond to adverts disseminated through their network, for example, social media or newsletters. Other advocacy groups may be contacted based on recommendations from the Oxford City Council. If participants do not want to participate in a focus group, they will be given the option for an individual interview.

Phase 2:

Interviews: We will attempt to undertake follow up interviews with participants from the semi-structured interviews in Phase 1 via email inviting them to participate in Phase 2. Any additional key stakeholders identified during Phase 1 will be invited to participate in a semi-structured interview via email and the same recruitment procedures as Phase 1 will be followed. Depending on findings from Phase 1, we may invite relevant participants from Phase 1 focus groups to participate in focus groups or semi-structured interviews in Phase 2. Additional recruitment via the same methods as in Phase 1 may be required if uptake is low among previous participants.

Focus groups: We will recruit residents and commuters in Oxford to participate in focus groups including those who are non-bus users. We will share recruitment materials through local social media, WhatsApp groups, posters at key community locations (including GP surgeries, faith group spaces, community centres, supermarkets), posters on buses and at park and ride sites, leaflet drops at houses along key bus routes, leaflet distribution at park and ride sites and railway stations. Door knocking to households that received leaflets may be used as an additional recruitment strategy. We will explore the availability of the Thames Valley and South Midlands Clinical Research Network (CRN) to assist with recruitment. We will distribute recruitment materials through existing groups identified by the project working group, including but not limited to local RNIB groups, Oxford Community Research Network, Oxford Breathe Easy. We will also distribute recruitment materials to key employment sites including Oxford University Hospitals NHS Foundation Trust, Oxford Brookes University, BMW factory. An example recruitment strategy is included in Appendix B, but will be refined with local PPI representatives and findings from Phase 1.

All recruitment materials for focus groups with residents and commuters will include a QR code and web link to a participant information sheet, a screening questionnaire, consent form and a short online survey of travel patterns and key demographic information, including age, gender, disability, postcode to identify Index of Multiple Deprivation, status as resident (inside or outside Oxford ring road) or commuter. Recruitment materials will also include contact details (email and telephone number) for the study team so that participants can request paper copies of the questionnaire or complete via telephone. The demographic information collected will be used to purposefully sample participants with maximum variation according to the demographic characteristics. We will group participants into focus groups based on their travel patterns (exclusive bus user/partial bus user/non-bus user) to maintain homogeneity of participants according to the key topic of the focus groups, and invite participants that represent a broad range of demographic characteristics to participate. We will also conduct focus groups in community locations within areas of high deprivation levels in Oxford. Once the sample has been selected, participants will be invited to participate in a focus group at a specified time and location. A reminder email or text will be sent two days before the focus group. Participants who express an interest but are not selected will be contacted after the

study has finished to thank them for their interest and inform them that they were not selected as a focus group participant. Residents and commuters who participate in focus groups will receive a £40 voucher as compensation for their time.

If key demographic groups are under-represented in the sample, or a participant is unable or unwilling to participate in a focus group, we will invite them to participate in semi-structured interviews. All participants will provide informed consent and a topic guide following the same questions as the focus group will be used.

Intercept interviews: We will conduct short intercept interviews across key city centre bus routes. They will last approximately five minutes. These bus routes are the key focus of the quantitative evaluation as it is the bus route with the highest proportion of electric buses. It is therefore expected that intercept interviews along this route will provide the richest accounts of the impacts of the ZEBRA scheme. We will select key locations on these routes, including within the socially deprived residential areas along the route to recruit participants. If there are key target groups that we have not captured in the focus groups, we will select additional locations that are likely to capture views of participants under-represented in the focus groups. For example, if we do not capture views of commuters, we will conduct intercept interviews at park and ride sites serving key employment locations.

8.3.3. Qualitative data collection

Semi-structured interviews: All participants will provide online informed consent prior to commencing the data collection. Semi-structured interviews will be conducted in-person, online or via telephone, depending on participant preference. Each semi-structured interview will follow a pre-prepared topic guide developed specifically for Phase 1 and Phase 2. We will develop draft topic guides to align with the research aims, logic model and expertise of the research team, and refine them in collaboration with the PPI group. All interviews will be audio recorded and we will write detailed field notes following each interview. Where a participant completed an interview in Phase 1, the researcher will summarise their responses to repeat questions and ask participants to elaborate or explain any changes they have observed since the previous interview.

Focus groups: Separate focus groups will be held with members of staff from each of the two bus operators to respect commercial sensitivities. All participants will complete informed consent prior to participating in the focus groups. Focus groups will take place at locations in Oxford at a range of times. Each focus group will follow a pre-prepared topic guide, which will be adapted according to whether participants are bus operator staff, bus user advocates or residents and commuters in Oxford. We will develop draft topic guides based on the research aims, logic model and expertise of the research team and refine them in collaboration with the PPI group. All focus group topic guide will include introductory questions to make participants feel comfortable ahead of key questions which will focus on the feasibility and acceptability (Phase 1) or impacts (Phase 2) of the ZEBRA scheme. Focus groups will last 90 minutes. All focus groups will be audio recorded and researchers will write detailed field notes following the focus group.

