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Differences in public's perception of air quality and acceptability of a clean air zone: A mixed-methods cross sectional study

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ABSTRACT

Background: Air pollution is a major cause of morbidity and mortality. Clean Air Zones (CAZs) which restrict the entry of polluting vehicles in targeted areas have been identified as potentially effective in improving health and reducing air pollution; however, their implementation can be controversial.

Methods: A cross-sectional survey was completed by 1949 respondents who lived or worked in Bradford, a multi-cultural deprived city in England, between April and December 2021. Of these, 1137 were recruited from the longitudinal Born in Bradford (BiB) family cohort (families with children born in the city during 2007–2011) and 812 were from the general public. Bradford is the seventh largest metropolitan district in England and Wales with a population of over half a million mainly white British and Pakistani origin. The BiB families cohort and the general public respondents were used for descriptive analysis of perception of air quality and acceptability of CAZ, then the relationship between participants responses with demographic characteristics were investigated using the BiB families cohort. Outcomes included perceptions of air quality and acceptability of the CAZ supplemented by free-text questions. Thematic analysis was used to code free-text data. Descriptive analyses were performed on the entire sample. Latent class analysis was used to characterise participants was performed in the BiB dataset for whom detailed existing socio-demographic data were available.

Results: The majority of participants (67%) considered improving air quality in Bradford as extremely important; 70% supported implementation of the CAZ. Three latent classes were identified within the BiB sample: deprived white British families (25%), more affluent white British families (32%) and deprived Pakistani-origin families (43%). Deprived white British (OR = 0.54, 95% CI: 0.34 to 0.84) and more affluent white British families (OR = 0.53, 95% CI: 0.36 to 0.79) were less likely to say the air quality was good/excellent when compared with deprived Pakistani-origin families. Affluent White British families were more likely to support the CAZ compared with deprived white British families (OR = 2.24; 95% CI: 1.55. to 3.25) and deprived Pakistani-origin families (OR = 2.06, 95% CI: 1.50 to 2.85). Qualitative analysis suggested that a perceived lack of cohesion in the policy and concerns about financial impacts drove negative attitudes.

Conclusion: Families in Bradford were generally supportive of the planned CAZ and efforts to reduce pollution; however, support was weaker in more deprived communities. Pakistani-origin

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communities living in deprived areas perceived air quality as better than other groups. Tailored approaches to communicate about the proposed benefits of policies such as CAZ prior to implementation may be an important way to increase acceptability amongst vulnerable groups.

1. Introduction

Air pollution is the single largest global environmental health risk, where 99% of people worldwide breathe polluted air (World Health Organisation, 2021a). Poor birth outcomes, cardiovascular infection and mortality, respiratory ailments, mental ill health and neurological issues have all been connected to poor air quality (Manisalidis et al., 2020). In the UK, 64,000 deaths are attributable to outdoor air pollution each year (Lelieveld et al., 2019) with a greater burden of air quality related illness apparent in young people and the older adults (Pimpin et al., 2018), and those living in deprived areas (World Health Organisation, 2021b). In the UK, the costs of treating of air quality related illnesses between 2017 and 2025 is estimated to be £5.56 billion (Pimpin et al., 2018), with the wider economic cost estimated to be £20 billion/year (World Health Organisation, 2021b).

The WHO sets recommended air quality limits for a number of key pollutants, which were first published in 2005 (World Health Organisation, 2005), and subsequently updated in 2021 (World Health Organisation, 2021c). Based on the earlier guidelines, the European Union established ambient air quality standards to be achieved by all EU countries. Where compliance is not met, member states are required to take necessary action to reduce the concentrations of air pollutants and prepare an air quality plan that sets appropriate measures to reduce pollution as quickly as possible (European Environment Agency, 2022).

Traffic-related emissions are a major contributor to outdoor pollution. Of the 944 separate areas in Europe that were identified as in exceedance of EU air quality standards, 64% were caused by traffic pollution between 2014–2020 (European Environment Agency, 2022).

Low emission zones (LEZ) are popular across Europe as a way to reduce outdoor pollution levels, with over 260 zones in place across EU member states before 2018 (Transport and Environment group, 2018). Although the details of how LEZ operate vary by location, the fundamental premise is that they impose targeted restrictions on older polluting vehicles entering a predefined geographical zone (either by imposing a fee, or by banning entirely). Evidence suggests that LEZs may be effective at reducing air pollution, although findings are mixed (Burns et al., 2020). To the extent that they are effective in reducing pollution, they have been identified as having the potential to improve health (National Institute for Health and care Excellence (NICE), 2017; Mudway et al., 2019).

LEZ can be controversial within communities, with research suggesting that they can disadvantage communities (De Vrij and Vanoutrive, 2022). Despite the popularity of LEZ, there is very little evidence on public acceptability. Recent studies which have explored acceptability of actual (Oltra et al., 2021; Tarrío-Ortiz et al., 2021) or hypothetical (Morton et al., 2021; Rashid et al., 2021) LEZ schemes find mixed support. A number of factors influence perceptions of acceptability including demographic factors, beliefs about efficacy of the schemes, personality traits, and the extent to which citizens are personally affected (Kowalska-Pyzalska, 2022). The extent to which air pollution is a priority for communities can influence how ready they are to accept LEZ policy (Rashid et al., 2021). Unanticipated or adverse consequences of LEZs are a concern for some. For example, more disadvantaged groups may not be able to afford to upgrade vehicles and therefore either will be faced with a choice of accruing fines, or having to stop travelling within the area. In this sense, policies may widen economic (Rashid et al., 2021) or social inequalities (De Vrij and Vanoutrive, 2022). Exploring perceptions and beliefs prior to implementation can help to identify appropriate mitigation strategies (e.g. subsidies for low income populations or small business to upgrade vehicles, or exemptions for those living in LEZ areas) to ensure the success of these policies.

In 2018 the UK was identified as breaching legal annual limits of key pollutants such as Nitrogen Dioxide (NO₂) (Wise, 2018) and was regularly exceeding the recommended limits for particulate matter (PM) (World Health Organisation, 2005). As a result, the UK Government issued directives to a number of local government authorities across the UK to develop plans to reduce pollution as quickly as possible by implementing charging ‘clean air zones’ (CAZ) (Department for Environment Food and Rural Affairs, 2018). A new policy in the UK, ‘CAZ’ are a type of LEZ which would see charges imposed on vehicles not meeting the requisite Euro emissions standards (Euro 4 for petrol vehicles, implemented in 2005, Euro 6 for diesel vehicles, implemented in 2015, and Euro 3 for motorcycles, implemented in 2001). The UK identified four classes of CAZ. Class A, the least restrictive, would see charges for non-compliant buses, coaches and taxis. Class B would also restrict heavy goods vehicles and class C would see restrictions expanded to vans and minibuses. The most restrictive CAZ class (D) would see charge for all non-compliant vehicles including private vehicles (UK Government, 2017).

