Sustainable Cities and Society 41 (2018) 525–537

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

An assessment of perceptions of air quality surrounding the implementation of a traffic-reduction measure in a local urban environment

Seán Schmitz[a,*], Laura Weiand[a], Sophia Becker[a], Norman Niehoff[b], Frank Schwartzbach[b], Erika von Schneidemesser[a]

[a] Institute for Advanced Sustainability Studies, Potsdam, Germany
[b] Department of Urban Planning, Urban Renewal, and Traffic Development, Landeshauptstadt Potsdam, Potsdam, Germany

ARTICLE INFO

Keywords:
Air quality
Perception
Sustainable urban transport
Spatial analysis
Local
Transdisciplinary

ABSTRACT

Poor air quality remains a major environmental and health risk in Europe, despite improvements over the last few decades. Consistent exceedances of the nitrogen dioxide air quality limit values at a roadside monitoring station in Potsdam, owing to heavy local and commuter individual motorized traffic, prompted the city administration to implement a trial traffic measure aimed at reducing motorized traffic to improve air quality. This study analysed data (n = 3553) from a questionnaire carried out prior to the implementation of the trial traffic measure. This research provides a case-study to contribute to the understanding of general determinants of air quality perceptions, and policy-relevant information regarding how citizens perceive air quality in the context of a 'hard' policy measure. A subset of variables was used to build an ordinal logistic regression model to assess the explanatory power for air quality perceptions. Gender, perceived health status, level of concern for air quality, level of concern for climate change, and the desire for greater access to information regarding air quality were factors found to be significant in their explanatory power of perceptions of air quality. The results are discussed in the broader policy context of attempts to improve air quality in urban environments.

1. Introduction

1.1. Air pollution

Air pollution is a substantial problem that continues to threaten public health and contributes to climate change. Pollutants such as particulate matter with an aerodynamic diameter smaller than 2.5 µm ($PM_{2.5}$), nitrogen oxides (NO_x), and tropospheric ozone (O_3) continue to be a cause of cancer, respiratory and cardiovascular disease, and premature death (EEA, 2016). Poor air quality is detrimental to human health, with a number of studies finding short-term and long-term pulmonary and cardiovascular health effects of PM_{10} and $PM_{2.5}$ (Rückerl, Schneider, Breitner, Cyrys, & Peters, 2011). Air pollution also incurs major economic costs to the European Union, on the order of billions of Euros a year (EEA, 2016). Additionally, air quality and climate change are connected, in that a number of air pollutants are also short-lived climate forcers. Attempts to tackle issues of poor air quality often have the additional benefit of mitigating climate change (Kopp, Mauzerall, Chameides, & Wilson, 2010; Melamed, Schmale, & von Schneidemesser, 2016).

A variety of different policy measures are currently being implemented across Europe aimed at reducing air pollution. As a major source of air pollution is the transport sector, many policies are targeting this area for improvement. Road transport is the largest source of NO_x emissions in the EU, accounting for 39% of total emissions in 2015, and is also a minor source of PM_{10} and $PM_{2.5}$ emissions, contributing 13% to each in 2015 (EEA, 2017). Cities, as hotspots for air pollution with higher emissions from transport than the EU average (Mayer, 1999), are thus making important strides by implementing a variety of urban access regulations that impose restrictions on traffic in demarcated areas. These include urban road tolls, low emission zones (LEZs), and key access regulation schemes (European Commision, 2016). Particularly in Germany, exceedances of NO_2 limit values at roadside air quality monitoring stations are a major challenge due to the high proportion of diesel vehicles on the road, with 'hard' policy measures currently being considered to address the issue. For example, the German federal court recently ruled that the implementation of bans on diesel vehicles from entering highly-polluted areas of cities as a last resort to meet EU air quality regulations is legally acceptable (Bundesverwaltungsgericht, 2018).

Potsdam, the capital city of the federal state of Brandenburg, Germany, recently implemented its own trial traffic measure to improve

* Corresponding author at: Institute for Advanced Sustainability Studies e.V. (IASS), Berliner Straße 130, 14467 Potsdam, Germany.
E-mail address: Sean.Schmitz@iass-potsdam.de (S. Schmitz).

https://doi.org/10.1016/j.scs.2018.06.011
Received 3 April 2018; Received in revised form 29 May 2018; Accepted 7 June 2018
Available online 15 June 2018

air quality at its southwestern principal access route: the Zeppelinstraße. The Zeppelinstraße is a highly-frequented street in the city that has for years been exceeding safe thresholds of air pollutants. In 2016, the Zeppelinstraße air quality monitoring station recorded a yearly average value for NO_2 of 43 µg m^{-3}, exceeding the EU and World Health Organization (WHO) limit-values of 40 µg m^{-3} (Landesamt für Umwelt, 2016). This infringement of EU air quality regulations has continued on the Zeppelinstraße for more than a decade. On an average weekday, the street can experience between 18,000 and 35,000 cars traveling through, about half of which is commuter traffic from neighbouring regions and not from Potsdam itself (Mobil in Potsdam, 2017). The trial implementation of a measure to reduce individual motorized traffic (see Section 2.1. for more details) began in July of 2017 and continued for 6 months, through December 2017, with the possibility to extend indefinitely depending on its success in reducing roadside air pollution levels (Mobil in Potsdam, 2017).

1.2. Perceptions of air quality and air pollution

In the last two decades, a variety of studies have been conducted investigating the perceptions of air quality in cities all around the world. Sociodemographic factors such as age, gender, education, and health status have been found to be correlated with perceptions of air quality (Oltra & Sala, 2014). Guo et al. (2016) found that, in their sample, those respondents over the age of 40, with a college-level education, living in an urban residential area, or with a child in poor health condition were more likely to perceive the air quality to be poor. Several studies have found women to be more likely to acknowledge that air pollution will lead to adverse health effects or to perceive the air quality as poor compared with men (Elliott, Cole, Krueger, Voorberg, & Wakefield, 1999; Howel, Moffatt, Bush, Dunn, & Prince, 2003; Jacquemin et al., 2007). Health status was found to be associated with perceptions by Jacquemin et al. (2007), where people with respiratory symptoms such as night dyspnoea and phlegm reported higher levels of annoyance from air pollution. Howel et al. (2003) also found some weak associations between people with chronic illness status and perceptions of disease affected by air pollution.

A set of contextual factors includes urban and rural settings and proximity to industry (Howel et al., 2003; Oltra & Sala, 2014). Respondents living closest to heavy industry (steel and petrochemical plants) were more likely to rate air quality as poor in their neighbourhood, whereas those living farthest away tended to disassociate their neighbourhoods with air pollution and poor air quality (Howel et al., 2003). A similar dichotomy between urban and rural settings was found in Brody, Peck, and Highfield, (2004), where respondents living in rural settings perceived the air quality to be better than those living in urban settings. This supports the common finding that respondents have a perception of rural settings being 'safe' spaces with unpolluted air to which urban residents can escape (Smallbone, 2012).

A smaller subset of these studies used Geographic Information Systems (GIS) techniques to analyse perceptions of air quality in a spatial context. GIS tools allow for a more precise exploration of spatial patterns of air quality perceptions. Brody et al. (2004) conducted surveys in Houston and Dallas, Texas, USA, in which they asked respondents to rate air quality on a Likert scale from 1 (very bad) – 7 (very good). These responses were then allocated spatially to the zip codes in which respondents' addresses fell and averaged to produce an overall measure of air quality perception by zip code in both cities. The generation of maps based on these responses showed the spatial differences in perceptions across each city, with respondents from urban areas perceiving the air quality to be worse than those from rural areas. In a similar study, Mally (2016) mapped perceptions of Ljubljana, Slovenia but instead of using postal codes, used respondents' addresses to spatially depict perceptions of air quality across the city at a higher resolution. The study also found that a higher proportion of residents in the city center than in outer districts perceived air pollution to be problematic.

With air quality remaining a significant challenge to cities in Europe, it is important to produce policy-relevant research that can help guide decision-making towards making cities healthier, more accessible, and, ultimately, sustainable. This, however, remains a major challenge in cities and significantly more needs to be done to address urban transport and transition to sustainable urban mobility (Banister, 2011), particularly concerning the integration of urban planning with transportation infrastructure (Hickman, Hall, & Banister, 2013). This study seeks to add not only to previous literature on perceptions of air quality, but to provide policy-relevant information useful to the city of Potsdam during their implementation of traffic measures to improve air quality, with broader implications for cities across Germany struggling with similar challenges. This paper follows the working hypotheses that: (i) perceptions of air quality vary spatially across Potsdam, Berlin, and Brandenburg; (ii) respondents' environmental concern is significantly associated with their perceptions of air quality; and (iii) age, gender, income, health status, and education are significantly associated with respondents' perceptions. Finally, the results are discussed in the broader context of the policy implications – not only for Potsdam, but more broadly for cities in Germany and Europe.

2. Materials and methods

2.1. Context: trial implementation of a traffic measure

This study was conducted during the trial implementation of a traffic measure in Potsdam aimed at improving roadside air quality by reducing individual vehicular traffic. The Brandenburg Ministry for Rural Development, Environment and Agriculture (MLUL) is the responsible authority for Potsdam's Air Quality Plan and therefore advised the city administration to implement a measure to improve air quality and address NO_2 exceedances on the heavily trafficked Zeppelinstraße. In response, the city parliament (Stadtverordnetenversammlung) approved the implementation of a trial traffic measure with the following changes to infrastructure and mobility services (i) the Zeppelinstraße was reduced from a four-lane road with two-way traffic down to a two-lane road, with some sections containing a third lane for turn-offs; (ii) the additional space was allocated as a right-turn lane, a dedicated bike lane (with corresponding sections that were previously a shared bike/pedestrian area, thereby also improving the pedestrian infrastructure), and as a bus lane; (iii) the frequency of bus service along the main route traversing the street was increased from 4 to 6 trips per hour; (iv) pedestrian "islands" were built to better facilitate pedestrian crossings; and (iv) more park and ride infrastructure connecting to the city's tram network was provided.

The infrastructural changes aimed to discourage individual motorized driving and increase the modal share of alternative forms of urban mobility – especially walking, cycling, and public transport. As such, it directly affected commuters living outside and working inside Potsdam or Berlin, as well as residents of Potsdam. The public was informed about the intervention through TV, radio, newspapers, and leaflets that indicated the objectives of the measure and when and where it would take place. Public engagement in the decision-making process was limited, but was more generally integrated into the development of the air quality plan.

2.2. Data collection

In June of 2017, one month prior to the implementation of the 6-month trial traffic measure, an online survey was conducted by the Institute for Advanced Sustainability Studies (IASS e.V.) to assess various aspects of public perceptions regarding not only the traffic measure itself, but also the topics of sustainable mobility and air quality. The questionnaire was developed in collaboration with the Potsdam city council (Landeshauptstadt Potsdam), specifically the traffic development, city planning, and civic participation departments and supported by the mobility campaign “Besser Mobil. Besser Leben.” (English: “Better Mobility. Better Living.” Hereafter referred to as the Potsdam mobility campaign). Furthermore, the design was informed by previous survey research conducted by the Potsdam city council (Landeshauptstadt Potsdam, 2015), the German Environment Ministry (Benthin, Gellrich, Scholl, Holzhauer, & Schipperges, 2016), and the European Commission (European Commission, 2013), as well as by studies from the literature that assessed topics surrounding air quality perceptions (Bickerstaff & Walker, 2001; BMVI, 2010; Brody et al., 2004; Elliott et al., 1999; European Commission, 2013; Lan et al., 2016; Oltra & Sala, 2016; Simone, Eyles, Newbold, Kitchen, & Williams, 2012; Valeri et al., 2016).

