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Low carbon transport interventions and health inequalities: a scoping review

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A R T I C L E I N F O

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A B S T R A C T

Background: Strategies to reduce carbon emissions can yield co-benefits for health but also have the potential to cause unintended adverse consequences and widen inequalities. This scoping review synthesises how health inequality outcomes have been measured in studies evaluating low carbon transport interventions.
Methods: The scoping review followed JBI methodology and PRISMA-ScR guidelines. We identified studies through searches across nine databases, screened them using predefined inclusion criteria, and assessed them for eligibility and quality. We extracted data using a structured tool and synthesised narratively. We evaluated how health inequalities were measured, including whether they were a primary or secondary focus, the use of gap, gradient, or targeted approaches, and whether they reported absolute, relative, or population attributable risk measures.
Results: We identified a total of 26,422 records. Following title and abstract screening and full-text review, 31 studies were retained in the final synthesis. Of the 31 studies, most were from high-income countries (n = 28). The most common decarbonisation interventions included active travel (n = 8), low emission zones (n = 6), and vehicle electrification (n = 3). Health outcomes assessed included physical health, air quality, and quality of life. Socioeconomic (n = 21), place-based (n = 14), and race/ethnicity (n = 13) metrics were most frequently examined. Health inequalities were often treated as a secondary focus (n = 17), with limited use of robust metrics to evaluate inequality outcomes.
Conclusion: There is a lack of methodological consistency in how health inequalities are assessed in evaluations of low carbon transport interventions. Future research should prioritise equity focused approaches to ensure that the health impacts of decarbonisation are better understood.

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1. Introduction

Transport is responsible for a substantial proportion of global and national greenhouse gas emissions, making it a critical sector for achieving decarbonisation (UK Health Security Agency, 2023). The importance of tackling emissions from transport extends beyond environmental necessity. It directly shapes many of the conditions that influence population health, including air quality, opportunities for physical activity, environmental noise, injuries from traffic collisions, and the liveability of neighbourhoods (World Health Organization, 2026; European Environment Agency, 2025). In response, governments and cities have increasingly implemented low carbon transport interventions, defined as policies or actions that aim to minimise emissions associated with delivering and using transport (Claro, 2010). When these interventions are designed and implemented effectively, they can generate wide-ranging co-benefits for health, including improved air quality, increased physical activity and strengthened social cohesion (ITF, 2024; UK Health Security Agency, 2023; Whitmee et al., 2024). However, poorly designed or unevenly implemented decarbonisation actions can also create or exacerbate risks, including potential disbenefits that disproportionately affect certain communities, and can widen health inequalities.

Health inequalities are “avoidable, unfair and systematic differences in health between different groups of people” (The King’s Fund, 2025). These inequalities stem from a complex interaction of structural, social, economic and environmental factors that influence access to resources, exposure to risks and the ability to maintain good health. Climate change acts to intensify existing social and health inequalities by magnifying underlying vulnerabilities and uneven patterns of exposure (Greer, 2023). As a result, groups already experiencing disadvantage are more likely to bear the greatest health impacts, reinforcing and deepening inequities over time. There is clear evidence that climate-related hazards are already harming human health and widening existing inequalities, both in the UK (UK Health Security Agency, 2023) and globally (Whitmee et al., 2024). Understanding how low carbon transport interventions influence health inequalities is therefore essential to ensure that decarbonisation efforts support a just transition and do not reinforce or deepen disparities.

Despite the growing interest in equity within transport decarbonisation, there remains limited clarity and consistency in how health inequalities are measured in this context. Health inequities are defined as the “differences in health status or in the distribution of health resources between different population groups, arising from the social conditions in which people are born, grow, live, work and age” (World Health Organization, 2018). There is therefore a need to understand how health inequality outcomes, metrics and methodological approaches have been used to evaluate low carbon transport interventions, and through this to identify opportunities to strengthen future equity-focused research and policy evaluation.

The potentially beneficial pathways between transport interventions and health include improved access to green spaces and enhanced aesthetics, increased physical activity, better access to essential services, greater mobility independence, and opportunities for social interaction (Glazener et al., 2021; Mindell and Watkins, 2024). These factors can promote physical and mental wellbeing, strengthen social cohesion, and support healthier behaviours. Potentially detrimental pathways include exposure to air, water, and soil pollution; social exclusion; urban heat islands; road traffic injuries; community severance; electromagnetic fields; stress; greenhouse gas emissions and climate change; loss of biodiversity; safety concerns; and noise (Glazner et al., 2021). These pathways can exacerbate health risks and contribute to widening health inequalities if interventions are not designed with equity in mind.

Within the UK, there has been a concerted effort to embed equity into local and national policy frameworks aimed at reducing health inequalities. Initiatives such as Marmot Places have been established to design and implement interventions that improve health equity, integrate equity principles into local systems, and adopt long-term, whole-system approaches to tackling inequalities (Local Government Association, 2025). Similarly, in Scotland, the Institute of Health Equity launched a two-year collaboration for health equity with Public Health Scotland to support public service reform and apply the Marmot eight principles to advance health equity at both national and local levels (Allen, 2024). These developments illustrate a growing policy emphasis on equity focused strategies, however the relationship between low carbon transport interventions and health inequality remains under explored.

To ensure a just transition to net zero, it is important to ensure equitable distribution of health benefits of low carbon interventions across society (Whitmee et al., 2024). Transport decarbonisation provides an exciting opportunity to develop cross-sectoral interventions to reduce health inequalities, but strategies need to be carefully designed, implemented and evaluated to achieve this (ITF, 2024). For example, a recent systematic review demonstrated that active travel interventions can generate substantial co-benefits beyond physical activity, including improvements in health, environmental quality, safety, economic outcomes and transport experience (Ding et al., 2024). However, it is important that existing evidence syntheses move beyond active travel alone and give attention to equity impacts. Our review broadens the scope to encompass a wider range of low carbon transport interventions and explicitly examines how their health effects are distributed across population groups.

Reflecting on health inequalities in relation to low carbon transport interventions more broadly aligns with wider environmental justice frameworks (Raymond et al., 2025). For example, distributional justice might consider how the outcomes of low carbon transport interventions are shared across populations; whilst recognitional justice might highlight how interventions may differentially affect groups with distinct needs or vulnerabilities (European Environment Agency, 2024). Finally, procedural justice might focus on how those groups with distinct needs or vulnerabilities can be included in the decision-making and judicial processes when implementing low carbon interventions (European Environment Agency, 2024). These dimensions can shape how health inequalities are operationalised in empirical studies. For example, studies grounded in distributional equity may focus on gradient to quantify differences across groups, whereas those adopting recognitional justice perspectives may prioritise targeted metrics or analyses of specific inequality-related groups. By acknowledging this diversity in environmental justice frameworks, our review highlights how underlying conceptual assumptions might guide methodological choices and ultimately shape how the equity impacts of low carbon transport interventions are analysed and interpreted.