Bradford, a city in the North of England was identified by the UK government as exceeding legal limits of pollutants at several locations across the city, many of which are in inner-city areas with high levels of ethnic diversity and deprivation (Rashid et al., 2021). The local Government authority (Bradford Metropolitan District Council) was directed to develop the clean air plan for Bradford, including a CAZ to reduce pollution as quickly as possible (Bradford Metropolitan District Council (BMDC), 2020). The plan was informed by Government guidance, extensive modelling, consultation with business (e.g. bus and taxi companies), communities, including bespoke work with ‘seldom heard’ and ‘underserved’ communities (Rashid et al., 2021) and local councillors (McEachan et al., 2022) and was approved in 2020 (Bradford Metropolitan District Council (BMDC), 2020). The Bradford clean air plan includes a Class C CAZ which charges non-compliant buses, coaches, heavy goods vehicles, vans, minibuses, taxis and private hire vehicles a daily fee to enter the zone. Local businesses and taxis were able to access grants to contribute to the cost of upgrading or replacing their

vehicles. The CAZ went live on the 26th September 2022.

The primary aims of this study were to explore differences in perceptions of air quality in Bradford, and explore acceptability of the proposed CAZ plans amongst people living or working in Bradford prior to implementation. A secondary aim was to explore whether perceptions of air quality and the CAZ differ based on key socio-economic characteristics, occupational or location characteristics (e.g. whether people live within or outside the zone).

2. Methods

2.1. Study design

A cross-sectional survey was used to explore the perceptions of Bradford residents on air quality and attitudes of the CAZ. Data were collected between April and December 2021. This study is part of a wider evaluation of the health and economic impact of the Bradford Clean Air Plan (McEachan et al., 2022).

2.2. Setting

Bradford is the 7th largest metropolitan district in England and Wales with a population of >546,000 (Office of National Statistics, 2022). It is ethnically diverse, with 56.7% identifying as of White British origin, and 25.5% identifying as Pakistani-origin. The population consists of 25.8% under 18 years and 74.2% 18 and over. Thirty-six percent of the adult population is 25–44 age group (11.6% are age 18–24; 17.9% are aged 25–34; 18.2% are aged 35–44; 16.8% are aged 45–54; 15.0% are aged 55–64; and 20.5% are 65+) and equally divided by sex (female = 51.7%, male = 48.3%) (Office of National Statistics, 2022).

A third of Bradford population live in the most deprived Index of Multiple Deprivation (IMD) decile according to England averages (Bradford Metropolitan District Council (BMDC), 2019) and the city has higher than average levels of ill-health (Mebrahtu et al., 2015; 2016; Mebrahtu, 2015). There are entrenched patterns of spatial injustice which see the most deprived areas bearing a disproportionate burden of environmental stressors such as pollution, noise and lack of green space (Mueller et al., 2018). It is home to the multi-ethnic longitudinal Born in Bradford (BiB) birth cohort which has been tracking the lives of 12,453 mothers, 3353 partners and 13,776 children born in the city since 2007; 45% of the cohort are of Pakistani origin (Wright et al., 2013; Bird et al., 2019).

2.3. Study population

The study included people who were aged 18 or over, residents of, or working in, Bradford city, and willing to participate in the air quality survey between April 2021 and December 2021. There were two groups of participants: 1) people who were directly invited to take part from the BiB cohort (Wright et al., 2013) and, 2) members of the general public who responded to adverts and consented to participate. BiB families were contacted by a member of the BiB team and completed questionnaires remotely, online, via post, telephone, or face-to-face. Members of the general public completed the questionnaires online or on paper at community events such as those held in public parks. The survey invitation was distributed widely via email networks, social media and local media.

2.4. Survey measures

2.4.1. Attitudes towards air quality

Attitudes towards air quality were assessed with three key questions: i) what do you think about the air quality in Bradford generally? (very poor, poor, fair, good, excellent, don't know); ii) how concerned are you about air quality in Bradford (not at all, slightly, somewhat, moderately, extremely, don't know); iii) how important do you think it is to improve air quality (not at all important, slightly important, somewhat important, moderately important, extremely important, don't know).

Participants were also asked: iv) how they felt air quality compared to other parts of the UK (better, the same, worse, don't know), v) whether they thought other people in Bradford were concerned about air quality (not at all, slightly, somewhat, moderately, extremely, don't know) and vi) whose responsibility it was to improve air quality in Bradford (council; general public; factory owners; other business owners, others).

2.4.2. Attitudes towards the clean air zone

Respondents were asked if they were aware of the plans to implement a CAZ in Bradford (yes, no). A description of the CAZ was given to participants (before they were asked to rate acceptability of the CAZ plans using the following three key questions: i) do you think the CAZ is a good idea? (yes, no, don't know) and ii) do you think the CAZ will reduce air pollution in Bradford (yes, no, don't know) and iii) [the CAZ] will improve the health of my family (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree) (McEachan et al., 2022).

A free text option (is there anything else you would like to tell us about your thoughts on the CAZ or air quality more generally?) was included also allowed respondents to record Any additional thoughts about the CAZ or air quality.

2.4.3. Other variables

Socio-demographic information including age, sex, ethnicity (coded as Pakistani-origin, white British, Other), marital status, household size, National Statistics Socioeconomic Classification (NS-SEC) and address history was available for BiB participants.

Table 1
Characteristics of the included sample.

	BiB families (N = 1137),n (%)	General public (N = 812), n (%)
Age (in years)		
18–24	0 (0.0)	48 (5.9)
25–34	110 (9.7)	115 (14.2)
35–44	629 (55.3)	173 (21.3)
45–54	370 (32.5)	130 (16.0)
55–64	21 (1.9)	97 (12.0)
65+	0 (0.0)	89 (11.0)
Prefer not to say	0 (0.0)	14 (1.7)
Missing	7(0.6)	146(18.0)
Ethnicity		
White British	498 (43.8)	444 (54.7)
Pakistani-origin	431 (37.9)	87 (10.7)
Other	170 (15.0)	82 (10.1)
Missing	38(3.3)	199(24.5)
Gender		
Male	104 (9.2)	214 (26.4)
Female	1026 (90.2)	418 (51.5)
Prefer to use own term	0 (0.0)	4 (0.5)
Prefer not to say	0 (0.0)	19 (2.0)
Missing	7(0.6)	0(0)
Driver as an occupation in the household(Taxi, LGV, HGV)		
Yes	135(11.9)	346(42.6)
No	1002(88.1)	466(57.4)
Missing	0	0
Financial status		
Living comfortably	324(28.5)	162(20.0)
Doing alright	420(36.6)	176(21.7)
Just about getting by	254 (22.3)	78(9.6)
Finding it quite difficult	59(5.2)	24(3.0)
Finding it very difficult	25(2.2)	17(2.1)
Do not wish to answer/Don't know	24(2.0)	16(2.0)
Missing	31(2.7)	339(41.8)
Main earner travels to work now by petrol/diesel car/van		
Yes	680(59.8)	361(44.5)
No	457(40.2)	451 (55.5)
Main earner travels to work now by electric/hybrid car		
Yes	58 (5.1)	28(3.5)
No	1079(94.9)	784(96.6)
Main earner travels to work now by bus or train		
Yes	59(5.2)	77(9.5)
No	1078(94.8)	735 (90.5)
Main earner travels to work now by cycling or walking		
Yes	109(9.6)	117(14.4)
No	1028(90.4)	695(85.6)
Marital status		
Married and living with partner	719 (63.2)	–
Not married and living with partner	89(7.8)	–
No living with partner	106(9.3)	–
Missing	223(19.6)	–
Education		
<5 GCSE equivalent	117(10.3)	–
5 GCSE equivalent	213(18.7)	–
A-level equivalent	144(12.7)	–
Higher than A-level	346(30.4)	–
Other/do not know/unknown	88(7.7)	–
Missing	229(20.1)	–
Bradford Index of Multiple Deprivation (IMD)		
Quintile 1	230 (20.2)	–
Quintile 2	268 (23.6)	–
Quintile 3	261 (23.0)	–
Quintile 4	228 (20.1)	–
Quintile 5	113 (9.9)	–
Missing	37(3.3)	–
Household number		
Two	24 (2.1)	–
Three	105(9.2)	–
Four	273(24.0)	–
Five	205(18.0)	–