Following recommendations from the literature (Draugalis, Coons, & Plaza, 2008), the questionnaire was pre-tested with a focus group at an information event hosted by the Potsdam city council to inform residents about the planned measure, open to all citizens from Potsdam and the surrounding regions. The 55 responses to the pre-test were used to scrutinize the questionnaire for ambiguous wording, unclear instructions, and relevance of items and scales given the answers received. Social science experts at the IASS also gave advice on the wording, the overall length, and the validity of the items and scales used.

The questionnaire was assembled using the online survey tool Limesurvey and disseminated via the web. The final version contained questions in the following thematic areas: (i) perceptions and attitudes concerning the traffic reduction policy trial being implemented on Zeppelinstraße; (ii) transportation and mobility behaviour; (iii) environmental awareness and public health attitudes; (iv) perceived communication of air quality information; and (v) socioeconomic and demographic information. In total, the questionnaire contained 40 items (consult Supplementary information for the complete questionnaire).

Using the Potsdam mobility campaign for visibility, the questionnaire was announced through various mediums. A link to the questionnaire was made available on several websites (e.g., the Potsdam city website), the Potsdam mobility campaign published a press release regarding the effort, a number of news outlets picked up this news and mentioned it in short print and online news platforms, and a mention of the questionnaire, including a link to the webpage, was displayed on digital traffic boards around the city. In total, 4661 questionnaires were submitted, of which 3553 were fully-completed, over the 4-week period (between June 1st and June 30th, 2017).

2.3. Variable selection

To assess the potential influence of variables on the perception of air quality, a total of 18 independent variables out of the 133 generated by the questionnaire in Limesurvey were selected for comparison with the dependent variable of air quality rating (*aq_rating*). The choice of independent variables was informed by previous studies from the literature. Age, education, health status, and other sociodemographic characteristics, for example, have been found to be correlated with perceptions of air quality (Bickerstaff & Walker, 2001; Guo et al., 2016; King, 2015; Oltra & Sala, 2014). As such, the sociodemographic variables of age (*age*), education level (*qualification*), health status (*healthstatus*), gender (*gender*), and income (*income*) were selected from this survey for inclusion in the analysis. Location, in terms of urban and rural settings, was also found to influence perceptions of air quality in Brody et al. (2004), Guo et al. (2016), and Smallbone (2012). To assess the association between location and perceptions, the variables of whether or not the participant resided in or near the Zeppelinstraße (*resident_zepp*) and whether the participant was from Potsdam or surrounding regions (*resident_location*) were included. The variable *resident_location* was created manually by merging data from *resident_region* and *resident_other* and assigning respondent's location of residence into two categories: “Potsdam” and “Other regions”. This was done to assess differences in perceptions between respondents from Potsdam and those outside Potsdam. Since the questionnaire was directly linked to the implementation of the traffic measure, the frequency with which the participant used the Zeppelinstraße for work or private reasons with a car (*zep_freq_work_car* and *zep_freq_priv_car*, respectively), were also included in the study.

Finally, other studies have focused on relationships between value judgements and public perceptions (de Groot & Steg, 2008; Kandt, Rode, Hoffmann, Graff, & Smith, 2015; Nilsson, Hansla, Heiling, Bergstad, & Martinsson, 2016; Stern & Dietz, 1994) so as to understand where targeted information campaigns and environmental policies could have greater influence on environmentally significant behaviour. The variables from the present study selected to assess public value judgements regarding the traffic-reduction measure were: perception of the priority of air quality in the design of the measure (*priority_aq*), perceived effect of the measure on air quality (*effect_aq*), desired priority of the environment in the allocation of public funds (*budget_env*), support for the traffic policy measure (*support_measure*), and level of support for traffic-reduction policies generally (*support_nopkw*). To assess the role of communication of air quality information, the following variables were chosen: how informed the respondent felt regarding air quality (*informed_aq*), and whether the respondent wished to be better informed regarding air quality (*informed_wishes*). The final independent variables chosen were *aq_concern* and *cc_concern*, which assessed the level of concern respondents had for air quality in Potsdam and for climate change in general, respectively. The inclusion of these two variables sought to analyse respondents' value judgements regarding the importance of environmental issues in their decision-making. A summary of the variables included in the analysis can be found in Table S1 of the supplemental information, with the variable code (presented above in italics), question, and answer options.

2.4. Spatial analysis

To assess spatial patterns in perceptions across Potsdam, Berlin, and Brandenburg, averages were taken for the variables of *aq_rating*, *aq_concern*, and *cc_concern* across the different regions of residence identified by respondents. Using the open-source QGIS program, maps were generated of these averages organized by planning regions of Potsdam (provided by the Potsdam city council) and by postal code for regions outside Potsdam. The overall averages for *aq_concern* and *cc_concern* were assessed for a statistically significant difference using a paired *t*-test.

2.5. Statistical methods

The independent variables were scrutinized for their relationship with the dependent variable (*aq_rating*) using several statistical tests. The variables were first assessed for their correlation with the dependent variable using a chi-squared test of independence, as well as a linear trend alternative to independence test. The results from these correlation tests, weighed against the importance of variables to answering questions of the study, were used to determine which variables were included in the ordinal logistic regression model. Variables found to be uncorrelated were generally excluded from the regression analysis. This determination is further discussed in Section 3. It is worth noting that the analysis was tested for response bias using a randomly selected subset of the data that included an equal number of responses from those who supported the measure and those who did not. This analysis revealed the same variables to be significantly associated with air quality rating, indicating that the bias in number of responses from people unsupportive of the measure did not influence the results.

2.5.1. Chi-squared test of independence

The chi-squared test of independence was used to determine if two categorical variables were significantly associated. However, large sample size, as was the case in this study, frequently leads to a rejection of the null hypothesis with extreme statistical significance because the power to detect misfit is so great that all items will misfit (Bergh, 2015; Lantz, 2013), even if the effect sizes are relatively small. In other words, with a large sample size, cells in a contingency table that contain counts of observations even slightly higher than expected can cause the table to be statistically significant under the chi-squared test of independence, although the actual difference may be marginal. Therefore, a cell-by-cell test of standardized Pearson residuals for each contingency table was conducted with a significance level of 0.05, adjusted using the Bonferroni method by dividing the significance level by the number of cells in the contingency table. Two statements can be made regarding those cells for which the standard residual was *greater* than the z-value corresponding to the Bonferroni-adjusted significance level (Sharpe, 2015):

1) They show a greater discrepancy than would be expected if the variables were truly independent.
2) There is a lack of fit of H_0 in that cell; i.e the variables are NOT independent.

Those variables with enough categories that supported the alternative hypothesis were deemed to be NOT independent of the dependent variable, indicating the presence of an underlying, though unknown, relationship.

2.5.2. Linear trend alternative to independence

Though chi-squared tests of independence are useful in determining associations between categorical data, for ordinal data, such as that created by this survey research, a linear trend alternative to independence test is more powerful than chi-squared tests of independence (Agresti, 2002). In such contingency tables with ordinal rows and/or columns, a positive or negative linear association is common and can be quantified using this test. It calculates a Pearson correlation value, *r*, between −1 and +1, that equals the sample covariance of the two values in the table divided by the product of their sample standard deviations:

$$r = \frac{\sum_{i,j} (u_i - \bar{u})(v_j - \bar{v})p_{ij}}{\sqrt{\left[\sum_i (u_i - \bar{u})^2 p_{i+}\right]\left[\sum_j (v_j - \bar{v})^2 p_{+j}\right]}} \quad (1)$$

This is additionally used to generate a test statistic:

$$M^2 = (n-1)r^2 \quad (2)$$

The larger the correlation value (*r*) and, consequently, the larger the test statistic (M^2), the more unlikely it is that the data are independent. A key point, however, is that this does not imply that the relationship is linear, but instead provides evidence to build power against the H_0 statement of independence (Agresti, 2002).

Therefore, those variables with ordinal categories (*aq_concern, cc_concern, age, healthstatus, income, informed_aq, priority_aq, effect_aq, budget_env*, and *support_nopkw*) were analyzed using the linear trend alternative to independence test. Additionally, nominal variables with only two categories (binary) can be subjected to this test, therefore the variables of *gender*, *informed_wishes*, *support_measure*, *resident_zepp*, and *resident_location* were also tested after the removal of the answer option “I don’t know”, when present.

2.5.3. Ordinal logistic regression

Ordinal regression models allow for the analysis of categorical dependent variables in which the order of the categories is vital (Agresti, 2002, 2010; McCullagh, 1980). The model selected for use in this analysis is a cumulative link model with a “logit” link, found in the “ordinal” package of R (Christensen, 2015a, 2015b). Following the proportional odds method first outlined by McCullagh (1980), the model equation is:

$$logit\,[P(Y_i \le j)] = \alpha_j - \beta_k x_{ik} \quad (3)$$

Where *j* represents the number of response categories, *i* is the observation containing a set of values for *k* number of predictor variables. The intercepts are represented by α_j and each predictor variable has effect β_k on the probability that the response category for observation *i* will be ≤ *j*.

Before engaging in the model selection process, the variables were tested for multicollinearity. This was done first by conducting linear trend alternative to independence tests between all the variables and second by coercing the variables into a linear model in R and calculating the variance inflation factor (VIF). To determine the model of best fit, the backward elimination method was used to test different variations of the model. The Akaike information criterion (AIC), Nagelkerke’s pseudo-R^2, and the results of likelihood-ratio tests were used to make this determination. Once the most appropriate model was selected, the parameter estimates were calculated to determine the strength of effects of predictor variables on response outcomes. The results from the ordinal logistic regression were then compared with results of the aforementioned chi-squared and linear trend independence tests.

3. Results

3.1. Spatial analysis

Figs. 1–3 depict the mean *aq_rating, aq_concern*, and *cc_concern*, respectively, in the regions of Potsdam, Berlin, and Brandenburg. It is clear from Fig. 1 that the average air quality rating for Potsdam does not vary across different regions, with almost all areas falling in the same category of 3 (air quality is somewhat good). Even with varying sample sizes in each region, the average perception of air quality did not change drastically, with an overall average across Potsdam, Berlin, and Brandenburg of 2.75 (1 = very good air quality, 6 = very bad). There was no evidence of a difference in perceptions between the residents of the city of Potsdam and surrounding rural regions.

The level of concern for air quality does differ somewhat across these regions. The overall average concern across Potsdam, Berlin, and Brandenburg is 2.76 (1 = very unconcerned, 6 = very concerned), similar to the air quality rating. However, respondents from Werder (Havel), Kirchsteigfeld, and Nuthetal are slightly more unconcerned than the average (concerns of 2.45, 2.49, and 2.22, respectively) and respondents from Brandenburg Vorstadt, through which the Zeppelinstraße runs, are slightly more concerned (concern of 3.55). Fig. 3 stands out in comparison to the first two figures because respondents are more concerned about climate change generally than about air quality in Potsdam (an overall average concern of 3.83). Following a paired *t*-test comparing the mean of the differences between these two variables, concern for climate change is 1 point higher than for air quality concern, a result statistically significant at a confidence level of 0.99. Again, there is a distinct level of homogeneity in responses across all regions.