Finally, embedding equity principles in transport decarbonisation policies is critical to ensuring that the health benefits of these interventions are distributed fairly and do not inadvertently widen existing disparities. However, there is a need to identify and standardise how health inequalities are measured in relation to low carbon transport interventions. Therefore, the aim of this scoping review was to systematically map and describe how health inequalities have been measured in evaluations of low carbon transport interventions. In doing so, the review sought to clarify what types of health inequality outcomes have been assessed, which population groups have been examined, and which methodological approaches and metrics have been used to quantify differences between groups. This includes examining whether studies adopted targeted, gap, or gradient approaches; the extent to which they used absolute, relative or population-attributable measures; and whether health inequalities were treated as a primary or secondary focus of analysis. This focus supports the identification of gaps, areas of inconsistency, and opportunities to strengthen future evaluations of the equity impacts of transport decarbonisation policies.

2. Methods

The scoping review was conducted in accordance with the JBI methodology for scoping reviews (Peters et al., 2024) and follows a PRISMA-ScR (Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews) guidance (Tricco et al., 2018). A protocol for this scoping review was posted online (Scott-Collins et al., 2025).

2.1. Criteria for selecting relevant studies

2.1.1. Participants

Participants are defined by each individual study. The demographics of participants are one of the features of interest to our review. We considered studies with participants of any age and from any country.

2.1.2. Outcome measures

We developed a framework for considering the inclusion criteria as outlined in Table 1. Expanding on Table 1, firstly, there must have been an appropriate health outcome measures included depending on the time frame, intervention or focus of the study. Depending on the time frame of the study, this may have been a direct measure of the health impact of interest (such as premature mortality rate) or may have been an indirect measure – for example by measuring exposure to a risk factor (such as concentration of PM2.5) or a proxy health measure (such as prevalence of hypertension).

Secondly, studies must have considered groups of people across which there are known or suspected inequalities. A commonly used framework for considering these domains is the PROGRESS-Plus framework which includes characteristics such as ethnicity, gender and age (Kavanagh et al., 2008) (see Table 1). This framework acts as a guide for considering the most important characteristics associated with health inequality whilst allowing flexibility for considering other characteristics which may be relevant to specific situations or interventions.

Thirdly, the approach studies took to define and assess inequalities must have been clear. This includes a targeted, gap or gradient approach (Welch et al., 2022). A targeted approach involves measuring the health impact only in a group known to be disadvantaged or at higher risk of poor health outcomes (Benach et al., 2013). A gap approach involves measuring the difference between two or more groups. A gradient approach involves measuring the change in the gradient of exposure or outcome across different groups (Benach et al., 2013).

We additionally considered whether improvements in health outcomes across inequality groups were measured using absolute, relative, or population attributable risk (PAR) measures. Absolute measures are measures that demonstrate the actual difference in outcomes between groups (e.g., years of life gained or the number of people no longer reporting an outcome). Relative measures are expressed as proportional difference between groups. PAR estimates the proportion of disease burden in a population that could be prevented if a specific risk factor was eliminated. It is generally accepted that both absolute and relative measures should be calculated and reported when evaluating health inequalities (Keppel et al., 2005; The Marmot Review, 2010). However, for the purposes of this review, studies were included if they reported *either* an absolute, relative, or population attributable measure of difference between groups.

Table 1
Health inequalities outcome measures criteria for inclusion.

Features	Examples
Health outcome, proxy or exposure/risk factor measure	Premature mortality rate; prevalence of hypertension; average concentration of PM2.5
Characteristics to define groups for analysis	PROGRESS-Plus categories (place of residence, ethnicity, occupation, gender, religion, education, social capital, socioeconomic position, age, disability, sexual orientation and other vulnerable groups) (Kavanagh et al., 2008)
Targeted, gap or gradient approach	Collecting data from people in most deprived areas only; difference between male and female; gradient of slope across index of multiple deprivation scores
Calculate absolute difference, relative difference, or attributable risk between groups, against a population average or over time	Absolute reduction in incidence of road traffic collisions before and after intervention; risk ratio for road traffic collision between two groups; attributable risk for incidence of road traffic collision in low income group compared to high income group.

We included studies if the focus on health inequalities was the primary or secondary aim of the paper being reviewed, defined as the following:

> *Primary Aim:* Inequalities were considered a central focus of the study. This meant the paper was explicitly designed to test how low carbon interventions impact different population groups. The research questions, study design, and methods were structured from the outset to evaluate disparities.
>
> *Secondary Aim:* Inequalities were considered alongside, but not central to, the main research question. In these studies, the primary focus was to evaluate the overall effects of low carbon transport interventions, while analyses related to differences between population groups were included but not the main focus of the paper.

Given that the concept of interest was the measurement of impact of low carbon interventions on health inequalities, papers that discussed health inequalities but did not provide measured or modelled health outcomes, proxy measures or exposures relating to dimensions of inequality were excluded from the review. Studies were accepted for inclusion if they measured and reported health related outcomes at either the individual level, geographical or population level.

2.1.3. Context

The context of interest was low carbon transport interventions and policies with a focus on road transport and active travel. Our search included broad terms such as decarbonisation and low carbon transport but also specific terms such as low emission zones, low traffic neighbourhoods, active travel and home working to capture a broad range of interventions. Any intervention or policy with a primary or secondary aim of avoiding (reducing requirement to travel), shifting (changing the mode of transport to low carbon options) or improving transport (improving the efficiency and emissions) to reduce carbon emissions were included. Studies which modelled potential health inequalities from achieving a target in terms of transport decarbonisation or increased levels of active transport without a specific intervention to achieve such targets were excluded. This was because we aimed to evaluate how the impact of specific low carbon transport interventions on health inequalities has been measured rather than just estimating equity impacts of achieving a goal. Studies with a focus on logistics or rail, maritime or aviation transport were not included in our study.

2.2. Types of sources

This scoping review considered quantitative, original, primary research studies or evaluations of a policy or intervention. Grey literature was considered for inclusion but there was no comprehensive grey literature searching. Systematic reviews and opinion pieces were not included as we aimed to understand how impact on health inequalities have been measured in primary research and policy evaluations.