(continued on next page)

Table 1 (continued)

	BiB families (N = 1137), n (%)	General public (N = 812), n (%)
More than five	220(19.3)	–
Missing	310(27.2)	–
National Statistics Socioeconomic Classification (NS-SEC)		
Managerial, administrative and professional occupations	331(29.1)	–
Intermediate occupations	181(15.9)	–
Small employers and own account workers	46(4.0)	–
Lower supervisory and technical occupations	48(4.2)	–
Semi-routine and routine occupations	133(11.8)	–
Missing	398(35.0)	–
CAZ boundary		
Inside	268(23.6)	–
Outside	754(66.3)	–
Missing	115(10.1)	–

Addresses were used to calculate IMD quintiles for all participants using Bradford based IMD scores, and to calculate whether respondent lived within or outside the CAZ boundary. Financial security was measured for all respondents using the item: how well would you say you are managing financially right now? (response options: living comfortably, doing alright, just about getting by, finding it quite difficult, finding it very difficult, don't know, do not wish to answer). General public respondents were asked to report age, sex and ethnicity.

Respondents were asked if any member of their household was employed (including self-employed) in a profession that involved driving a taxi/private hire vehicle; light goods vehicle (e.g. delivery driver) or heavy goods vehicle. Other variables were measured but are not reported here. A full copy of the survey can be found in the study protocol paper (McEachan et al., 2022).

2.5. Analysis

Baseline characteristics and responses to survey questions by participants were described and stratified by whether they were BiB participant responses or from the general public survey. To explore whether perceptions differed by key socio-demographic characteristics we used Latent Class Analysis(LCA) modelling (McCutcheon, 1987) to characterise BiB participants based on thirteen indicators (ethnicity, marital status, education, household number, financial status, NE-SES, driver as an occupation in household, and mode of travel to work (4 types), IMD scores and boundary of CAZ). Only information on some indicators (ethnicity, financial status, driver as an occupation and mode of travel to work) was available for the general public survey participants so this group was not included in the LCA analyses.

In determining the optimal number of classes, models with 2–10 classes were fitted to the data. Missing data on the indicators were estimated using a Full Information Maximum Likelihood (FIML) method in which parameters are estimated using all available observations in the dataset(Enders and Bandalos, 2001). In selecting the best fitting LCA model three model fit statistics were used: Akaike information criterion (AIC) (Akaike, 1987), Bayesian Information Criterion (BIC) (Schwarz, 2007) and Log-likelihood. In addition, entropy (Celeux and Soromenho, 1996), smallest class proportion and smallest class count were used as measures of classification quality. In the event of the model fit statistics not agreeing, decision was based on the combination of BIC and entropy. Logistic regression models were conducted to assess the association between the latent classes and the perceptions/attitudes of participants about air quality and CAZ. A 'three-step' approach was used where the latent classes were determined in the first two steps and the 'class assignment' variable regressed on the perception questions (Vermunt, 2010; Asparouhov and Muthén, 2014).

Analyses were carried out using in R 4.2.1 (R Core Team, 2022), PoLCA r package (Linzer and Lewis, 2011). Five percent significance level and 95% confidence intervals were adopted throughout.

Free-text data were coded using inductive thematic analysis (Braun and Clarke, 2006). Emerging themes were identified by two researchers (RH, RM) and a coding frame developed. All data were then fully coded by RH who met regularly with the team to discuss and reflect on the coding framework.

2.6. Ethics approval

Ethical approval was granted from the Bradford Leeds Research NHS research ethics committee (Ref 20/YH/0158).

3. Results

3.1. Baseline characteristics

A total of 2147 individuals consented to participate; however, not all fully completed the questionnaire. A total of 1949 (1137 BiB cohort participants and 812 from the general public) completed the survey and were included in the analyses (Table 1).

BiB cohort participants were mostly female (90%), married (63%) and lived with up to 5 co-habitants (53%, including children). All were aged 25–64, with 55% aged between 35 and 44 years. Forty-four percent of BiB participants were White British and 38% were of Pakistani origin. A high proportion of participants lived in deprived circumstances, with 44% in the bottom two quintiles of

deprivation based on Bradford averages and 30% reporting that they were 'just about getting by' or struggling financially. Twenty-four percent lived within the CAZ boundary and 12% reported living with someone who drove taxis, heavy goods vehicles or light good vehicles as an occupation.

The general public, included a wider range of ages (18–65+ years), with fewer (21%) aged 35–44. Just over half were white British (55%) and female (52%). Forty-three percent reported living with someone who drives as an occupation. Forty-two percent did not provide information on their financial status. However, of those who did, about a quarter reported that they were just about getting by or struggling financially.

3.2. Perceptions of air quality

Responses to perceptions of air quality questions split by BiB family or general public sample can be found in Table 2. Few participants believed that the air quality in Bradford was good (14% of BiB families and 8% of general public), and the general public sample were more likely to rate air quality as poor or very poor (19%) compared with BiB families (7%). Twelve percent of BiB families compared with 32% of the general public were extremely concerned about air quality. The majority of participants (65% of BiB families and 70% of the general public) considered improving air quality in Bradford as extremely important.

3.3. Acceptability of the clean air zone

Forty-nine percent of all participants had heard of the proposed CAZ before completing the survey. Two thirds of respondents agreed that the CAZ would improve the health of their families and community (64% of BiB families and 61% of general public). However, only about half of the participants thought that the CAZ would reduce air pollution in Bradford (44% of BiB families and 43% general public) whilst only one fifth thought otherwise (19% of BiB families and 23% of general public). Nearly three-quarters of respondents said they supported the implementation of the CAZ (71% of BiB families and 75% of general public).

Table 2

Survey responses to air quality perception and attitudes towards CAZ.