3.2. Chi-squared test of independence

All independent variables were found to be statistically significant at α ≤ 0.001, with the exceptions of *qualification* and *zep_freq_work_car*, which were significant at α ≤ 0.01 (Table 1). Correspondingly, the chi-squared test statistics are very large, further reflecting the extreme significance of each variable found by this test, owing likely to the large sample size as discussed in the methods section (Bergh, 2015; Lantz, 2013). Considering that these results reveal all variables to be statistically significant with very small p-values, post-hoc tests were vital in determining the true effects of each variable.

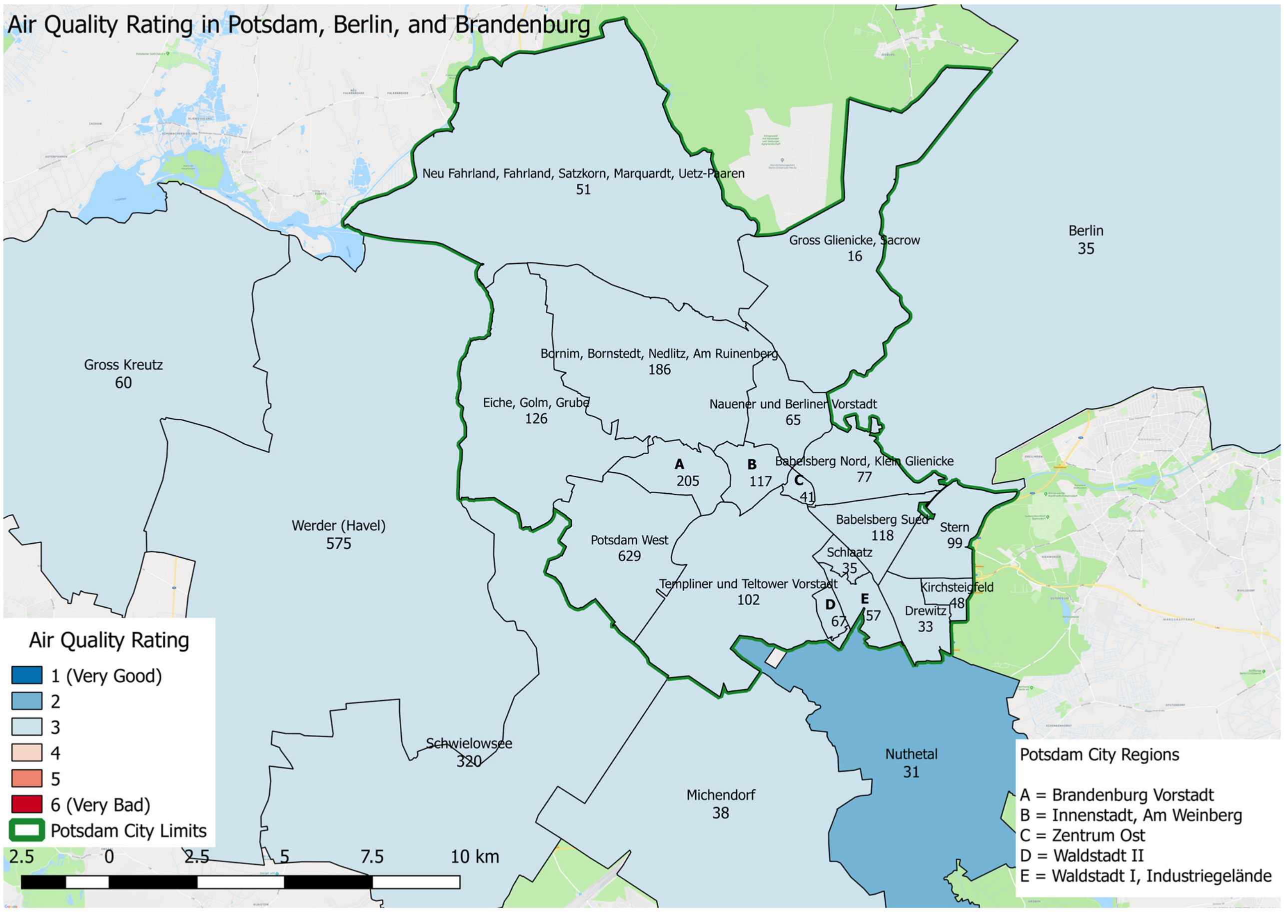

Fig. 1. Map of the average air quality rating (*aq_rating*) by planning areas of Potsdam, postal code areas of the Brandenburg region, and the Berlin city limits. Names of each region are included as well as the sample size. *Source for shapefiles: City of Potsdam (Landeshauptstadt Potsdam).*

The post-hoc analysis was conducted for each predictor variable, resulting in 18 tables of standardized residuals that were assessed (see Tables 2 and 3, and Supplementary Information, Tables S1–S16). Tables 2 and 3 are included here to exemplify variables that were found to reject (*aq_concern*) or support (*effect_aq*) the H_0 of independence. Each depicts the observed and expected counts for the predictor variable with the response variable, with an additional calculation of the Pearson standardized residual for each cell.

What can be elucidated from these tables are the specific cells which influence the overall significance of the association. The cells of 1/1, 2/2, 3/3, 4/4, 5/5, and 6/6 (*aq_rating/aq_concern*) in Table 2, for example, all contained *more* observations than expected at the Bonferroni adjusted alpha level of significance. Each cell that contains a standardized residual exceeding the z-value of the Bonferroni adjusted alpha supports the alternative hypothesis that these two variables are NOT independent. In total, 31 out of 49 cells support the H_A for *aq_concern* and 6 out of 35 support the H_A for *effect_aq*.

After the initial chi-squared independence test for the contingency table, the relationships between these predictors and the response variable were both deemed significant with very low p-values (Table 1). Post-hoc analysis using standardized residuals distinguishes more effectively, however, that *effect_aq* likely is independent of *aq_rating* (Table 3) and that *aq_concern* indeed is not independent of it (Table 2). For 9 of these 18 variables, (*aq_concern, cc_concern, gender, healthstatus, support_measure, support_nopkw, budget_env, informed_wishes*, and *resident_zepp*) the results indicated that the H_A was supported and that the variables were not independent of *aq_rating*. It is important to note that the final decision regarding independence was based on subjective interpretation of the standardized residuals and that other researchers might conclude differently.

3.3. Linear trend alternative to independence

Following the chi-squared test of independence, the linear trend alternative to independence test was conducted (Agresti, 2002), the results of which are found in Table 4. Of the 18 variables tested, only *aq_concern* was found to have a moderately strong linear trend, indicated by an r-value of 0.59 and an M^2-value of 1070. Six other variables, *cc_concern, healthstatus, support_measure, budget_env, support_nopkw*, and *informed_wishes*, showed moderate evidence of linear trends, with r-values of 0.25, 0.23, −0.20, −0.25, −0.23, and −0.24, respectively. All other variables had r-values below ± 0.2 (closer to 0), in most cases below ± 0.1, and showed weak to no evidence of linear trends in their contingency tables. The predictor variable of *gender* was found to have an r-value of −0.18, showing weak evidence of a negative linear trend. All variables, with the exception of *resident_location*, were statistically significant in this analysis. This is likely a further reflection of the influence of large sample size on statistical significance, just as with the chi-squared test of independence.

3.4. Ordinal logistic regression

Nine independent variables were selected after the previous statistical tests for inclusion in the regression analysis: *aq_concern, cc_concern, gender, healthstatus, support_measure, support_nopkw, budget_env, informed_wishes*, and *resident_zepp*. In all cases, the variables were found to have significant associations with the response variable following analysis of the standardized Pearson residuals. These variables were

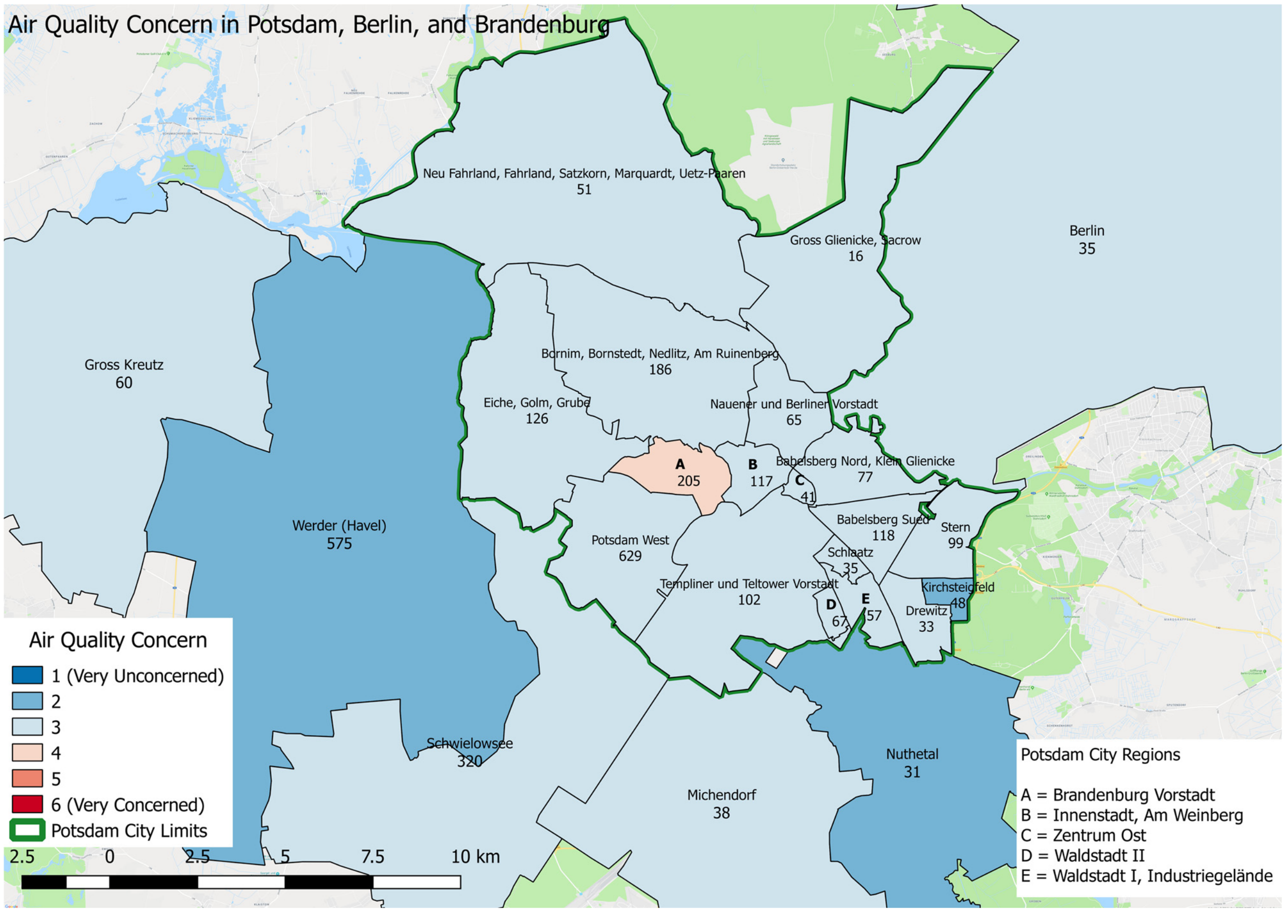

Fig. 2. Map of the average air quality concern (*aq_concern*) by planning areas of Potsdam, postal code areas of the Brandenburg region, and the Berlin city limits. Names of each region are included as well as the sample size. *Source for shapefiles: City of Potsdam (Landeshauptstadt Potsdam).*

also found to have a linear trend r-value of at least ± 0.2, with the exceptions of *gender* (−0.18) and *resident_zepp* (−0.11). Though the linear trend for *resident_zepp* is negligible, the table of standardized residuals seemed to indicate evidence of a relationship with *aq_rating*, leading to its inclusion in the regression analysis.

