Supplementary Information for:

Quantifying impacts of local traffic policies on PM concentrations using small sensors in Berlin

Seán Schmitz[1], Alexandre Caseiro[1], Andreas Kerschbaumer[2], Erika von Schneidemesser[1]

[1] Research Institute for Sustainability, Helmholtz Centre Potsdam, Berliner Strasse 130, 14467 Potsdam, Germany

[2] Senate Department for the Environment, Urban Mobility, Consumer Protection and Climate Action, Am Köllnischen Park 3, 10179 Berlin, Germany

1. Calibration for PM_{10}

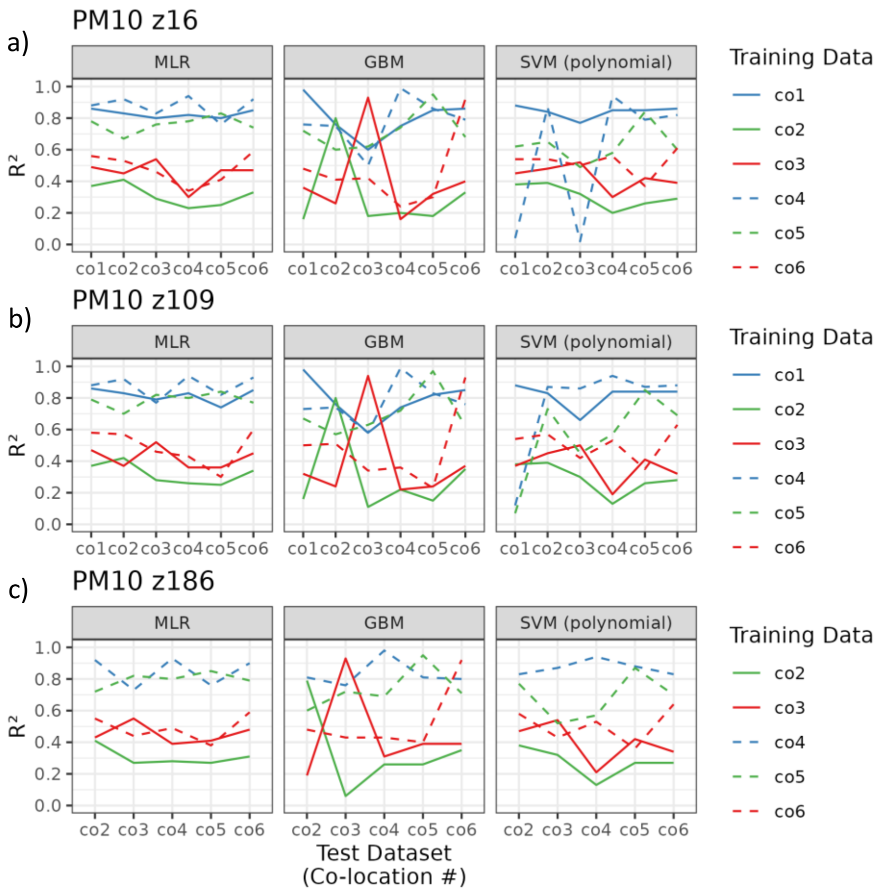

Figure S1: MAE of calibration models trained with one co-location and tested on all others for three Zephyrs used in the campaign. Winter co-locations are shown in blue, spring co-locations in green, and summer co-locations in red. Solid lines represent co-locations completed in 2020, dashed lines for those in 2021. The ticks on the x-axis (co1, co2, etc.) represent the co-locations completed (see Table 2).

To assess Plantower PMS5003 performance across various seasons, ratios of $PM_{10}/PM_{2.5}$ concentrations from proprietary black-box Plantower algorithms were compared to reference concentrations at MC117 for all six co-locations for the same three Zephyr units (Table S1). The lowest $PM_{10}/PM_{2.5}$ ratios for reference instruments occur in the winter, with the highest occurring in the summer. For Plantowers, the relationship is reversed, with ratios decreasing from winter to summer. This is largely because Plantowers capture the lower winter PM_{10} concentrations well, but perform very poorly in the spring and summer, especially with peak events (see Figure S2). Peak pollution events are not captured by the Plantowers, especially in the spring and summer, where no peak PM_{10} concentrations are measured and the ratio of $PM_{10}/PM_{2.5}$ remains close to 1. This relationship remains consistent across all Plantowers co-located at this site, with good inter-sensor agreement.

Table S1: Ratios of PM_{10} / $PM_{2.5}$ for all six co-locations at MC117 for reference concentrations and for Plantower proprietary PM_{10} / $PM_{2.5}$ calibrated concentrations averaged across the entire co-location. All available data for Zephyrs co-located at MC117 are included.