	BiB families (N = 1137), n (%)	General public (N = 812), n (%)
What do you think about the air quality in Bradford generally?		
Very Poor	83 (7.3)	150 (18.5)
Poor	303 (26.7)	347 (42.7)
Fair	570 (50.1)	239 (29.4)
Good	156 (13.9)	63 (7.8)
Excellent	12 (1.1)	10 (1.2)
Missing	13(1.1)	3(0.4)
How concerned are you about air quality in Bradford?		
Not at all Concerned	123 (10.8)	74 (9.1)
Slightly Concerned	282 (24.8)	130 (16.0)
Somewhat Concerned	310 (27.3)	152 (18.7)
Moderately Concerned	205 (18.0)	175 (21.6)
Extremely Concerned	136 (12.0)	262 (32.3)
Don't know	70 (6.2)	17 (2.1)
Missing	11(1.0)	2 (0.3)
How important do you think it is to improve air quality?		
Not at all Important	6 (0.5)	16 (2.0)
Slightly Important	45 (4.0)	43 (5.3)
Somewhat Important	126 (11.1)	65 (8.0)
Moderately Important	185 (16.3)	107 (13.2)
Extremely Important	733 (64.5)	568 (70.0)
Don't know	33 (2.9)	8 (1.0)
Missing	9(0.8)	5(0.6)
Do you think the Clean Air Zone is a good idea?		
Yes	786 (69.1)	571 (70.3)
No	108 (9.5)	109 (13.4)
Don't Know	213 (18.3)	84 (10.3)
Missing	30(2.6)	48(5.9)
Do you think the Clean Air Zone is going to reduce the air pollution in Bradford?		
Yes	504 (44.3)	350 (43.1)
No	206 (18.1)	176 (21.7)
Don't Know	396 (34.8)	243 (29.9)
Missing	31(2.7)	43(5.3)
How much do you agree or disagree with the following statement: the CAZ will improve the health of my family/community?		
Strongly Disagree	66 (5.8)	55 (6.8)
Disagree	63 (5.5)	67 (8.3)
Neither Agree nor Disagree	249 (21.9)	151 (18.6)
Agree	515 (45.3)	326 (40.2)
Strongly Agree	218 (19.2)	170 (20.9)
Missin0067	26(2.3)	43(5.3)

3.4. Exploring variations by key socio-demographic characteristics of the BiB families

Our model fit statistics for determining the optimal number of classes did not agree. Whilst the AIC indicated LCA model with 9 classes as the best, the Log-likelihood indicated an LCA model with 10 classes. The BIC, however, indicated that an LCA model with three classes performed the best. The smallest class proportion and smallest class count also indicated that the three class model had relatively better proportion and count, respectively (see Table 3). Hence, a three class LCA model was chosen as an optimal model to describe the BiB cohort group participants of the survey.

3.5. Characterising of participants (BiB families) using the 3-class LCA model

The first class (see Class 1 in Fig. 1) which comprised 25% of the survey participants, were mostly white British, less educated, single women who live with four co-habitants and work in semi-routine and routine occupations. Twenty-nine percent of the group come from the most deprived area of the city and 11% of them live within the CAZ area. This group of participants can be termed as 'single deprived white British'. The second group (see class 2 in Fig. 1) that consisted of 31% of the survey participants, were mostly married, white British, women who work in professional occupations and live with a spouse and two other co-habitants and have relatively best financial status (i.e. 'live comfortably'). Only 2% the participants come from the most deprived part of the city and 89% of them live outside the CAZ area. The group can be characterised as 'married, affluent white British'. The third class (see Class 3 in Fig. 1), consisted 44% of the BiB air quality survey participants. These respondents were mostly, married, Pakistani-origin women who lived with more than five co-habitants and worked in non-professional occupations. Twenty-nine percent of the group come from the most deprived part of the city and just half (55%) of them lived inside the CAZ boundary. This group reported the highest number of people who drove as an occupation in their household. We refer to this group subsequently as 'married, deprived Pakistani'.

3.6. Association between latent classes and survey questions for the BiB families

3.6.1. Perceptions of air quality

In comparison to those 'married deprived, Pakistani' participants (class 3), those who are 'single deprived white British'—Class 1—(OR = 0.52, 95% CI: 0.32 to 0.80) and 'married affluent white British'—Class 2—(OR = 0.57, 95% CI: 0.38 to 0.84) were less likely to say the air quality was good/excellent (Table 4). Although those 'single deprived white British' and 'married deprived Pakistani' did not have significant difference in their degree of concern about the air quality, the 'married affluent white British' group were more concerned than the other two groups. When asked if improving air-quality was important, the response was not significantly different amongst the three groups of participants.

3.6.2. Acceptability of the CAZ

The 'married affluent White British' respondents (class 2) were twice as likely to agree that the CAZ was a good idea compared to either 'married deprived Pakistani' (OR = 2.04, 1.48 to 2.83) (class 3) or 'single deprived white British' groups (OR = 2.06, 95% CI: 1.42 to 2.98) (class 1), with no difference between these latter two groups (class 1 and class 3; OR: 0.99, 95% CI: 0.72 to 1.37).

Participants in the 'single deprived white British' group (class 1) were less likely to say the CAZ would improves health (OR = 0.58, 95% CI: 0.42 to 0.79) compared with those in the 'married, deprived Pakistani' group (class 3). However, class 1 response was not significantly different (OR = 0.94, 95% CI: 0.70 to 1.27) from those in the 'married affluent white British' group (class 2). When asked if CAZ reduces air pollution, those in class 1 were less likely to agree (OR = 0.63, 95% CI: 0.46 to 0.86) than those in class 3, whereas those in class 2 responded not significantly different (OR = 1.05, 95%CI: 0.80 to 1.38) from those in class 3, see Table 4 for details.

3.6.2.1. Qualitative analysis of BiB families and general public participants. A total of 566 participants completed free text questions asking about their thoughts about the CAZ and air quality. Although the quantitative data suggested that the majority of respondents

Table 3

Model fit statistics and diagnostics of data analysis for the BiB families.

n-Classes	Model fit Criterion			Classification quality		
	AIC‡	BIC‡	-2LL‡	entropy‡	Smallest class proportion (%)	Smallest class count
1	22438	22594	22376	—	—	—
2	21571	21888	21444	0.77	0.48	546
3	21287	21765	21096	0.79	0.25	284
4	21161	21800	20906	0.80	0.12	136
5	21897	21096	20778	0.82	0.06	68
6	21040	22002	20658	0.79	0.05	57
7	20990	22113	20544	0.81	0.04	45
8	20974	22258	20464	0.80	0.05	57
9	20988	22434	20414	0.80	0.03	34
10	20977	22584	20340	0.80	0.04	45

Note: AIC, Akaike Information Criterion; BIC, Bayesian Information Criterion; LL, Log-likelihood; ‡, best model is with lowest figure; ‡, best model is highest figure.

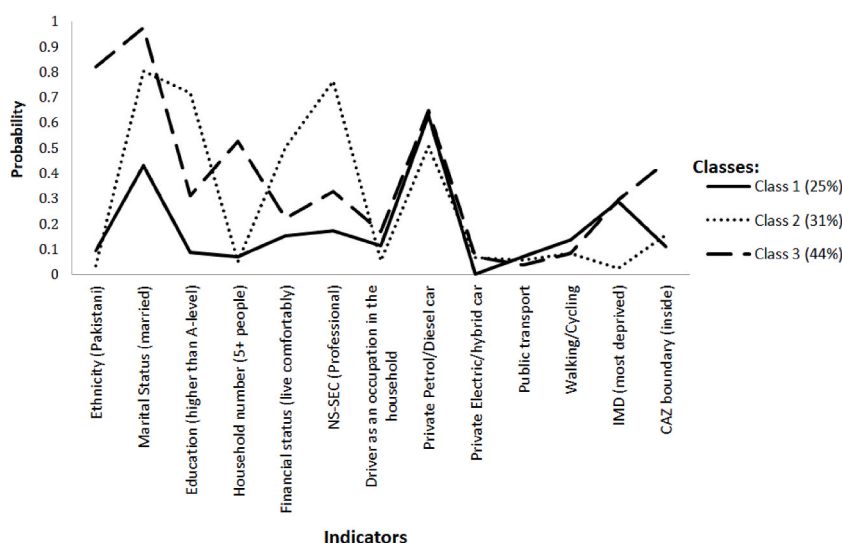


Fig. 1. Latent classes in relation to characteristics of BiB participants.

