Effect of public transport strikes on air pollution levels in Barcelona (Spain)

Xavier Basagaña [a,b,c], Margarita Triguero-Mas [a,b,c], David Agis [a,b,c], Noemí Pérez [d], Cristina Reche [d], Andrés Alastuey [d], Xavier Querol [d]

[a] ISGlobal, Centre for Research in Environmental Epidemiology (CREAL). C/ Doctor Aiguader 88, 08003 Barcelona, Spain
[b] Universitat Pompeu Fabra (UPF), C/ Doctor Aiguader 88, 08003 Barcelona, Spain
[c] CIBER Epidemiología y Salud Pública (CIBERESP), C/ Doctor Aiguader 88, 08003 Barcelona, Spain
[d] Institute of Environmental Assessment and Water Research (IDÆA-CSIC), C/Jordi Girona 18-26, 08034 Barcelona, Spain

** Correspondence to: X Basagaña. ISGlobal, C/ Doctor Aiguader 88, 08003 Barcelona, Spain. Telephone: (+34) 932147306. E-mail: xavier.basagana@isglobal.org*

Abstract

Public transport strikes can lead to an increase of the number of private vehicle trips, which in turn can increase air pollution levels. We aimed to estimate the change in air pollution concentrations during public transport strikes in the city of Barcelona (Spain). Data on strikes of the metro, train or bus systems were collected from government records (2005-2016). We collected daily concentrations of NOx; particulate matter with an aerodynamic diameter smaller than 10 μm (PM10), 2.5 μm (PM2.5), and 1 μm (PM1); particle number concentration (N); black carbon (BC) and CO from research and official monitoring stations. We fitted linear regression models for each pollutant with the strike indicator as an independent variable, and models were adjusted for day of the week, month, year, and holiday periods.– During the study period, there were 208 days affected by a strike of the metro (28), train (106) or bus (91) systems. Half of the strikes were partial, most of them were single-day strikes, there was little overlap between strikes of the different transport systems, and all strikes had to comply with mandatory minimal services. When pooling all types of strikes, NOx and BC showed higher levels during strike days in comparison with non-strike days (increase between 4.1% and 7.7%, with higher increases for NO). The increases in these concentrations were more evident during full day and multiday metro strikes. In conclusion, alterations in public transport have consequences on air quality. This highlights the importance of public transport in reducing air pollution concentrations in cities.

Keywords: air pollution; public transport; strike; black carbon; particulate matter; NO2

1. Introduction

Traffic-related air pollution is a problem in most urban areas around the world, producing important health effects on the exposed population (Brunekreef and Holgate 2002; Lim et al. 2012). All strategies to reduce air pollution levels highlight improving and promoting the public transport system as one of the key aspects, as it can lead to a reduction in the number of trips made by private vehicles and, consequently, to a reduction of emissions. During public transport strikes, the opposite situation happens, i.e. public transport services are canceled or their frequencies drastically reduced. This can lead to an increase of the number of private vehicle trips, which in turn can increase air pollution levels.

Some studies have examined the effect of public transport strikes on traffic (an intermediate marker of increased emissions) or air pollution levels. Most of the existing studies focused on single strikes or on a reduced number of strikes, some of them of long duration (up to 35 days) (Addler and van Ommeren 2016; Anderson 2014; Tsapakis et al. 2012; Van Exel and Rietveld 2001; Meinardi et al. 2008; Chaloulakou et al. 2005; Pereira et al. 2014; da Silva et al. 2012; Fuller et al. 2012). In general, the effects of public transport strikes reported in those studies were: i) increase in travel times, ranging from 3% to 74% (Addler and van Ommeren 2016; Anderson 2014; Tsapakis et al. 2012; Van Exel and Rietveld 2001); ii) increases in traffic volume ranging from 3% to 20% (Meinardi et al. 2008; Van Exel and Rietveld 2001); iii) changes in air pollution levels, going from a 41% reduction in a strike that also included diesel-powered taxis (Chaloulakou et al. 2005) to an increase of up to doubling the concentrations (Pereira et al. 2014; da Silva et al. 2012); and iv) increases in travels by bicycle (Fuller et al. 2012, Van Exel and Rietveld 2001). The study that analyzed the largest number of strikes was conducted in the five largest cities in Germany, and included 71 one-day strikes (Bauernschuster et al. 2017). This study quantified that strikes led to increases in traffic volume of 13%; a 14% increase in vehicle crashes; a 20% increase in accident-related injuries; increases in pollution levels (14% increase for PM_{10} and 4% increase for NO_2); and an 11% increase in hospital admissions for respiratory causes in children.

In this paper, we analyzed the effect of a large number of public transport strikes on air pollution levels in the city of Barcelona (Spain).

