



*Supplement of*

## **From direct emission factors to inverse and indirect impact factors of road traffic: influence of emerging and unregulated pollutants**

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## Measurement site and conditions

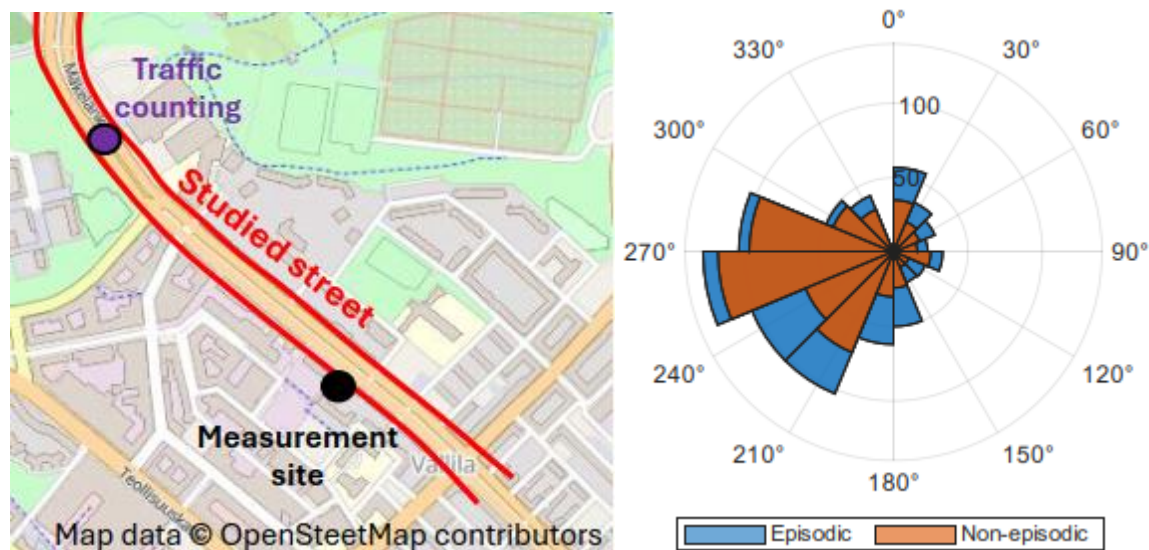


Figure S1: Map of the studied street as well as a wind rose plot during the measurement campaign, showing both the episodic and non-episodic periods stacked. Map data from <https://www.openstreetmap.org/copyright>

## Shares of mileages of different vehicle types and emissions classes in Finland in 2022

Table S1: Relative shares of different vehicle types for mileages, NO<sub>x</sub> and PM<sub>2.5</sub> exhaust emissions at the studied street canyon. The values are based on the VTT's Lipasto Aliisa model 2021 results (see Table S2) and the emission factor database of the Handbook of Emission Factors for Road Transport (HBEFA version 4.1).

| Vehicle type          | Mileage | NO <sub>x</sub> | PM <sub>2.5</sub> |
|-----------------------|---------|-----------------|-------------------|
| Car gasoline          | 45 %    | 5 %             | 6 %               |
| Car diesel            | 34 %    | 52 %            | 38 %              |
| Van                   | 12 %    | 19 %            | 36 %              |
| City bus diesel       | 6 %     | 11 %            | 10 %              |
| Truck without trailer | 3 %     | 9 %             | 8 %               |
| Truck with trailer    | 1 %     | 4 %             | 2 %               |
| Sum                   | 100 %   | 100 %           | 100 %             |

Table S2: Shares of mileages for different vehicle types and EURO emission classes in Finland in 2022. The values are interpolated from VTT's Lipasto Aliisa model 2021 results.

| Vehicle type | EURO0 | EURO1 | EURO2 | EURO3 | EURO4 | EURO5 | EEV** | EURO6 | PHEV*** | Electric | Sum   |
|--------------|-------|-------|-------|-------|-------|-------|-------|-------|---------|----------|-------|
| Car gasoline | 0 %   | 1 %   | 4 %   | 14 %  | 14 %  | 19 %  | 0 %   | 42 %  | 5 %     | 0 %      | 100 % |
| Car diesel   | 0 %   | 0 %   | 1 %   | 6 %   | 18 %  | 33 %  | 0 %   | 41 %  | 0 %     | 0 %      | 100 % |
| Van          | 1 %   | 1 %   | 4 %   | 10 %  | 23 %  | 18 %  | 0 %   | 43 %  | 0 %     | 0 %      | 100 % |
| City bus*    | 0 %   | 0 %   | 0 %   | 0 %   | 0 %   | 0 %   | 15 %  | 66 %  | 0 %     | 18 %     | 100 % |
| Truck        | 0 %   | 0 %   | 2 %   | 9 %   | 12 %  | 26 %  | 0 %   | 51 %  | 0 %     | 0 %      | 100 % |

\*The values for buses are from the Helsinki Region Transport HSL for the Helsinki metropolitan area.

\*\*Environmentally enhanced vehicle, i.e. emission class between Euro 5 and Euro 6.

\*\*\*Plug-in hybrid electric vehicle

## Instrumentation and utilized time resolutions in the EF/IF calculation

Table S3: Utilized time resolutions in the EF/IF calculation.

| Instrument   | Parameter(s)                                   | Resolution in EF/IF calculation |
|--------------|------------------------------------------------|---------------------------------|
| Airmodus A20 | PN > 5.4 nm                                    | 1 min                           |
| AE33         | BC                                             | 1 min                           |
| Fidas 200    | PM <sub>2.5</sub> , PM <sub>10</sub>           | 1 min                           |
| AQ Urban     | LDSA                                           | 1 min                           |
| APNA 370     | NO, NO <sub>2</sub> , NO <sub>x</sub>          | 1 min                           |
| APMA 360     | CO                                             | 1 min                           |
| APOA 370     | O <sub>3</sub>                                 | 1 min                           |
| SP-AMS       | Organics, Nitrate, Sulfate, Ammonium, Chloride | 10 min                          |
| TD-GC-MS     | VOCs                                           | 30–45 min                       |
| DMPS         | Particle number size distribution              | 60 min                          |
| NAIS         | Particle number size distribution, ions        | 60 min                          |

