Environmental Research Letters

LETTER • OPEN ACCESS

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To cite this article: Laura Weiand *et al* 2019 *Environ. Res. Lett.* **14** 085008

Environmental Research Letters

OPEN ACCESS

RECEIVED
31 March 2019

REVISED
7 June 2019

ACCEPTED FOR PUBLICATION
13 June 2019

PUBLISHED
31 July 2019

LETTER

Climate change and air pollution: the connection between traffic intervention policies and public acceptance in a local context

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Keywords: air quality, climate change, policy attitudes, travel behaviour, sustainable urban transport, cluster analysis, transdisciplinary

Supplementary material for this article is available online

Abstract

Urban mobility is the main source of air pollution in Europe and accounts for 25% of greenhouse gas emissions. In order to address this, a range of interventions and policies are being implemented across major European cities and studies in sustainable urban transport have proliferated. One such mitigation strategy involves redesigning urban form through 'hard' traffic policies, with a view of decreasing emission levels and therefore mitigating the effects of air pollution and climate change. However, efforts to assess public response to such interventions and the effectiveness of policy instruments in promoting sustainable travel in cities remain sparse. The city of Potsdam, Germany implemented a trial traffic measure aimed at reducing motorized traffic and promoting the use of bicycles and public transport systems. This study analysed data from 3553 survey participants who responded to a survey conducted prior to the implementation of the traffic measure. We aimed to identify mobility behaviours and underlying attitudes within the context of a 'hard' policy instrument, in order to obtain insight into the opportunities to more effectively define policy priorities that improve air quality and upscale climate mitigation. An exploratory cluster analysis identified four groups, characterised by mobility habits, their attitudes towards the measure, and general level of environmental concern. By identifying and understanding the differing attitudes and perceptions across population groups we are able to highlight group-specific barriers and opportunities, as well as potential transition pathways to encourage more sustainable transportation use. This study exemplifies how context can help to further shape mobility group typologies, identify policy-related priorities useful for decision-makers and assess the feasibility of policy instruments to facilitate a transformation towards more sustainable cities.

1. Introduction

In 2018, the road transport sector contributed 25% of the total carbon dioxide emissions in Europe (International Energy Agency 2018), and was the largest contributor to air pollutant emissions, such as total nitrogen oxides (NO_x), and a significant contributor to particulate matter (European Environment Agency 2018). Improving air quality by reducing emissions not only improves human health and the health of ecosystems and agriculture, but also mitigates climate change (Shindell *et al* 2012, Melamed *et al* 2016). In order to improve air quality, holistic solutions involving technological developments, structural changes and societal behaviour changes are needed to transform and decarbonise the transport sector, particularly in cities (European Environment Agency 2018).

While the solution lies heavily in redesigning urban form by making cities more compact and providing greater space for sustainable transport modes (Banister 2011, Hickman *et al* 2013, Creutzig *et al* 2016), understanding and transforming individual mobility behaviour is vital to the success of transport policies (Banister 2011, Mattauch *et al* 2015). Mattauch *et al* (2015) indicate that transport policy instruments fall into four general categories: (i) bans and direct regulations,

(ii) monetary incentives, (iii) education and information, and (iv) changes to the built environment. Implementing these policies, however, remains challenging and there is evidence that policy interventions utilizing only a single instrument are often ineffective at modifying mobility behaviour (Graham-Rowe *et al* 2011). Combining so-called 'hard' instruments (i.e. bans and regulations) with 'soft' interventions (i.e. education and communication) is recommended as an effective strategy when designing interventions (Gärling and Schuitema 2007). The most difficult question, though, seems to be when to implement such policies (Bemelmens-Videc *et al* 1998), and for whom? As such, identifying underlying mobility behaviours and attitudes of the target population is a crucial step in tailoring policies to more effectively influence the mobility patterns of different sub-groups.

Segmentation techniques have often been used to identify mobility groups based on travel behaviour, sociological constructs, and environmental perceptions (Anable 2005, Hunecke *et al* 2010, Prillwitz and Barr 2011, Kandt *et al* 2015, Nilsson *et al* 2016). Such analyses can be done at a variety of scales and are useful for discerning context-specific differences in mobility habits and preferences to enhance the effectiveness of transport policy and better guide its evaluation (Mattauch *et al* 2015). Although previous studies have built high-quality typologies based on mobility attitudes and behaviour, such studies are rarely tested in the context of a mobility *intervention policy* seeking to improve air quality and are therefore often limited in scope with regards to giving an estimation of how different groups would behave under such policy regimes. This study takes an explorative approach to analyse and identify patterns in reaction to policies by contextualising these typologies within an air quality related traffic-reducing measure. We thereby aim to contribute to the knowledge about sustainable transformation of the transport sector, the improvement of air quality, and the mitigation of climate change.