Table 4

Response to air quality questions by class membership for BiB families, odds ratio (95% CI).

Latent classes	Air quality good or excellent? ^a	Air-quality not a concern? ^b	Air-quality improvement extremely important? ^c	CAZ is a good idea? ^d	CAZ improves health? ^e	CAZ reduces pollution? ^f
Class 3 (ref.)	–	–	–	–	–	–
Class 1	0.52(0.32–0.80)	0.96(0.61–1.48)	0.90(0.66–1.22)	0.99(0.72–1.37)	0.58(0.42–0.79)	0.63(0.46–0.86)
Class 2	0.57(0.38–0.84)	0.36(0.21–0.59)	1.12(0.84–1.50)	2.04(1.48–2.83)	0.94(0.70–1.27)	1.05(0.80–1.38)
Class 1 (ref.)	–	–	–	–	–	–
Class 2	1.10(0.67–1.84)	0.37(0.20–0.66)	1.25(0.89–1.74)	2.06(1.42–2.98)	1.64(1.17–2.28)	1.66(1.20–2.31)

Note: CAZ, clean air zone; Class 1, 'single deprived white British'; class 2, 'married affluent white British'; class 3, 'married deprived Pakistani'.

^a, those who answered "good" or "excellent" compared with "fair", "poor" and "very poor" combined.

^b, those who answered "not concerned at all" compared with "slightly", "somewhat", "moderately", "extremely", "don't know" combined.

^c, those who answered "extremely important" compared with "not at all", "slightly", "neutral", "moderately", "important", "don't know" combined.

^d, those who answered "yes" compared with "no" and "don't know" combined.

^e, those answered "agree" or "strongly agree" compared "strongly disagree", "disagree", "neither agree nor disagree" combined.

^f, those answered "yes" compared with the "no" and "do not know" combined.

supported the CAZ, the subset of respondents who provided free text responses mainly raised negative issues, providing important contextual information to the possible reasons behind less favourable attitudes. Key themes included cohesion of the CAZ policy, criticisms of the CAZ scope, potential adverse consequences, impact on inequalities and other contextual factors. The key themes emerging from the analysis, along with example quotes can be found in Table 5.

The cohesion of the CAZ policy was a key emerging theme. For many, the policy just did not make sense in the context of other decisions they thought had been taken within the city which they felt would increase pollution (i.e. conflicting policies or actions). For example, many participants mentioned controversial plans for an incinerator in the local area, other planning decisions which were expected to bring more cars into the area, or road widening schemes.

There were many criticisms of the CAZ scope. Some respondents felt that it did not go far enough by not charging private vehicles. Others felt that it was limited by only addressing vehicle emissions when emissions from industry (for example factories) or other sources such as wood burning were felt to be key contributors to pollution. There was some negativity towards the local government with respondents viewing the plans as a "money making scheme" or "half-baked plan".

Potential adverse consequences were a key concern. Many respondents expressed concern that the CAZ would simply displace traffic with commuters taking a "longer journey going around [the] CAZ" thereby moving the problem of air pollution elsewhere. Others felt that there would be a negative impact on local businesses, particularly the self-employed who could be pushed out of business. It was also felt that increased costs borne by businesses would ultimately be passed onto consumers.

Another key concern for respondents was around the potential of the CAZ to increase inequalities. It was felt that lower income groups, particularly taxi drivers, and small business would be disproportionately impacted by the plans, which some referred to as a "stealth tax". As poverty and ill-health are linked, it was felt that this could lead to worse health for already deprived communities.

Finally, contextual issues were raised as a key theme impacting on the acceptability of the CAZ. The lack of affordable public

Table 5Key themes from free text analysis of BiB families and general public participants^a.

Theme	Description	Example quotes
Theme 1: Health impacts of pollution and need for the CAZ		
Health impacts of pollution	Recognising that pollution is a cause of ill-health	<p><i>"I have moved to Shipley [...] this year and live very close to [redacted] road. The pollution is horrendous and [I] have started having a persistent cough since I moved to the area. I will have to sell the house and move if things [don't] change"</i> (BiB participant, white British origin female, lives outside CAZ)</p>
Support for the CAZ	Recognition that the CAZ is an important thing to do	<p><i>"[The CAZ] step in the right direction. This isn't an optional thing to do. We need cleaner air"</i> (General public participant, Pakistani origin female)</p> <p><i>"The CAZ should be seen as a realistic start point to provide a springboard for future work to progress/expand its positive effects and mitigate any negative effects."</i> (General public participant, male)</p>
Theme 2: The CAZ policy lacks cohesion		
The CAZ policy does not make sense	The CAZ policy does not make sense to many as they perceive many competing and counterproductive policies approved by the council which would increase pollution	<p><i>"Problem will be made even worse for the Aire valley with upwards of 120 extra lorries heading to the Aire valley incinerator and the discharges from the incinerator."</i> (BiB participant, Pakistani origin female, lives inside CAZ)</p> <p><i>"The council are still approving plans that invite more cars into the area like the completely irrational development of apartments on green space on [Redacted] Road"</i> (General public participant, white British origin male)</p>
Theme 3: Criticisms of the CAZ scope and development		
The CAZ is not ambitious enough	The scope of the proposed CAZ falls short of what people perceive is needed to improve pollution levels	<p><i>"I think we should charge private cars as well unless they are electric as we should be encouraging people to use public transport and upgrading this so electric and more frequent with subsidised fares."</i> (BiB participant, Pakistani origin male, lives outside the CAZ)</p> <p><i>"While it is good to see some action, this appears to be a limited intervention on a small area. For any kind of meaningful impact there needs to be more national legislation - greater tax on pollutants and certain materials, greater protection of environment etc".</i> (BiB participant, Pakistani origin female, lives outside the CAZ)</p>
Confidence in the Council	People don't have confidence in Council decisions and feel that communication from the Council on the CAZ has been poor	<p><i>"Usual story: half-baked plan from the council which will cost loads, kill off business and ultimately fail to deliver the promised goal."</i> (BiB participant, Pakistani origin female, lives outside the CAZ)</p> <p><i>"This is a money making scheme. It doesn't actually help or prevent pollution."</i> (General public participant, female)</p> <p><i>"The council leaders may well be having many discussions, but as a Bradfordian, there appears to be a lack of information re keeping the public informed of the potential plans."</i> (General public participant, white British origin female)</p>
The CAZ isn't targeting the right sources of pollution	People feel other sources of pollution, such as those from industry or wood burning rather than vehicle emissions should be targeted to reduce pollution	<p><i>"I think industry should be doing more to improve the air quality in the clean air zone, rather than the public in the first instance. The amount of chimneys exhaling visibly into the air is extremely distressing"</i> (General public participant, female)</p> <p><i>"I think a bigger concern is that more people are burning rubbish, cutting down tree and turning greenland into concrete jungles. This to me is more of a concern than vehicle pollution"</i> (General public participant, Pakistani origin female)</p>
Theme 4: Adverse impacts of the CAZ		
The CAZ will have adverse consequences on traffic flow	People will change their driving patterns as a result of the CAZ	<p><i>"In order to avoid the charges, commuters might take a longer journey going around CAZ to reach the destination which would otherwise have been a quick one going through the CAZ area. This I believe will not reduce overall air pollution - instead it would increase it and increase the air pollution outside the CAZ areas!"</i> (General public participant, white British origin female)</p>