## Road traffic's contribution to measured concentrations

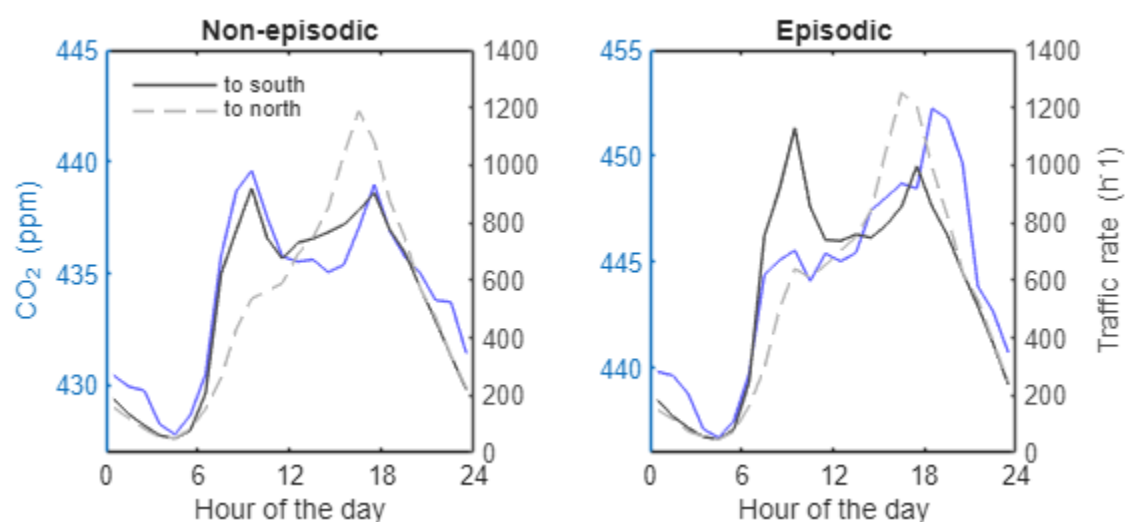


Figure S2: The diurnal variation of CO<sub>2</sub> concentration as well as road traffic rate (vehicles/hour) at the studied street during the non-episodic and episodic periods. The traffic rate is shown separately for traffic towards south and north. The measurement site is located in immediate vicinity of the lane towards south.

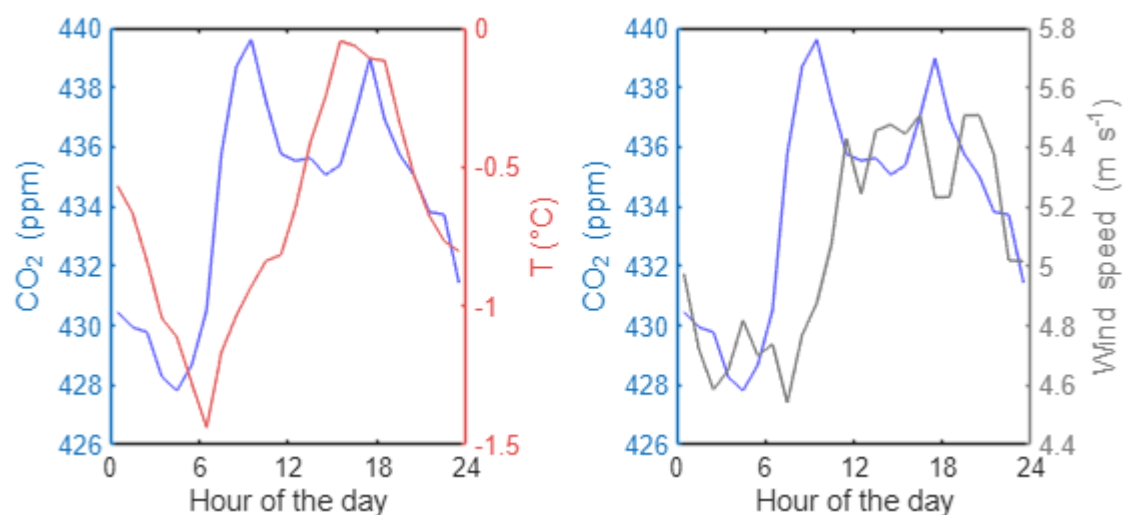


Figure S3: The diurnal variation of CO<sub>2</sub> concentration as well as temperature and wind speed during the non-episodic period.

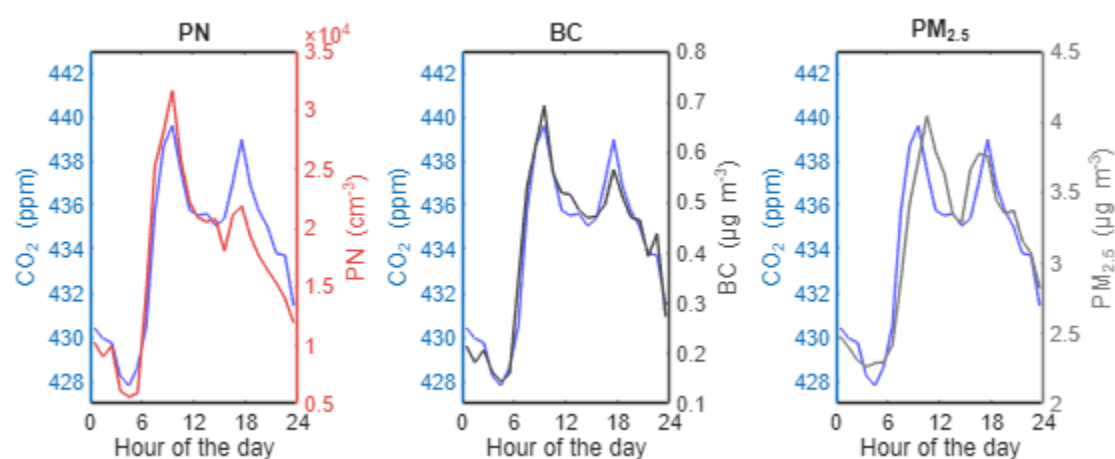


Figure S4: The diurnal variation of CO<sub>2</sub> concentration together with PN, BC and PM<sub>2.5</sub> concentrations during the non-episodic periods.

