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HOURLY ROADSIDE TRAFFIC EMISSIONS FROM BOTTOM-UP INVENTORY FOR THE CITY OF BERLIN

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Abstract: Emissions of nitrogen oxides (NO_x) and particulate matter (PM) from traffic sources are modelled for the City of Berlin with a bottom-up approach using HBEFA emission factors. Road network topology, vehicle fleet distribution, traffic activities, as well as meteorological conditions are used in tandem for generating hourly emissions at road segment resolutions. Aggregated annual daily mean emissions are presented and have been shown to be consistent with officially reported inventory values. Meanwhile, street level hourly emission data for different day types (i.e., workdays, Fridays, Saturdays, and Sundays/Holidays) are generated to coincide with local conditions representing recent observational campaigns using low-cost sensors (LCSs). These locations reflect different road types, where corresponding influences of traffic volume and traffic flow state on the emission output are evident. The results from this exercise provide high-resolution boundary conditions for future meso- and urban scale model evaluation studies, or further as a starting point for exposure assessment to traffic pollutants under different traffic activity scenarios.

***Key words:** Emissions, Traffic, Exposure, Modelling, HBEFA, low-cost sensors (LCS).*

INTRODUCTION

Despite generally decreasing overall NO_x emissions in recent years, the transport sector still accounts for over 40% of NO_x emissions in the EU region. In particular, the German transport sector contributes 19% of all NO_x emissions in transport sector in the EU, amounting to 8.8% of aggregate NO_x in the region (EEA, 2021). As such, accurate quantification of traffic emission sources is important in establishing relevance and trustworthiness of air quality measurements and model results (Thunis et al, 2016). On one hand, roadside traffic emissions can be calculated using the so-called “bottom-up” approach, performed for each road segment at an hourly interval using traffic activity and fleet composition with existing databases for vehicle emission factors such as COPERT (Ibarra-Espinosa et al, 2018, Guevara et al, 2020) and HBEFA (Chan et al., 2022). On the other hand, to further expand the understanding of micro-scale dispersion of airborne pollutants in urban environments, field-calibrated low-cost sensors (LCS; Peltier et al, 2020) have become a popular emerging technology, complimentary to traditional reference-grade instrumentation, as their accuracy and applicability continually improve (Malings et al, 2019; Zimmerman et al, 2019). Using the city of Berlin as focal point, this study first presents the modelled traffic emissions with the bottom-up inventory tool Yeti (Chan et al, 2022), where annual aggregate emissions are compared with official reported figures (Diegmann et al, 2020). This is followed by the examination of hourly roadside NO_x emissions with observed NOx concentration obtained from existing measurement campaigns conducted (Schmitz et al, 2021; 2022). The degree of compatibility between the modelled and observational data are discussed. The outcome of this study can serve as a starting point for evaluation of urban- and regional scale models and investigation on population exposure to airborne pollutants in urban regions, either as a standalone tool for investigating emissions source attribution, or as part of a scale air quality modelling tool chain (Kuik et al, 2018; Chan and Butler, 2021).

DESCRIPTION OF INPUT DATA

Yeti requires input data for traffic flow, meteorology, and HBEFA emission factors. Table 1 shows the source data that are used to generate traffic input for Yeti, which include fleet distribution, road topology and properties, vehicle count and level of service (LOS) distributions. A generalized representation of traffic activity and emission data affords a high degree of scalability and flexibility in the use and execution of Yeti, while accommodating a wide range of details on topological, traffic, and meteorological data. The resulting hourly traffic emission data are calculated at road level resolution.

Table 1. Source data for Berlin for generating Yeti traffic emissions

Data type	Resolution	Year
Vehicle fleet distribution	Annual city mean	2020
Road network topology and properties	Per road link	2016
Vehicle category distribution (morning, evening, night)	Per road link, hourly	2014
Total vehicle count	Per road link, hourly	2015
Level of service (LOS) distributions for all day types	Per road link, hourly	2015
HBEFA emission factors (version 4.1)	Per vehicle	2019

Two different sets of meteorological data are used in this study, as they influence contributions from cold excess emissions. First, the default seasonal diurnal temperature profiles for Germany from HBEFA are used to generate the annual aggregate emissions, as presented in Figure 1(L). Second, roadside emissions are obtained from measurement campaigns conducted on two different streets: Frankfurter Allee in August 2018 (Schmitz et al, 2022), and Kottbusser Damm in February, 2020 (Schmitz et al, 2021). The mean diurnal temperature profile for the corresponding observation period is taken from the German Weather Service station in Berlin Tempelhof, shown in Figure 1(R).