2.3. Search strategy

The search strategy aimed to identify both published and unpublished studies. First an initial limited search of Scopus and Web of Science was undertaken to identify articles on the topic. The text words contained in the titles and abstracts of relevant articles, and the index terms used to describe the articles were used to develop a full search strategy for Scopus, Web of Science Core Collection, Medline (Ovid), GreenFILE (EBSCO), IBSS (ProQuest), Public Health Database (ProQuest), ASSIA (ProQuest), PAIS Index (ProQuest) and Transport Database (OVID) (see Supplementary Materials 1). The search strategy included all identified keywords and index terms and was adapted for each included database and/or information source. The reference list of all included sources of evidence was screened for additional studies. Only studies published in English and after the year 2000 were included.

2.4. Screening and eligibility checking

Following the search, all identified citations were collated and uploaded into EndNote 21 (The EndNote Team, 2013) and transferred to Rayyan (Ouzzani et al., 2016) where duplicates were removed. Following a pilot test, titles and abstracts were screened by the primary reviewer (ASC) for assessment against the eligibility criteria for the review, and a random 10% of the sample were screen by an

Table 2
Eligibility criteria.

Inclusion criteria	Exclusion criteria
• Original, primary research study or evaluation of a policy or intervention. • Analysis of health impact of an intervention(s) or policy with primary or secondary aim to reduce transport related carbon emissions. • Reports measured or modelled health outcome, proxy or risk factor/exposure measure(s) in relation to at least one dimension of health inequality (e.g. one of the PROGRESS-Plus categories) with comparison between groups, against a population average or over time. • Full text available in English. • Published in 2000 or later.	• Newspaper articles, blog entries, reviews, opinion pieces, study protocols, conference proceedings, poster presentations. • Intervention/policy is not a low carbon transport intervention • Intervention/policy focussed on logistics, rail, aviation or maritime transport. • Analyses in context of COVID-19 pandemic only. • Studies which measure equity of uptake of or exposure to an intervention alone without reporting health-related measures relating to one or more dimension of health inequality.

additional independent reviewer (JB) with disagreements resolved through discussion. Then the full text of selected citations was assessed in detail against the eligibility criteria highlighted in Table 2 by two reviewers (ASC/SS). Again, a random 10% of the sample were screened by the same independent reviewer (JB) and disagreements resolved through discussion. Reasons for exclusion of sources of evidence at full text that do not meet the inclusion criteria were recorded. The results of the search and the study inclusion process are presented in a PRISMA flow diagram in Fig. 1 (Page et al., 2021).

2.5. Data extraction

Data was extracted from papers included in the scoping review by two reviewers (ASC/SS) using a data extraction tool (Supplementary Materials 2). The data extraction tool included a critical appraisal checklist informed by existing quality appraisal tools with the aim of providing a basic evaluation of the quality of evidence available (Barker et al., 2024; Duval et al., 2023; Hosking et al., 2024). The data extracted included specific details about the participants, concept, context, study methods and key findings relevant to the review question. Any uncertainties during data extraction were discussed with an independent reviewer (JB).

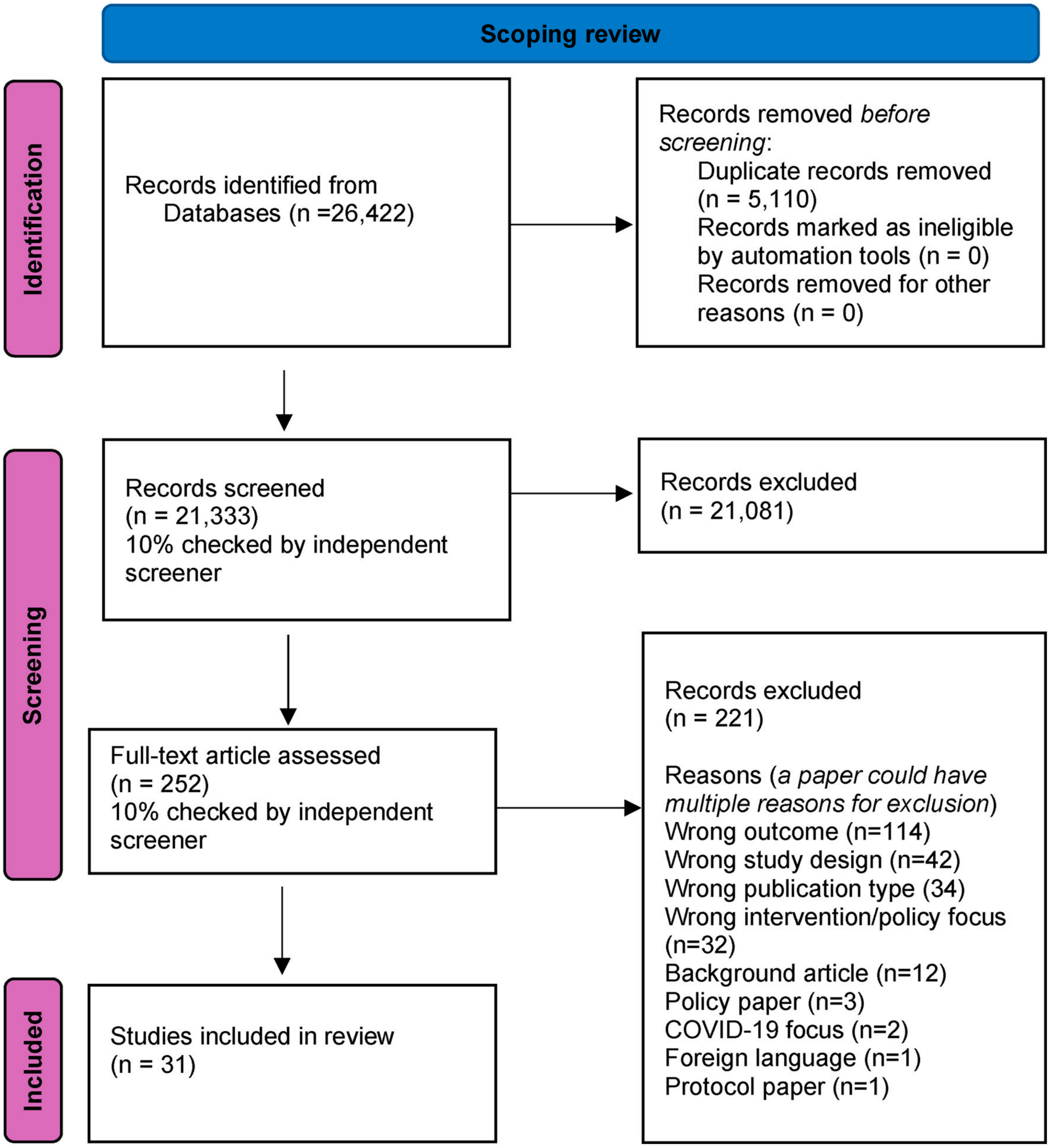

Fig. 1. A PRISMA flow diagram of search, screening and inclusion stages.