3.4.1. Multicollinearity

There appears to be no evidence of multicollinearity between the explanatory variables included in the regression analysis (Section S2, Tables S17 and S18). No r-value exceeded ± 0.5 and in most cases r-values were quite low. There appears to be some evidence of a relationship between *aq_concern* and several other variables, but in no cases is it compelling enough to conclude that the variables are collinear. Such a conclusion would require the r-values to be very strong, upwards of ± 0.8. Furthermore, after coercing the variables to a linear model to test the variance inflation factor, the variables were not found to be collinear as no VIF was greater than 2. Further investigation of the variables is typically warranted at a VIF of 4 and collinearity is usually indicated by a VIF greater than 10, though these are rules of thumb and do not necessarily require variable removal (O'Brien, 2007).

3.4.2. Model selection

Applying a backward selection procedure to test the model, using the "drop1″ function in R, likelihood-ratio tests were conducted between each nested model and the saturated model, revealing that *aq_concern, cc_concern, gender, healthstatus*, and *informed_wishes* were the most significant variables in the model. Removing these variables worsens the model fit, as can be seen by the subsequent *increase* in AIC for each of these variables (Table 5). The greatest increase in AIC is seen for the removal of *aq_concern*, with individual removal of *gender* and *healthstatus* also substantially increasing the AIC. As is reflected in their likelihood-ratio test statistics and p-values, the models without *cc_concern* or *informed_wishes* are only slightly worsened. Overall these results indicate that *aq_concern* has the greatest importance to the model fit, *gender* and *healthstatus* are also quite important, and *cc_concern* and *informed_wishes* are minimally important. The other four variables (*support_measure, support_nopkw, budget_env, resident_zepp*) improve the model fit when individually removed, but only very slightly in each case.

Once each variable was tested for its individual importance to the saturated model, a simplified model was created using only those variables found to be statistically significant at α = 0.05. The AIC and Nagelkerke R^2 values for the saturated vs simplified model (*aq_concern* + *cc_concern* + *gender* + *healthstatus* + *informed_wishes*) are 6086.92 and 0.411 vs 6085.03 and 0.408, respectively (Table S19). After removing the four variables of *support_measure*, *support_nopkw*, *budget_env*, and *resident_zepp*, the simplified model improves the model fit (according to the AIC) only very slightly. Additionally, the simplified model has a slightly smaller pseudo-R^2 value. A likelihood-ratio test between these two models (Table S20), revealed that the saturated model was a better fit at α = 0.1 significance. These results indicate that there is very little difference in model fit between the two models and favours the saturated model over its simplified counterpart.

3.4.3. Model estimates

The saturated model, selected as being better representative of the data, was used to estimate the vital model parameters for the nine predictor variables. Table 6 presents the estimates of the variable

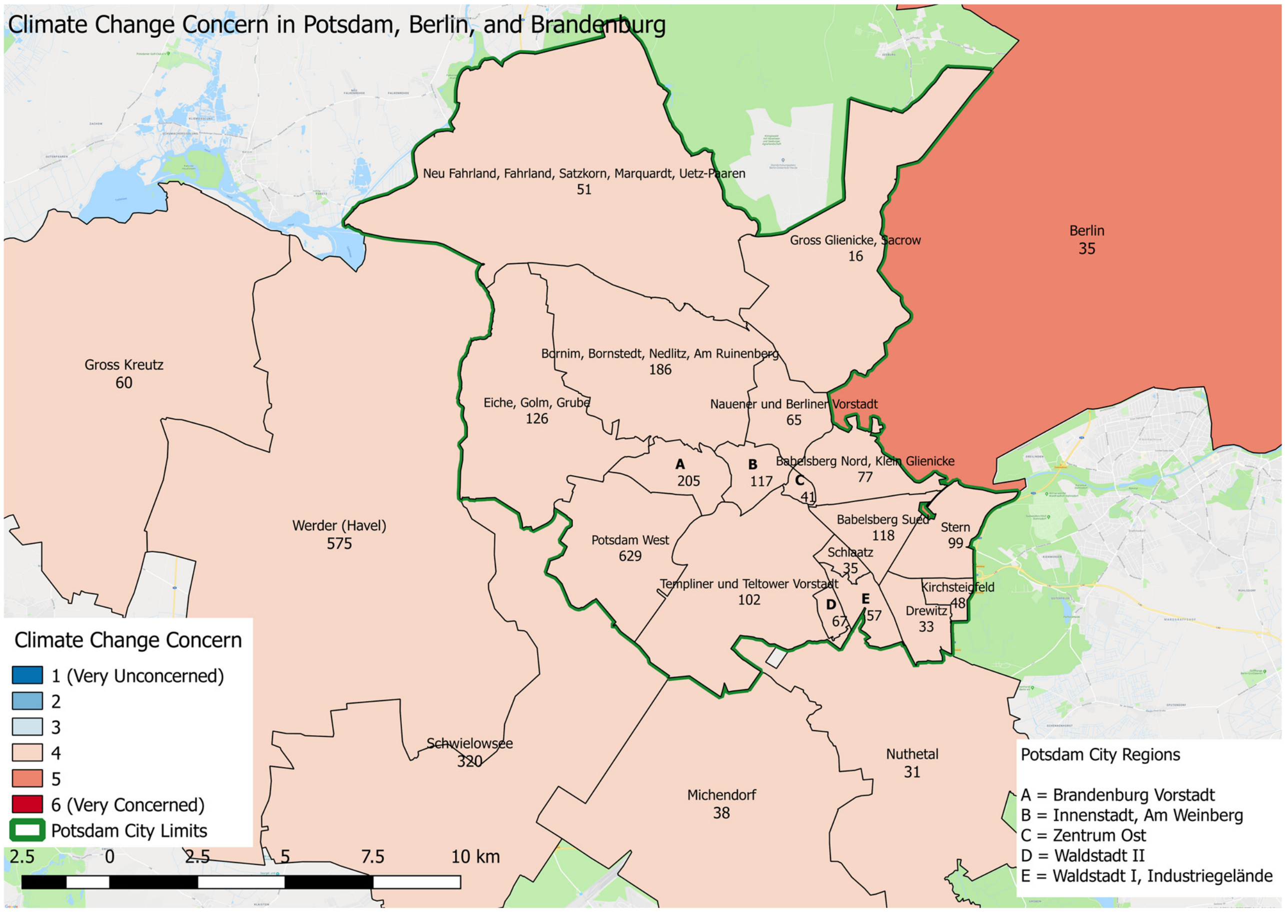

Fig. 3. Map of the average climate change concern (*cc_concern*) by planning areas of Potsdam, postal code areas of the Brandenburg region, and the Berlin city limits. Names of each region are included as well as the sample size. *Source for shapefiles: City of Potsdam (Landeshauptstadt Potsdam)*.

Table 1
Results of the Chi-squared test of independence of each predictor variable with the response variable, air quality rating (*aq_rating*). Included are the chi-squared test statistic (χ^2), the degrees of freedom (df), the corresponding Z-value from the chi-squared distribution, and the statistical significance.

Variable code	χ^2	df	Z-value	p-value
aq_concern	2710	36	3.285	0
cc_concern	375	36	3.285	5.49E-58
age	53.3	12	3.038	3.65E-07
gender	122	6	2.914	5.15E-24
qualification	60.7	36	3.285	6.24E-03
healthstatus	208	18	3.124	2.33E-34
income	107	42	3.322	1.62E-07
informed_aq	247	24	3.189	5.75E-39
support_measure	150	12	3.038	6.75E-26
priority_aq	53.0	18	3.124	2.66E-05
effect_aq	151	24	3.189	2.23E-20
budget_env	325	24	3.189	1.56E-54
support_nopkw	250	24	3.189	1.72E-39
informed_wishes	176	12	3.038	2.40E-31
resident_zepp	62.8	6	2.914	1.21E-11
resident_location	40.1	6	2.914	4.37E-07
zep_freq_work_car	48.7	24	3.189	2.05E-03
zep_freq_priv_car	77.4	24	3.189	1.56E-07

effects (β_k) with their standard errors, z-values, and corresponding p-values. The values most important to this analysis are the variable effects, as they quantitatively represent the association between each variable and the response variable, *aq_rating*. The results show that *aq_concern* has a strong effect on *aq_rating*, as an increase in *aq_concern* increases the odds of a higher *aq_rating* by 1.88. *Gender* also has a strong effect on *aq_rating* as the odds of a better air quality rating are 0.66 times lower for women. In other words, women rate the air quality somewhat worse than men. Both of these effects are significant at $\alpha = 0.001$ (Table 6).

Although also significant at $\alpha = 0.001$, the effect of *healthstatus* is smaller in comparison to *aq_concern* and *gender*, as a an increase in *healthstatus*, say from "bad" to "somewhat good", increases the odds of a higher air quality rating by 1.22. Thus, these results indicate that people that perceive themselves to be in good health rate the air quality better than people in poor health. The categorical variable *informed_wishes* was also found to be statistically significant as responses of "yes" or "I don't know" would decrease the odds of a higher air quality rating by 0.893 and 0.837, respectively. The last variable deemed statistically significant is that of *cc_concern*, which decreases the odds of a higher air quality rating by 0.952 at $\alpha = 0.05$ significance. All other variable β_k estimates were not found to be statistically significant.