Intercept interviews: Bus users (along key city centre bus routes) will be approached as they are waiting to board a bus or as they come off the bus. We will use the method of approaching the next available person. Researchers will stop bus users and ask if they would be willing to participate in the research that would take approximately five minutes. If a bus user declines, this will be noted and the researcher will approach the next bus user. If a bus user agrees, the researcher will explain the purpose of the research and the procedure and ask participant if they have any questions. The interview will follow a pre-prepared topic guide. The researcher

will ask participants basic demographic details, that include resident status, age, gender, ethnicity, education and employment status (as a proxy for socioeconomic status), followed by open-ended questions about their journey today and their views on the impacts of the ZEBRA scheme. At the end of the interview, participants will be thanked for their time and given a participant information sheet. We will not record the interviews, rather we will write detailed field notes immediately following each interview, summarising the participants responses to the interview questions.

8.3.4. Qualitative data analysis

Interviews and focus groups will be audio-recorded and a clean transcript will be produced by a specialist GDPR compliant company. A hybrid deductive and inductive approach will be employed using the Framework Method of analysis (Ritchie and Spencer, 2002; Gale et al., 2013). We will use the core domains of the logic model as a theoretical basis and deductively apply this coding to the dataset. Within each domain from the logic model, we will code inductively. This approach charts data into a matrix, with each interview/focus group represented as a 'case' along the rows of the matrix, and categories and codes identified in columns. This preserves the perspectives of the different participants from interview and focus group (i.e., bus drivers, bus users, non-bus users), while also allowing comparisons to be made between them. Time comparisons may also be made by exploring similarities and differences between interviews conducted during Phase 1 and Phase 2 where data are available.

Data analysis will follow the seven steps outlined by Gale et al., (2013):

1. Verbatim transcription: Audio recordings of each interview, focus group and intercept interview will be transcribed verbatim by a specialist GDPR compliant company. A researcher will check the transcriptions against the original audio file.
2. Data familiarisation: Familiarisation with the data will be achieved by listening to the audio recordings and reading the interview/focus group transcripts.
3. Coding: Preliminary codes will be identified across all transcripts. This process will be undertaken independently by two members of the research team.
4. Developing a framework: Overarching domains within the framework will be identified deductively, based on the logic model and research aims. Codes will then be derived inductively within each of these categories, based on commonalities within the data identified during Step 3. Two researchers will develop a framework iteratively, coding a defined number of transcripts and meeting to discuss the emerging framework. This process will be repeated until all transcripts have been coded and the analytical framework is finalised.
5. Indexing: We will apply the framework developed in Step 4, identifying codes within each transcript using NVivo software (version 14). One researcher will complete this analysis stage.
6. Charting data into the framework matrix: Data will be charted into a framework matrix on an Excel spreadsheet. During this process, data for each case and code will be summarised using illustrative quotations, while preserving the meaning and context.
7. Interpreting the data: Analytic themes will be identified based on interpretation of the framework matrix.

8.4. Quantitative study design

The quantitative study will adopt three key methodological approaches (time series analysis, controlled before-after study, health impact assessment) to understand air, noise quality and

direct health impacts of the ZEBRA scheme (workstream 1), with findings used to inform scientifically robust methods for long-term evaluation (workstream 4).

8.4.1. Quantitative data collection

Air quality data

We will collect hourly measured air quality data for key gaseous pollutants (NO_2, NOx) and Particulate Matter ($PM_{2.5}$) from the UK Department for Environment, Food and Rural Affairs (Defra) Automatic Urban and Rural Network (AURN) Defra sites in Oxford City (Defra, 2024)comprising an urban background site located within air-conditioned housing within the grounds of St Ebbe's School and Oxford Centre Roadside at St Aldates in the city centre (NO_2 and NOx only). Air quality data (NO_2) at monthly time resolution will also be collected from a network of ~100 diffusion tubes deployed by Oxford City Council, South Oxfordshire District Council, Vale of the White Horse District Council and Cherwell District Council across the ZEBRA defined area (locations shown in Figure 3). Relevant NO_2 diffusion tube bias adjustment factors will be derived locally from diffusion tube co-location at the AURN Oxford City Roadside (where available) or national bias adjustment following Defra LAQM guidance (Defra 2008, 2011). All air quality data will be collected for a full 10-year period (1 Dec 2015 to 30 Nov 2025).