Table S4: The arithmetic mean concentrations of CO<sub>2</sub>, PN, BC, PM<sub>2.5</sub> and NO<sub>x</sub> during the non-episodic and episodic periods.

|                                         | Non-episodic | Episodic |
|-----------------------------------------|--------------|----------|
| CO <sub>2</sub> (ppm)                   | 434          | 444      |
| PN (cm <sup>-3</sup> )                  | 17 100       | 20 500   |
| BC (μg m <sup>-3</sup> )                | 0.41         | 1.04     |
| PM <sub>2.5</sub> (μg m <sup>-3</sup> ) | 3.1          | 10.3     |
| NO <sub>x</sub> (μg m <sup>-3</sup> )   | 35.3         | 52.3     |

## Emission factors of regulated and non-regulated emerging pollutants

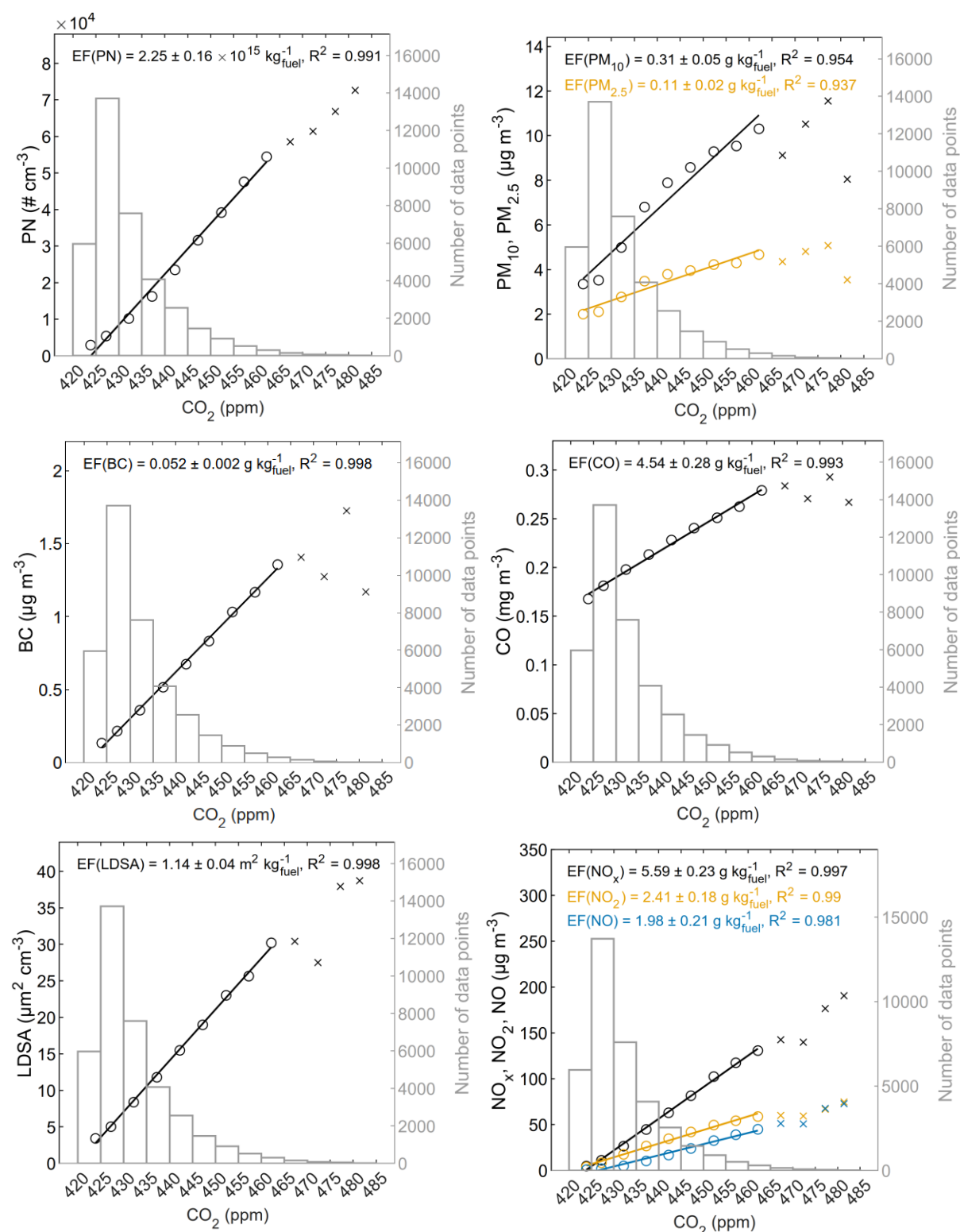


**Figure S5:** Concentrations of PN (> 5.4 nm), PM<sub>10</sub>, PM<sub>2.5</sub>, BC, CO, LDSA<sup>al</sup>, NO<sub>x</sub>, NO and NO<sub>2</sub> as a function of CO<sub>2</sub> concentration and the determined EFs, including 95 % confidence intervals and R<sup>2</sup> of the averaged linear fits. Also, the number of data points in each CO<sub>2</sub> concentration bin is shown. The pollution episodes were not included in the data.

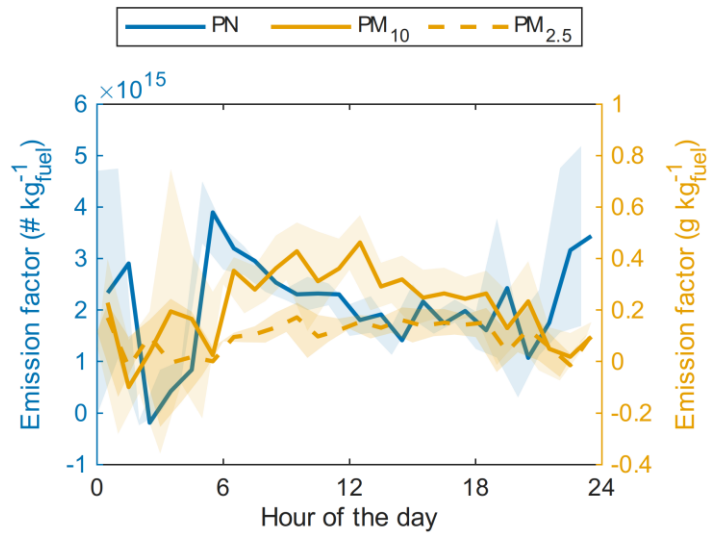


**Figure S6:** Diurnal PN, PM<sub>10</sub>, and PM<sub>2.5</sub> EFs with 95 % confidence intervals (shaded areas). Weekends and the pollution episodes were not included in the data.