In the city of Potsdam, Germany, air pollution on one of the most heavily-trafficked streets, the Zeppelinstrasse, exceeded the European Union (EU) and World Health Organization limit-value of 40 μg m^{-3} for nitrogen dioxide (NO_2) concentrations for almost a decade. In June 2017, the city implemented a series of traffic-reducing measures to improve air quality and comply with EU law. These measures were designed to encourage more sustainable transportation use through greater uptake of active and public transport and involved a reduction in the number of lanes available for cars, the re-allocation of road space for a dedicated bike lane and increased frequency of public buses. For the purpose of this study they will hereafter be referred to as the 'Potsdam Air Quality (AQ) Measure'. Prior to and after the implementation of the Potsdam AQ measure, online surveys were conducted in the region. These were specifically designed to assess the attitude of respondents towards the measure specifically and similar types of measures more generally, and their general level of environmental concern, particularly in relation to air quality and climate change. This study aimed to identify and describe specific groups within the population based on the survey responses, to improve understanding of these groups, their mobility behaviours and underlying values. This can provide valuable insight useful for designing similar policies targeting behavioural change more effectively in the future. Moreover, because of the recent ruling in the German Federal Administrative Court in 2018 approving bans on diesel vehicles to improve air quality on heavily polluted streets (Bundesverwaltungsgericht 2018), 'hard' transport measures may become more common in German cities. Thus, this study also seeks to exemplify how scientific research can be coupled with urban transport policy to assist in evaluating the effectiveness of such measures in changing underlying mobility behaviours to improve air quality and mitigate climate change.

2. Methodology

In coordination with the Potsdam AQ measure, an online survey was conducted seeking to assess varying aspects of public perceptions regarding the traffic measure, mobility habits, and air quality and climate change. The questionnaire was developed in collaboration with the traffic development, city planning, and civic participation departments of the Potsdam city council and informed by previous survey research conducted by the Potsdam city council (Landeshauptstadt Potsdam 2015), the German Environment Ministry (Benthin *et al* 2016), and the European Commission (European Commission 2013), and other studies on environmental perceptions (Bickerstaff and Walker 2001, Brody *et al* 2004, BMVI 2010, Simone *et al* 2012, Oltra and Sala 2018, Valeri *et al* 2016). Further detail on study context and data collection methods can be found in Schmitz *et al* (2018).

2.1. Multiple correspondence analysis (MCA)

MCA is a commonly-used method in analysing survey data for reducing the high number of variables in a categorical dataset into more precise 'factors' or 'dimensions' for the purpose of exploratory data analysis (Benzécri 1973, Greenacre and Blassius 2006, Di Franco 2016). It can be likened to a principal component analysis for categorical data due to similarities in interpretation and purpose. In order to break down the categorical data from the survey into a smaller number of dimensions, an MCA was performed using the FactoMineR package (Husson *et al* 2010, Husson *et al* 2018), conducted in R Version 1.0.153. Owing to the voluntary nature of surveys, a common and challenging problem is the occurrence of missing responses in the questionnaire data. Due to the large size of the dataset (~3500 observations of

100 + items), and the occurrence of cells with missing values (5.6% of the cells in the observation by variable matrix produced by this questionnaire), the missMDA package was used to impute missing values (Josse and Husson 2016). This allowed for a complete dataset to be passed on for analysis using the MCA. Categories with low counts were then 'ventilated' by randomly distributing individual responses across the other categories of a particular variable (Di Franco 2016), while retaining the proportions associated with each variable (Husson *et al* 2010).