Co-Location	Season	Reference	z16	z109	z186	z115	z119
co1	Winter	1.45	1.36	1.18	*N/A*	1.14	1.16
co2	Spring	1.87	1.24	1.11	1.10	1.08	1.09
co3	Summer	1.96	1.13	1.07	1.06	1.05	1.06
co4	Winter	1.33	1.29	1.21	1.21	*N/A*	1.19
co5	Spring	1.58	1.05	1.18	1.16	*N/A*	*N/A*
co6	Summer	1.69	1.12	1.08	1.09	*N/A*	*N/A*

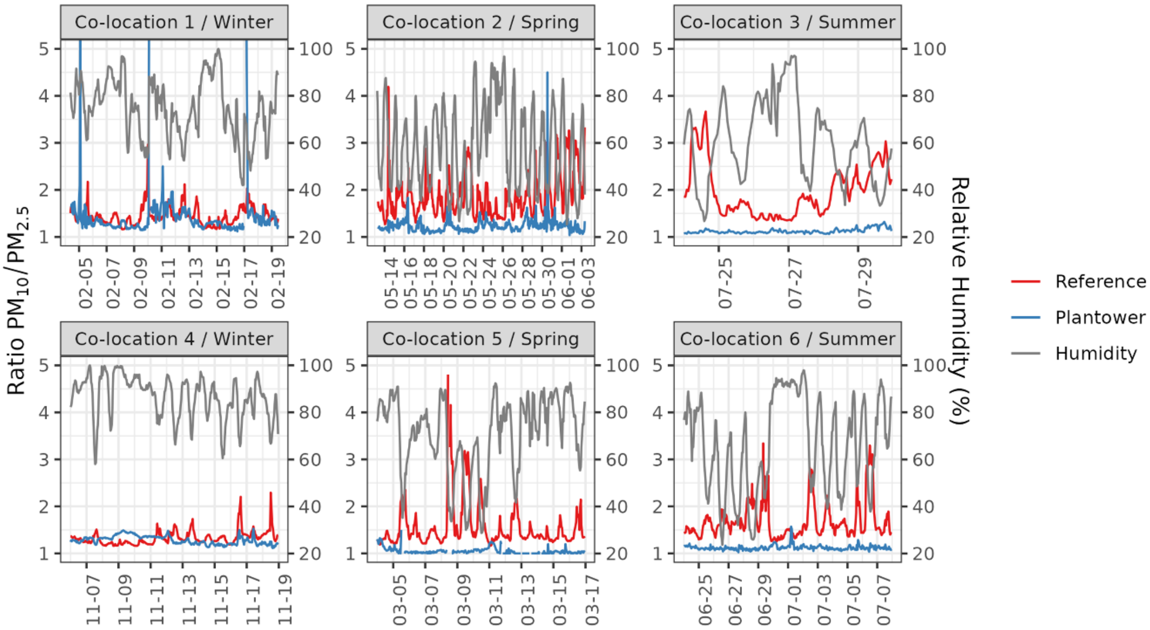

Figure S2: Ratios of PM_{10} / $PM_{2.5}$ for all six co-locations at MC117 for reference concentrations and for Plantower proprietary PM_{10} / $PM_{2.5}$ calibrated concentrations. Also shown is ambient relative humidity measured from DWD weather station 433 at Tempelhof airport. Values are averaged to one hour means. Values shown here are from only one Plantower sensor as an example, as all sensors follow a similar pattern (Table S1).

2. Diurnal concentrations for PM_{10}

After testing three different calibration models on the Plantower PMS5003, MLR appears to be the best performing model. For PM_{10}, MLR performs better than GBM and SVM, but with a clear impact of seasonality. Models trained with winter co-locations and the early spring co-location (Co-location 5) perform well when tested against all other co-location datasets, whereas those trained with summer co-locations or the late spring co-location (May) perform poorly on test co-locations.

As depicted in Figure S3, calibrated PM_{10} concentrations on KD generally match urban background concentrations with respect to peaks and daily pattern. There are marginal differences in PM_{10} concentrations across the different measurement locations on weekdays and no differences on weekend, with no differences exceeding the range of uncertainty. Slightly higher concentrations were measured at the SW and the 4th floor sites during weekdays from 7:00 – 17:00, likely as a result of construction works on the building at that location. There are no differences in PM_{10} concentrations across different streets at FR. There are also few differences in concentrations on weekdays versus on weekends. Calibrated concentrations on both streets do not match the pattern in the urban background of PM_{10} as well as they do for $PM_{2.5}$ (see Figure 4).