**Table S5:** Average emission factors for different vehicle types at the studied street canyon in 2022. The values are based on the VTT's Lipasto Aliisa model 2021 results (see Table S2) and the emission factor database of the Handbook of Emission Factors for Road Transport (HBEFA version 4.1).

| Vehicle type          | NO <sub>x</sub> EF (g km <sup>-1</sup> ) | PM <sub>2.5</sub> EF (g km <sup>-1</sup> ) |
|-----------------------|------------------------------------------|--------------------------------------------|
| Car gasoline          | 0.0648                                   | 0.0015                                     |
| Car diesel            | 0.8291                                   | 0.0139                                     |
| Van                   | 0.8749                                   | 0.0374                                     |
| City bus diesel       | 1.0362                                   | 0.0211                                     |
| Truck without trailer | 1.7632                                   | 0.0330                                     |
| Truck with trailer    | 3.6786                                   | 0.0555                                     |
| Mean                  | 0.5447                                   | 0.0123                                     |

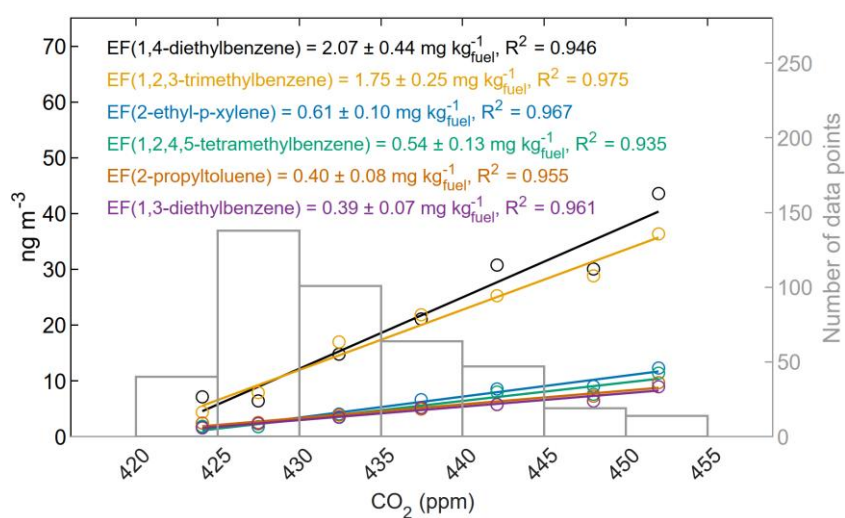
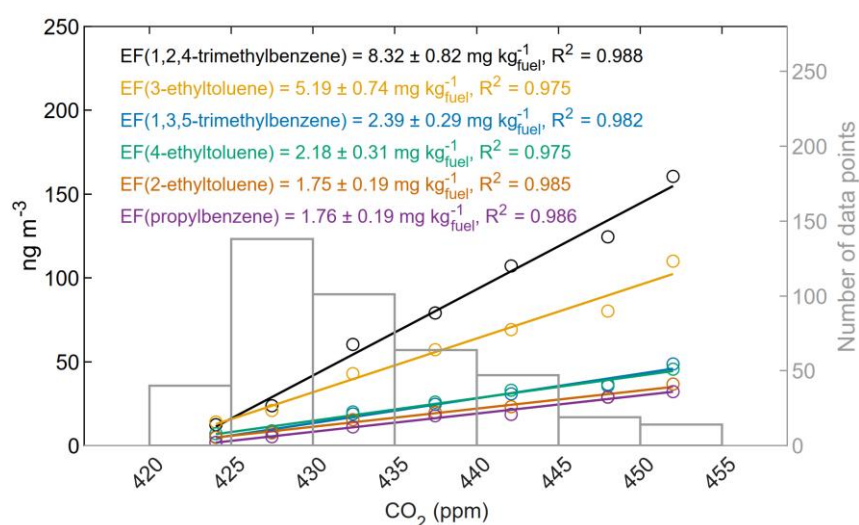
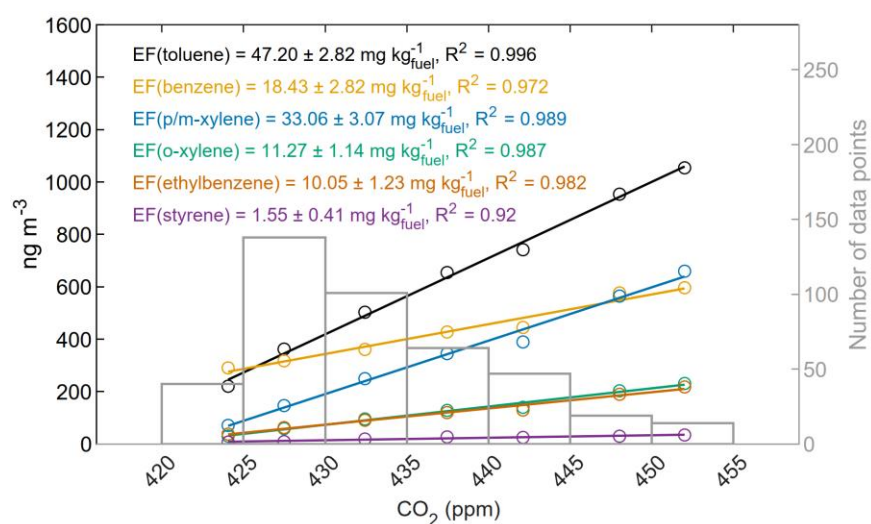


**Figure S7: Concentrations of the studied aromatic hydrocarbon VOCs as a function of CO<sub>2</sub> concentration and the determined EFs, including 95 % confidence intervals and R<sup>2</sup> of the averaged linear fits. Also, the number of data points in each CO<sub>2</sub> concentration bin is shown. The pollution episodes were not included in the data. Note the varying y-axes.**