A crucial component of MCA is the initial designation of variables as 'active' or 'supplementary' when creating the dimensions. 'Active' variables and their categories contribute directly to the formation of the dimensions. 'Supplementary' variables and categories do not exert an influence on dimension construction, however, they can still be useful to analysis as they will appear on the factorial axes in relation to the dimensions (Di Franco 2016). As this analysis sought to assess mobility behaviours of survey respondents, only those variables directly related to mobility behaviours were designated as 'active'. These included (1) car and bike ownership; (2) perceived access with, frequency of use of, and perceived future use of four modes of transport (car, bike, public transit, and walking); (3) frequency of use of the Zeppelinstrasse for private and work transport with those same four modes; (4) commute distance (km) to place of work or study; and (5) which routes belong to their daily routines (to work, to school/university, etc). All other variables were classified as 'supplementary' and were used for further analysis and characterisation of each dimension.

2.2. Agglomerative hierarchical clustering

Following completion of the MCA, the FactoMineR package was used to complete a cluster analysis on the MCA object using the *HCPC* function. This function uses an agglomerative hierarchical clustering method with Ward's algorithm to group respondents using the dimensions identified from the MCA analysis (Husson *et al* 2010). Further details on the incorporation of this method into the HCPC function in R can be found in Husson *et al* (2010). Once created, the relationships between each cluster and variable categories, MCA dimensions, and individuals were scrutinized to determine the defining characteristics of each cluster. These were then represented graphically in a Euclidean space with the top two-dimensions on the x and y axes.

3. Results

3.1. Cluster variables

Four groups were derived from the hierarchical cluster analysis: cluster 1 '*unconcerned car-dependent policy-rejecters*'; cluster 2 '*multimodal policy-sceptics*'; cluster 3 '*green-travel policy-optimists*', and cluster 4 '*bike-dedicated policy-enthusiasts*'. The hierarchical clustering performed on the MCA found the following variables to have the largest influence on the characterisation of the clusters: (i) support for investments in traffic-reducing measures and the Potsdam AQ measure, (ii) the objectives and diverse effects of the Potsdam AQ measure, and (iii) the importance of the environment when making mobility decisions. As presented in tables 1 and 2, the cluster results are described according to their within-cluster membership i.e. the percentage of respondents within a cluster that selected the respective category (Mod.Cla) and by their across-cluster membership i.e. the percentage of respondents belonging to a cluster that selected the respective category (Cla.Mod). Only statistically significant categories were included in tables 1 and 2. Sociodemographic characteristics are presented in table 3, grouped according to their cluster assignment. Corresponding question codes and categories are presented in the supplementary information, available online at stacks.iop.org/ERL/14/085008/mmedia.

3.2. Within-cluster characteristics

3.2.1. Cluster 1-unconcerned car-dependent policy-rejecters

Cluster 1 is characterised by high car use and strong rejection of the Potsdam AQ measure (table 1). This group had the highest proportion of members across the four clusters, with 46% of all respondents assigned to this cluster. This group was characterised by frequent and largely exclusive car usage relative to other mobility options. 95% travelled by car on a daily basis and 81% commute daily by car on the Zeppelinstrasse, while bicycles are used less than once a month or never by 40%, and public transit by 77%. While bicycles and public transit are used less than once a month or never by 40% and 77%, respectively. More than half answered that they have no future intentions to cycle or increase public transport usage (71% and 62%, respectively).

The majority of this group opposed the Potsdam AQ measure, with 98% indicating that they did not support the Potsdam AQ measure (table 2). This group also had the highest share of individuals that believe reducing traffic in polluted cities would not be an effective measure to improve air quality (94%) and that the measure would worsen their own mobility 'a lot' (88%). They also displayed a relatively low concern for air quality and climate change, with 24% and 8% indicating they were 'unconcerned' about these issues. Furthermore, 49% of participants in this group believed they would not be affected by climate change, and 53% stated that air pollution is not a major health threat.

3.2.2. Cluster 2—multimodal policy-sceptics

Cluster 2 was the second largest cluster (35% of total respondents) and displayed the greatest mixed use of mobility options of identified clusters (table 1). The

Table 1. Shows the within-cluster distribution of active mobility variables (car, bike and public transit use). A v.test value greater than 1.96 corresponds to a p-value less than 0.05; the sign of the v.test indicates if the mean of the cluster is under or over-expressed for the category. Only items with a p-value less than 5% are included as this shows that one category is significantly linked to the other categories.