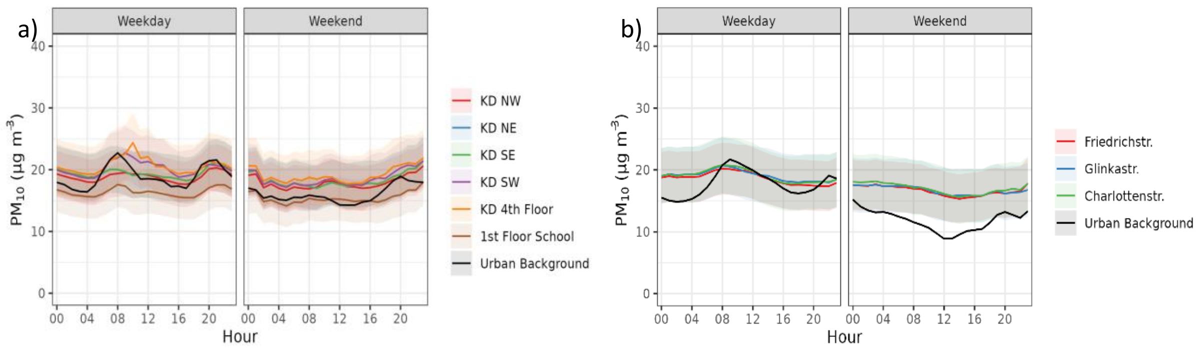

Figure S3: Diurnal plots with weekday / weekend split for PM_{10} concentrations from stationary Zephyrs for KD (a) and FR (b). Urban background concentrations on KD were drawn from one nearby station (MC042), whereas those on FR are an average of four urban background stations (MC010, MC018, MC042, MC171). On KD, NW, NE, SW, and SE refer to the rough location of lamppost Zephyrs according to cardinal directions relative to the street (see Figure 2).

3. Impact of traffic policies on PM_{10} concentrations at Kottbusser Damm

Only marginal differences in PM concentrations were measured on KD and on the Böckhstrasse following the implementation of the traffic policies (Figure S4 and Table S2). Although the changes of the medians and the 95th percentiles on both routes were statistically significant (WMW U-test), they were never larger than the uncertainty. For the community space, changes were neither statistically significant nor larger than the uncertainty.

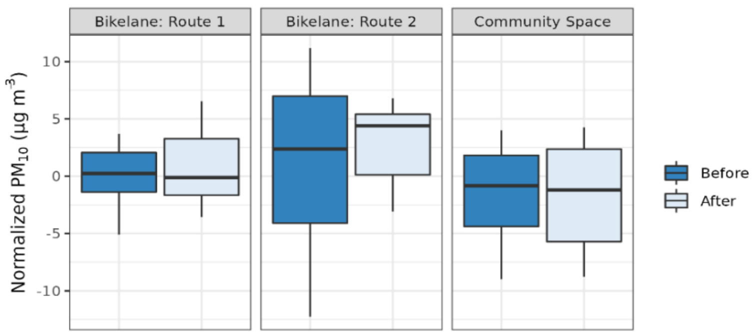

Figure S4: Boxplots of normalized PM_{10} concentrations from the mobile measurements and the community space measurements on KD. Whiskers extend to the 10th and 90th percentiles. In dark blue are measurements taken *before* the implementation of each policy and the light blue are measurements taken *after (or during)* the implementation of the policy.

Table S2: Differences in median concentrations, calculated by subtracting the median after from the median before the policy implementation on KD for PM_{10} with propagated error. These were also calculated at the 95th percentile to assess changes in extreme concentrations. Statistically significant differences in distributions via the WMW U-test are designated with asterisks ($p < 0.005$ = ***, $p < 0.05$ = **, $p < 0.01$ = *). Negative differences in medians indicate increases in concentrations following the implementation of the policies.

PM_{10}	Median Difference	± error	Median Difference (95th Percentile)	± error (95th Percentile)
Route #1	0.35	5.23	5.73***	6.83
Route #2	-2.03***	5.09	9.02***	6.94
Community Space	0.37	5.03	-2.50***	5.45

4. Impact of traffic policies on PM_{10} concentrations at Friedrichstrasse

The changes registered at the three streets in the PM_{10} concentrations were statistically significant (see Table S3 and Figure S5) and smaller than the error term. Such a similarity is an indication that the changes were not specific to the Friedrichstrasse nor related to the policy put in place there.

As in the case of $PM_{2.5}$, the density plots (Figure S6) indicating that local traffic at Friedrichstrasse is not a major contributor to the local total PM load.