2. Material and methods

Barcelona is a city of 102.16 km^2 and 1,604,555 inhabitants in 2015. The Barcelona metropolitan area includes 35 adjacent cities with 3,239,337 inhabitants within an area of 636 km^2. The main public transport systems in the city of Barcelona are the subway system (metro), which currently includes 8 lines and 156 stations; the bus system, with about 100 lines; and the train system. While the subway and bus systems only cover the city of Barcelona and a few other adjacent cities, the train system connects Barcelona with other parts of Catalonia, Spain and other countries.

A total of 73% of daily trips are internal (from and to the same city). Of those, 56% are done walking or by bicycle, 29.6% by public transportation and 14.4% by private vehicle. Among the 27% of trips connecting two cities, 2.9% are done walking or by bicycle, 50% are done by public transportation and 47.1% are done with private vehicle (Barcelona mobility data, 2015 report, retrieved from http://mobilitat.ajuntament.barcelona.cat/ , accessed October 28th, 2016).

Data on public transport strikes was retrieved from the Official Gazette of the Autonomous Government of Catalonia (Diari Oficial de la Generalitat de Catalunya, DOGC), where Catalan laws and resolutions are published. Since public transport is an essential service, the government publishes in the DOGC mandatory minimal services that need to be followed during the strike. We used the advanced search of the DOGC website to retrieve public strike dates and additional details on the strike (http://dogc.gencat.cat/ca/pdogc_canals_interns/pdogc_cercador_de_normativa/?destParam=cercaAdv).

In particular, we searched for documents containing the words "garanteix el servei essencial de transport" (guarantees the essential transport service) in the title, as all public transport strike documents contained those words. The search was conducted on June 22nd 2016, and only strikes that occurred during the period January 2005-June 2016 and affecting the city of Barcelona were included. From the files, we extracted information on the date and time of the strike, the type of transport affected, and the minimal services during the strike. Transport strikes that occurred during a general strike were not considered.

Ambient air levels were derived from automatic monitoring stations located in the city of Barcelona. Data availability differed by pollutant and station (Supplementary Tables 1 and 2). Only NO and NO_2 had enough completeness and overlap between stations for the entire period to compute city-wide averages. Thus, only for NO and NO_2, we computed city averages by averaging the concentrations of five stations (urban background: Poblenou, Ciutadella and Sants; traffic: Gràcia and Eixample). For particulate matter with an aerodynamic diameter smaller than 10 µm (PM_{10}), 2.5 µm ($PM_{2.5}$) and 1 µm (PM_1), as well as particle number (>5nm) concentration (N) and black carbon (BC), the main analyses were conducted using the concentrations from a single research urban background super-site (Palau Reial, IDAEA-CSIC), which had the maximum data completeness. Specifically, in this station, data were available for the entire period for all PM fractions, and N and BC were available for 2009-2016. We conducted secondary analyses using the available data from other stations on PM_{10}, $PM_{2.5}$ and CO (the same stations mentioned above plus another traffic station, Plaça Universitat).

Missing values on air pollution data were imputed using the method of chained equations using all pollutants from all monitoring stations as predictors (White et al. 2011). To assess the relationship between daily air pollution levels and strike occurrence, we fitted separate linear regression models for each air pollutant and included the strike indicator as an explanatory variable. Models were additionally adjusted for day of the week, month, year, and two variables indicating whether the present day or the previous day belonged to a holiday period. The final results of the models were obtained combining the results of 10 multiply imputed datasets using Rubin's rules (White et al. 2011).

2.1. Sensitivity analyses

We conducted a number of sensitivity analyses to assess if the conclusions changed when taking into account additional variables or when alternative modeling strategies were considered.

2.1.1. Additional Air pollution metrics

In order to have markers of air pollution that are less influenced by background concentrations, we derived urban increment variations using a regional background reference station located in Montseny Natural Park. This park is at 25 km from the Mediterranean coast and at 40 km from the Barcelona urban area. The station is located in a densely forested area, relatively far from urban and industrial zones, specifically at 41º 46’ North 2º 21’ East. The urban increment could not be calculated for N as the regional station had counts of particles >10nm while those available for the city were counts of particles >5nm. Moreover, we also repeated the analyses using maximum 1h concentrations instead of 24h averages, as the effects of strikes on air pollution levels could potentially be more noticeable with the maximum 1h metric.

2.1.2. Strike characteristics

Our main analyses used data from partial, full-day, single and multiday strikes. To evaluate the effect of different types of strikes, we repeated the aforementioned analyses by strike characteristic.

2.1.3. Restricting the time period

Our main analyses used observations from 2005 until 2016 whenever information was available. This resulted in having different analysis periods for different pollutants (e.g. N and BC were not available before 2009). To evaluate the effect of using different time periods on our findings, we carried out a sensitivity analysis including only the time period 2009-2016 for all pollutants.