		C1–unconcerned car-oriented policy-rejecters		C2-multimodal policy-skeptics		C3-green-travel policy-optimists		C4-dedicated-cyclists and policy-enthusiasts	
Variable	Category	Mod. Cla (%)	v.test	Mod. Cla (%)	v.test	Mod. Cla (%)	v.test	Mod. Cla (%)	v.test
Car use	Daily	95	33 543	61	−6229	25	−18 941	2	−24 263
	1–3 d/week	3	−24 643	33	13 141	55	16 442	13	−3080
	1–3 d/month	1	−12 340			15	7887	17	7701
	Less than monthly	0	−7382	1	−5243			20	14 222
	Never	1	−10 436	0	−9871			47	23 392
Bike use	Daily	4	−26 726	28	4172	54	13,904	77	19 304
	1–3 d/week	29	−2944	41	8718	25	−3118	14	−7003
	1–3 d/month	26	8229			10	−5507	4	−8085
	Less than monthly	20	12 758	8	−6722	4	−6004	2	−6628
	Never	20	14 266	4	−10 680	7	−3671	4	−4807
Public transit use	Daily	6	−16 836	16	−2089	56	18 752	37	7741
	1–3 d/week	4	−14 493	15	4701	22	6232	29	7984
	1–3 d/month	13	−11 065	33	12 338	13	−4424	28	2814
	Less than monthly	30	8804	12	−15 411	3	−11 592	5	−8430
	Never	47	26 211			6	−11 332	2	−11 522

respondents in this group showed some support for the Potsdam AQ measure, but were mostly undecided. Their mobility tendencies are diverse; on 1–3 d a week, 33% use a car, 41% use a bike and 15% use public transit, while 28% stated daily bike use. Access to bicycles and public transit were mostly 'good' while car access was 'moderate', although two-thirds of the cluster members owned a car (67%), suggesting car use for convenience.

This group had the second highest proportion of individuals that rejected the measure (88%) (table 2). As was the case with cluster 1, 65% of this group perceived that the Potsdam AQ measure would worsen their own mobility. Along with this group's tendency to use environmentally friendly modes of mobility more often, they show a moderate concern for climate change (20%). The importance of the environment when making mobility decisions was only moderate, as 39% selected category 3 (where 1 = absolutely important − 6 = not important at all). However, 64% of this group supported a 'high priority' for the allocation of public funds for environmental protection.

3.2.3. Cluster 3—green-travel policy-optimists

Cluster 3 was composed predominantly of daily bike and public transit users that showed high acceptability for the Potsdam AQ measure and a high level of concern for air quality and climate change. This group represented only 11% of all respondents, considerably smaller than clusters 1 and 2. Just over half of this group (54%) cycle daily and 56% use public transit daily, while 22% use it 1–3 d a week. Over half (55%) of the cluster members also stated a car use of 1–3 d a week and the majority owned a car (81%).

Compared to the clusters 1 and 2, this group had relatively higher level of support for the Potsdam AQ measure (18%). Similarly, more than half of the cluster members were supportive or highly supportive of investments in traffic-reducing measures (29% and 37%, respectively). This cluster showed a high concern for air quality and climate change, however, the share of participants who selected category 6 (*very concerned)* was larger for climate change than air quality (29% and 11%, respectively). This was further reflected in the moderate importance of the environment when making mobility-related decisions, as 66% selected categories 1 or 2 (where 1 = *absolutely important* − 6 = *not important at all*).

3.2.4. Cluster 4—bike-dedicated policy-enthusiasts

Cluster 4 was characterised by dedicated bicycle users who have a high acceptability for the Potsdam AQ measure, as well as a high level of concern for air quality and climate change. This group included only 8% of total participants, and was therefore the smallest group. Bike usage was high, 77% of this group cycle on a daily basis, while 37% use public transit daily and 29% use it 1–3 d a week (table 1). 67% of the individuals in this cluster stated that they never use a car or use it less than once a month, which is reflected in the high share of individuals that do not own a car (71%). Their willingness to use alternative forms of

Table 2. Shows the within-cluster (Mod.Cla) and across-cluster (Cla.Mod) distributions of active environmental and measure-related variables. A v.test value greater than 1.96 corresponds to a p-value less than 0.05; the sign of the v.test indicates if the mean of the cluster is under or over-expressed for the category. Only items with a p-value less than 5% are included as this shows that one category is significantly linked to the other categories.