2.6. Data synthesis and presentation

We conducted a qualitative synthesis of included studies due to their heterogeneity. A narrative summary accompanied the tabulated results and described how the findings related to the review question and objectives.

Firstly, we reported outcome measures according to the features outlined in Table 1 and documented whether each paper treated health inequalities as a primary or secondary focus. We additionally categorised each low carbon intervention according to whether it had been implemented in real-world settings. For interventions without real-world implementation, evidence was primarily derived from simulated or hypothetical datasets although these were often grounded in existing evidence assessing similar interventions. For interventions implemented in real-world setting, these papers used effect estimates derived from the intervention to assess health outcomes. These health outcomes included directly measured effects as well as modelled outcomes projected over longer time periods.

Finally, we considered the study design of the papers, these were categorised as natural experiment (including quasi-experimental evaluations of real-life interventions), cohort studies (including prospective cohort studies), modelling studies (including those modelling effect estimates from simulated intervention scenarios, and those using real world data) and other. The other category included ecological studies, which examine groups or populations, and controlled field experiments, which involve researcher-led studies conducted in participants' natural environments rather than in laboratory or artificially controlled settings.

3. Results

A total of 26,422 records were identified through the searching of databases including: Scopus, Web of Science Core Collection, Medline (Ovid), GreenFILE (EBSCO), IBSS (ProQuest), Public Health Database (ProQuest), ASSIA (ProQuest), PAIS Index (ProQuest) and Transport Database (OVID). After removing 5110 duplicates, 21,333 records were screened by title and abstract. Of these, 21,081 were excluded. The full text of 252 articles was assessed for eligibility, resulting in 31 studies included in the final review. Reasons for exclusion at full-text stage included wrong outcome (n = 114), wrong study design (n = 42), wrong publication type (n = 34), wrong intervention focus (n = 32), lack of health inequality assessment (n = 16), and other criteria such as background articles, policy papers, COVID-19 focus, and language limitations (n = 19).

3.1. Background characteristics of the studies reviewed

Table 3 describes the characteristics of the 31 papers reviewed. Of the 31 studies reviewed 28 were from high income countries (HIC) (12 - USA, 6 - UK, 2 - France and New Zealand, 1 - Italy, Sweden, Australia and Israel), two were from upper-middle income countries (UMIC) (2 - China) and one study was from a lower-middle-income country (LMIC) (1 - India).

3.2. Classification of intervention evidence sources

The studies reviewed drew on a range of intervention evidence sources (Table 3). 15 studies assessed interventions that had been implemented in real-world settings, while 16 relied on simulated or hypothetical intervention scenarios. Evidence in the latter group was primarily derived from modelling or hypothetical datasets, although these were sometimes informed by existing empirical research evaluating similar interventions but in different settings. For example, Dadashev et al. (2023) simulated the effects of hypothetical congestion pricing and reduced car ownership on air quality in Tel Aviv, and Schmitt et al. (2024) modelled air quality and mortality outcomes associated with hypothetical vehicle fleet electrification in the United States.

In contrast, studies drawing on real-world evidence used measured or observed data to estimate health impacts. Muennig et al. (2014) applied a Markov model to effect estimates from the New York Safe Routes to School Programme to evaluate long term impacts on injury risk, medical costs, disability and mortality. Hunter et al. (2021) used baseline and follow-up household surveys to assess the public health impacts of a new urban greenway in Ireland, while Panter and Ogilvie (2017) analysed changes in walking behaviour following the introduction of new cycling and walking infrastructure in Kenilworth, Cardiff and Southampton.

3.3. Study design

The majority of study designs were based on modelling (n = 19). This group included papers that used effect estimates derived from simulated scenarios, as well as those that applied effect estimates from real-world data to model long term health implications. For example, Peshin et al. (2024) modelled the hypothetical effect of switching to net zero-emitting electricity generation for vehicle charging on air pollution attributable deaths. Tonne et al. (2008) similarly used empirical data on the introduction of the congestion charging scheme in Central London to model its effects on mortality and life expectancy.

Nine study designs were classified as natural experiments. These studies evaluated interventions implemented in real-world settings and included those using a before and after framework (n = 5) and those using effect estimates derived from real-world data (n = 4). For instance, Patterson et al. (2023) used longitudinally linked individual level Census data to assess changes in cycling following the implementation of the Cycling Demonstration Towns and Cycling Cities and Towns programmes in England and Wales. He et al. (2022) used baseline and follow-up survey data collected before and after the completion of the East Lake greenway in Wuhan to examine changes in body mass index.

Three further studies adopted other research designs. Lundberg and Lindfors (2002) conducted a controlled field experiment in which participants engaged in activities such as office work, teleworking and home-based tasks, with physiological stress markers were

Table 3
Methodological summary of papers reviewed.

Reference	Intervention evidence source		Study design				Population /Setting	Description of intervention	Public involvement
	Real-world data	Hypothetical or simulated	Natural experiment	Modelling study	Cohort	Other			
Auchincloss et al. (2022)	X				X		Philadelphia, USA (HIC)	Bike-share program	
Dadashev et al. (2023)		X		X			Tel-Aviv, Israel (HIC)	Simulated effect of congestion pricing and reduced car ownership	
Baghestani et al. (2022)		X		X			Manhattan NYC, USA (HIC)	Cordon pricing – a type of congestion charge	
Berberian et al. (2024)		X		X			12 US states (HIC)	Three transport cap-and-invest scenarios – focussed on public transport, active mobility and vehicle electrification	
Cesaroni et al. (2012)	X		X				Rome, Italy (HIC)	Central low traffic zones	
He et al. (2022)	X		X				East Lake Greenway, China (UMIC)	Conversion of a motorized vehicle road into a traffic-free greenway	
Griffin et al. (2020)		X		X			Leeds and Bradford, UK (HIC)	Low emission zones	
He et al. (2021)	X		X				East Lake Greenway, China (UMIC)	Conversion of a motorized vehicle road into a traffic-free greenway	
Hunter et al. (2021)	X		X				Belfast, Northern Ireland (HIC)	Urban regeneration with increased activity travel infrastructure	X
Mizdrak et al. (2019)		X		X			New Zealand (HIC)	Trip switch – from cars to walking/cycling	
Muennig et al. (2014)	X		X				New York, USA (HIC)	Improving safe routes to school	
Tonne et al. (2008)	X			X			Greater London, UK (HIC)	Congestion Charging Scheme	
Peshin et al. (2024)		X		X			India (LMIC)	Vehicle electrification	
Patterson et al. (2023)	X		X				England and Wales (HIC)	Cycling Demonstration Towns and Cycling Cities and Towns	
Poorfakhraei, 2018		X		X			Atlanta, USA (HIC)	Evaluation of long-range transportation plans	
Rose et al. (2021)	X					Ecological study	North West England (HIC)	Air Quality Management Areas	
Schmitt et al. (2024)		X		X			USA (HIC)	Fleet electrification	
Singh et al. (2024)		X		X			USA (HIC)	Fleet electrification	
Lundberg and Lindfors (2002)	X					Controlled field experiment	Sweden (HIC)	Teleworking	
Wu et al. (2019)		X		X			Sacra-mento, USA (HIC)	3 hypothetical transport scenarios to reduce greenhouse emissions	
Host et al. (2020)		X		X			Paris, France (HIC)	Low emission zone - 4 scenarios	
Standen et al. (2021)		X		X			Sydney, Australia (HIC)	Two new cycle infrastructure	
Edwards et al. (2014)	X		X				London, UK (HIC)	Free bus travel for young people	