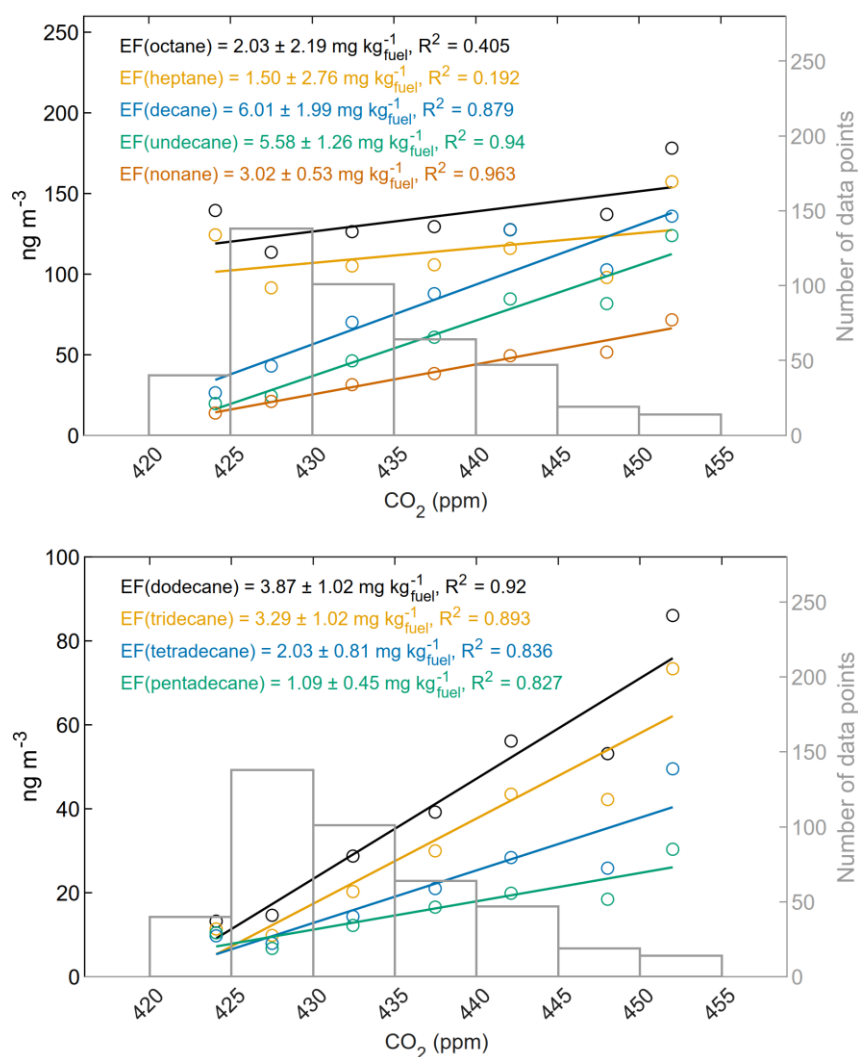


**Figure S8: Concentrations of the studied alkane VOCs as a function of CO<sub>2</sub> concentration and the determined EFs, including 95 % confidence intervals and R<sup>2</sup> of the averaged linear fits. Also, the number of data points in each CO<sub>2</sub> concentration bin is shown. The pollution episodes were not included in the data. Note the varying y-axes.**

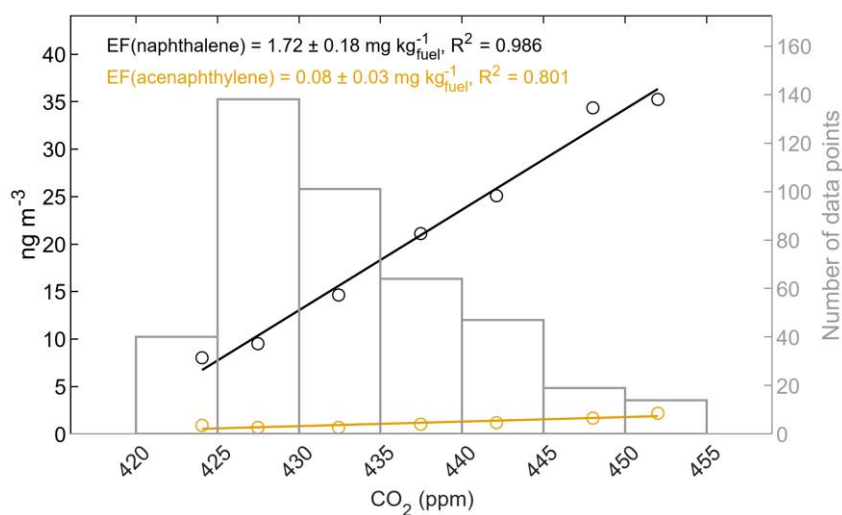


**Figure S9:** Concentrations of the studied gaseous PAHs as a function of CO<sub>2</sub> concentration and the determined EFs, including 95 % confidence intervals and R<sup>2</sup> of the averaged linear fits. The pollution episodes were not included in the data. Also, the number of data points in each CO<sub>2</sub> concentration bin is shown.

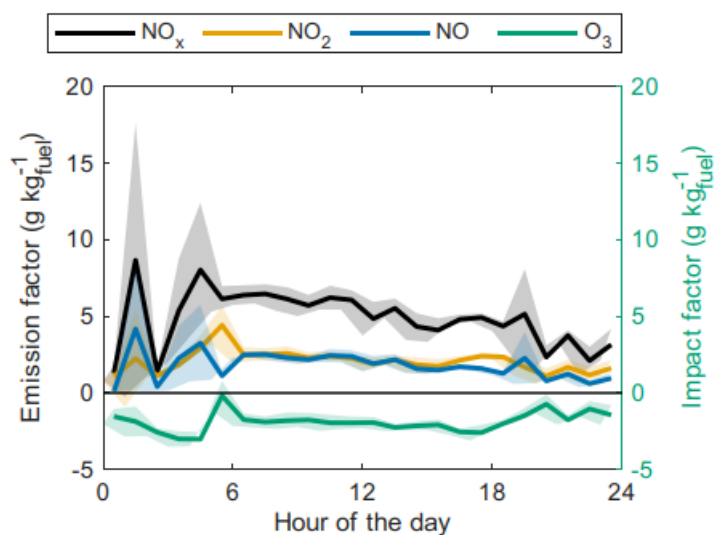


**Figure S10:** The diurnal variation of NO<sub>x</sub>, NO<sub>2</sub>, NO EFs, and O<sub>3</sub> IF, with 95 % confidence intervals (shaded areas). Weekends and the pollution episodes were not included in the data.

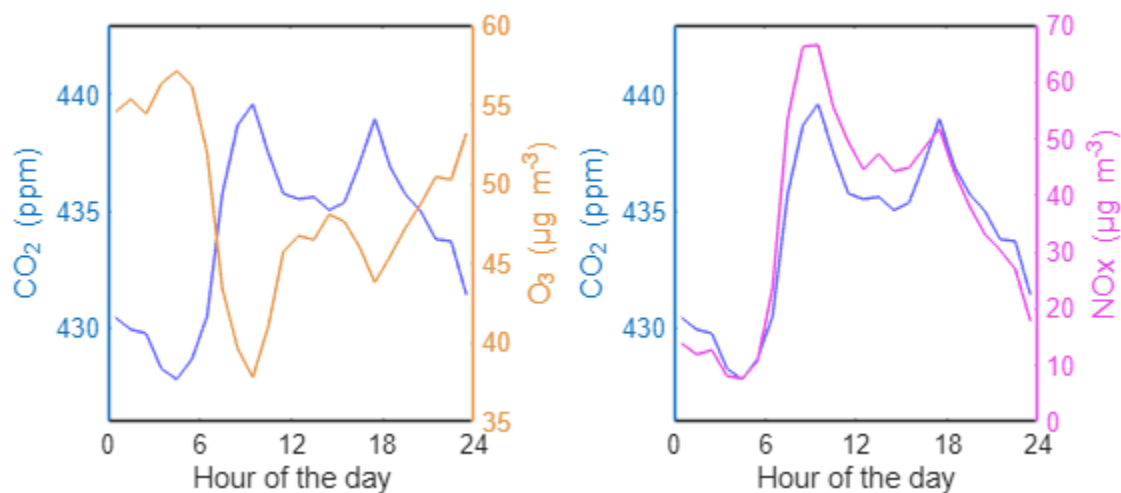


Figure S11: The diurnal variation of CO<sub>2</sub>, O<sub>3</sub> and NO<sub>x</sub> concentrations during the non-episodic periods.