3.4.4. *Significant variables visualized*

Those variables that were found significant by the regression model were visualized with bar charts to compare the model estimates with the data. Figs. 4–9 visually depict results consistent with the estimates produced by the model. Though the strengths of the relationships are not strong (the model fit was adequate, but below pseudo-$R^2 = 0.5$), the direction identified by the estimates was consistent with the visualized data plotted in Figs. 4b–9b. The only exception to this is *cc_concern*, which appeared to have a weakly positive linear relationship with *aq_rating* (Fig. 5b), but was calculated as having a β_k estimate of -0.049. The spread of responses is depicted for each predictor

Table 2
A cell by cell comparison of the standardized residuals for the contingency table with predictor variable *aq_concern* and response variable *aq_rating*. The cells with standardized residuals in bold font are those that exceeded the corresponding z-value of the Bonferroni-adjusted alpha at significance 0.05 (in this case α = 0.001 with z-value = +/- 3.28 after adjustment). This variable was deemed to be NOT independent of *aq_rating* as it had 31/49 cells supporting the H_A, with clear evidence for a linear trend in the table. The three components of each cell from top to bottom are the observed counts, the expected counts if the variables were independent, and the standardized residuals. The total observed counts are tallied for both rows and columns.

	aq_concern							
aq_rating	1	2	3	4	5	6	Don't know	Total
1	148 32.4 **(23.0)**	18 44.5 **(-4.69)**	11 49.7 **(-6.61)**	3 26.5 **(-5.08)**	2 16.3 **(-3.82)**	1 8.35 (-2.68)	1 6.15 (-2.17)	184
2	289 191 **(9.52)**	457 262 **(16.8)**	192 293 **(-8.37)**	90 156 **(-6.96)**	36 96.0 **(-7.80)**	10 49.2 **(-6.95)**	9 36.2 **(-5.59)**	1083
3	104 224 **(-11.2)**	266 307 **(-3.42)**	530 343 **(15.0)**	204 183 (2.11)	107 113 (-0.71)	37 57.6 **(-3.53)**	22 42.5 **(-4.06)**	1270
4	12 67.7 **(-7.92)**	42 92.9 **(-6.44)**	91 104 (-1.56)	129 55.4 **(11.4)**	80 34.1 **(8.77)**	23 17.4 (1.45)	7 12.8 (-1.76)	384
5	2 28.5 **(-5.61)**	5 39.2 **(-6.43)**	26 43.8 (-3.22)	31 23.4 (1.75)	52 14.4 **(10.7)**	45 7.35 **(14.6)**	1 5.42 (-1.98)	162
6	1 10.9 **(-3.34)**	2 15.0 **(-3.89)**	4 16.8 **(-3.68)**	6 8.94 (-1.07)	12 5.50 (2.93)	36 2.81 **(20.4)**	1 2.07 (-0.77)	62
Don't know	34 35.9 (-0.37)	20 49.3 **(-4.95)**	51 55.1 (-0.67)	20 29.4 (-1.94)	8 18.1 (-2.56)	0 9.26 (-3.21)	71 6.82 **(25.8)**	204
Total	590	810	905	483	297	152	112	3349

variable in Figs. 4a–9a. Most respondents have an air quality concern between 1 and 3, whereas their level of climate change concern was rated more frequently between 3 and 6. This further supports the conclusion that respondents to this questionnaire are more concerned about climate change than air quality. What is also clear is the level to which respondents feel informed regarding air quality. The majority perceive their level of awareness regarding air quality to be "somewhat bad" (Fig. 8a) and would like to receive more information to the subject (Fig. 9a).

4. Discussion

4.1. Perceptions of air quality

The results of the analyses performed here show that air quality in Potsdam is perceived to be somewhat good (an average rating of 3). These perceptions are spatially uniform and are significantly associated with several sociodemographic characteristics and with environmental concern. As can be seen in Fig. 1, there is very little spatial variability in the subjective evaluation of air quality among the regions of the city of Potsdam, or among the surrounding Brandenburg municipalities. Furthermore, both variables that tested for location effects (*resident_zepp* and *resident_location*) were found to have no significant association with respondents' air quality ratings. In contrast to these results, previous research has often found a discrepancy between urban and rural perceptions of air quality, despite differences in population densities of the regions studied (Texas, USA; Nanchang, China; Ljubljana, Slovenia) (Brody et al., 2004; Guo et al., 2016; Mally, 2016). In this study, however, regardless of whether respondents live in more rural areas (i.e. Schwielowsee, Neu Fahrland, Eiche) or in more urban areas (i.e. Zentrum Ost, Innenstadt), public perceptions of air quality in Potsdam remained relatively homogenous.

Of the sociodemographic variables tested, *healthstatus* and *gender* were found to be significantly associated with *aq_rating*. The results showed that women rate the air quality slightly poorer than men, a finding consistent with that of Howel et al. (2003) and Jacquemin et al. (2007). Additionally, those that rated their health as poor perceived the air quality to be slightly worse than those in good health. This linkage between health and perceptions has also been found in previous literature, as individuals with respiratory conditions such as asthma or night dyspnoea and people with chronic illness often perceive the air quality to be worse, reporting higher levels of annoyance from air pollution (Howel et al., 2003; Jacquemin et al., 2007; Oltra & Sala, 2014). Other variables such as income, qualification, or age were not found to be influential on respondents' perceptions of air quality. This is in contrast to a number of previous studies that have found evidence that older age groups perceive the air quality as better (Brody et al., 2004; Guo et al., 2016) or those with at least college-level education rate the air quality as worse than those without (Guo et al., 2016).

Of the 18 independent variables tested, air quality concern is the most significantly associated with air quality rating. The results indicate the presence of a moderately strong, positive linear relationship between these two variables: as respondents' air quality ratings increase (air quality is perceived as better) their level of concern decreases, and vice-versa. Figs. 1 and 2 reflect this relationship spatially, as most regions in Potsdam and Brandenburg have similar ratings of, and levels of concern for, air quality. This is further exemplified by Fig. 4b, which clearly depicts the linearity of the relationship between the two variables. Though *cc_concern* is significantly associated with individual perceptions of air quality, the strength of the direction of that relationship was much less than that of *aq_concern* (the β_k estimates were -0.049 and 0.632, respectively). However, the β_k estimate of *cc_concern* and the results depicted in Fig. 5b appear to contradict one another, with Fig. 5b showing a slightly positive linear relationship with *aq_rating* and the regression model identifying a negative relationship. Overall, respondents' environmental concern, as represented by their levels of concern for air quality and climate change, is the factor most significantly associated with perceptions of air quality in Potsdam.

Table 3
A cell by cell comparison of the standardized residuals for the contingency table with predictor variable *effect_aq* and response variable *aq_rating*. The cells with standardized residuals in bold font are those that exceeded the corresponding z-value of the Bonferroni-adjusted alpha at significance 0.05 (in this case $\alpha = 0.0014$ and z-value = +/- 3.19 after adjustment). This variable was deemed to be independent of *aq_rating* as it had only 6/35 cells supporting the H_A, four of which had observed counts less than 20. The three components of each cell from top to bottom are the observed counts, the expected counts if the variables were independent, and the standardized residuals. The total observed counts are tallied for both rows and columns.

	effect_aq					
aq_rating	Greatly worsened	Worsened	No effect	Improved	Greatly improved	Total
1	83 68.8 (2.25)	54 51.5 (0.42)	31 40.4 (-1.73)	8 12.3 (-1.30)	2 5.08 (-1.43)	178
2	367 414 **(-3.60)**	342 310 (2.60)	290 243 **(4.16)**	58 73.9 (-2.33)	15 30.6 **(-3.48)**	1072
3	470 483 (-0.95)	373 362 (0.89)	278 284 (-0.48)	94 86.2 (1.11)	35 35.7 (-0.15)	1250
4	160 146 (1.62)	87 109 (-2.67)	74 85.5 (-1.51)	37 26.0 (2.38)	19 10.8 (2.71)	377
5	76 61.4 (2.43)	32 46.0 (-2.51)	18 36.0 **(-3.51)**	19 11.0 (2.58)	14 4.54 **(4.62)**	159
6	30 24.0 (1.59)	13 18.0 (-1.40)	5 14.1 (-2.78)	5 4.27 (0.37)	9 1.77 **(5.57)**	62
Don't know	86 75.3 (1.62)	52 56.4 (-0.72)	51 44.2 (1.19)	6 13.4 (-2.17)	0 5.57 (-2.47)	195
Total	1272	953	747	227	94	3293

Table 4
Results of the linear trend alternative to independence test. The *r* is a measure of the linear trend found in the contingency table of each predictor variable and the response variable, *aq_rating*. Each has an associated test statistic, M^2, which follows the chi-squared distribution with 1 degree of freedom and reflects the strength of association.

Variables	***r***	M^2	**p-value**
aq_concern	0.59	1070	3.08E-234
cc_concern	0.25	185	3.48E-42
age	0.09	23.0	1.66E-06
gender	−0.18	97.5	5.37E-23
healthstatus	0.23	160	1.15E-36
qualification	0.05	8.45	3.65E-03
income	0.13	38.6	5.28E-10
informed_aq	0.13	48.8	2.82E-12
support_measure	−0.20	123	1.44E-28
priority_aq	−0.05	6.59	1.03E-02
effect_aq	−0.05	6.41	1.13E-02
budget_env	−0.25	186	2.00E-42
support_nopkw	−0.23	162	4.12E-37
informed_wishes	−0.24	137	1.13E-31
resident_zepp	−0.11	34.0	5.69E-09
resident_location	−0.01	0.18	6.72E-01
zep_freq_work_car	0.08	19.8	8.44E-06
zep_freq_priv_car	0.09	23.5	1.25E-06

A further point of interest involves the result that, on average, there is a higher level of concern for climate change than for air quality in Potsdam. The most recent report on air quality in Europe by the European Environment Agency calculated 332,000 premature deaths attributable to $PM_{2.5}$ pollution and 229,000 to NO_2 pollution in the EU-28 in 2014. In both cases, Germany was calculated to have the highest number of deaths attributable to $PM_{2.5}$ and NO_2 (54,180 and 44,960, respectively) (EEA, 2017). What this indicates is that, although air quality is more regionally relevant than climate change as an environmental and extreme health risk, respondents do not seem as concerned by it. Considering climate change has received a substantial amount of media coverage over the last two decades, both locally and globally (Schmidt, Ivanova, & Schäfer, 2013), one hypothesis is that it may be overshadowing the current and local issue of air quality in Potsdam. Prevalence of a lower level of concern for air quality could be a potential hindrance to support for changes at the local, national, or regional level to address the issue. Given this difference in the level of concern, it may be more effective to frame policies, including those on air quality, around the co-benefits for climate change. Furthermore, a better understanding of citizen's concern for a wider variety of environmental issues could also provide additional information to help inform the contextual framing of policies, but was unfortunately

Table 5
The results of the first step in the backward elimination process through likelihood-ratio tests of the removal of each variable individually from the model. Shown are the degrees of freedom (df) of each test, the AIC (Akaike Information Criterion) for the saturated model and the nested models with each corresponding variable removed, the associated LRT (likelihood-ratio test statistic), and the Pearson chi-square p-values. For significance, the alpha values are represented as follows: **** = 0.001, *** = 0.01, ** = 0.05, and * = 0.1.

	df	AIC	LRT	p-value
Saturated Model		6086.92		
Variables				
aq_concern	1	6807.68	722.75	0.0000****
cc_concern	1	6091.84	6.91	0.0086***
Gender	1	6163.27	78.34	0.0000****
healthstatus	1	6131.67	46.74	0.0000****
informed_wishes	2	6089.83	6.91	0.0316**
support_measure	2	6085.22	2.30	0.3171
support_nopkw	1	6086.72	1.80	0.1798
budget_env	1	6085.78	0.85	0.3556
resident_zepp	1	6085.04	0.12	0.7332

Table 6
The model estimates using ordinal logistic regression for the saturated, best-fit model. Shown here are the estimate, the proportional odds ratio, the standard error (Std. error), the Z statistic of the normal distribution (z-value), and the corresponding Pearson p-value. The variables that contain supplements to the original code (e.g "gender *female*", "informed_wishes *yes*") are those that were considered nominal in the analysis. Each category that is missing an estimate, which in gender is "male" and the other three variables is "no", is used by the model as the reference category. Therefore the estimates for these variable categories should be interpreted as the effect on air quality rating following a shift (or "increase") from the reference category to the indicated category. For significance, the alpha significance values are represented as follows: **** = 0.001, *** = 0.01, ** = 0.05, and * = 0.1.