(continued on next page)

Table 5 (continued)

Theme	Description	Example quotes
The CAZ will economically disadvantage businesses and consumers	The CAZ will result in small businesses being driven out of business and increased costs passed to consumers	<p><i>"Self-employed people will suffer if charges are brought in for small businesses with vans"</i> (General public participant, white British origin female)</p> <p><i>"This is a city that already struggles and it may push even more businesses away"</i> (General public participant, Pakistani origin female)</p> <p><i>"I don't think the Grants are going to be enough to help smaller businesses plus there aren't enough electric charging stations yet and electric vehicles are still too expensive."</i> (General public participant: white British origin male)</p>
Theme 5: Impact on equality Financial and health inequalities will rise	Low income groups will be disproportionately burdened by the CAZ charges	<p><i>"I think that the scheme is discriminating against honest hard working people who are just trying to provide for their family and can't afford to upgrade to such vehicles. As a family [whose] sole income is generated through self-employment which involves the use of a van, the clean air [zone] would kill our income and increase other health issues that arise with poverty."</i> (BiB participant, Pakistani origin female, lives outside the CAZ)</p> <p><i>"This is a stealth tax on a generally low income population."</i> (BiB participant, white British origin female, lives outside the CAZ)</p>
Theme 6: Contextual factors Lack of affordable public transport	The city lacks an affordable public transport system which means people are unable to stop using their cars	<p><i>"We need better options for public transport to get into the city - the congestion charge in London works because you can use public transport (or often walk/cycle). Public transport is v expensive and slow here - if it wasn't I wouldn't drive"</i> (BiB participant, Pakistani origin male, lives outside CAZ)</p>
Community and environmental factors	There are other environmental problems in local communities like fly-tipping, smells and vermin which are bigger priorities for communities than pollution	<p><i>"Bradford Council should look at the rubbish tipped in the streets which is not cleansed up which causes risk to our health. Dustbins not emptied regularly causing rats and smell risk to our health"</i> (General public participant, Pakistani origin woman).</p>

^a Characteristics of participant providing quote given where available.

transport was also an issue for many and a limitation to the potential impact of the CAZ in encouraging more sustainable travel. Others identified other pressing concerns in their local communities such as fly tipping, presence of vermin and smells which they felt were more important concerns for their health.

In addition to these key themes, a number of positive suggestions were made by respondents about other ideas which could tackle pollution in the city including: imposing bans or sanctions on businesses, factories and industries that contribute towards large amount of pollution in Bradford; reducing vehicle speeds; discouraging short journeys; making streets safer to walk along; promoting cycling infrastructure and electric bikes; improving availability of affordable public transport; controlling traffic in school areas and implementing vehicle-free zones.

4. Discussion

We aimed to explore perceptions of air quality and acceptability of a proposed LEZ (the Bradford Clean Air Zone, CAZ) before its implementation in the large, multi-ethnic, deprived city of Bradford in the UK. Our survey indicated that residents of Bradford recognised that air quality is poor and the majority felt that its improvement is extremely essential. Whilst many acknowledged the potential benefits of the CAZ, around a quarter of respondents did not support its implementation. Our latent class analysis identified three broad groups of participants who held different views towards air quality and the Clean Air Zone. The most affluent group of White British origin families, who lived outside the CAZ boundary, were twice as likely to support the CAZ compared with the more deprived white British origin and Pakistani origin groups. In contrast, more deprived Pakistani origin communities, of whom nearly half lived within the CAZ boundary, were more likely than either the more affluent, or more deprived white British origin respondents to rate the air quality in their area as good or excellent.

Our finding that the majority of respondents (~75%) supported the implementation of the proposed Bradford CAZ are not too dissimilar with previous studies from Spain (Tarrino-Ortiz et al.; [Oltra et al., 2021](#)), where around two thirds of participants reported positive attitudes to LEZ following its implementation in Madrid and Barcelona, respectively. This suggests that LEZ policies are, on the whole, thought to be acceptable methods of reducing pollution. However, it is important to understand the drivers of negative attitudes as dissenting voices. Even if they are not representative, if they are loud, they can hinder implementation of such policies. Survey respondents had strong and contradictory views about the scope of the CAZ; some felt it did not go far enough, whilst others felt it went too far. This finding echoes previous studies which have highlighted the controversial natures of such policies ([De Vrij and Vanourive,](#)

2022).

Our qualitative analysis gave greater depth to understanding the reason for negative attitudes towards the CAZ. It was clear that, for many, the policy lacked cohesion in the city in the face of what were perceived to be counter-productive or contradictory policy decisions in the city, many of which were felt to increase pollution levels. Although the CAZ does not target private vehicles, many respondents raised issues about barriers which make it impractical to stop using their cars (e.g., a lack of affordable public transport infrastructure). This highlights the importance of cohesive and consistent policy making when implementing large scale initiatives to improve pollution. If communities feel that efforts are not 'joined up' across different systems and departments then public confidence in decisions is diminished.

As theorised by Kowalska-Pyzalska (Kowalska-Pyzalska, 2022), our findings showed clear differences in how different socio-economic groups felt about air quality and the CAZ. Families of Pakistani-origin, who were more likely to live in the most deprived parts of the city, within the CAZ boundary, and experience high levels of pollution, were less likely to support the CAZ and were less concerned about air quality as a whole. These families reported the highest numbers of people who were drivers of taxi's, vans and lorries who would incur a charge to enter the zone.

Much of the narrative around social justice in relation to LEZ suggests that families living in areas of higher pollution will benefit the most (Barnes et al., 2019), and that therefore these initiatives can be a way of reducing inequality. However, our findings indicate that communities living in highly polluted areas do not all see these potential benefits. Our qualitative analysis suggested potential reasons including real concern about the negative financial impacts of CAZ charges on local businesses and families, and that for many families, other community issues such as fly-tipping, smells and vermin were more important issues to tackle. Research in this area is sparse, however these observations aligns with our previous research which has shown that for these communities pollution is often a 'hidden' issue and therefore not perceived as important as other environmental burdens (Rashid et al., 2021). A recent community priority setting exercise within Bradford also highlighted the important of 'safe' and 'clean' environments free from anti-social behaviour such as littering (Cartwright et al., 2023).