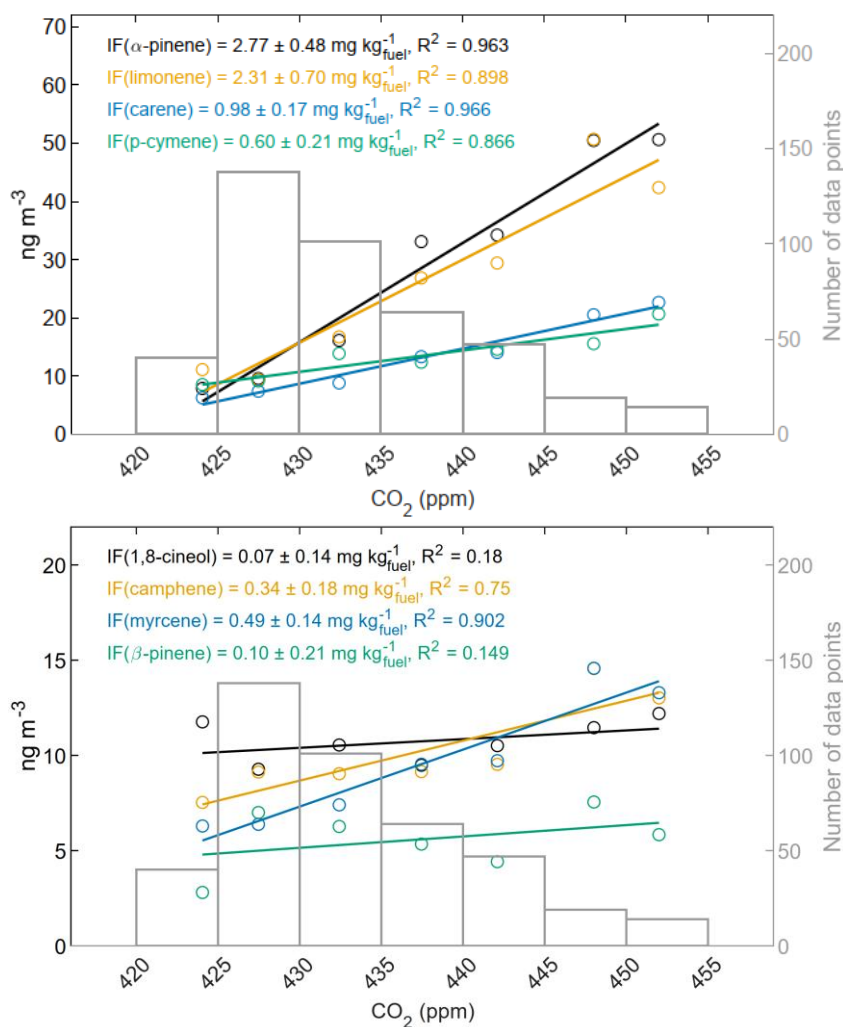


Figure S12: Concentrations of the studied terpenoid VOCs as a function of CO<sub>2</sub> concentration and the determined IFs, including 95 % confidence intervals and  $R^2$  of the averaged linear fits. The pollution episodes were not included in the data. Also, the number of data points in each CO<sub>2</sub> concentration bin is shown.