β_k (variable effects)	Estimate	Odds Ratio	Std. Error	z-value	p-value
aq_concern	0.632	1.88	0.099	6.404	0.000****
cc_concern	−0.049	0.952	0.020	−2.477	0.013**
gender *female*	−0.416	0.660	0.081	−5.152	0.000****
healthstatus	0.197	1.22	0.042	4.644	0.000****
informed_wishes *yes*	−0.113	0.893	0.061	−1.853	0.064*
informed_wishes *I don't know*	−0.178	0.837	0.076	−2.331	0.020**
support_measure *Yes*	−0.125	0.882	0.085	−1.475	0.140
support_measure *I don't know*	−0.054	0.948	0.120	−0.447	0.655
support_nopkw	0.025	1.03	0.019	1.313	0.189
budget_env	−0.026	0.975	0.028	−0.915	0.360
resident_zepp *Yes*	−0.019	0.982	0.054	−0.340	0.734

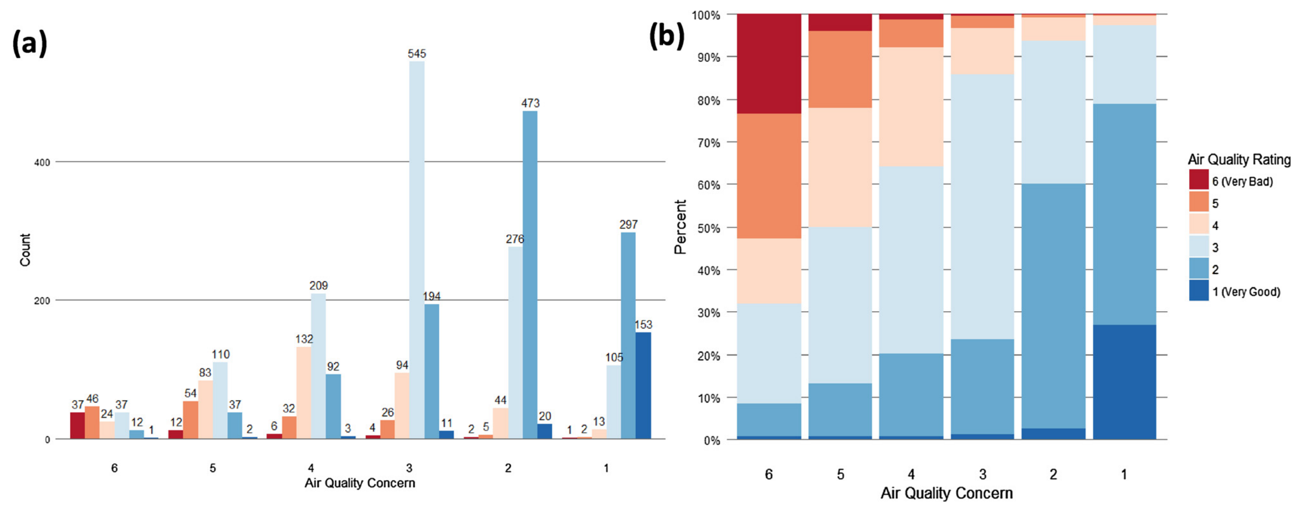

Fig. 4. (a) number of responses recorded in the questionnaire for *aq_concern* organized by their respective ratings of air quality (*aq_rating*), (b) the same responses organized by *aq_rating*, with counts of each category presented as percent of the total counts for *aq_concern* in that category.

beyond the scope of this study. These results have particular implications in Potsdam for the trial of the new policy measure on the Zeppelinstraße.

Air quality rating does not appear to be influenced by how informed about air quality the respondents perceive themselves to be (*informed_aq*). Most respondents do feel poorly informed about air quality, but this was not found to be significantly associated with air quality rating. There was, however, a significant relationship between air quality rating and *informed_wishes*. In other words, respondents that feel no need for further information perceive the air quality to be better than those that desire more air quality information. These results highlight an interesting disagreement between perceptions of air quality in Potsdam and the reality of the situation. Specifically, regulatory monitoring data reveal that Potsdam has an ongoing issue with adhering to EU air quality standards. However, when respondents do not perceive a need for further access to information on air quality, they perceive the air quality to be good. Whether respondents who reject further information do so because they already feel well-informed or because they believe air quality to be good and an unimportant issue is not clear. That said, one of the variables included in the questionnaire (but not included in the more detailed analysis presented here) asked how regularly the participants informed themselves about the air quality situation – only 8% of respondents indicated that they did so on a regular basis, 53% indicated that they did, but only rarely, while ca. 33% indicated that they never did so. Considering that 86% of respondents either rarely inform themselves or do not inform themselves regarding air quality, it is possible that respondents rated air quality without consulting available monitoring data.

4.2. Policy context

The Zeppelinstraße in Potsdam continues to experience poor air quality, as documented by the roadside monitoring station located there. This was the impetus for the implementation of the trial traffic-reduction measure at that site. The main problem is with NO_2, for which the Zeppelinstraße monitoring station recorded a yearly average of 43 μg m^{-3} for NO_2 in 2016, with a maximum 1-hour average of 157 μg m^{-3} (Landesamt für Umwelt, 2016). The current EU annual limit-value for NO_2 is 40 μg m^{-3} (European Commission, 2017) which means that at this station in Potsdam NO_2 standards are not being met. Since 2007, the annual average NO_2 concentrations have consistently remained above the legal limit-value, not once meeting this requirement (Landesamt für Umwelt, 2016). Furthermore, while the PM_{10} values are not legally exceeding EU limit values – there were 15 of 35 allowed exceedances of the PM_{10} EU daily limit-value of 50 μg m^{-3} in 2016 and the yearly average was 26 μg m^{-3} compared to the annual limit-value of 40 μ m^{-3} – more could be done for the protection of human health. The WHO has recommended an annual average

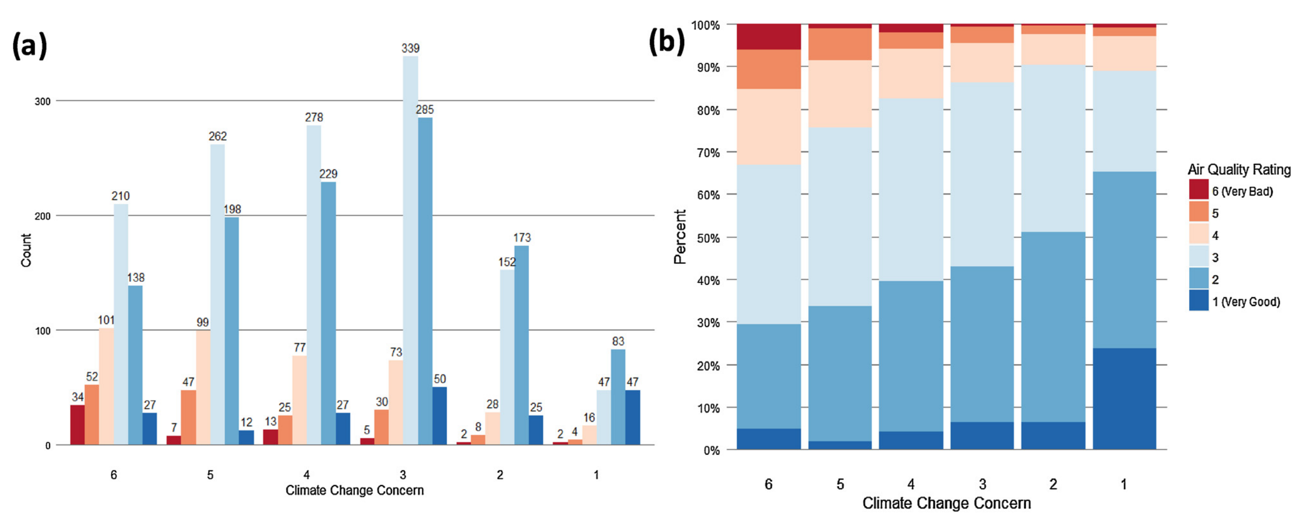

Fig. 5. (a) and (b) as Fig. 4, but for *cc_concern*.

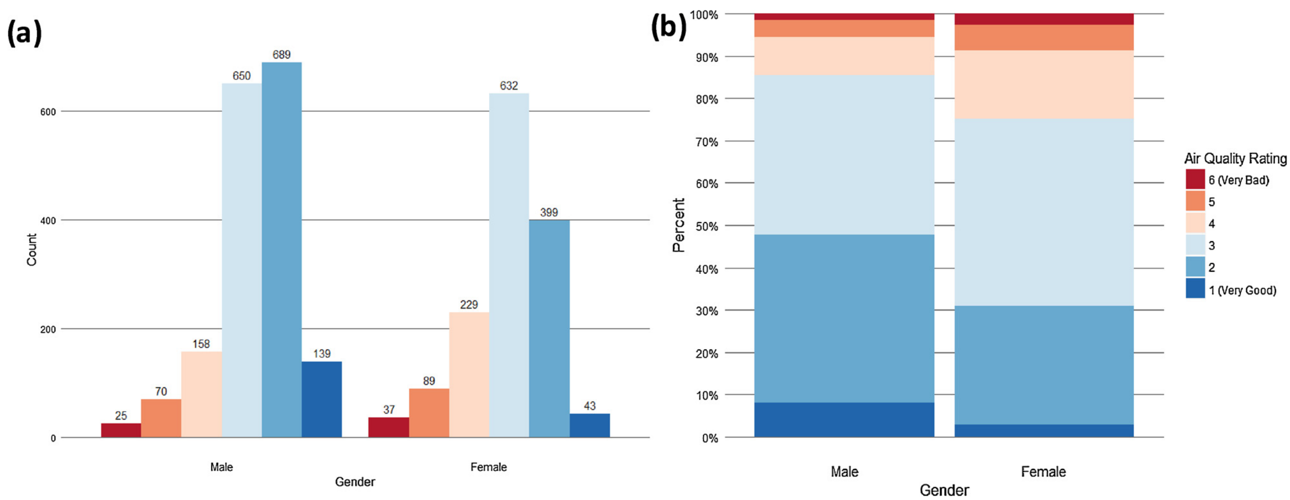

Fig. 6. (a) and (b) as Fig. 4, but for *gender*.

concentration of no more than 20 µg m^{-3} for the protection of human health (World Health Organization, 2006). An urban background monitoring station in Potsdam recorded similar, but slightly lower numbers for 2016, with 6 daily exceedances and a yearly average of 20 µg m^{-3} for PM_{10} (Land Brandenburg, 2017). While it is difficult to compare objective measurements to subjective perceptions, the monitoring station data indicates that the air quality in Potsdam exceeds legal limit values of NO_2 and could be improved upon for the protection of human health for not only NO_2 but also PM_{10}. As discussed previously, the respondents perceive the air quality to be somewhat good in Potsdam. Though the data are not spatially representative of the air quality in each municipal region of Potsdam, it appears that objective air quality monitoring data likely do not influence respondents' perceptions. This finding adheres with other studies from the literature that have found a similar disconnect (Brody et al., 2004; Mally, 2016; Schwartz, 2006).