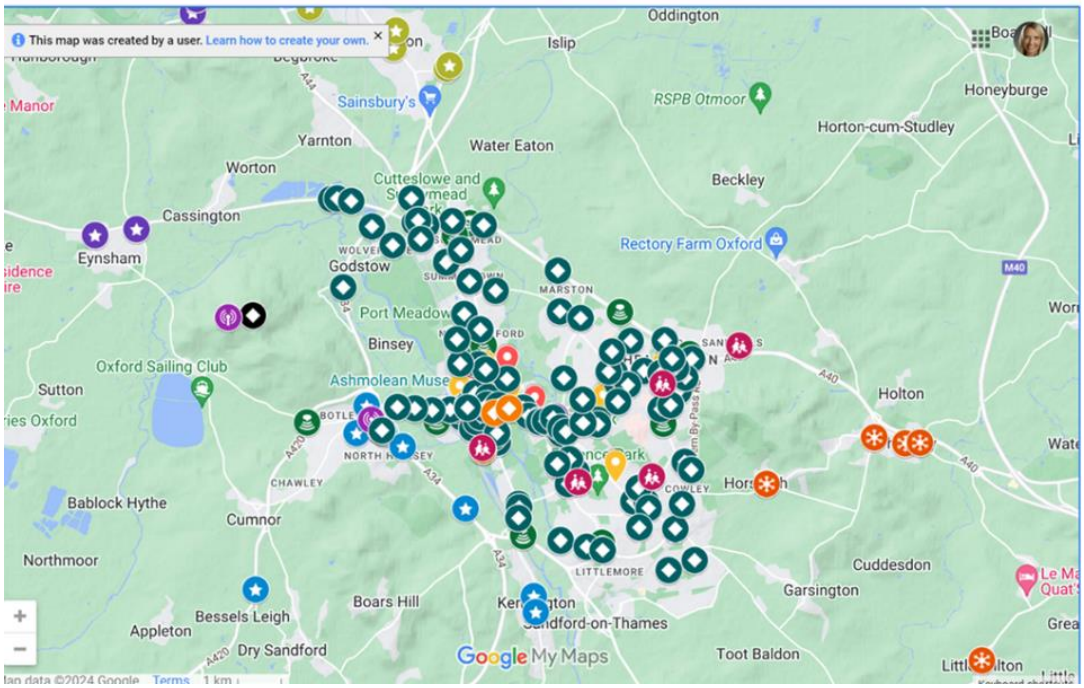

Figure 3 Map of air quality monitoring locations across the ZEBRA defined area
Green diamonds, orange stars, green stars, blue stars = NO_2 diffusion tubes
Orange diamonds = AURN regulatory sites (NOx, NO_2, PM2.5)

Acoustic (noise) data

Noise data will be captured by deployment of Audiomoth devices (Hill, Prince et al. 2018, Hill, Prince et al. 2019), which are low-cost microphones (which records sound) combined with data-logger, powered by 3 x AA batteries. The devices record data at a sampling rate of 48 kHz which will detect noise up to 24 kHz just above the human perception limit, enabling the capture of all human-audible sounds with data recorded to an internal microSD card. From the data captured it is possible to reconstruct the original sound therefore to reduce privacy

concerns the Audiomoth devices are deployed to log for a duration of five minutes, three times per hour (for example at 00, 20 and 40 minutes past the hour). This approach also prolongs battery life of the device, which has previously been ~30 days (with high performance AA batteries). (Leach, 2024)

Devices may be readily deployed on items of street furniture (such as lampposts or street signs) as close as possible to the area of interest by high enough to avoid interference (e.g. >2m) and as far as practically possible from reflective surfaces. We will utilise existing pre-intervention baseline data collected from Audiomoth device deployment by Oxfordshire County Council at roadside locations (ZEBRA routes) and control locations selected as those where noise levels would not be influenced by ZEBRA bus introduction as shown in Figure 4. Noise quality data have previously been collected for a sampling period within a ~2 month period at baseline (January-February 2024) with follow-up post -implementation data collection phase (withiin the period January -February 2025) following full ZEBRA implementation.