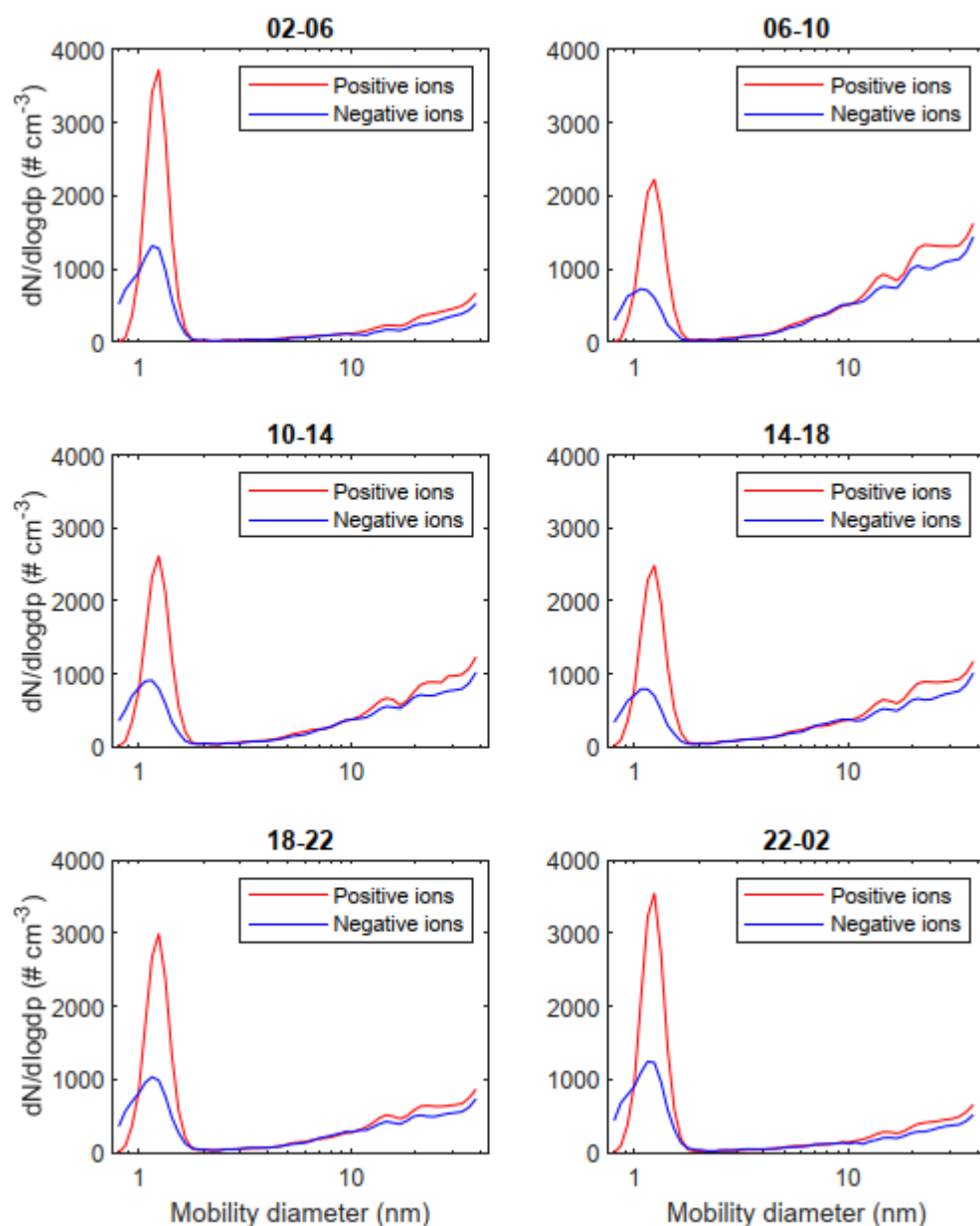


Figure S13. Size distributions of positive and negative ions during different times of the day. The pollution episodes and weekends were not included in the data.

**Table S6: Comparison of VOC EFs and IFs together with 95 % confidence intervals (CI) and the R<sup>2</sup> of the averaged linear fits during the episodic and non-episodic periods.**

| Class                                   | VOC                        | Episodic                                                         |                                                 | Non-episodic                                                     |                                                 |
|-----------------------------------------|----------------------------|------------------------------------------------------------------|-------------------------------------------------|------------------------------------------------------------------|-------------------------------------------------|
|                                         |                            | EF (IF) and<br>95 % CI<br>(mg kg <sup>-1</sup> <sub>fuel</sub> ) | R <sup>2</sup> of the<br>averaged<br>linear fit | EF (IF) and<br>95 % CI<br>(mg kg <sup>-1</sup> <sub>fuel</sub> ) | R <sup>2</sup> of the<br>averaged<br>linear fit |
| <b>Aromatic hydrocarbons</b>            | Benzene                    | 43.6 ± 16.4                                                      | 0.876                                           | 18.4 ± 2.8                                                       | 0.972                                           |
|                                         | Toluene                    | 36.9 ± 18.2                                                      | 0.805                                           | 47.2 ± 2.8                                                       | 0.996                                           |
|                                         | Ethylbenzene               | 7.9 ± 4.7                                                        | 0.743                                           | 10.1 ± 1.2                                                       | 0.982                                           |
|                                         | p/m-xylene                 | 21.1 ± 11.2                                                      | 0.765                                           | 33.1 ± 3.1                                                       | 0.989                                           |
|                                         | Styrene                    | 4.4 ± 3.7                                                        | 0.590                                           | 1.6 ± 0.4                                                        | 0.920                                           |
|                                         | o-xylene                   | 9.1 ± 5.1                                                        | 0.759                                           | 11.3 ± 1.1                                                       | 0.987                                           |
|                                         | Propyl benzene             | 1.5 ± 0.9                                                        | 0.719                                           | 1.8 ± 0.2                                                        | 0.986                                           |
|                                         | 3-ethyltoluene             | 3.3 ± 3.0                                                        | 0.537                                           | 5.2 ± 0.7                                                        | 0.975                                           |
|                                         | 4-ethyltoluene             | 3.1 ± 2.6                                                        | 0.582                                           | 2.2 ± 0.3                                                        | 0.975                                           |
|                                         | 1,3,5-trimethylbenzene     | 4.1 ± 3.8                                                        | 0.543                                           | 2.4 ± 0.3                                                        | 0.982                                           |
|                                         | 2-ethyltoluene             | 3.0 ± 2.7                                                        | 0.551                                           | 1.8 ± 0.2                                                        | 0.985                                           |
|                                         | 1,2,4-trimethylbenzene     | 4.6 ± 3.4                                                        | 0.645                                           | 8.3 ± 0.8                                                        | 0.988                                           |
|                                         | 1,2,3-trimethylbenzene     | 1.1 ± 0.9                                                        | 0.575                                           | 1.8 ± 0.3                                                        | 0.975                                           |
|                                         | 1,3-diethylbenzene         | -0.1 ± 0.1                                                       | 0.255                                           | 0.4 ± 0.1                                                        | 0.961                                           |
|                                         | 1,4-diethylbenzene         | 0.7 ± 0.4                                                        | 0.752                                           | 2.1 ± 0.4                                                        | 0.946                                           |
|                                         | 2-propyltoluene            | 0.1 ± 0.1                                                        | 0.611                                           | 0.4 ± 0.1                                                        | 0.955                                           |
|                                         | 2-ethyl-p-xylene           | 0.2 ± 0.1                                                        | 0.805                                           | 0.6 ± 0.1                                                        | 0.967                                           |
|                                         | 1,2,4,5-tetramethylbenzene | 0.1 ± 0.2                                                        | 0.280                                           | 0.5 ± 0.1                                                        | 0.935                                           |
| <b>Alkanes</b>                          | Heptane                    | 5.0 ± 4.3                                                        | 0.582                                           | 1.5 ± 2.8                                                        | 0.192                                           |
|                                         | Octane                     | 3.3 ± 4.3                                                        | 0.378                                           | 2.0 ± 2.2                                                        | 0.405                                           |
|                                         | Nonane                     | 1.5 ± 0.9                                                        | 0.734                                           | 3.0 ± 0.5                                                        | 0.963                                           |
|                                         | Decane                     | 2.0 ± 1.3                                                        | 0.697                                           | 6.0 ± 2.0                                                        | 0.879                                           |
|                                         | Undecane                   | 3.5 ± 0.8                                                        | 0.951                                           | 5.6 ± 1.3                                                        | 0.940                                           |
|                                         | Dodecane                   | 1.8 ± 0.7                                                        | 0.865                                           | 3.9 ± 1.0                                                        | 0.920                                           |
|                                         | Tridecane                  | 1.5 ± 1.0                                                        | 0.705                                           | 3.3 ± 1.0                                                        | 0.893                                           |
|                                         | Tetradecane                | 1.0 ± 0.4                                                        | 0.868                                           | 2.0 ± 0.8                                                        | 0.836                                           |
|                                         | Pentadecane                | 1.2 ± 0.5                                                        | 0.826                                           | 1.1 ± 0.5                                                        | 0.827                                           |
| <b>Polycyclic aromatic hydrocarbons</b> | Naphthalene                | 1.3 ± 0.9                                                        | 0.651                                           | 1.7 ± 0.2                                                        | 0.986                                           |
|                                         | Acenaphthylene             | 0.06 ± 0.05                                                      | 0.596                                           | 0.08 ± 0.03                                                      | 0.801                                           |
| <b>Terpenoids</b>                       | a-pinene                   | 7.6 ± 5.8                                                        | 0.635                                           | 2.8 ± 0.5                                                        | 0.963                                           |
|                                         | Camphene                   | 1.2 ± 1.1                                                        | 0.532                                           | 0.3 ± 0.2                                                        | 0.750                                           |
|                                         | Myrcene                    | 1.7 ± 1.5                                                        | 0.547                                           | 0.5 ± 0.1                                                        | 0.902                                           |
|                                         | b-pinene                   | 1.6 ± 2.5                                                        | 0.285                                           | 0.1 ± 0.2                                                        | 0.149                                           |
|                                         | Carene                     | 2.1 ± 2.1                                                        | 0.496                                           | 1.0 ± 0.2                                                        | 0.966                                           |
|                                         | p-cymene                   | 0.4 ± 0.8                                                        | 0.230                                           | 0.6 ± 0.2                                                        | 0.866                                           |
|                                         | Limonene                   | 3.4 ± 2.2                                                        | 0.706                                           | 2.3 ± 0.7                                                        | 0.898                                           |
|                                         | 1,8-cineol                 | 0.8 ± 1.0                                                        | 0.401                                           | 0.1 ± 0.1                                                        | 0.180                                           |