(*continued on next page*)

Table 3 (*continued*)

Reference	Intervention evidence source		Study design				Population /Setting	Description of intervention	Public involvement
	Real-world data	Hypothetical or simulated	Natural experiment	Modelling study	Cohort	Other			
Brown et al. (2024)	X			X			England (HIC)	Active travel, anti-idling, ride-share, low emission zones and improved travel routes	X
Dimaggio et al. (2015)	X		X				Texas, USA (HIC)	Education and built environment interventions to improve safety of travel to school	
Dimaggio et al. (2014)	X			X			New York, USA (HIC)	Education and built environment interventions to improve safety of travel to school	
Gallagher and Holloway (2022)		X		X			USA (HIC)	3 nationwide de-carbonization scenarios	
Liu et al. (2024)		X		X			England and Wales (HIC)	future policies scenarios including - business as usual, the Balanced Net Zero Pathway	
Moreno et al. (2022)		X		X			Paris, France (HIC)	Low emission zone - 4 scenarios analysed	
Hosking (2023)		X		X			Auckland, New Zealand (HIC)	distance-based pricing and free public transport	
Panter and Ogilvie (2017)	X		X				Kenilworth, Cardiff, Southampton, UK (HIC)	Constructing and improving cycling and walking routes	

Table 4
Outcomes and inequalities assessed within the papers reviewed.

Reference	Health outcome	Other outcomes	Inequalities analysed											Intersectionality
			Place	Race/ ethnicity	Occupation	Gender/ Sex	Religion	Education	Socioeconomic	Social capital	Age	Disability	Other	
Auchincloss et al. (2022)	Activity status			X	X	X		X	X		X			
Dadashev et al. (2023)	Air quality	PM2.5 concentration, CO2, NO2							X		X			
Baghestani et al. (2022)	Asthma, mortality, lung cancer, ischaemic heart disease	PM2.5 concentration	X	X										
Berberian et al. (2024)	Infant mortality, preterm birth, low birth weight, asthma, lower respiratory infections, acute bronchitis, autism spectrum disorder	PM2.5 concentration, CO2	X	X							X			
Cesaroni et al. (2012)	Years of life gained	PM10 concentration, NO2	X						X					
He et al. (2022)	BMI				X	X		X	X				Marital status	
Griffin et al. (2020)	QALY/QALE/ Equally distributed equivalent (EDE) QALY								X				Baseline health	
He et al. (2021)	Physical activity (from walking)		X		X	X		X	X				Marital status	
Hunter et al. (2021)	Physical activity, mental wellbeing and quality of life		X						X					
Mizdrak et al. (2019)	QALY	Greenhouse gas emissions		X		X					X			
Muennig et al. (2014)	QALE										X			
Tonne et al. (2008)	Years of life gained	PM10 concentration, NO2							X					
Peshin et al. (2024)	Mortality	PM2.5 concentration	X	X				X	X					
Patterson et al. (2023)	Physical activity (from cycling)			X	X	X		X	X		X			
Poorfakhraei, 2018	COPD mortality, ischemic heart disease mortality, lung cancer mortality	PM2.5 concentration,		X					X					

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Table 4 (*continued*)

Reference	Health outcome	Other outcomes	Inequalities analysed											
			Place	Race/ ethnicity	Occupation	Gender/ Sex	Religion	Education	Socioeconomic	Social capital	Age	Disability	Other	Intersectionality
Rose et al. (2021)	Hospital admissions for respiratory illness								X					
Schmitt et al. (2024)	Mortality	PM2.5 concentration, socio-economic impacts	X											
Singh et al. (2024)	Mortality	PM2.5 concentration, socio-economic outcomes	X	X					X					
Lundberg and Lindfors (2002)	Blood pressure, heart rate, urinary catecholamines, salivary cortisol, stress					X								
Wu et al. (2019)	Mortality, physical activity, traffic injuries		X	X					X					
Host et al. (2020)	Life expectancy gains, asthma, ischemic heart disease, low birth weight	PM10 concentration, NO2	X						X					
Standen et al. (2021)	Physical activity (from cycling)					X			X		X			
Edwards et al. (2014)	Road injuries, physical activity (from walking and cycling)		X	X					X					
Brown et al. (2024)	Air Quality	NO2									X			
Dimaggio et al. (2015)	Pedestrian and cycling injuries										X			
Dimaggio et al. (2014)	Pedestrian injuries										X			
Gallagher and Holloway (2022)	Air quality	Public health monetary benefits, PM10 concentration, NO2	X	X										
Liu et al. (2024)	Air quality	PM10 concentration, NO2	X	X	X			X	X		X			X
Moreno et al. (2022)	Mortality and child asthma	PM10 concentration, NO2,	X						X					

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Table 4 (*continued*)

Reference	Health outcome	Other outcomes	Inequalities analysed											
			Place	Race/ ethnicity	Occupation	Gender/ Sex	Religion	Education	Socioeconomic	Social capital	Age	Disability	Other	Intersectionality
Hosking (2023)	DALYs, physical activity, road traffic accident	Economic health benefits Greenhouse gas emissions							X					
Panter and Ogilvie (2017)	Physical activity (from walking)		X	X		X		X	X				Health	

measured across settings. Rose et al. (2021) implemented a longitudinal controlled ecological study to investigate whether declaring an Air Quality Management Area in the North West Coast region of England was associated with reduced emergency hospital admissions for respiratory conditions. One study, Auchincloss et al. (2022), used a cohort design to follow new bikeshare members in Philadelphia and assess whether within person moderate and vigorous physical activity increased with greater use of the programme.