2.1.4. Type of statistical model

Our main analyses used linear regression models. To explore the robustness of our findings to other modeling techniques, we repeated the aforementioned analyses using time series models and additionally controlled for the effect of meteorological variables. In particular, to account for temporal and seasonal trends, we included a natural spline of time with 4 degrees of freedom per year. The number of degrees of freedom was chosen because it was the one that minimized the absolute value of the partial autocorrelation function (Peng et al. 2006). Models included the lagged dependent variable as a predictor, as air pollution levels depend on previous day levels. The inclusion of the lagged dependent variable corrected the remaining autocorrelation of the residuals (Beck and Katz 2011). These models were additionally adjusted for day of the week; two variables indicating whether the present day or the previous day belonged to a holiday period; two variables indicating whether the present day or the previous day had any precipitation; the average wind speed in the present day and in the previous day; the average temperature in the current day and in the two previous days; and an indicator of African dust intrusions.

3. Results

During the study period, covering 11.5 years, there were 208 days affected by a strike of the metro, train or bus systems. The train system registered the highest number of strike days, with 106, followed by the bus system, with 91 days, and the metro system, with 28 (Table 1). Half of the strikes were partial, in the sense that they only affected the service during some hours as opposed to the entire day. For the train strikes, 66% were full day strikes, but for the metro and bus system full day strikes only represented around 40% of all strikes. Figure 1 illustrates the case of the 28 days with metro strikes. Almost all strikes affected the rush hour periods, and there were very few periods with no service at all. There was very little overlap in the strikes of the different transport systems. Only 12 days had more than one service on strike, and only in 5 days all transport systems had a strike simultaneously (Supplementary Table 3). Most strikes were single day strikes and 92% occurred during weekdays (Table 1). A lower percentage of strikes was observed in the first months of the year and in summer, compared to the rest of the year. In terms of temporal trends, fewer strikes were observed in the period 2007-2010.

Completeness of the pollutant data was in general higher than 90% for the stations used in the primary analyses, and well above 80% for the stations in the secondary analyses (Supplementary Tables 1 and 2). The city-wide average levels of NO_2 and NO were 48.52 μg/m^3 and 24.28 μg/m^3, respectively. The average levels of PM_{10}, $PM_{2.5}$, PM_1, N and BC in the station used for the main analyses were ~~50.0~~ 30.62 ~~30.4~~ μg/m^3, 20.22 ~~20.1~~ μg/m^3, 14.40 ~~14.3~~ μg/m^3, 15801 ~~15960~~ cm^{-3} and 1.91 ~~2.17~~ μg/m^3, respectively (Figure 2). Pollution levels were higher during weekdays (Supplementary Table 4). Most of the pollutants exhibited strong seasonality. However, the seasonal patterns of PM_{10} and N were less clear. The concentration of all pollutants decreased during the study period.

Days with strikes in the public transport system showed levels of NO_2, NO, PM_{10} and BC that were 2.05 μg/m^3 (95% confidence interval (CI): 0.19, 3.09), 1.99 μg/m^3 (95%: -0.67, 4.66), 1.91 μg/m^3 (95% CI: 0.02, 3.81) and 0.07 μg/m^3 (95% CI: -0.08, 0.23) higher than days without a strike, respectively (Table 2). These represented between a 4.1% and a 7.7% increase in concentrations during strike days (Figure 3). No differences were observed for $PM_{2.5}$, PM_1 or N. The highest increase was observed for metro strikes, with increases of 4.80 μg/m^3 (95% CI: -0.14, 9.75) for NO_2, 12.46 μg/m^3 (95% CI: 5.31, 19.61) for NO, 2.49 μg/m^3 (95% CI: -2.53, 7.51) for PM_{10}, and 0.49 μg/m^3 (95% CI: 0.13, 0.85) for BC (Table 2). These increases represented between an 8.2% and a 48.1% increase in the concentrations during strike days (Figure 3). For the case of NO_2, significant increases were also observed for train strikes (3.16, 95%CI:

0.61, 5.72), representing a 6.3% increase in concentrations. No associations were found for bus strikes, although BC showed higher levels (0.23, 95% CI: -0.01, 0.47), representing a 13.2% increase in concentrations.

Similar results were obtained when analyzing the NO_2 and NO monitoring stations separately, and when evaluating the data from additional monitoring sites for PM_{10}, (Figure 4 and Supplementary Table 5). For $PM_{2.5}$, all additional stations showed significantly increased levels during metro and/or bus strikes (Supplementary Table 5). In terms of CO, two monitoring stations showed significantly higher levels during strikes, while another station showed significantly lower levels (Figure 4).