Table S7: Episodic and non-episodic EFs of of PN (> 5.4 nm), PM<sub>10</sub>, PM<sub>2.5</sub>, BC, CO, LDSA, NO<sub>x</sub>, NO and NO<sub>2</sub>, together with confidence intervals (CI), and R<sup>2</sup> values of the averaged linear fits. Also, the IF of O<sub>3</sub> is shown.

| Metric                                                  | Episodic                      |                                           | Non-episodic                  |                                           |
|---------------------------------------------------------|-------------------------------|-------------------------------------------|-------------------------------|-------------------------------------------|
|                                                         | EF (IF) and 95 % CI           | R <sup>2</sup> of the averaged linear fit | EF (IF) and 95 % CI           | R <sup>2</sup> of the averaged linear fit |
| PN > 5.4 nm (# kg <sup>-1</sup> <sub>fuel</sub> )       | $(1.1 \pm 0.1) \cdot 10^{15}$ | 0.985                                     | $(2.3 \pm 0.2) \cdot 10^{15}$ | 0.991                                     |
| BC (g kg <sup>-1</sup> <sub>fuel</sub> )                | $0.068 \pm 0.007$             | 0.984                                     | $0.052 \pm 0.002$             | 0.998                                     |
| PM <sub>10</sub> (g kg <sup>-1</sup> <sub>fuel</sub> )  | $0.51 \pm 0.10$               | 0.933                                     | $0.31 \pm 0.05$               | 0.954                                     |
| PM <sub>2.5</sub> (g kg <sup>-1</sup> <sub>fuel</sub> ) | $0.36 \pm 0.06$               | 0.959                                     | $0.11 \pm 0.02$               | 0.937                                     |
| LDSA (m <sup>2</sup> kg <sup>-1</sup> <sub>fuel</sub> ) | $1.12 \pm 0.08$               | 0.992                                     | $1.14 \pm 0.04$               | 0.998                                     |
| NO <sub>x</sub> (g kg <sup>-1</sup> <sub>fuel</sub> )   | $4.04 \pm 0.54$               | 0.969                                     | $5.59 \pm 0.23$               | 0.997                                     |
| NO <sub>2</sub> (g kg <sup>-1</sup> <sub>fuel</sub> )   | $1.87 \pm 0.18$               | 0.984                                     | $2.41 \pm 0.18$               | 0.990                                     |
| NO (g kg <sup>-1</sup> <sub>fuel</sub> )                | $1.22 \pm 0.36$               | 0.864                                     | $1.98 \pm 0.21$               | 0.981                                     |
| CO (g kg <sup>-1</sup> <sub>fuel</sub> )                | $7.89 \pm 0.76$               | 0.984                                     | $4.54 \pm 0.28$               | 0.993                                     |
| O <sub>3</sub> (g kg <sup>-1</sup> <sub>fuel</sub> )    | $-2.81 \pm 0.33$              | 0.976                                     | $-2.17 \pm 0.20$              | 0.985                                     |

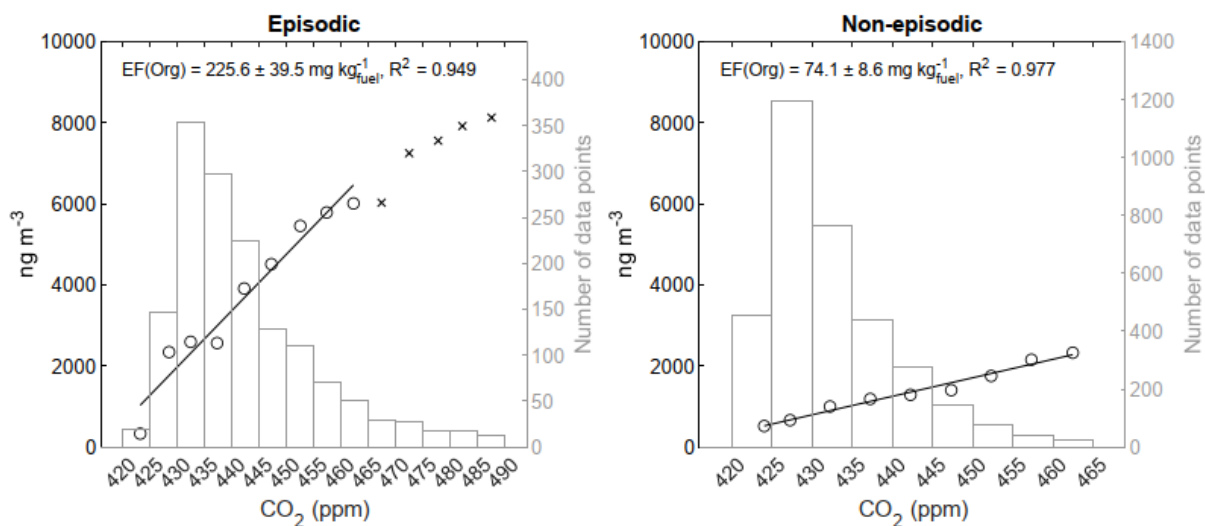


Figure S14. Episodic (left) and non-episodic (right) EFs of organics. Note the different x-axis.