These results have implications for the implementation of the traffic-reduction measure on the Zeppelinstraße. The Potsdam city administration have clearly stated that the goal of the measure is to improve air quality on the highly-frequented street, as the current levels are unacceptable according to federal German and EU law (European Parliament, 2008; Mobil in Potsdam, 2017). This study found that the respondents perceive air quality as somewhat good and are relatively unconcerned by the issue, which indicates that this trial measure is occurring in a social climate non-conducive to its success. Supportive of this conclusion are the results displayed in Fig. S1; respondents that live near the Zeppelinstraße, as well as those that do not, overwhelmingly reject the traffic-reduction measure. Furthermore, support for the traffic-reduction measure (*support_measure*) is not significantly related to respondents' air quality rating, indicating that perceptions of air quality are not influential on respondents' support for the Zeppelinstraße traffic measure. Support for traffic-reduction measures in general (*support_nopkw*) is also not significantly related to air quality perceptions, revealing that for respondents there remains a disconnect between the implementation of such measures and their purpose of improving air quality. With such an apparent gap between the goals of the Zeppelinstraße measure and perceptions of air quality, successfully implementing it without encountering substantial public resistance may remain challenging. This has broader implications for future implementation of traffic reduction measures in municipalities throughout Germany and Europe that continue to exceed EU air quality limit values for NO_2. In Germany, for example, about 60% of roadside monitoring stations exceeded the NO_2 annual limit value in 2016 (Minkos, Dauert, & Feigenspan, 2018). This trend has continued for many years now, with over 70% of stations exceeding limit values in 2010 and 2011 (Minkos et al., 2018). As such, it is likely that similar stringent traffic measures will continue to be implemented in cities in the coming years in Germany. The results of this study indicate that, although poor air quality is the catalyst for such measures, citizens' support for them may not be influenced by their perceptions of air quality.

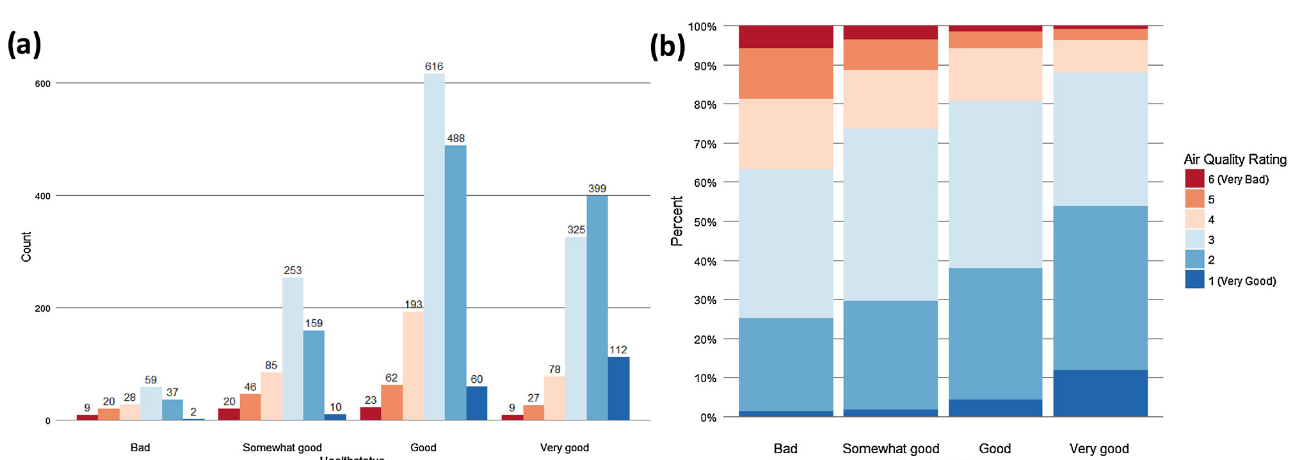

Fig. 7. (a) and (b) as Fig. 4, but for *healthstatus*.

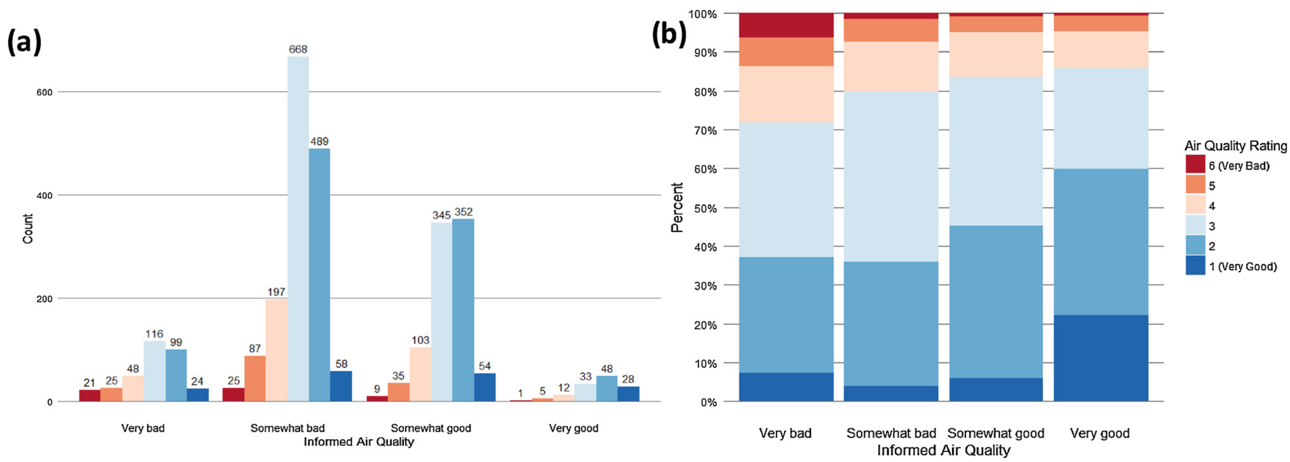

Fig. 8. (a) and (b) as Fig. 4, but for *informed_aq*.

4.3. Limitations and further analysis

There are several limitations in this study that must be acknowledged, as well as improvements that could be made if further analyses were conducted. First, the questionnaire was accessible to any individual who wanted to participate. In other words, the sample was not initially selected to be representative of the structure of the population of Potsdam. Instead, it consists of self-selected participants and might be biased towards those who rejected the trial measure and were more motivated to participate in the study (Whitehead, 1991). Thus, the results of this study should be interpreted with care when being attributed to Potsdam as a whole. If considered together, however, the total number of respondents that came from Potsdam represents an acceptable sample size for the city, given its population, at a 95% confidence level (Bartlett, Kotrlik, & Higgins, 2001).

Another important limitation of this analysis is the variable selection process whereby 18 independent variables were chosen from 133 total variables output by Limesurvey. The scope of the research was limited by selecting specific variables for analysis to not only create a manageable dataset, but also to address variables that had been evaluated in previous studies. Furthermore, the scope of the study resulted in a limitation in the definition of "environmental concern". There are a multitude of environmental issues that can be included in this concept, but for the purposes of this study, "environmental concern" is composed only of climate change and air quality concern. Interpretation of the results should therefore also consider this limitation. Finally, the influence of large sample size on significance tests with the chi-squared and linear trend analyses proved to be a challenging obstacle. This added a level of complexity in determining which predictor variables were truly correlated with air quality rating and necessitated the post-hoc analysis of standardized Pearson residuals. All of these tests for determining the associations among variables, however, have a level of subjectivity and do not follow an objective standard. In some cases it was clear that relationships were not present and the variables were independent, but in other cases the distinction was far less clear. Therefore, in an attempt to overcome this subjectivity, the results of multiple statistical tests were scrutinized together to test the association of the independent variables with the dependent variable.

4.4. Conclusions

The results of this study indicate that perceptions of air quality are driven mostly by respondents' level of concern for air quality (*aq_concern*). Gender (*gender*), health status (*healthstatus*), level of concern for climate change (*cc_concern*), and desire for information regarding air quality (*informed_wishes*) were also significantly associated with air quality perceptions. It appears that these perceptions are not driven by objective air quality, despite the availability of monitoring stations, and are relatively homogenous across all regions of Potsdam and the surrounding Brandenburg regions. Levels of concern for air quality and climate change follow a similar homogeneity, but respondents reported a higher level of concern for climate change than for air quality. In combination, these results indicate that traffic-reduction measures intending to curb air pollution such as that implemented on the Zeppelinstraße can encounter significant opposition from the public. With air quality rating not significantly associated with public support

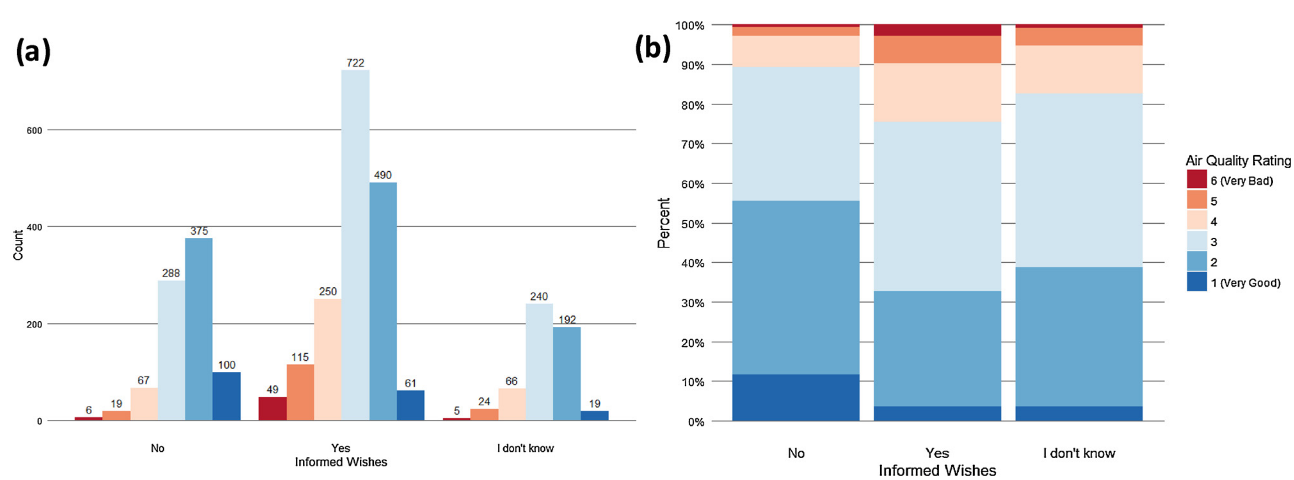

Fig. 9. (a) and (b) as Fig. 4, but for *informed_wishes*.

for this measure, or with support for traffic-reduction measures in general, it appears that perceptions of air quality do not play a role in public acceptability for traffic-reduction measures. This has particular implications for German and European cities that continue to exceed limit-values for NO_2, as they will likely need to implement similar, potentially unpopular measures in the future. The aforementioned limitations, however, indicate that a more detailed and longer-term study with a random sample is necessary to confirm the strength and accuracy of these findings.

Declarations of interest

None.