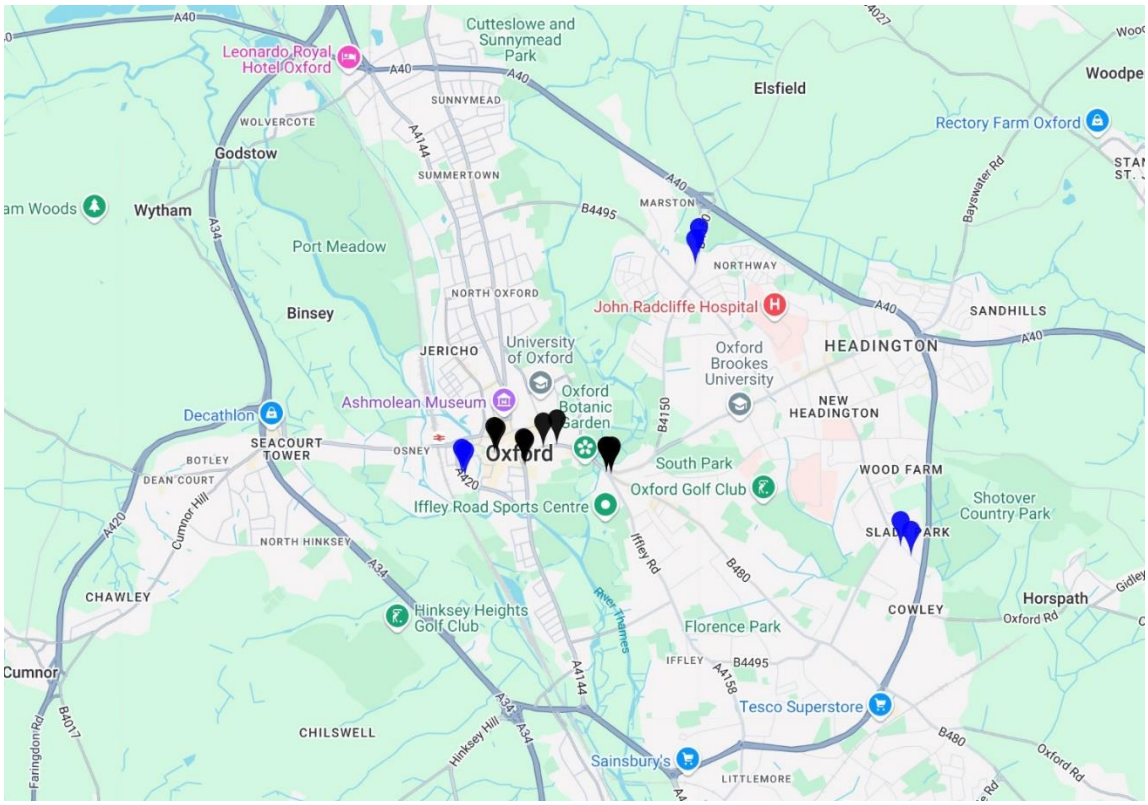

Figure 4. Map of Audiomoth noise data capture intervention (black markers) and control (blue marker) locations across the ZEBRA defined area (Jan-Feb 2024).i

Meteorological data

Hourly meteorological variables (i.e. air temperature, wind speed, wind direction, relative humidity, atmospheric pressure, total cloud cover, planetary boundary layer height, surface net solar radiation) will be obtained for Oxford from the ERA5 reanalysis dataset via the Copernicus Climate Change Service (C3S) Climate Data Store (Hersbach et al, 2018) for the time series study time period (1 Dec 2015 to 30 Nov 2025). Deweathering analysis will be undertaken using the The Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model (Stein et al., 2015) following methods described in Shi et al. (2021).

Traffic and bus emissions data

Traffic data for key bus routes served by the ZEBRA scheme will be obtained from Vivacity Labs (VL) roadside detection sensors managed by Oxfordshire County Council. VL sensors obtain camera images and apply motion and shape detection algorithms to detect and classify transport modes and urban movement including classified counts, vehicle path, journey time and speed. Daily vehicle counts for the study period will be categorised by vehicle type to (i.e bus, car, cycle, pedestrian) at the main arterial traffic route at Oxford High Street, approximately 200 m from the St Aldate's roadside AURN site.

Bus passenger and operational data

Monitoring and evaluation of the ZEBRA scheme is undertaken by DfT for all relevant Local Transport Authorities (LTAs). The DfT evaluation return includes baseline data (for the 12-month period prior to ZEBRA introduction) and subsequent post-intervention returned on a quarterly basis from July 2024 to January 2026 for all routes included in the ZEBRA scheme. For the PHIRST PHRESH evaluation we will use this secondary data to understand intervention costs and to inform development of long-term evaluation methods.

We will access the DfT data evaluation return through a data-sharing agreement with Oxfordshire County Council to include: bus infrastructure information, passenger demand (ticket sales), scheme bus models, vehicle maintenance and operating information and further local data subject to availability. Data will be used to identify wider scheme impacts and to inform data capture for long-term evaluation.

Health and Demographic data

Baseline demographic data for health and economic impact assessment will be obtained from the Office for National Statistics (ONS) including Lower Super Output Area (LSOA) level mid-2023 population estimates by age and gender for the ZEBRA defined area (ONS, 2024)

Morbidity and mortality impact estimates

Health impact assessment will be undertaken using literature derived concentration-response functions (CRFs) for air pollutant (NO_2) morbidity and mortality outcome pairs in accordance with causal associations identified by the Committee on the Medical Effects of Air Pollutants (COMEAP, 2022) as shown in Table 6.