		C1			C2			C3			C4		
Variable	Category	Cla. Mod (%)	Mod.Cla (%)	v.test	Cla. Mod (%)	Mod.Cla (%)	v.test	Cla. Mod (%)	Mod.Cla (%)	v.test	Cla. Mod (%)	Mod.Cla (%)	v.test
Effect of Potsdam AQ measure on mobility													
	Improve a lot	2	0	−10 262	15	1	−4532				68	26	15 745
	Improve	3	0	−10 696	18	2	−4125	23	7	3512	57	24	14 080
	No change	9	2	−14 248				22	16	5569	29	31	11 455
	Worsen	29	10	−8527	52	23	8665	15	20	2780	4	8	−3778
	Worsen a lot	58	88	22 223	32	65	−4896	9	54	−7581	1	12	−21 077
Effect of Potsdam AQ measure on life quality													
	Improve a lot	4	0	−10 842	18	2	−4212	21	7	3251	57	27	14 847
	Improve	11	2	−12 733							43	43	17 221
	No change										5	9	−3064
	Worsen				41	34	5028				4	13	−6144
	Worsen a lot	56	55	11 026	32	41	−3444				1	8	−1385
Support for Potsdam AQ measure													
	Yes, I support it	4	1	−19 045	24	7	−4808	20	18	5201	52	70	25 374
	No, I do not support it	52	98	20 964	36	88	2205	10	75	−6154	2	22	−25 498
	I am Undecided	12	1	−8216	50	5	3514	20	6	2880	18	8	3724
Investments in traffic-reducing measures													
	I strongly support it	13	6	−20 452				21	37	8591	32	82	23 217
	I support it	36	19	−6911	47	33	8625	13	29	2027	4	11	−5597
	I do not support it	58	29	7671				7	15	−4470	1	3	−9368
	I do not support it at all	70	42	17 275	24	19	−8274	6	14	−6623	0	1	−12 307
	I am Undecided				42	6	2030				3	2	−2357
Traffic reducing measures improve air quality													
	Yes	14	6	−19 681				19	32	6571	32	80	22 757
	No	54	94	19 681				10	68	−6571	2	20	−22 757
Consideration of environment in mobility decisions													
	1 = absolutely important	25	6	−9306	22	7	−5772	17	18	3799	35	53	17 808
	2	36	18	−6608				17	33	4979	11	31	3257
	3	51	39	4036	38	39	2778	9	29	−3031	2	11	−9729
	4	52	15	2749	39	15	1994	8	9	−2807	1	3	−6432
	5	58	9	3741				7	5	−2059	2	1	−4219
	6 = not important at all	63	10	5878	28	6	−2438				1	1	−5393

Table 2. (Continued.)

Variable	Category	C1 Cla. Mod (%)	C1 Mod.Cla (%)	C1 v.test	C2 Cla. Mod (%)	C2 Mod.Cla (%)	C2 v.test	C3 Cla. Mod (%)	C3 Mod.Cla (%)	C3 v.test	C4 Cla. Mod (%)	C4 Mod.Cla (%)	C4 v.test
Aim of Potsdam AQ measure to improve mobility alternatives													
	Very high priority	17	2	−8167	27	4	−2252				40	26	12 256
	High priority	27	6	−8226				17	16	3365	24	34	10 774
	low priority	38	18	−5245	40	25	3629				10	27	2175
	Very low priority	55	74	13 242				10	54	−3840	2	13	−17 410
Air quality concern													
	1 = unconcerned	62	24	8781	28	14	−4298	9	14	−2154	2	4	−7293
	2	52	28	4312				8	17	−3823	3	8	−7090
	3				39	30	2854	9	22	−2458	5	17	−4193
	4	33	10	−6560	39	16	2201	14	18	1991	14	26	5302
	5	23	4	−8845				20	16	4831	24	27	9424
	6 = very concerned	18	2	−7377	27	3	−2205	28	11	5848	27	16	7420
Air quality (aq) rating													
	1 = aq is very good										3	2	−2606
	2										4	17	−5860
	3				37	40	2081	10	33	−2156			
	4	41	10	−1986							14	21	4928
	5	30	3	−4437				22	9	3890	20	12	5160
	6 = aq is very bad							25	4	3116			
Climate change concern													
	1 = unconcerned	60	8	4366	27	5	−2381				4	3	−2105
	2	53	13	2911							2	4	−4742
	3	57	31	7672	31	22	−2680	9	20	−2407	2	8	−7490
	4				39	22	2762	9	16	−2280	5	12	−3376
	5	36	15	−5630	40	22	3018				11	27	3230
	6 = very concerned	29	11	−9255				19	29	5831	20	46	11 340
Affected by climate change													
	Yes	35	30	−10 204	37	42	2181	15	53	5668	12	63	8115
	No	55	49	8742	33	39	−2049	8	30	−4675	4	20	−7461

Table 2. (Continued.)