When using urban increments, maximum one-hour daily concentrations, restricting the analyses to the period 2009-2016, using time series models instead of linear regression models, similar results were found (Supplementary Tables 6-9). However, the associations between days with strikes and PM_{10} levels disappeared in the models for urban increment (Supplementary Table 7), when restricting to the 2009-2016 period (Supplementary Table 8) and when using time series models (Supplementary Table 9). When using maximum 1h levels, we obtained higher estimates of change in concentrations for NO_2, NO, PM_{10}, $PM_{2.5}$ (in this case with the exception of train strikes) and BC. However, the statistically significant results were mainly the same than in the main analysis, with the addition of a significant increase of $PM_{2.5}$ with metro strikes and increases in NO and PM_{10} with train strikes (Supplementary Table 6). Levels of $PM_{2.5}$ were significantly higher in days with metro strikes when the models were restricted to the period 2009-2016 (Supplementary Table 8) and in those using maximum one-hour daily concentrations (Supplementary Table 6).

When analyzing separately partial strikes and full-day strikes, or single day strikes and multiday strikes, NO_2, NO, PM_{10} and BC levels were higher during multiday strikes and full-day strikes. The highest increases were observed for full-day strikes of the metro, with increases ranging from 17% to 86% for all pollutants (Supplementary Table 10).

4. Discussion

This study examined the changes in air pollution levels during 208 days affected by public transport strikes in the city of Barcelona. The city-wide concentrations of NO_2**,** NO, PM_{10} and BC were between 4% and 8% higher during public transport strikes. These modest increases could be explained by the fact that half of the strikes were partial, all strikes had mandatory minimum services and there was practically no overlap between the strikes of the different public transport services, allowing travelers to potentially use alternative public transport modes. Despite that, we found high increases during metro strikes for NO, BC and CO, with increases reaching 30% for BC, 60% for NO and 80% for CO in some monitoring stations. The increases were even higher, and found also for most of the other pollutants, during full-day metro strikes.

We found the highest increases during public transport strikes for BC, NO and CO. This could be explained by the fact that they are primary pollutants and therefore could better detect daily changes in traffic emissions. Very relevant proportions of NO_2, PM_{10}, $PM_{2.5}$, PM_1 and N are secondary in origin in sub-urban, urban background and urban environments in Southern Europe (Reche et al. 2011; Amato et al. 2016). Since there are a number of environmental patterns that influence the particle and NO_2 formation from precursors, it is more difficult to detect changes using the concentrations of these pollutants. Even though we found some significant increases for PM_{10}, these results were the most sensitive to alternative analyses. In particular, those effects were drastically reduced when using urban increments or time series models, which suggest that those increases may be due to factors other than increases in traffic. Results for the other pollutants were more stable in sensitivity analyses.

No previous studies have assessed the impacts of public transport strikes on NO or BC. However, our results for PM_{10} and NO_2 are similar to the ones reported Bauernschuster et al. (2017). This previous study examined the associations in a context with a similar public transport network than Barcelona, using a high number of strike days and monitoring stations. The comparison of results across different locations is difficult, though, as the effect of public transport strikes is expected to be very city-specific. In particular, factors such as the size of the city, its pollution levels and the weather features that affect its accumulation, the capacity of the road network to absorb additional drivers, the existing laws regulating vehicle emissions, the posted speed limits, the type and amount of public transport available, the modal share of travelers and the type of strike can all affect the impact of strikes on air quality (Bauernschuster et al, 2017). In our case, Barcelona represents a city with high air pollution levels and a high density of private vehicles for European standards; a good public transport system, especially for internal trips; and strikes that are regulated in terms of minimal services.

Our results suggest that metro strikes have a stronger effect on air pollution levels in Barcelona than other strikes of the public transport system. This could be explained by metro being the public transport most used in Barcelona (41% of all trips in public transport in 2015 were done by metro according to Barcelona mobility data, 2015 report, retrieved from http://mobilitat.ajuntament.barcelona.cat/ , accessed October 28th, 2016). However, this should be interpreted with caution, as the number of days with metro strikes was the lowest in our study (28).

Our analyses were based on a long time period, including a large number of strike days and several traffic and urban background monitoring stations, enabling a detailed analysis of the effects of strikes, including assessing variations by type of strike. Our study, however, faced some limitations. We did not have traffic data, modal share data or data on hydrocarbon concentrations, which could provide additional insights. In addition, the comparison of effects across pollutants in our study was hampered by the fact that not all pollutants are available in all stations, and the monitoring stations had data from different periods.

5. Conclusions

This study detected increases in air pollutant concentrations during public transport strikes, even in situations in which there were minimal services and alternative public transport modes. This shows that alterations in public transport systems have consequences on air quality and gives an idea of the much larger air pollution concentrations that would be observed in the absence of a public transport system.