3.4. Health outcomes

Table 4 identifies the health outcomes considered across the papers reviewed. The studies encompassed a broad range of health outcomes linked to low carbon transport interventions, with many considering multiple outcomes. Physical health outcomes were the most commonly assessed (n = 15), including mortality, asthma, cardiovascular diseases, cancer, respiratory infections, road traffic injuries, and body mass index (BMI). Physical activity levels and air quality (PM2.5 concentrations, CO_2, and NO_2), used as proxies for health outcomes, were examined in 7 and 4 studies, respectively. Broader health impacts were quantified in 7 studies using quality of life metrics such as Quality-Adjusted Life Years (QALYs), quality-adjusted life expectancy (QALE), life expectancy gains, and Disability-Adjusted Life Years (DALYs). A smaller subset of studies (n = 2) explicitly explored mental health and wellbeing, including stress and psychological outcomes, and 1 study using QALEs included a question about mental health within the quality of life metrics (Muennig et al., 2014). Beyond health outcomes, several studies assessed broader environmental and economic impacts. 11 studies reported air quality outcomes in addition to health outcomes, including greenhouse gas emissions, PM2.5 concentrations, CO_2, and NO_2. Four studies reported socioeconomic or monetary impacts associated with the transition to low carbon transport (Table 4).

3.5. Inequalities considered

A range of inequality dimensions were examined across the studies, as indicated in Table 4. Socioeconomic status (SES) was the most frequently analysed (n = 21), followed by place-based (n = 14), race/ethnicity (n = 13), and age-related inequalities (n = 11). Gender/sex (n = 8) and education (n = 7) were also considered, while occupation (n = 5) and marital status (n = 2) were less commonly addressed. Only one study explored differences by baseline long-term conditions. No studies examined disability, social capital, or religion, and just one explicitly incorporated intersectionality into their analysis through using a multivariate clustering technique to generate five distinct clusters based on demographic, housing and socioeconomic factors (Liu et al., 2024).

3.6. Equity impacts of interventions

Across the reviewed studies, the equity impacts of interventions varied by SES, ethnicity, gender, and age. Several interventions, such as bike-share programs, low traffic zones, and urban regeneration, showed no differential effects across inequality groups including place-based and socioeconomic (Cesaroni et al., 2012; Hunter et al., 2021); and ethnicity, occupation, gender, education, socioeconomic and age (Auchincloss et al., 2022). In contrast, cordon pricing schemes (a congestion pricing program) in the central business district area of New York City were projected to reduce PM2.5 exposure most significantly for non-Hispanic White populations, compared to African American and Hispanic groups (Baghestani et al., 2022). Cap-and-invest scenarios (a system that caps carbon emissions and allows businesses to buy or trade emission allowances) in the US were associated with the greatest reductions in pollution in densely populated areas (Berberian et al., 2024). This study also found that these interventions were associated with greater improvements in asthma outcomes among children of Hispanic or "Other" ethnicity compared to non-Hispanic White children (Berberian et al., 2024). Similarly, congestion charging in London was associated with the largest reductions in air pollutants and mortality among residents of the most deprived areas, though these communities still faced higher baseline exposure (Tonne et al., 2008). Air quality management areas in England were also associated with reduced emergency respiratory admissions, with greatest gains seen in deprived communities (Rose et al., 2021). While achieving long-range transport plans (regional transportation plans for urban areas with 50,000 or more people) in the US were projected to result in the greatest absolute reduction in mortality risk for low income and minority communities (Poorfakhraie, 2018).

Active travel and green infrastructure interventions showed mixed equity effects. Living near greenways in China was associated with increased physical activity among women, low SES groups, and working-age adults, but not among men, high-SES groups, or older adults (He et al., 2022). Cycling initiatives in England and Wales saw higher levels of participation among women, older adults, and those in deprived areas (Patterson et al., 2023), while walking interventions were associated with sustained gains in physical activity levels mainly among individuals with lower education and income (Panter and Ogilvie, 2017). Gender and ethnicity also influenced outcomes: Māori populations and men saw greater QALY gains from mode shifts to walking (from car travel) in New Zealand (Mizdrak et al., 2019), and Hispanic or "Other" ethnicity children experienced the largest projected reductions in asthma under certain transport intervention scenarios in the US (Berberian et al., 2024). However, some policies, such as low emission zones (LEZ) in Paris, risked reinforcing existing inequalities, despite overall health improvements. This was because the largest reductions in air pollution would occur inside the LEZ, where wealthier populations live (Host et al., 2020; Moreno et al., 2022). Further, Whitmee et al. (2024) found that after modelling future low carbon policies scenarios in England and Wales overall patterns of inequalities would persist.

3.7. Inequalities metrics

Measurement approaches varied across the included studies, as suggested in Table 5. Absolute differences were reported in 19

Table 5
A Summary of how health inequalities were assessed and measured.

Reference	Primary or secondary aim:		Measurement approach:				Metric to quantifying health inequalities:				Other comments
	Primary	Secondary	Absolute	Relative	Population attributable risk	Other	Gap	Gradient	Targeted	Other	
Auchincloss et al. (2022)		X	X						X		
Dadashev et al. (2023)		X		X				X			
Baghestani et al. (2022)	X		X	X				X			Absolute reduction and percentage reduction by group reported
Berberian et al. (2024)		X		X				X			Atkinson Index
Cesaroni et al. (2012)		X	X	X				X			Absolute reduction and group-specific concentration-Response Function reported
He et al. (2022)		X		X				X			
Griffin et al. (2020)	X		X	X				X			Atkinson Index
He et al. (2021)		X		X				X			
Hunter et al. (2021)	X			X				X			
Mizdrak et al. (2019)		X	X				X				
Muennig et al. (2014)		X				X			X		Inequalities subgroups not analysed
Tonne et al. (2008)		X	X					X			
Peshin et al. (2024)	X		X					X			
Patterson et al. (2023)	X			X				X			
Poorfakhraei, 2018		X	X					X			
Rose et al. (2021)	X		X					X			
Schmitt et al. (2024)		X	X					X			
Singh et al. (2024)	X		X					X			
Lundberg and Lindfors (2002)		X		X			X				
Wu et al. (2019)	X		X				X				
Host et al. (2020)		X	X					X			
Standen et al. (2021)	X		X					X			
Edwards et al. (2014)	X			X				X			
Brown et al. (2024)	X		X						X		
Dimaggio et al. (2015)	X			X					X		
Dimaggio et al. (2014)	X			X					X		
Gallagher and Holloway (2022)	X			X				X			
Liu et al. (2024)	X		X					X			
Moreno et al. (2022)	X				X			X			
Hosking (2023)	X		X					X			
Panter and Ogilvie (2017)		X	X					X			

studies, for example Tonne et al. (2008) provided the absolute reduction in pollutant concentrations and years of life gained per 100, 000 population for different geographic and socioeconomic groups. Rose et al. (2021) reported the absolute change in emergency hospital admissions for respiratory conditions per 100,000 population in intervention and control neighbourhoods. Relative differences were reported in 15 studies, for example the reporting of concentration of CO_2 and NO_2 by socioeconomic groups across different congestion pricing and reducing car ownership scenarios (Dadashev et al., 2023). Whilst He et al., (2021) reported the relative dose-response effect of a large scale greenway intervention (landscaped and traffic-calmed pathways that link parks, open spaces, and public facilities) on walking time by residential proximity. They also produced regression estimates for effect of intervention on walking time by other characteristics including gender, education and socioeconomic factors (He et al., 2021).