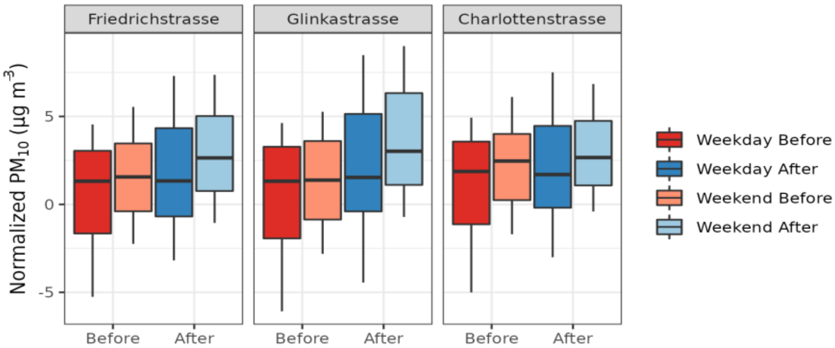

Figure S5: Boxplots of PM_{10} concentrations from the stationary measurements on FR normalized to the urban background. Whiskers extend to the 10^{th} and 90^{th} percentiles. In dark blue and red, respectively, are measurements taken *before* and *after* the implementation of each policy on weekdays, whereas lighter colours represent the same but for weekend.

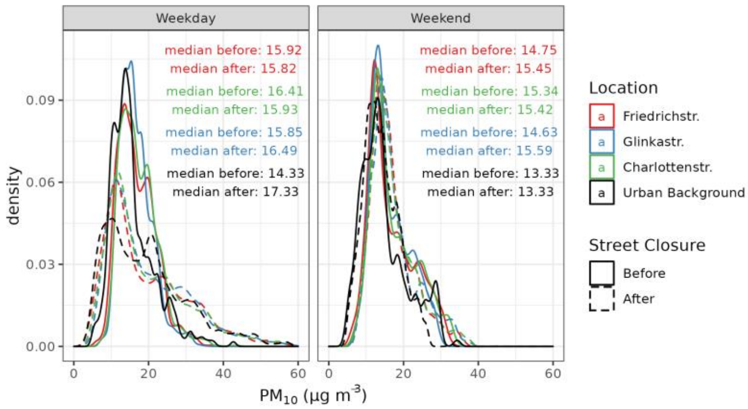

Figure S6: Density plots of all PM_{10} concentrations measured before and after the implementation of the street closure on FR. Concentrations are presented for weekdays and weekends separately, with median values presented for before and after the implementation of the policy. Colors are used to delineate results for each location.

Table S3: Differences in median concentrations, calculated by subtracting the median after from the median before the policy implementation on FR for PM_{10} with propagated error. These were also calculated at the 95^{th} percentile to assess changes in extreme concentrations. Statistically significant differences in distributions via the WMW U-test are designated with asterisks ($p < 0.005$ = ***, $p < 0.05$ = **, $p < 0.01$ = *). Negative differences in medians indicate increases in concentrations following the implementation of the policies.

PM_{10}	Median Difference	± error	Median Difference (95^{th} Percentile)	± error (95^{th} Percentile)
Friedrichstrasse	-0.43***	5.72	-0.71***	6.31
Glinkastrasse	-0.82***	6.20	3.30**	7.06
Charlottenstrasse	-0.06***	6.25	-0.86***	6.90

5. Conclusions on PM_{10} concentrations

This study further corroborates previous work indicating that Plantower PMS5003 sensors are suitable for measuring $PM_{2.5}$, but are inadequate for measuring PM_{10} (Cowell et al., 2022; Kaur & Kelly, 2023). Furthermore, we provide evidence that performance of these sensors following calibration in Berlin is seasonally dependent. Models built exclusively with training data from winter co-locations performed better when validated against test data, independent of the test data's season. Models built with training data from the summer, perform substantially worse against test data, even if that data was also collected in the summer. This is corroborated by the fact that the Plantowers do not capture spring and summer increases in PM_{10} in Berlin, missing all peaks and effectively measuring only $PM_{2.5}$ during these seasons. This is in line with findings from a study in Chile (Gramsch et al., 2021) which found a substantial dependence of PM_{10} measurement performance on the number of larger particles available, as well as their composition. It also matches findings from He at al. (2020), who found that Plantowers substantially underestimate PM mass, especially for larger particles, largely due erroneous particle number distributions across the six size bins.

6. Sampling sites

Figure S7: Zephyr system on the 4th floor on Kottbusser Damm

Figure S8: Zephyr system on the bicycle for the mobile measurements on and around Kottbusser Damm