Variable	Category	C1 Cla. Mod (%)	C1 Mod.Cla (%)	C1 v.test	C2 Cla. Mod (%)	C2 Mod.Cla (%)	C2 v.test	C3 Cla. Mod (%)	C3 Mod.Cla (%)	C3 v.test	C4 Cla. Mod (%)	C4 Mod.Cla (%)	C4 v.test
Air pollution effect on health													
	Yes	38	47	−10 600				14	68	4968	12	90	12 350
	No	56	53	10 600				8	32	−4968	2	10	−12 350
Allocation of funds to environmental protection													
	Very high priority	30	11	−8738	28	14	−3807	18	28	5522	23	53	13 855
	High priority				38	64	4129	10	52	−2982	6	43	−5584
	low priority	55	15	3920				8	9	−2369	2	3	−5845
	Very low priority	61	3	2492							1	0	−2123
Intention to increase bicycle use													
	Yes	10	6	−28 063	47	36	9097	21	49	10 033	23	80	18 869
	No	71	77	30 046	20	28	−18 886	8	34	−6876	2	10	−14 295
Intention to increase public transit use													
	Yes	10	4	−20 801				28	42	12 761	27	61	16 970
	No	62	82	24 878	28	48	−10 346	7	37	−9817	2	17	−15 099

Table 3. Socio-demographic differences between clusters.

Variable	Category	C1 %	C2 %	C3 %	C4 %	Variable	Category	C1 %	C2 %	C3 %	C4 %
Gender	Male	50	59	50	60	Kids at home	0	57	57	63	66
	Female	50	41	50	40		1	24	22	18	16
Age	18–34 years	27	32	40	47		2	16	17	14	14
	35–54 years	56	51	39	47		3	3	4	5	4
	>55 years	17	17	21	6	Household size	1 person	11	14	12	23
Residence	Not Zeppelinstraße	12	23	64	47		2 people	42	41	47	33
	Zeppelinstraße	88	77	36	53		3 people	25	21	22	18
Region	Potsdam region	43	71	86	90		4 people	17	19	14	18
	Surrounding regions	57	29	14	10		5 people	4	4	6	5
Education	Vocational training	40	27	23	17		6 people	1	1	1	3
	High school	8	8	10	10	Income	< 10.000 EUR	2	2	7	11
	Secondary school	1	1	1	0		10–19.999 EUR	8	7	14	11
	Middle school	7	3	3	2		20–29.999 EUR	13	12	18	14
	Other	4	4	3	3		30–39.999 EUR	23	25	26	19
	University (Bachelor)	12	13	22	16		40–49.999 EUR	11	12	9	11
	University (Master)	27	44	38	53		50–59.999 EUR	8	10	9	10
Occupation	Student	3	5	14	17		60–69.999 EUR	5	8	5	6
	Pensioner	2	4	15	1		>70.000 EUR	29	24	12	17
	Other	3	4	4	4						
	Part-time employee	9	11	12	23						
	Full-time employee	82	76	55	56						

transport was moderate to high, such as carpooling, car sharing, public transit and bicycling (21%, 26%, 61%, and 80%, respectively).

Compared to the other clusters, this group had the highest proportion of respondents who showed support for the Potsdam AQ measure (70%). They also showed the greatest support for investments in measures that would reduce car traffic (82%). As with cluster 3, this cluster showed a high concern for air quality and climate change. The share of participants who selected category 6 (*very concerned)* was larger for climate change than air quality (46% and 16%, respectively). It also included the highest proportion of individuals who stated that the environment is 'absolutely important' when making mobility decisions (53%), which was reflected in the high share of individuals (90%) in this cluster that perceived air pollution as a major threat to human health.