Several studies used multiple metrics, for example Baghestani et al. (2022) reported both the absolute reduction in air quality by area of New York City as well as the relative difference in improved air quality by ethnic group. Population attributable risk was analysed in only one study, where Moreno et al. (2022) used a health impact equation that included calculating attributable fractions to determine the attributable number of deaths and childhood asthma cases avoided following the implementation of the Paris LEZ.

Finally, most studies employed gradient-based approaches (n = 22), with gap metrics used in three studies and targeted metrics in six. The Atkinson Index, a relative inequality measure that quantifies the extent to which a given income distribution is more unequal than a perfectly equal distribution (Atkinson, 1970), was used in two studies.

3.8. *Data quality*

In Supplementary Materials 3, we present a critical appraisal of the 31 studies reviewed. Overall, most studies clearly defined their outcome measurements (n = 27/31) and described the intervention being assessed (n = 24/31). Where applicable, valid and reliable methods were used to assess outcomes (n = 23/24, with 7 studies not applicable). Statistical analyses were typically appropriate (n = 29/31), although the clarity of results varied. Only 18 out of 31 studies presented results with sufficient clarity, and 14 out of 31 failed to consider any level of uncertainty when presenting their findings. Control groups were often absent or not applicable (n = 7/15, with 16 studies not applicable), and blinding procedures were not used in any study - likely due to the predominance of modelling methodologies. Confounding factors were inconsistently addressed (n = 13/31), and justification of assumptions and exploration of uncertainty varied (n = 15/24 justified; 7/24 partially justified; 7 not applicable). Funding bias appeared unlikely in any studies (n = 31/31). However, the specification of target populations and settings (n = 22/31) and the comparability of participants (n = 6/10, with 21 studies not including a comparison group) were not consistently reported.

4. Discussion

This scoping review synthesised how health inequalities have been measured in studies assessing low carbon transport interventions. This includes the types of inequality outcomes reported, the population groups examined, and the methodological and statistical approaches used to quantify differences between groups. By focusing on the measurement of health inequalities this review responds directly to the lack of clarity, consistency, and conceptual grounding in how equity impacts are operationalised in the current literature. We found 31 studies that met the inclusion criteria and were retained for the final analysis. 28/31 studies were from HIC with a dominance of papers from the USA (12/28) and the UK (6/28).

Just over half of the studies drew on simulated or hypothetical intervention data, with the rest using real-world evidence sources. Common interventions included active travel infrastructure, low emission zones, and vehicle electrification, with relatively few addressing demand reduction. Health outcomes predominately focused on physical health indicators and air quality proxies, while mental health and broader wellbeing were less frequently considered. Inequality analysis was uneven, with socioeconomic and place-based dimensions most frequently examined. Intersectional perspectives and public involvement were largely absent from studies reviewed. These trends underscore the narrow scope and methodological inconsistency in current evaluations.

Our review found that interventions often have uneven impacts across socioeconomic, ethnic, gender, and age groups, and the nature of these impacts differed between studies using simulated or hypothetical modelling scenarios and those drawing on real-world evaluations. Modelling studies frequently projected that policies such as congestion charging, air quality management, and long-range transport planning may deliver greater health benefits for low income and minority communities, suggesting a potential narrowing of inequality gaps. In contrast, evaluations based on observed data provided evidence of behavioural and health changes following active travel and green infrastructure interventions, with increases in cycling or walking more commonly seen among women, older adults, and people living in deprived areas, while men and higher socioeconomic groups tended to see fewer gains. Despite these overall improvements, both modelled scenarios and real-world studies indicated that some interventions may inadvertently reinforce existing inequalities, highlighting the importance of equity focused design and evaluation. These findings align with a recent scoping review of active travel interventions, which reported mixed effects across inequality subgroups and emphasised the need for future studies to embed equity considerations throughout intervention design, implementation, and evaluation (Ding et al., 2024).

The difference in health outcomes across groups was most commonly reported using a gradient approach. In particular, raw outcome numbers were often reported without any specific measure to quantify the difference between groups. This meant that for some papers effect estimates (using statistical testing) were not provided and, therefore, this may limit to a certain extent how confidently we can evaluate these policies and interventions in relation to health inequalities outcomes.

We found that during screening several papers discussed health inequalities without providing explicit measures and were subsequently excluded from the final 31 papers. Conversely, some studies included relevant outcomes but did not label them as health inequality-related, making them easy to overlook. This highlights the need for greater consistency in how health inequalities are defined and reported. A number of papers were also identified that modelled health inequality outcomes in relation to transport but did not evaluate any specific intervention or policy. Instead, these studies relied on assumptions about achieving predefined goals, such as increasing population levels of physical activity. Although they were excluded from the final set of 31 studies because they did not meet the inclusion criteria, they form a relevant body of work that contributes to the wider understanding of health inequalities within the transport and health literature.

We initially considered the Avoid–Shift–Improve (ASI) framework as a way to categorise interventions but found its application challenging. While ASI distinguishes between strategies that avoid travel, shift to sustainable modes, or improve efficiency (Jarre et al., 2024), most interventions in the papers we reviewed overlapped across two or more categories. For example, active travel initiatives often combined elements of both shift (from car to cycling/walking) and subsequently improve (enhancing cycling infrastructure). Because of this overlap, classifying interventions under ASI did not add meaningful insight to our paper, and we opted not to present results by this framework. This reflects the complexity of real-world interventions, which rarely fit neatly into single categories and often require integrated multisystem approaches to understand their impacts on decarbonisation and equity goals.

A substantial proportion (52%) of the included studies relied on simulated or hypothetical intervention scenarios rather than directly observed data. These modelling studies provide important insights into potential equity impacts but are based on assumptions that may not reflect real-world behavioural responses or contextual factors. Their findings therefore indicate projected, rather than empirically observed, equity effects. In contrast, studies using real-world evaluations offer evidence based on measured health outcomes and observed distributional effects. Distinguishing between projected and observed impacts is important to avoid implying causal conclusions where the evidence base is primarily model-based.