Table 6 CRFs used to parameterise morbidity and mortality impacts for health impact assessment

Condition	Data Source	Disease definition	Concentration -Response Coefficient
Childhood asthma (0-18 years)	Systematic review (Khreis et al. 2016)	Variability in asthma definitions	Children > 6 yrs RR 1.09 per 10 µg/m^3 Children < 6 yrs RR 1.23 per 10 µg/m^3
Adult asthma (>18 years)	Large European cohort study (ESCAPE) (Jacquemin et al. 2015)	Specific clinical definition (see Appendix 4)	RR 1.10 per 10 µg/m^3
Lung Cancer	Systematic review and meta-analysis	Studies combining lung cancer	RR 1.04 per 10 µg/m^3

	(Hamra et al. 2015)	mortality and incidence	
All-cause mortality[4]	COMEAP (2018, 2022)	All-cause mortality	RR 1.08 per 10 µg/m^3

8.4.2. Quantitative data analysis

8.4.2.1. Interrupted Time Series Analysis (Air Quality)

We will undertake an Interrupted Time Series (ITS) analysis to understand impacts of the ZEBRA scheme on NO_2 concentrations across the city over the 10-year period (1 December 2015 – 30th November 2050. This time period is selected to provide adequate pre-intervention data (including before and after the COVID-19 pandemic) and a full year of post-intervention data, to enable adequate assessment of seasonal and meteorological impacts. We will undertake two analyses to understand ZEBRA impacts on spatial and temporal pollutant trends:

Using monthly diffusion tube and AURN air quality data we will explore changes in roadside NO_2 concentrations along key bus routes. Routes will be classified by bus-to-traffic flow rates as high flow/medium flow/low-flow rates based upon previously published bus to traffic flow ratios in the Oxfordshire Source Apportionment Study (Figure 5) and validated by traffic flow data obtained from VL detection sensors. We will explore any abrupt or gradual changes in air quality trends around the ZEBRA intervention phase-out dates and undertake comparisons between route clusters.

As air pollution is also influenced by national trends, seasonal influences and weather patterns, we will undertake 'de-weathering' and de-trending' using the approach developed by Shi and colleagues and previously used by the study team to understand COVID-19 lockdown impacts in Oxford City (Singh et al, 2022). We will repeat each time series analyses using crude and 'deweathered'/'detrended' datasets enabling comparisons to be made which will improve understanding of the magnitude of wider contextual and environmental influences.

We will repeat time-series analysis using hourly air quality data at two AURN locations in the city centre (urban background and roadside) to generate higher temporal resolution assessment of NO_2 changes than can be considered across the wider city area. The monitor is located on a with high bus-to-traffic flow (St Aldates) and will therefore be suitable for capturing ZEBRA scheme impacts which may be of lesser or marginal magnitude elsewhere.

[4] Reduced NO2 mortality coefficient within the range of 1.006 to 1.013 per 10 µg/m3 of NO2 for estimating the effects attributable to NO_2 alone as recommended by COMEAP for policy assessment (COMEAP, 2018

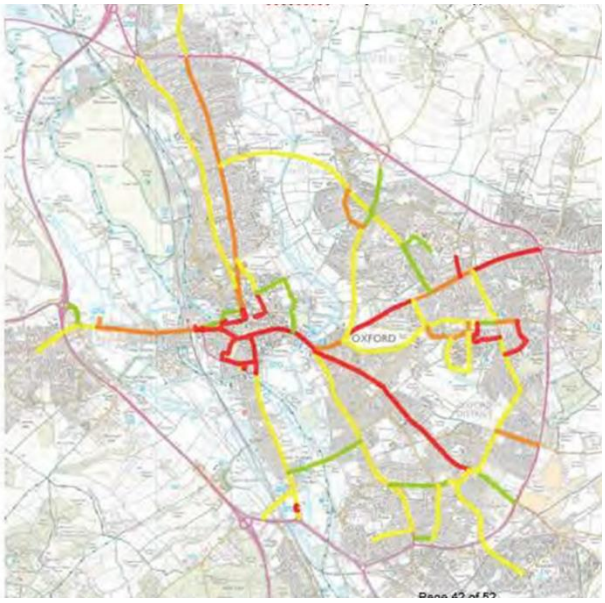

Figure 5 ZEBRA bus route classification by bus-traffic-flow. Adapted from ZEBRA Business Case, Oxfordshire County Council (2022). Red= high flow, Orange = Medium flow, Yellow/Green = low flow.

8.4.2.2. Controlled Before-After Study (Noise Quality)

Acoustic energy of the noise measured at each sensor location will be evaluated before and after introduction of the ZEBRA scheme following methods previously developed by Leach and colleagues for evaluation of the impact of Low Traffic Neighbourhoods on noise quality (Leach et al, 2024) Comparisons of acoustic energy will be made both within and between control and intervention sites to identify impacts which may be attributed of the ZEBRA intervention. In addition, the Normalised Difference Soundscape Index (NDSI) will be used to apportion the measured noise from biotic and anthropogenic sources. NDSI assumes that biophony and anthropophony occur in different bands as the sounds from man-made machinery, such as vehicle engines, are most prominent in the frequency range 1-2 kHz and biological sounds, such as birds tweeting are most prevalent between 2 and 8 kHz. It therefore provides a method to identify if there has been a change in noise sources (anthropogenic or biotic) on ZEBRA bus routes, comparing pre- and post-intervention sites.

8.4.2.3. Health and Economic Impact Assessment

We will use findings from the ITS analysis to estimate reductions in asthma incidence, attributable mortality, life years saved and associated economic benefits if equivalent NO2 reductions were sustained on an annual basis. We will use similar health and economic impact assessment methods adopted previously to assess benefits of lockdown related improvements in air quality in Oxford City (Singh et al, 2022).