Acknowledgements: The authors thank Jordi Sunyer, Mark Nieuwenhuijsen and David Rojas-Rueda for their comments to an earlier version of the manuscript. ISGlobal is a member of the CERCA Programme, Generalitat de Catalunya. The graphical abstract was built with the following images: De JT Curses, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=31732894; By Carlos L´H from es, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=1808966; De Alf van Beem - Trabajo propio, CC0, https://commons.wikimedia.org/w/index.php?curid=24322434.

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Adler MW, van Ommeren JN. Does public transit reduce car travel externalities? Quasi-natural experiments' evidence from transit strikes. Journal of Urban Economics. 2016;92:106-19.

Amato F, Alastuey A, Karanasiou A, Lucarelli F, Nava S, Calzolai G, Severi M, Becagli S, Gianelle VL, Colombi C, Alves C. AIRUSE-LIFE+: a harmonized PM speciation and source apportionment in five southern European cities. Atmospheric Chemistry and Physics. 2016;16(5):3289-309.

Anderson ML. Subways, strikes, and slowdowns: The impacts of public transit on traffic congestion. The American Economic Review. 2014;104(9):2763-96.

Bauernschuster S, Hener T, Rainer H. When Labor Disputes Bring Cities to a Standstill: The Impact of Public Transit Strikes on Traffic, Accidents, Air Pollution and Health. American Economic Journal: Economic Policy. 2017; 9(1), 1-37.

Beck N, Katz JN. Modeling dynamics in time-series-cross-section political economy data. Annual Review of Political Science. 2011;14:331-52.

Brunekreef B, Holgate ST. 2002. Air pollution and health. Lancet 360(9341):1233–1242.

Chaloulakou A, Kassomenos P, Grivas G, Spyrellis N. Particulate matter and black smoke concentration levels in central Athens, Greece. Environment International. 2005;31(5):651-9.

da Silva CB, Saldiva PH, Amato-Lourenço LF, Rodrigues-Silva F, Miraglia SG. Evaluation of the air quality benefits of the subway system in São Paulo, Brazil. Journal of environmental management. 2012;101:191-6.

Fuller D, Sahlqvist S, Cummins S, Ogilvie D. The impact of public transportation strikes on use of a bicycle share program in London: interrupted time series design. Preventive medicine. 2012;54(1):74-6.

Meinardi S, Nissenson P, Barletta B, Dabdub D, Rowland FS, Blake DR. Influence of the public transportation system on the air quality of a major urban center. A case study: Milan, Italy. Atmospheric Environment. 2008;42(34):7915-23.

Lim SS, Vos T, Flaxman AD, Danaei G, Shibuya K, Adair-Rohani H, et al. 2012. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. Lancet 380(9859):2224–2260.

Peng RD, Dominici F, Louis TA. Model choice in time series studies of air pollution and mortality. Journal of the Royal Statistical Society: Series A (Statistics in Society). 2006;169(2):179-203.

Pereira BB, de Campos Jr EO, de Lima EA, Barrozo MA, Morelli S. Biomonitoring air quality during and after a public transportation strike in the center of Uberlândia, Minas Gerais, Brazil by Tradescantia micronucleus bioassay. Environmental Science and Pollution Research. 2014;21(5):3680-5.

Reche C, Querol X, Alastuey A, Viana M, Pey J, Moreno T, Rodríguez S, González Y, Fernández-Camacho R, Rosa JD, Dall'Osto M. New considerations for PM, Black Carbon and particle number concentration for air quality monitoring across different European cities. Atmospheric Chemistry and Physics. 2011;11(13):6207-27.

Tsapakis I, Turner J, Cheng T, Heydecker B, Emmonds A, Bolbol A. Effects of Tube Strikes on Journey Times in Transport Network of London. Transportation Research Record: Journal of the Transportation Research Board. 2012 (2274):84-92.

van Exel NJ, Rietveld P. Public transport strikes and traveller behaviour. Transport Policy. 2001 Oct 31;8(4):237-46.

White IR, Royston P, Wood AM. Multiple imputation using chained equations: issues and guidance for practice. Statistics in medicine. 2011;30(4):377-99.

Table 1. Description of days with public transport strikes.