In addition to ethnicity, deprivation also appeared to be a key driver of differences in opinions, with more deprived white British and Pakistani-origin communities holding more negative attitudes towards the implementation of the CAZ than more affluent communities. This is not surprising given that the impacts of charges are more likely to be felt by poorer communities. Both of these findings highlight the importance of tailoring messages to different communities about the reasons for implementing policies such as CAZ, but also the importance of ensuring appropriate mitigation strategies are in place to help those most vulnerable families.

Our paper has a number of strengths. It recruited a large multi-ethnic sample of participants, many of whom were living in the most deprived area of Bradford, whose voices are often seldom heard. We asked about attitudes towards air quality and the CAZ pre-implementation which will enable us to explore how the Bradford CAZ influences attitudes once it is implemented. We used sophisticated analyses techniques to segment survey respondents into similar groups based on key indicators. This is important as many socio-economic indicators of interest (for example, ethnicity, financial security, living with the CAZ zone) are highly correlated. We supplemented our quantitative analysis with qualitative analysis of free text data which added richness and depth to our interpretation. Mixed methods approaches are increasingly common and are often to use to highlight the 'voice' of participants, and provide can a more comprehensive and holistic exploration of certain research topics (O'Cathain et al., 2007). The inclusion of open, free text questions meant that participants were able to more fully articulate their thoughts and perceptions about the Clean Air Zone and helped to ascertain some of the driving factors behind positive or negative perceptions identified via closed questions. Future work plans to explore community and stakeholder views in more detail using a range of qualitative approaches including focus groups, interviews and documentary analysis (McEachan et al., 2022).

However, our survey also has certain limitations. First, the majority of respondents were recruited from the BiB cohort that consists mainly of women who gave birth in the city between 2007 and 2011. Participants from the general public were likely subjected to self-selection bias where those with a vested interest in the topic may have been more likely to respond, for example, this group had a much higher proportion of drivers within the household (though participation bias was possible in both groups). Hence, the two groups may not be representative of the broader population of the district. Second, detailed socio-demographic information were only available for the BiB cohort participants and some baseline characteristics of participants (e.g. marital status and household number) were substantially missing although we have used advanced data estimation technique to address missing data.

Our findings indicate that families in Bradford recognise that pollution is an important issue to tackle and are generally supportive of a LEZ approach and efforts to reduce pollution; however, support is weaker within communities living in deprived areas of the Bradford. We found that groups living within the CAZ boundary, who were more likely to living in deprived areas and of Pakistani origin, to perceive fewer problems with pollution. For those planning to implement LEZ approaches within deprived, multi-ethnic communities we recommend a tailored approach to communication, ensuring that community concerns are addressed before focusing on the proposed benefits of such policies. A key challenge to those implementing LEZ is to ensure that efforts to reduce pollution are linked up across different system partners including transport, health, and education to ensure that activities across a city or region are perceived as cohesive and aligned instead of piecemeal or disparate. Finally, we found many contradictory views about the potential effectiveness of LEZ and many potential negative impacts were identified. Future research should thoroughly evaluate the impact of LEZ policy on health and economic outcomes and explore unanticipated consequences.

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Authors' contribution

TM: Conceptualisation, data curation, formal analysis - quantitative, methodology, writing - original draft, writing – review and editing.

RMc: Conceptualisation, funding acquisition, methodology, project administration, writing – original draft, writing – review and editing.

TY: Conceptualisation, funding acquisition, methodology, project administration, writing – review and editing.

KC: Data curation, investigation, methodology, project administration, writing – review and editing.

RR: Conceptualisation, methodology, project administration, writing – review and editing,

RH: Formal analysis - qualitative, writing – review and editing.

IV: Writing – review and editing.

MB: Conceptualisation, funding acquisition, methodology, project administration, writing – review and editing.

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Declaration of competing interest

A conflict of interest may exist when an author or the author's institution has a financial or other relationship with other people or organizations that may inappropriately influence the author's work. A conflict can be actual or potential. At the end of the text, under a subheading 'Disclosure Statement', all authors must disclose any actual or potential conflict of interest including any financial, personal or other relationships with other people or organizations within three (3) years of beginning the work submitted that could inappropriately influence (bias) their work. Examples of potential conflicts of interest which should be disclosed include employment, consultancies, stock ownership, honoraria, paid expert testimony, patent applications/registrations, and grants or other funding.

Data availability

The data that has been used is confidential.

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References

- Akaike, H., 1987. Factor analysis and AIC. *Psychometrika* 52 (3). <https://doi.org/10.1007/BF02294359>.
- Asparouhov, T., Muthén, B., 2014. Auxiliary variables in mixture modeling: three-step approaches using mplus. *Struct. Equ. Model.* 21 (3) <https://doi.org/10.1080/10705511.2014.915181>.
- Barnes, J.H., Chatterton, T.J., Longhurst, J.W.S., 2019. 'Emissions vs exposure: increasing injustice from road traffic-related air pollution in the United Kingdom', *Transportation Research Part D: Transport and Environment*, 73. <https://doi.org/10.1016/j.trd.2019.05.012>.
- Bird, P.K., et al., 2019. Growing up in Bradford: protocol for the age 7–11 follow up of the Born in Bradford birth cohort. *BMC Publ. Health* 19 (1), 939. <https://doi.org/10.1186/s12889-019-7222-2>.
- Bradford Metropolitan District Council (BMDC), 2019. Poverty and deprivation: deprivation and poverty in bradford district. Available at: <https://ubd.bradford.gov.uk/about-us/poverty-in-bradford-district/>. . (Accessed 19 October 2022).
- Bradford Metropolitan District Council (BMDC), 2020. Reports and consultations: bradford clean air plan – final business case documents. <https://www.bradford.gov.uk/breathe-better-bradford/news-events-and-other-projects/clean-air-zone-consultation/>.
- Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. *Qual. Res. Psychol.* 3 (2) <https://doi.org/10.1191/1478088706qp0630a>.
- Burns, J., et al., 2020. Interventions to reduce ambient air pollution and their effects on health: an abridged Cochrane systematic review. *Environ. Int.* <https://doi.org/10.1016/j.envint.2019.105400>.
- Cartwright, C., et al., 2023. People powered research: what do communities identify as important for happy and healthy children and young people? A multi-disciplinary community research priority setting exercise in the City of Bradford, United Kingdom (UK). *Int. J. Equity Health* 22 (1), 71. <https://doi.org/10.1186/s12939-023-01881-y>.
- Celeux, G., Soromenho, G., 1996. An entropy criterion for assessing the number of clusters in a mixture model. *J. Classif.* 13 (2) <https://doi.org/10.1007/BF01246098>.
- Department for Environment Food and Rural Affairs, 2018. Supplement to the UK plan for tackling roadside nitrogen dioxide concentrations. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/915958/air-quality-no2-plan-supplement.pdf. .