To assess baseline NO2 exposure at residential locations, dwellings in the ZEBRA defined area will be classified into three exposure zones: Zone 1 (within 25m of centre lines of main roads); Zone 2 (26-50m from centre lines of major roads (far roadside); Zone 3 >50m from centre lines of major roads (urban background). Annual mean NO_2 concentrations measured at ~100 diffusion tube sites and AURN sites in 2023 will be used to calculate a mean annual NO_2 concentration representative of each exposure zone. Using GIS mapping in ArcMap 10.6.1) residential properties will be identified in the National Land and Property Gazetteer

(NLPG) layer and multiple by the mean city household size of 2.47 to estimate population size resident within each exposure zone. Estimated benefits of NO_2 reductions attributable to the ZEBRA scheme will be calculated for the relevant population at risk residing within each exposure zone, for childhood asthma (age <6, 7-18, >18 years), emergency asthma admissions, lung cancer and all-cause mortality (age>30 years), using CRFs.

To estimate the economic benefits arising from NO_2 changes the approach recommended by COMEAP will be used. Adopting the methods applied in Singh et al (2022) a 10.67 multiplier will be used to convert each death in the defined area into total years of life lost so for each premature death attributable to air pollution the person would have been expected to live for 10.67 additional years. Each year of life lost will be costed by applying a standard £27630 Value of Life Years lost (VOLY) updated to 2023 prices using HM Treasury GDP deflators.

We will explore spatial difference in morbidity and mortality impacts across the ZEBRA area including how these are patterned by socio-demographic characteristics, including Index of Multiple Deprivation and therefore impacts on health inequalities across the area.

9. Data Management

The University of Birmingham will be the data controller for the study.

9.1. Data governance

All research data will be held in compliance with The University of Birmingham Data Protection Policy and the Conditions of Use of Computing and Network Facilities. All research will be registered with the Data Protection Officer (at which time a Data Protection Officer is designated) and all personal data will be held in accordance with the Data Protection Act 2018 and General Data Protection Regulation (GDPR). UoB has arrangements in place for the secure storage and processing of health data including the following security countermeasures:

- Physical security measures
- Logical measures for access control and privilege management
- Network security measures System design
- Operational processes
- Data processing System audit
- Data Protection Registration

The UoB Data Protection Registration number is Z6195856.

9.2. Data sharing

A research contract between the three Universities within PHIRST PHRESH will cover research activity between members of the PHIRST team. A datasharing agreement willbetween the University of Birmingham and Oxfordshire County Council to enable transfer of environmental data (air quality, traffic information) and DfT monitoring and evaluation data including that provided by commercial bus operators. Oxfordshire County Council will be the data holder for noise quality data. All data will be transferred over secure encrypted connections.

9.3. Data storage and retention

Research datasets will be held on secure institutional servers, using password-protected secure storage systems (see below policies). All questionnaires and audio recordings will be

retained in their original form, with any hard copies transferred securely and maintained in a locked cabinet within a locked office in a building restricted to staff (using a swipe-card system). Collaboration between HEIs (including data transfer) will be facilitated through secure online cloud storage systems (OneDrive) with shared areas available to all collaborators and separate secure areas for specific access. Where a partner is unable to use OneDrive, secure data transfer will be used.

Metadata standards and data documentation: All metadata will comply with established practice. Study databases will include variable descriptions for each data field. Any analysis or recoding of qualitative data will have a description attached. Evaluation protocols will include data collection instruments to guide further interpretation.

Data preservation strategy and standards: All research data and related material will be retained for a minimum of 20 years (for population health research data) and 10 years (for basic research data) after the study has been completed.

10. Research Ethics and Governance

10.1. Ethical Issues

The study will be conducted in accordance with:

- Good Clinical Practice (GCP) guidelines
- UK Policy Framework for Health and Social Care Research
- Data Protection Act 2018
- General Data Protection Regulation

GCP is an international ethical and scientific quality standard for designing, conducting, recording and reporting studies that involve the participation of human subjects.

Ethical approval will be sought from the University of Birmingham Science, Technology, Engineering and Mathematics (STEM) ethics committee (approval number to be provided).

10.2. Confidentiality, safeguarding and data management

The research team will ensure that issues of consent, confidentiality, safeguarding and data management are appropriate addressed across all aspects of the research process, including participant recruitment, data collection, analysis and dissemination.

Informed consent:

- All participants will be provided with a verbal description of the research and information sheet detailing the project. All participants will be provided time to read the information sheet and consider participation, and time and contact details to ask any questions they may have about the study.
- All participants will be required to sign a consent form (before participating)
- All participants will be informed of their rights to withdraw from participation.

Confidentiality:

- Participants' confidentiality will be maintained throughout the study where this is practical and feasible. The limits of confidentiality will be explained to all participants
- Participant contributions will be anonymised in all outputs, and any interview or focus group participants will not be linked to any direct quotes.