	Strikes			
	All	Metro	Train	Bus
All	208	28	106	91
Full day strike	104 (50%)	12 (43%)	70 (66%)	37 (40%)
Duration (consecutive days)				
1	75 (65%)	9 (60%)	58 (77%)	21 (51%)
2	20 (17%)	3 (20%)	13 (17%)	7 (17%)
3	5 (4%)	0 (0%)	2 (3%)	3 (7%)
4	4 (3%)	2 (13%)	1 (1%)	3 (7%)
5	10 (9%)	1 (7%)	0 (0%)	7 (17%)
12	1 (1%)	0 (0%)	1 (1%)	0 (0%)
Day of the week				
Sunday	9 (4%)	2 (7%)	3 (3%)	4 (4%)
Monday	40 (19%)	7 (25%)	21 (20%)	16 (18%)
Tuesday	29 (14%)	5 (18%)	11 (10%)	14 (15%)
Wednesday	41 (20%)	5 (18%)	19 (18%)	18 (20%)
Thursday	35 (17%)	4 (14%)	16 (15%)	20 (22%)
Friday	46 (22%)	3 (11%)	34 (32%)	15 (16%)
Saturday	8 (4%)	2 (7%)	2 (2%)	4 (4%)
Month				
Jan-Feb	25 (12%)	6 (21%)	1 (0%)	21 (23%)
Mar-Apr	33 (16%)	4 (14%)	19 (18%)	11 (12%)
May-Jun	44 (21%)	9 (32%)	27 (25%)	9 (10%)
Jul-Aug	19 (9%)	0 (0%)	8 (8%)	11 (12%)
Sep-Oct	33 (16%)	6 (21%)	25 (24%)	9 (10%)
Nov-Dec	54 (26%)	3 (11%)	26 (25%)	30 (33%)
Year				
2005-2006	33 (16%)	0 (0%)	26 (25%)	8 (9%)
2007-2008	15 (7%)	0 (0%)	0 (0%)	15 (16%)
2009-2010	24 (11%)	4 (14%)	22 (21%)	6 (7%)
2011-2012	46 (22%)	9 (32%)	17 (16%)	28 (31%)
2013-2014	49 (24%)	0 (0%)	25 (24%)	24 (26%)
2015-2016	41 (20%)	15 (54%)	16 (15%)	10 (11%)

Figure 1. Diagram of the 28 days with metro strikes, indicating the hours that were affected and the minimal service that was provided.

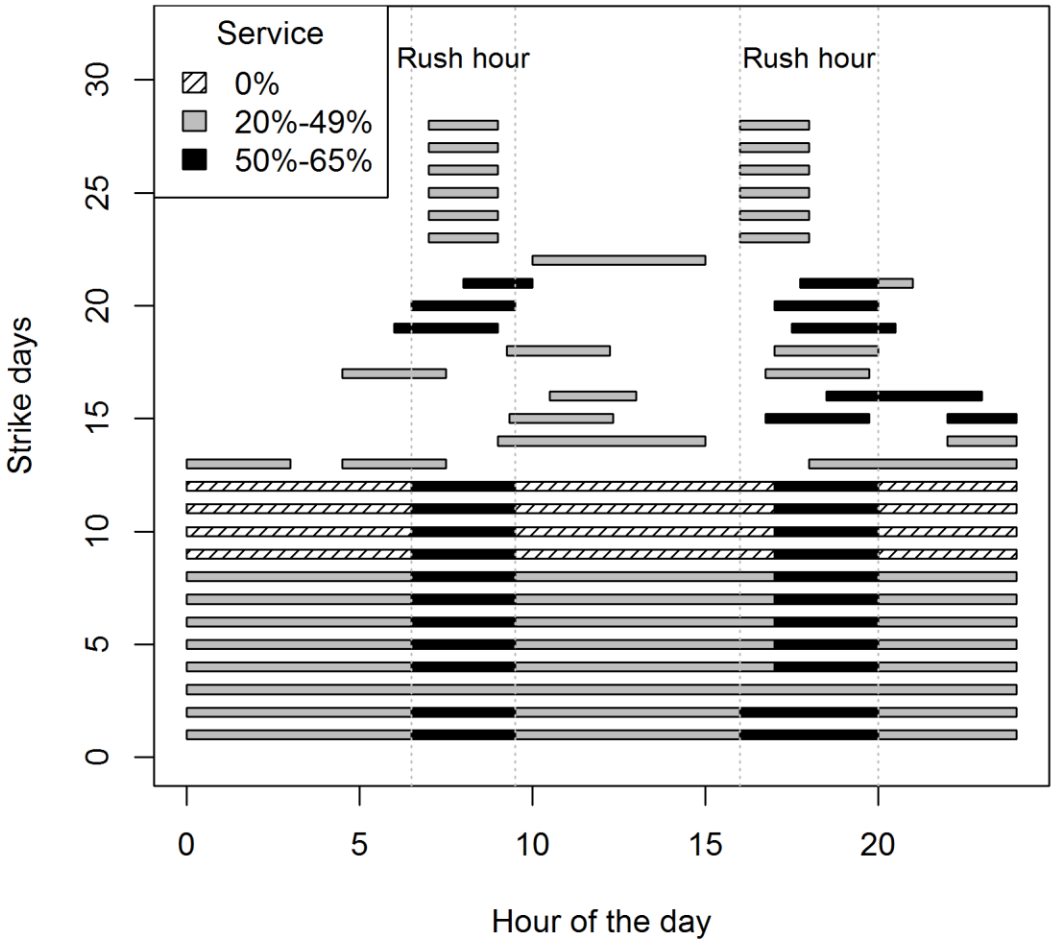

Figure 2. Mean and 25th and 75th percentiles of concentrations of air pollutants in days with public transport strikes in each monitoring station. City averages were only calculated for NO_2 and NO as the average of all available stations. PR: Palau Reial (urban background); Ciu: Ciutadella (urban background); Pobl: Poblenou (urban background); Gra: Gracia (traffic); Eix: Eixample (traffic); San: Sants (urban background); PU: Plaça Universitat (traffic).