3.3. Across-cluster characteristics

The clusters were found to be heterogeneous and generally showed a progressive increase from clusters 1 through 4 with regards to their concern for the environment, their positive attitude towards the Potsdam AQ measure and their level of environmentally-friendly mobility use. Across all four groups, cluster 1 exhibited the greatest rejection of the policy (52% of those that did not support the measure belong to cluster 1), followed by cluster 2 (32%). Furthermore, cluster 2 had the largest share of 'undecided' individuals (50%). Cluster 4 showed the highest support for the Potsdam AQ measure (52%). Regarding their belief that the Potsdam AQ measure would improve their life quality, the across-cluster membership shows the same progressive increase from clusters 1 through 4 (4%, 18%, 21% and 57%). Contrary to clusters 1 and 2, cluster 3 had a high share (23%) of respondents that believed the Potsdam AQ measure would 'improve' their own mobility, or would have 'no effect' at all (22%). Cluster 2 showed the highest across-cluster membership that perceived they were indeed affected by climate change (37%), however, cluster 4 was the most overrepresented for that category, despite the lower proportion (11%). It should be noted that this is likely due to cluster 4 having lower respondent counts. When asked about the importance for the environment when making mobility decisions, 63% of the respondents that stated the environment '*is not important at all*' belonged to cluster 1.

3.4. Socio-demographic characteristics

The four identified clusters were relatively homogenous across socio-demographic items including *gender, education, income,* and *household size* (table 3). The hierarchical clustering found *residency, vocation, education,* and *age* to be the sociodemographic variables that provided the best characterisation of the groups. The proportion of youngest age group increases from cluster 1 through to cluster 4. The more environmentally-conscious groups (cluster 3 and 4) had a greater proportion of younger respondents, which was reflected in the high proportion of university students. The majority of the respondents in the last two clusters lived in Potsdam (>80%), and a large share lived on the Zeppelinstraße (36% for cluster 3 and 53% for cluster 4). Although the majority of individuals in cluster 1 live outside of Potsdam, of the participants that do live in Potsdam, 88% live near the Zeppelinstraße. More than half of the participants in each cluster had no children and only two people living in the household. Clusters 1 and 2 included the largest proportion of participants residing outside of the city of Potsdam (57% and 29%, respectively) and of those living in Potsdam, only 12% of cluster 1 were residents of the Zeppelinstraße or lived within a two-street radius. Furthermore, cluster 1 also made up the largest share of full-time employees (82%) and participants with an education in vocational training.

4. Discussion

Our study identified four clusters with distinct characteristics regarding mobility behaviour as well as attitudes towards the Potsdam AQ measure, air pollution, and climate change. Perceptions of the measure and current mobility habits are important discriminators between the clusters and can also act as a barrier for the uptake of environmentally friendly travel, especially for groups sceptical of such measures. The analysis reveals a complexity behind implementing measures intended to induce a mobility switch. Overall, the results suggest that socio-demographic information and mobility behaviour profiles alone are insufficient to design policies targeting persistent car use, but rather that attitudes towards policies of the affected communities are a major aspect of attempting to develop and upscale effective interventions. While Anable (2005) suggested potential interventions to influence modal split based on psychographic groups and Kandt *et al* (2015) summarized policy options based on mobility attitudes and behaviour, in this paper we exemplify how local context can further shape population-based typologies and the implications it has for the feasibility of potential transition pathways towards a more sustainable society. This paper summarizes the current perceptions and behaviours for each cluster, based on the survey results, as well as potential transition pathways that could be considered when designing future interventions, formed on deductions from the statistical segmentation results (for detailed information, see supplementary information table S1).

As daily car drivers are the most disadvantaged by the Potsdam AQ measure in this study, *car-oriented policy-rejecters* had the most negative perception of the measure, a perception that is anchored in their distrust regarding the effectiveness of the measure and a general lack of concern for improving air quality. This group is characterised by a negative perception of alternative transport modes and an unwillingness to change their regular mode of transport. This is likely related to residing in locations outside of core urban areas that lack reasonable access to public transport, where switching to alternative transport methods would significantly reduce convenience and lengthen the perceived commute time. As seen in previous segmentation analyses (Steg 2005, Kandt *et al* 2015), these habits are likely to have been formed over a longer period as this cluster has the lowest share of young participants attributed to it. Car use is perceived as highly convenient and regarded as a daily necessity; inhibiting car use consequently reduces their perceived quality of life and increases hostility toward such policies. It is therefore unlikely that car usage will be reduced solely based on measures that encourage reductions in car use such as road infrastructure changes. Instead, mitigation efforts should be responsive to this group's motivation and constraints by improving accessibility to local alternative mobility services convenient for commuters, and reducing hostility towards policies by coupling them with contextualised 'soft' policies (table S1). In addition, a technological solution would be to motivate this group to switch from fossil-fuel cars to alternatives fuelled vehicles.