Safeguarding:

- Any safeguarding issues identified during study fieldwork will be reported in accordance with the University of Birmingham safeguarding policies.

Data protection:

- All data will be securely stored and processed in accordance with University of Birmingham data protection requirements.
- Any personal data will be stored in password protected files on the University of Birmingham server (for example, contact information for arranging interviews, audio recordings, interview transcripts)

11. Evaluation Timeline, Milestones and Risks

11.1. Evaluation timeline

The timeline has been estimated at approximately 18 months from May 2024 to end October 2025. Intervention implementation (i.e., complete zero emission bus fleet rollout) is expected to be completed by November 2024, enabling a full year of post-intervention data to be included in the evaluation.

11.2. Evaluation milestones

A project Gantt chart is provided in Appendix C.

11.3. Evaluation risk assessment

All activities will be undertaken in accordance with the University of Birmingham Risk Assessment Guidance (November 2022). A Project Risk Assessment form will be completed upon submission of ethical approval. The Risk Log will be reviewed and updated regularly at Project Working Group Meetings. All fieldwork activities will undergo a full risk assessment and be undertaken in accordance with the Code of Practice for Safety of Social Researchers

12. Study Management

Overall leadership for PHIRST PHRESH is provided by the PI and Co-PI. The Evaluation Lead will coordinate the evaluation, supported by the Project Working Group comprising PHIRST PHRESH, Oxfordshire County Council, Oxford City Council and PPI representatives and which will meet on a fortnightly basis for the study duration. The Evaluation Lead will report progress to the Senior Management Group (SMG), consisting of the PI/Co-PI, Co-investigators, Senior Academic advisors and PHRESH PPI representatives. Overall oversight will be provided will be provided by the PHIRST PHRESH Study Steering Committee.

13. Study Dissemination

13.1. Dissemination plan

The PHIRST PHRESH team will work with OxfordshireCC and relevant stakeholders to co-produce a dissemination strategy relevant to this evaluation. We expect evaluation findings will be available by end December 2025, with submission of a full NIHR report by end January 2026. Potential impacts of our findings will be considered across the short, medium and longer-term. We will actively engage with the PHRESH PAC and local PPI groups to consider how our findings are most effectively communicated, including with our research participants and PPI members.

We will adopt a diverse range of communication channels to include:

- NIHR PHIRST website
- NIHR PHIRST social media channels
- NIHR final evaluation report
- Open access academic journal articles
- Media interviews and press releases
- Trade and industry newsletters
- Community flyers and leaflets
- Professional and practitioner networks
- Local authority workshops, meetings and events

13.2. Publication policy

All publications and presentations relating to the project will be authored by the Project Working Group and members of the Senior Management Group. Criteria for authorship will be based on the CRediT Contributor Roles Taxonomy. All published outputs will be compliant with the NIHR Open Access Policy and include the appropriate NIHR funding acknowledgement and disclaimer.

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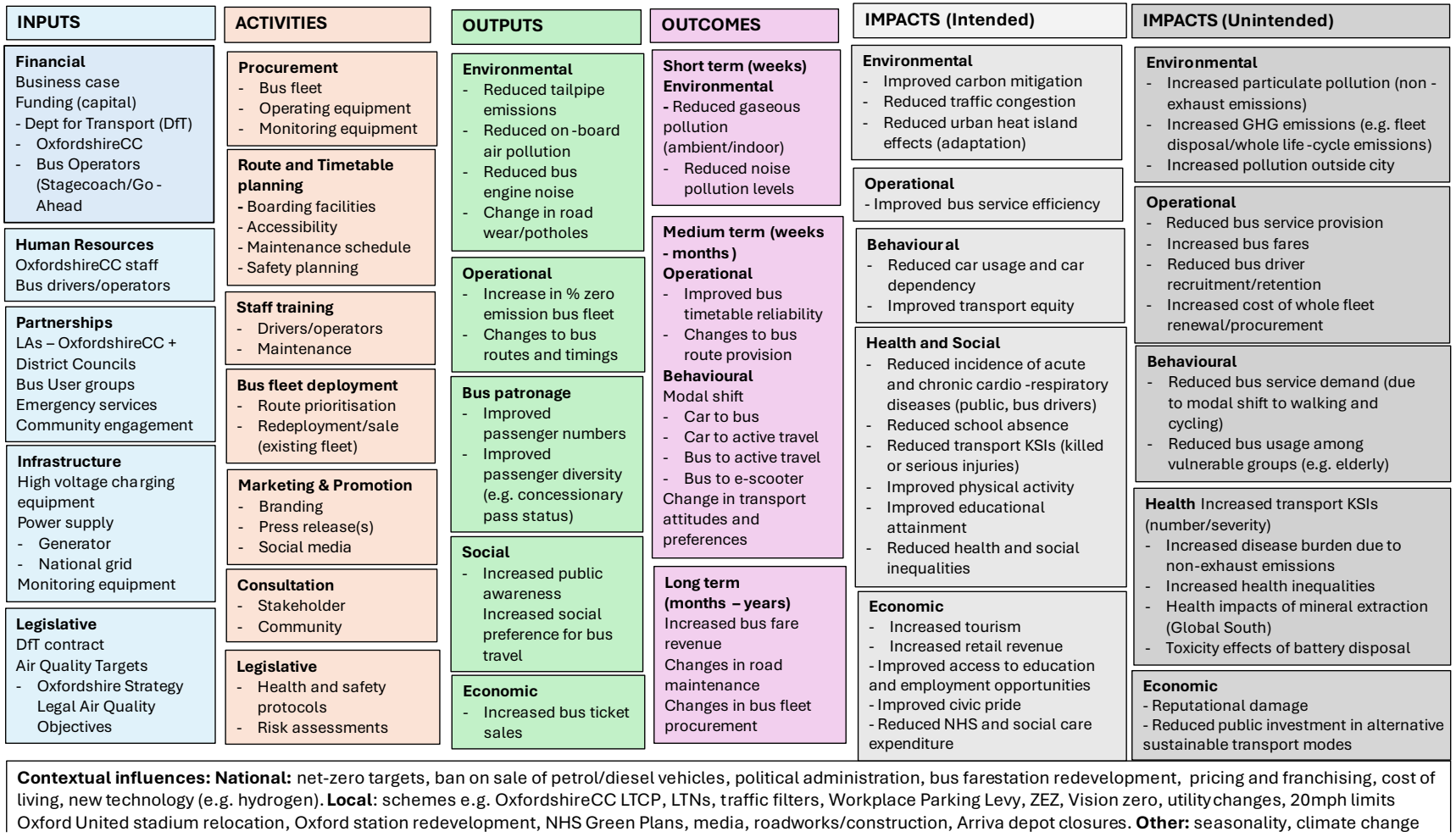
15. Appendices