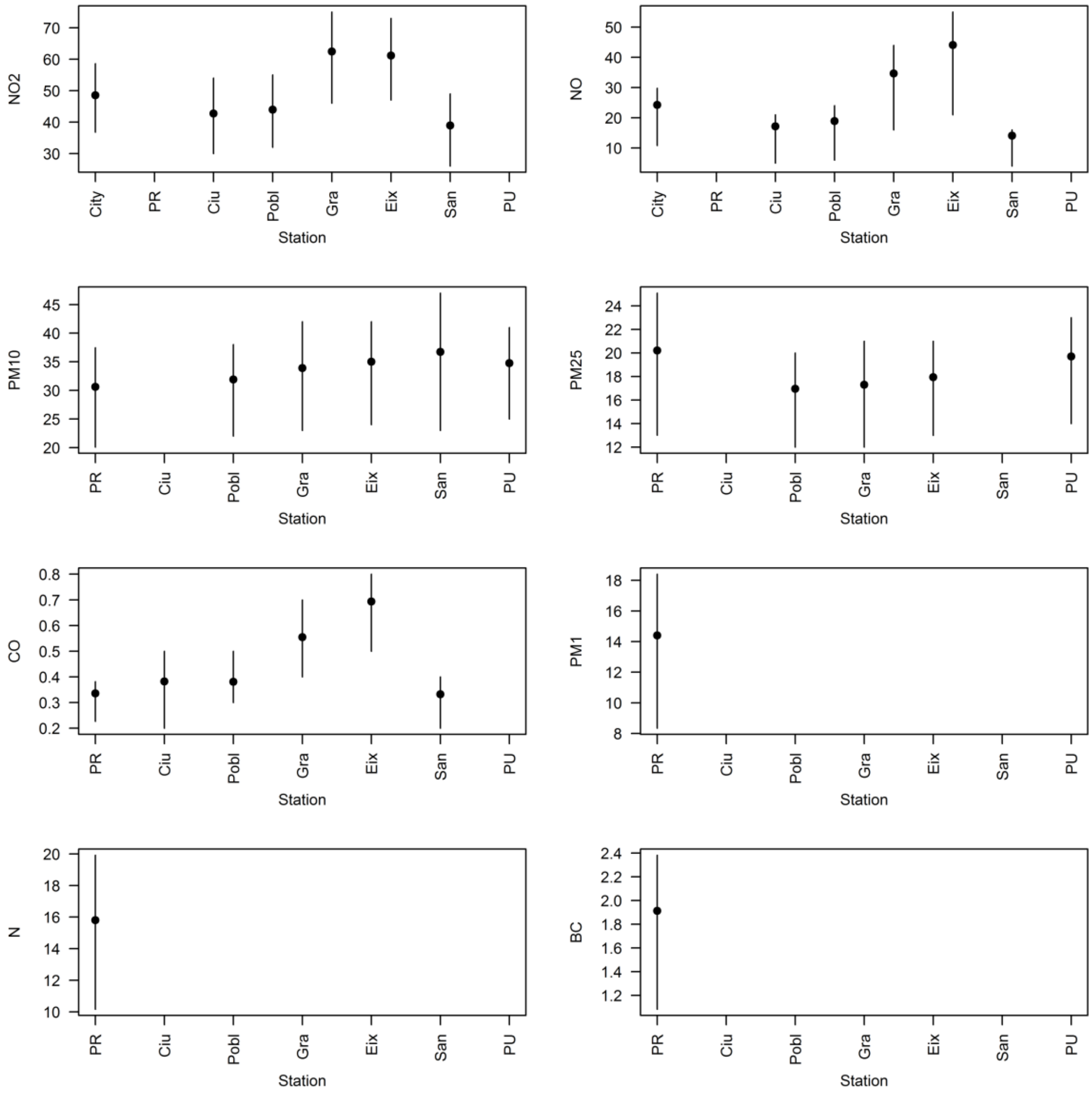

Table 2. Change in concentrations of air pollutants in days with public transport strikes. NO_2 and NO concentrations were averaged over 5 monitoring stations, while the other pollutants belonged to a single monitoring station (Palau Reial). Analyses conducted with linear regression models and using 24h average concentrations.