We found that only four studies employed conceptual frameworks to underpin the pathways through which low carbon transport interventions may influence health. Additionally, there was a strong emphasis on health outcomes related to air quality and particulate matter, which, while important, do not capture the broader potential health benefits of low carbon transport strategies. For example, only two studies considered either mental health or psychological as a primary outcome. It is also important to consider the determinants of health outcomes more holistically - for example, increases in physical activity should be evaluated alongside potential risks such as injury, exposure to air and noise pollution, and other environmental stressors. This was something that was not considered across the papers reviewed. Additionally, where air or noise pollution were considered, outcomes were often based on fixed measurement points which may not reflect individual level of exposure and therefore give misleading results in terms of health inequality.

Several studies assessed increases in physical activity following low carbon transport interventions, often operationalised as changes in cycling, walking, or both. While these measures provide useful indicators of behaviour change, they may not fully capture the net impact on overall physical activity. For example, individuals who increase cycling could simultaneously reduce (or substitute) other forms of activity, such as walking or gym-based exercise. These unobserved behavioural shifts could lead to overestimation of health benefits if analyses assume that all additional cycling or walking represents a net gain in physical activity. Evidence from studies that adjust for such displacement effects suggests that pro-active travel measures still deliver substantial net gains in physical activity, potential alleviating this concern (Goodman et al., 2014). However, displacement effects may vary across population groups, potentially reinforcing health inequalities. For instance, more deprived groups might face greater constraints on leisure time or access to facilities, influencing how they adapt their activity patterns. This in turn could widen the socioeconomic inequalities in sports participation (Richard et al., 2023). Future evaluations should consider total physical activity by certain population groups and explore potential compensatory behaviours to provide a more accurate assessment of health outcomes and equity impacts.

Our scoping review highlighted several limitations in how health inequalities are currently assessed within the literature evaluating low carbon transport interventions. Firstly, there was a notable lack of formal quantification of health inequalities. While many studies reported absolute differences as a primary outcome between population groups ($n = 19$), fewer studies employed more rigorous statistical metrics such as relative differences or population attributable fractions. These are important for understanding the proportional burden and potential impact of interventions across groups. Secondly, health inequalities were often treated as a secondary consideration rather than a central focus of the papers reviewed ($n = 18$), with inequalities often treated as an 'add-on' after the main analysis. This suggests that inequality impacts may be frequently underexplored or only superficially addressed, potentially overlooking important disparities in outcomes. Thirdly, there was considerable inconsistency in the methods used to measure inequalities. Studies varied widely in their use of raw numbers and relative measures, observed data and modelling outputs, making cross-study comparisons challenging and limiting the generalisability of findings. Finally, only one study explicitly considered intersectional factors, indicating a significant gap in the literature. This omission risks oversimplifying complex social realities and may obscure the compounded effects of multiple forms of inequality.

The relationship between transport and health inequalities is complex and multifactorial, yet most studies reviewed focused on single disease outcomes or single dimensions of inequality. This narrow scope risks reinforcing siloed approaches and competing priorities. A broader understanding of health inequalities could support more holistic, transdisciplinary intervention design. Few studies considered community-defined health outcomes, equity related factors such as participation, transport poverty, or uptake of interventions. These findings are echoed by a recent review exploring the co-benefits of active travel where social benefits, which are key to the wider determinants of health, were least likely to be measured (Ding et al., 2024). These gaps highlight the need for more inclusive, equity focused evaluations, potentially informed by health economics and community engagement.

Our findings indicate that policies aimed at decarbonising transport should integrate equity considerations from the outset. Strengthening policy guidance to require clear, standardised assessment of distributional impacts would help ensure that the health co-benefits of low carbon transport are equally distributed. Further, there should be an understanding that transport decarbonisation can generate unintended and uneven consequences, meaning proactive identification and mitigation of potential harms is essential, particularly for groups with higher baseline vulnerabilities. Together, our findings highlight the need for policies that prioritise both low carbon and equity in order to support a genuinely just transition.

While well-designed low carbon transport interventions can yield health benefits, this review highlights that the relationship between such interventions and health inequalities is often inconsistently assessed. Future research should adopt more methodologically consistent approaches, including robust measures of differences across inequality groups. Health inequalities should be a central focus, with studies considering a broader range of outcomes, both physical and psychological, and a wider set of inequality dimensions, particularly those underrepresented in current literature. Intersectionality must be explicitly addressed to capture the complexity of overlapping disadvantages. Importantly, researchers should engage with communities to identify the health outcomes and research prioritise that matter to them.

4.1. Strengths and limitations

We conducted a comprehensive scoping review across nine major databases, using an extensive range of search terms to review literature relevant to our broad research question. By applying a scoping review framework, we systematically mapped existing evidence and identified key gaps in the field. Additionally, our inclusion of a structured critical appraisal of the included studies strengthens the assessment of evidence quality and enhances the transparency of our findings. However, while grey literature was considered, comprehensive searching was not conducted. This may have led to the exclusion of relevant policy evaluations, local authority reports, or community-led initiatives not published in academic journals. The scoping review also excluded studies that did not evaluate a specific intervention or policy, even if they modelled relevant health inequality outcomes. This may have omitted valuable insights from other study designs such as scenario-based studies. Reviewer blinding was not implemented during screening or data extraction. This may have introduced a minor risk of bias in study selection and interpretation.

5. Conclusions

This scoping review sets out to examine how health inequalities have been defined, operationalised and measured within studies evaluating low carbon transport interventions. Rather than assessing just intervention effectiveness, our focus was on mapping the outcomes, population groups, and metrics used to quantify inequality impacts, in order to bring greater clarity and consistency to an area where methods remain highly varied. While many studies report health benefits, inequalities were often treated as a secondary concern, with limited use of robust metrics and minimal attention to underrepresented dimensions such as disability, religion, social capital, and intersectionality. The predominance of modelling based on simulated scenarios/data and narrow outcome focus (typically on physical health) limits the ability to fully understand the equity impacts of these interventions. Future research should prioritise methodological consistency, equity focused evaluation frameworks, and broader, community-informed health outcomes.

CRediT authorship contribution statement

Annabel Scott-Collins: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Sebastian Stannard:** Writing – review & editing, Writing – original draft, Visualization, Formal analysis, Data curation. **Jennifer Barker:** Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **John Preston:** Writing – original draft, Funding acquisition, Conceptualization. **John Nellthorp:** Writing – review & editing, Funding acquisition, Conceptualization. **Adam Martin:** Writing – review & editing, Funding acquisition, Conceptualization. **Nisreen A. Alwan:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization.

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Declaration of competing interest

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Appendix A. Supplementary data

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Data availability

No data was used for the research described in the article.

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