Appendix A Logic model



Appendix B. Sample focus group recruitment strategy

Focus groups	Rationale	Recruitment methods	Advice from
Phase 1			
Bus operator Staff (n=2)	Interesting insights into the feasibility and acceptability of the scheme from within the bus operators	Staff newsletters Posters in workplaces Direct invites to staff	Bus operators
'Informed' bus users	Selected as this group are informed about many issues affecting the key user groups identified as important. Likely to have a diverse network representing and understanding views from a broad range of users. This will include users with disabilities, young people, people on low incomes, rural areas.	Oxon4Buses Oxford Inclusive Transport & Movement Focus Group	PWG
Phase 2			
Blackbird Leys (socially deprived area)	Socially deprived area outside ring road where residents have lower car ownership, but walking and cycling not accessible across ring road. Don't need to match by travel patterns as homogeneity achieved by recruiting from same area. Individual focus group as recruitment likely to be more successful if recruitment and the focus group happens within the community.	Community Research Network Social media WhatsApp groups Posters at local community venues, key locations Leaflet drop	PPI groups Community Research Network OCC/City colleagues

		Working with local organisations or charities	
Cowley (socially deprived area)	Socially deprived area within the ring road, lower car ownership, walking and cycling accessible and bus likely to be an active choice. Don't need to match by travel patterns as homogeneity achieved by recruiting from same area. Individual focus group as recruitment likely to be more successful if recruitment and the focus group happens within the community.	Community Research Network Social media WhatsApp groups Posters at local community centres, key locations Leaflet drop Work with local charities or organisations	PPI groups Community Research Network OCC/City colleagues
Bus Users (n=2)	Targeted groups of bus users with interesting travel insights include, people travelling to hospitals and Oxford Brookes University, individuals with disabilities, pedestrians and cyclists and young people.	Posters on buses Leaflet distribution and posters at park and ride sites serving hospital. Oxford Brookes University Networks Local RNIB groups Youth groups Oxford Breathe Easy Oxford Community Research Network	PPI groups Community Research Network OCC/City colleagues

		Local social media, WhatsApp, websites. Leaflet drop along key bus routes Door knocking Posters in key community sites surrounding bus routes	
Non-bus users (n=1)	Non-bus users living along the bus route may notice changes in air and noise pollution.	Leaflet drop along key bus routes Door knocking Posters in key community sites surrounding bus routes	PPI groups Community Research Network OCC/City colleagues

Appendix C. Evaluation Gantt Chart

Draft Gantt chart	2024								2025													26
	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Project planning																						
Evaluability assessment																						
Protocol development																						
Arrange contracts with Local Authorities																						
Ethical approval																						
Workshops																						
Logic model development workshop																						
Interim workshop																						
Final workshop																						
Quantitative data collection and analysis																						
Air quality data collection																						
Noise pollution data collection																						
Health impact assessment																						
Qualitative data collection and analysis																						
Qualitative data collection																						
Data analysis																						
Dissemination																						
Reporting and Knowledge Mobilisation																						
Project specific academic output																						
Final report																						