Pollutant	Strikes			
	All	Metro	Train	Bus
Change in				
NO_2 (μg/m^3)	2.05 (0.19, 3.91)*	4.80 (-0.14, 9.75)	3.16 (0.61, 5.72)*	0.51 (-2.24, 3.27)
NO (μg/m^3)	1.99 (-0.67, 4.66)	12.46 (5.31, 19.61)*	3.21 (-0.45, 6.86)	1.19 (-2.75, 5.13)
PM_{10} (μg/m^3)	1.91 (0.02, 3.81)*	2.49 (-2.53, 7.51)	2.38 (-0.21, 4.96)	1.31 (-1.49, 4.10)
$PM_{2.5}$ (μg/m^3)	0.70 (-0.61, 2.02)	3.03 (-0.47, 6.53)	0.47 (-1.31, 2.26)	1.26 (-0.70, 3.22)
PM_1 (μg/m^3)	0.89 (-0.26, 2.03)	2.03 (-1.06, 5.12)	0.80 (-0.76, 2.36)	1.23 (-0.45, 2.92)
N>5nm (x1000/cm^3)[a]	0.04 (-0.96, 1.04)	1.17 (-0.84, 3.18)	0.61 (-0.80, 2.03)	-0.61 (-2.04, 0.82)
BC (μg/m^3) [a]	0.07 (-0.08, 0.23)	0.49 (0.13, 0.85)*	0.04 (-0.18, 0.26)	0.23 (-0.01, 0.47)

*p-value<0.05

[a] restricted to years 2009-2016

Figure 3. Percent change in concentrations of air pollutants (95% confidence intervals) in days with public transport strikes. NO_2 and NO concentrations were averaged over 5 monitoring stations, while the other pollutants belonged to a single monitoring station (Palau Reial). N and BC were restricted to the period 2009-2016, while the other pollutants included all the period. Analyses conducted with linear regression models and using 24h average concentrations.

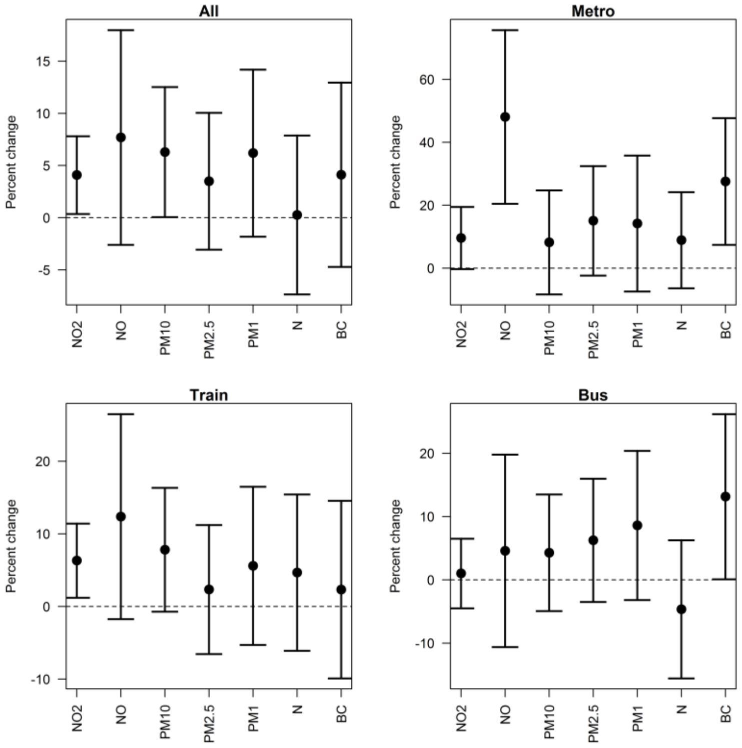

Figure 4. Percent change in concentrations of air pollutants (95% confidence intervals) in each monitoring station. Analyses conducted with linear regression models and using 24h average concentrations. Data from 2005 to 2016 for Poblenou NO_2, Poblenou NO, Gracia NO_2, Gracia NO, Gracia CO, Palau Reial PM_{10}, Palau Reial $PM_{2.5}$, Ciutadella NO_2, Ciutadella NO, Sants NO_2, Sants NO, Eixample NO_2, Eixample NO, Eixample CO. Data from 2008 to 2016 for Poblenou PM_{10}, Gracia PM_{10}, Pl.Universitat PM_{10}, Sants PM_{10}. Data from 2010 to 2016 for Gracia $PM_{2.5}$, Pl.Universitat $PM_{2.5}$, Palau Reial CO. Data from 2011 to 2016 for Poblenou $PM_{2.5}$, Eixample PM_{10}, Eixample $PM_{2.5}$. Data from 2005 to 2010 for Poblenou CO, Ciutadella CO, Sants CO.