- Enders, C.K., Bandalos, D.L., 2001. The relative performance of full information maximum likelihood estimation for missing data in structural equation models. *Struct. Equ. Model.* 8 (3) https://doi.org/10.1207/S15328007SEM0803_5.
- European Environment Agency, 2022. Managing Air Quality in Europe. European Environment Agency. Available at: <https://www.eea.europa.eu/publications/managing-air-quality-in-europe/managing-air-quality-in-europe>. (Accessed 18 October 2022).
- Kowalska-Pyzalska, A., 2022. 'Perspectives of development of low emission zones in Poland: a short review'. *Front. Energy Res.* 10 <https://doi.org/10.3389/fenrg.2022.898391>.
- Lelieveld, J., et al., 2019. Cardiovascular disease burden from ambient air pollution in Europe reassessed using novel hazard ratio functions. *Eur. Heart J.* 40 (20), 1590–1596. <https://doi.org/10.1093/eurheartj/ehz135>.
- Linzer, D.A., Lewis, J.B., 2011. polCA: an R package for polytomous variable latent class analysis. *J. Stat. Software* 42 (10). <https://doi.org/10.18637/jss.v042.i10>.
- Manisalidis, I., et al., 2020. Environmental and health impacts of air pollution: a review. In: *Frontiers in Public Health*. Frontiers Media S.A.
- McCutcheon, A.L., 1987. *Latent Class Analysis*. Sage, Newbury Park, CA. *Sage University paper series on Quantitative Applications in the Social Sciences, No.07-064*.
- McEachan, R.R.C., et al., 2022. Study Protocol. Evaluating the life-course health impact of a city-wide system approach to improve air quality in Bradford, UK: a quasi-experimental study with implementation and process evaluation. *Environ. Health* 21 (1), 122. <https://doi.org/10.1186/s12940-022-00942-z>.
- Mebrahtu, T.F., 2015. Incidence and burden of allergic conditions and the effects of birthweight and growth on wheezing disorders in the Born in Bradford cohort. White Rose eTheses Online. Available at: <https://etheses.whiterose.ac.uk/13283/>. (Accessed 7 March 2023).
- Mebrahtu, T.F., Feltbower, R.G., Parslow, R.C., 2015. Effects of birth weight and growth on childhood wheezing disorders: findings from the Born in Bradford Cohort. *BMJ Open* 5 (11), e009553. <https://doi.org/10.1136/bmjopen-2015-009553>.
- Mebrahtu, T.F., Feltbower, R.G., Parslow, R.C., 2016. Incidence and burden of wheezing disorders, eczema, and rhinitis in children: findings from the born in bradford cohort. *Paediatr. Perinat. Epidemiol.* 30 (6), 594–602. <https://doi.org/10.1111/ppe.12310>.
- Morton, C., Mattioli, G., Anable, J., 2021. Public acceptability towards Low Emission Zones: the role of attitudes, norms, emotions, and trust. *Transport. Res. Pol. Pract.* 150, 256–270. <https://doi.org/10.1016/j.tra.2021.06.007>.
- Mudway, I.S., et al., 2019. Impact of London's low emission zone on air quality and children's respiratory health: a sequential annual cross-sectional study. *Lancet Public Health* 4 (1), e28–e40. [https://doi.org/10.1016/S2468-2667\(18\)30202-0](https://doi.org/10.1016/S2468-2667(18)30202-0).
- Mueller, N., et al., 2018. Socioeconomic inequalities in urban and transport planning related exposures and mortality: a health impact assessment study for Bradford, UK. *Environ. Int.* 121 (Pt 1), 931–941. <https://doi.org/10.1016/j.envint.2018.10.017>.
- National Institute for Health and care Excellence (NICE), 2017. Air Pollution: Outdoor Air Quality and Health. *NICE guideline [NG70]*. Available at: <https://www.nice.org.uk/guidance/ng70>. (Accessed 23 September 2022).
- O'Cathain, A., Murphy, E., Nicholl, J., 2007. Why, and how, mixed methods research is undertaken in health services research in England: a mixed methods study. *BMC Health Serv. Res.* 7 (1), 85. <https://doi.org/10.1186/1472-6963-7-85>.
- Office of National Statistics, 2022. Ethnic Group, England and Wales: Census 2021. Available at: <https://www.ons.gov.uk/peoplepopulationandcommunity/culturalidentity/ethnicity/bulletins/ethnicgroupenglandandwales/census2021#how-ethnic-composition-varied-across-england-and-wales>. (Accessed 19 October 2022).
- Oltra, C., et al., 2021. Individual-level determinants of the public acceptance of policy measures to improve urban air quality: the case of the Barcelona low emission zone. *Sustainability* 13 (3), 1168. <https://doi.org/10.3390/su13031168>.
- Pimpin, L., et al., 2018. Estimating the costs of air pollution to the National Health Service and social care: an assessment and forecast up to 2035. *PLoS Med.* 15 (7) <https://doi.org/10.1371/journal.pmed.1002602>.
- R Core Team, 2022. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: <https://www.r-project.org/>.
- Rashid, R., et al., 2021. Taking a deep breath: a qualitative study exploring acceptability and perceived unintended consequences of charging clean air zones and air quality improvement initiatives amongst low-income, multi-ethnic communities in Bradford, UK. *BMC Publ. Health* 21 (1). <https://doi.org/10.1186/s12889-021-11337-z>.
- Schwarz, G., 2007. Estimating the dimension of a model. *Ann. Stat.* 6 (2) <https://doi.org/10.1214/aos/1176344136>.
- Tarriño-Ortiz, J., et al., 2021. Public acceptability of low emission zones: the case of "Madrid central". *Sustainability* 13 (6), 3251. <https://doi.org/10.3390/su13063251>.
- Transport and Environment group, 2018. City bans are spreading in Europe: low-emission zones are spreading in response to the air quality crisis. Available at: <https://www.transportenvironment.org/discover/city-bans-are-spreading-europe/>. (Accessed 22 September 2022).
- Uk Government, 2017. Air quality: clean air zone framework for England. Available at: <https://www.gov.uk/government/publications/air-quality-clean-air-zone-framework-for-england>. (Accessed 16 December 2022).
- Vermunt, J.K., 2010. Latent class modeling with covariates: two improved three-step approaches. *Polit. Anal.* 18 (4) <https://doi.org/10.1093/pan/mpq025>.
- De Vrij, E., Vanoutrive, T., 2022. No-one visits me anymore": low Emission Zones and social exclusion via sustainable transport policy. *J. Environ. Pol. Plann.* 1–13. <https://doi.org/10.1080/1523908X.2021.2022465>.
- Wise, J., 2018. UK is taken to court for failing to tackle air pollution. *Clinical research BMJ* 361. <https://doi.org/10.1136/bmj.k2209>.
- World Health Organisation, 2005. Air quality guidelines global update 2005: particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Available at: <https://www.who.int/publications/i/item/WHO-SDE-PHE-OEH-06.02>. (Accessed 18 October 2022).
- World Health Organisation, 2021a. Ambient (outdoor) air pollution. Available at: [https://www.who.int/news-room/fact-sheets/detail/ambient-\(outdoor\)-air-quality-and-health](https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health). (Accessed 16 December 2022).
- World Health Organisation, 2021b. *Review of Evidence on Health Aspects of Air Pollution – REVIHAAP Project: Technical Report*.
- World Health Organisation, 2021c. WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. <https://www.who.int/publications/i/item/9789240034228>. (Accessed 18 October 2022).
- Wright, J., et al., 2013. Cohort profile: the born in bradford multi-ethnic family cohort study. *Int. J. Epidemiol.* 42 (4) <https://doi.org/10.1093/ije/dys112>.