Funding

The Institute for Advanced Sustainability Studies (IASS) e.V., Potsdam, is funded by the German Federal Government's Ministry of Education and Research as well as the Federal State of Brandenburg's Ministry for Science, Research, and Culture.

Acknowledgements

This work has been funded by the Institute for Advanced Sustainability Studies (IASS) e.V., Potsdam. Spatially referenced data in the form of shapefiles for the city of Potsdam were generously provided to the authors by the City of Potsdam (Landeshauptstadt Potsdam) for use in this study.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.scs.2018.06.011.

References

Agresti, A. (2010). *Analysis of ordinal categorical data.* Hoboken, New Jersey: John Wiley & Sons, Inc.
Agresti, A. (2002). *Categorical data analysis.* Hoboken, New Jersey: John Wiley & Sons, Inc.
Banister, D. (2011). Cities, mobility and climate change. *Journal of Transport Geography, 19*, 1538–1546. http://dx.doi.org/10.1016/j.jtrangeo.2011.03.009.
Bartlett, J. E., Kotrlik, J. W., & Higgins, C. C. (2001). Organizational research: Determining appropriate sample size in survey research. *Information Technology, Learning, and Performance Journal, 19*, 43. http://dx.doi.org/10.1109/LPT.2009.2020494.
Benthin, R., Gellrich, A., Scholl, G., Holzhauer, B., & Schipperges, M. (2016). *Umweltbewusstsein in Deutschland*.
Bergh, D. (2015). Chi-squared test of fit and sample size – A comparison between a random sample approach and a chi-square value adjustment method. *Journal of Applied Measurement, 16*, 204–217.
Bickerstaff, K., & Walker, G. (2001). Public understandings of air pollution: The "localisation" of environmental risk. *Global Environmental Change, 11*, 133–145.
BMVI (2010). *Mobilität in Deutschland 2008.* Bundesministerium für Verkehr, Bau, und Stadtentwicklung214.
Brody, S. D., Peck, B. M., & Highfield, W. E. (2004). Examining localized patterns of air quality perception in Texas: A spatial and statistical analysis. *Risk Analysis, 24*, 1561–1574. http://dx.doi.org/10.1111/j.0272-4332.2004.00550.x.
Bundesverwaltungsgericht (2018). *Luftreinhaltepläne Düsseldorf und.* URLStuttgart: Diesel-Verkehrsverbote ausnahmsweise möglich [WWW Document]. Press. Nr. 9/2018. https://www.bverwg.de/pm/2018/9.
Christensen, R. H. B. (2015a). *Analysis of ordinal data with cumulative link models—Estimation with the ordinal package. CRAN R-project*1–31.
Christensen, R. H. B. (2015b). *Regression models for ordinal data*.
de Groot, J. I. M., & Steg, L. (2008). Value orientations to explain beliefs related to environmental significant behavior. *Environment and Behavior, 40*, 330–354.
Draugalis, J. R., Coons, S. J., & Plaza, C. M. (2008). Best practices for survey research reports: A synopsis for authors and reviewers. *American Journal of Pharmaceutical Education, 72*, 11. http://dx.doi.org/10.5688/aj720111.
EEA (2017). *Air quality in Europe — 2017 report, EEA technical report*http://dx.doi.org/10.2800/358908.
EEA (2016). *Air quality in Europe — 2016 report, EEA technical report*http://dx.doi.org/10.2800/413142.
Elliott, S. J., Cole, D. C., Krueger, P., Voorberg, N., & Wakefield, S. (1999). The power of perception: Health risk attributed to air pollution in an urban industrial neighbourhood. *Risk Analysis, 19*, 621–634. http://dx.doi.org/10.1111/j.1539-6924.1999.tb00433.x.
European Commision (2016). *What are urban access regulation schemes? [WWW document]. Urban access regul. Eur.* URL http://urbanaccessregulations.eu/urban-access-regulations/what-are-urban-access-regulations (Accessed 28 August 2017).
European Commission (2017). *Air quality standards [WWW document].* URL . (Accessed 20 November 2017) http://ec.europa.eu/environment/air/quality/standards.htm.
European Commission (2013). Attitudes of Europeans towards air quality. *Flash Eurobarometer, 360*, 167. http://dx.doi.org/10.2875/884639.
European Parliament (2008). *Directive 2008/50/EC of the European parliament and of the council of 21 May 2008 on ambient air quality and cleaner air for Europe*.
Guo, Y., Liu, F., Lu, Y., Mao, Z., Lu, H., Wu, Y., et al. (2016). Factors affecting parent's perception on air quality-from the individual to the community level. *International Journal of Environmental Research and Public Health, 13*(5), 493–507. http://dx.doi.org/10.3390/ijerph13050493.
Hickman, R., Hall, P., & Banister, D. (2013). Planning more for sustainable mobility. *Journal of Transport Geography, 33*, 210–219. http://dx.doi.org/10.1016/j.jtrangeo.2013.07.004.
Howel, D., Moffatt, S., Bush, J., Dunn, C. E., & Prince, H. (2003). Public views on the links between air pollution and health in Northeast England. *Environmental Research, 91*, 163–171. http://dx.doi.org/10.1016/S0013-9351(02)00037-3.
Jacquemin, B., Sunyer, J., Forsberg, B., Götschi, T., Bayer-Oglesby, L., Ackermann-Liebrich, U., et al. (2007). Annoyance due to air pollution in Europe. *International Journal of Epidemiology, 36*, 809–820. http://dx.doi.org/10.1093/ije/dym042.
Kandt, J., Rode, P., Hoffmann, C., Graff, A., & Smith, D. (2015). Gauging interventions for sustainable travel: A comparative study of travel attitudes in Berlin and London. *Transportation Research Part A: Policy and Practice, 80*, 35–48. http://dx.doi.org/10.1016/j.tra.2015.07.008.
King, K. E. (2015). Chicago residents' perceptions of air quality: Objective pollution, the built environment, and neighborhood stigma theory. *Population and Environment, 37*(1), 1–21. http://dx.doi.org/10.1007/s11111-014-0228-x.
Kopp, R. E., Mauzerall, D. L., Chameides, W. L., & Wilson, D. A. (2010). Assessing the climatic benefits of black carbon mitigation. *Proceedings of The National Academy of Sciences of the United States of America, 107*, 11703–11708.
Lan, G., Yuan, Z., Maddock, J. E., Cook, A., Chu, Y., Pan, B., et al. (2016). Public perception of air pollution and health effects in Nanchang, China. *Air Quality, Atmosphere and Health, 9*, 951–959. http://dx.doi.org/10.1007/s11869-016-0397-0.
Land Brandenburg (2017). *Luftgütedaten im detail [WWW document].* URLhttps://luftdaten.brandenburg.de/home/-/bereich/details.
Landesamt für Umwelt (2016). *Luftqualität in Brandenburg: 2016.* Land Brandenburg.
Landeshauptstadt Potsdam (2015). *Potsdam als Wissenschaftsstadt Bürgerumfrage 2015*.
Lantz, B. (2013). The large sample size fallacy. *Scandinavian Journal of Caring Sciences, 27*, 487–492. http://dx.doi.org/10.1111/j.1471-6712.2012.01052.x.
Mally, K. V. (2016). Perceptions of air quality in Ljubljana. *Dela, 46*, 77–88. http://dx.doi.org/10.4312/dela.46.3.67-88.
Mayer, H. (1999). Air pollution in cities. *Atmospheric Environment, 33*, 4029–4037.
McCullagh, P. (1980). Regression models for ordinal data. *Journal of the Royal Statistical Society: Series B, 42*, 109–142.
Melamed, M. L., Schmale, J., & von Schneidemesser, E. (2016). Sustainable policy – Key considerations for air quality and climate change. *Current Opinion in Environmental Sustainability, 23*, 85–91. http://dx.doi.org/10.1016/j.cosust.2016.12.003.
Minkos, A., Dauert, U., & Feigenspan, S. (2018). *Air quality 2017 preliminary evaluation*.
Mobil in Potsdam (2017). *Verkehrsversuch Zeppelinstraße [WWW document].* URL . (Accessed 28 August 2017) http://www.mobil-potsdam.de/de/nachhaltige-verkehrsentwicklung/verkehrsversuch-zeppelinstrasse/.
Nilsson, A., Hansla, A., Heiling, J. M., Bergstad, C. J., & Martinsson, J. (2016). Public acceptability towards environmental policy measures: Value-matching appeals. *Environmental Science & Policy, 61*, 176–184. http://dx.doi.org/10.1016/j.envsci.2016.04.013.
O'Brien, R. M. (2007). A caution regarding rules of thumb for variance inflation factors. *Quality & Quantity, 41*, 673–690. http://dx.doi.org/10.1007/s11135-006-9018-6.
Oltra, C., & Sala, R. (2016). Perception of risk from air pollution and reported behaviors: A cross-sectional survey study in four cities Christian Oltra & Roser Sala. *Journal of Risk Research,* 1366–9877. http://dx.doi.org/10.1080/13669877.2016.1264446.
Oltra, C., & Sala, R. (2014). *A review of the social research on public perception and engagement practices in urban air pollution*.
Rückerl, R., Schneider, A., Breitner, S., Cyrys, J., & Peters, A. (2011). Health effects of particulate air pollution: A review of epidemiological evidence. *Inhalation Toxicology, 23*, 555–592. http://dx.doi.org/10.3109/08958378.2011.593587.
Schmidt, A., Ivanova, A., & Schäfer, M. S. (2013). *Media attention for climate change around the world: A comparative analysis of newspaper coverage in 27 countries.* http://dx.doi.org/10.1016/j.gloenvcha.2013.07.020.
Schwartz, J. (2006). Air pollution: Why is public perception so different from reality? *Environmental Progress, 25*(4), 291–297. http://dx.doi.org/10.1002/ep.10160.
Sharpe, D. (2015). Your chi-square test is statistically significant: Now what? *Practical Assessment, Research and Evaluation, 20*, 1–10.
Simone, D., Eyles, J., Newbold, K. B., Kitchen, P., & Williams, A. (2012). Air quality in Hamilton: Who is concerned? Perceptions from three neighbourhoods. *Social Indicators Research, 108*, 239–255. http://dx.doi.org/10.1007/s11205-012-0064-2.
Smallbone, K. (2012). *Individuals ' interpretation of air quality information.* 1–56.
Stern, P. C., & Dietz, T. (1994). The value basis of environmental concern. *Journal of Social Issues, 50*, 65–84.
Valeri, E., Gatta, V., Teobaldelli, D., Polidori, P., Barratt, B., Kazepov, Y., et al. (2016). Modelling individual preferences for environmental policy drivers: Empirical evidence of Italian lifestyle changes using a latent class approach. *Environ. Sci. Policy, 65*, 65–74. http://dx.doi.org/10.1016/j.envsci.2016.05.019.
Whitehead, J. C. (1991). Environmental interest group behavior and self-selection bias in contingent valuation mail surveys. *Growth and Change, 22*, 1–87. http://dx.doi.org/10.1111/j.1468-2257.1991.tb00538.x.
World Health Organization (2006). *WHO air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: Global update 2005: Summary of risk assessment.* Geneva World Health Organization1–22. http://dx.doi.org/10.1016/0004-6981(88)90109-6.