Car-oriented policy-rejecters and *multimodal policy sceptics* both exhibit similar behaviour patterns. However, their perceptions towards the Potsdam AQ measure and environmental concern differ, as does their willingness to switch mobility. This group's mixed mobility tendencies, moderate environmental concerns and uncertainty about the effectiveness of the measure makes them interesting for mobility management strategies as the characteristics provide favourable grounds for policy implementation. Given the pragmatic approach to mobility use in this group, similar to types found by Kandt *et al* (2015), alternative options should be highlighted with a focus on convenience and feasibility motives. However, even if environmental concerns are present, they do not bring about enough self-motivation for favourable behaviour change (Anable 2005) and scepticism towards policies further inhibit responsiveness. Due to *multimodal policy-sceptics*' high propensity for car use and large share of members, this group shows significant potential to positively influence air quality if sustainable forms of transport are effectively encouraged.

Bike-dedicated policy-enthusiasts perceive the measure's improvement of bicycling infrastructure the most positively, which is reflected in their high acceptability of the measure. While this group shares similar sustainable mobility behaviours with the *green-travel policy optimists*, their attitudes towards the measure and their environmental obligations differ. This implies that although groups show the same environmentally-friendly mobility behaviour and intentions, these do not necessarily create high acceptance of the measure, but rather shows the complexity behind implementing air quality and climate policies. Given the *green-travel policy-optimists* high concern for the environment and its relatively high importance when making mobility decisions, this group expresses a high moral obligation and therefore high responsiveness to more sustainable travel. For *bike-dedicated policy-enthusiasts*, policy design should thus focus on further enhancing and supporting bicycle infrastructure to improve safety and connectivity.

Measures may be more successful coupled with informing and educating the affected population about the policy objectives to avoid counterproductive responses (Anable 2005). It should be noted that there is no strong evidence for the effectiveness of value-matching arguments to induce acceptability, but rather that biospheric value-oriented groups have a higher acceptability of suggested instruments (Nilsson *et al* 2016), as seen in clusters 3 and 4. Moving away from strategies comparable to the deficit-model, 'soft' policy communications should rather incorporate contextual models, tailored to group specific social climates (Gross 1994, Miller 2001). Considering the *car-oriented policy-rejecters* lack of environmental and health concerns related to driving, acceptability will likely not increase if ecocentric arguments are used to encourage a switch in mobility. It would be appropriate to decouple such arguments from environmental values and health, and reframe the policy objectives with regards to economic advantages and congestion relief (Tapp *et al* 2016).

5. Conclusions

It is crucial to explore how to link social perspectives and transition pathways towards sustainable cities. This exploratory cluster analysis exemplifies how implementation contexts can further shape mobility typologies and the implications they have for the feasibility of policy instruments and the resulting opportunities for group-specific policy options. It is clear that perceptions of policy measures are an important discriminator between mobility groups and that these can leverage or be a barrier for the transition to environmentally friendly mobility options that such policies aim to promote. The complexity of characteristics and attitudes of these groups reveal the need for policies to be responsive to the different motivations and constraints of the groups to react to 'hard' infrastructure changes in terms of both mobility behaviour and public perceptions, possibly differentiated according to comparable segments identified in this study. German and European cities that continue to exceed air quality limit-values will likely need to implement similarly disputed measures in the near future. Coupling cluster analyses outcomes with urban transport policy can more effectively define policy priorities and help identify the most feasible transition pathways for different sub-groups. Consequently, further research should assess potential transition pathways tailored to the social environment to contribute to the success of climate and air quality policies.

Acknowledgments

This work has been supported by the Institute for Advanced Sustainability Studies (IASS) e.V., Potsdam. The authors would like to thank Landeshauptstadt Potsdam, for their collaboration in co-designing this research, including the departments of Public Participation 'WerkStadt', Traffic Development, and Press and Communication. 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.

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