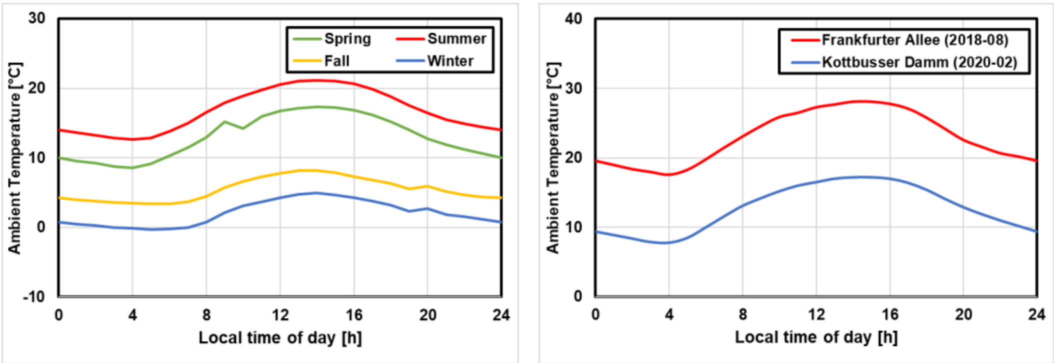

Figure 1. (L) Mean seasonal diurnal temperature profiles in Germany from HBEFA and (R) mean diurnal ambient temperature profiles on-site from the air quality campaigns conducted on (Red) Frankfurter Allee in August 2018 and (Blue) Kottbusser Damm in February 2022.

ANNUAL AGGREGATE EMISSIONS

Table 2 shows the annual aggregate emissions for NO_x PM, CO and HC for Berlin calculated in Yeti in conjunction HBEFA 3.3 emission factors, accompanied by figures obtained from officially reported emission inventory in 2015 (Diegmann, 2020), accompanied by a breakdown by vehicle emission contributions. While both sets of data are of comparable magnitude, the reduction of aggregate NO_x emissions in Yeti can be attributed to the displacement of vehicles belonging to Euro class III or lower with those of improved exhaust treatment technologies (Chan et al, 2022). Further, the apparent underprediction in PM emissions is due to the use of HBEFA 4.1 non-exhaust PM emission factors, where they were not available publicly in HBEFA 3.3, by retroactively mapping vehicle subsegments from version 4.1 to 3.3.

In terms of contributions, NO_x emissions are expectedly dominated by hot run emissions, while for the cold excess emissions take up the majority of CO emissions. On the other hand, a significant amount of PM emissions originates from non-exhaust sources e.g., abrasion and resuspension. Evaporative emissions (i.e., hot soak, diurnal, and running losses) apply only to HC emissions, but are generally an order of magnitude lower than exhaust HC emissions (i.e., hot run and cold excess). Figure 2 shows the spatial distribution of annual daily mean emissions of NO_x over the road network in Berlin. In general, higher NO_x emissions are observed along trunk roads, such a Frankfurter Allee, where overall vehicle counts are higher.

Table 2. Comparison between Yeti and reported annual aggregate emissions (Diegmann et al, 2020) and breakdown by contributions, from Chan et al (2022)

Emissions [tonnes/day]	NO_x	PM	CO	HC
Official inventory 2015	15.94	1.50	37.38	6.78
Yeti 2015 (HBEFA 3.3)	15.25	0.97	33.83	7.60
Yeti emissions breakdown				
Hot run	14.72	0.21	11.18	1.80
Cold excess	0.53	0.03	22.65	5.03
Evaporative diurnal	- -	- -	- -	0.62
Evaporative hot soak	- -	- -	- -	0.04
Evaporative running losses	- -	- -	- -	0.11
Non-exhaust PM	- -	0.74	- -	- -

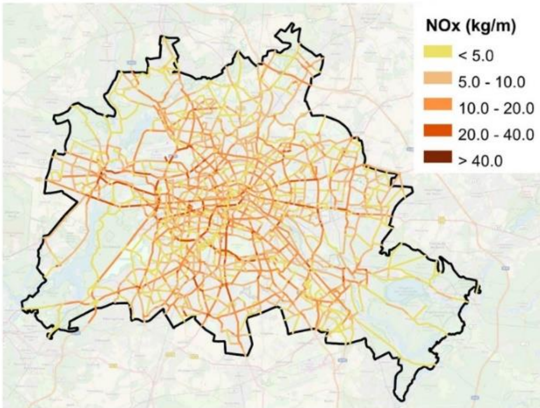

Figure 2. Spatial distribution of annual daily mean NO_x emissions from Yeti, from Chan et al (2022).

NOx EMISSIONS AND CONCENTRATIONS FOR ROADSIDE MEASUREMENT CAMPAIGNS

Yeti is then applied at specific road segments and during periods coinciding with air quality measurement campaigns in Berlin that took place on Frankfurter Allee in August 2018 (Schmitz et al, 2022, in preparation) and Kottbusser Damm in February 2020 (Schmitz et al, 2021), where NO_x concentration measurements from LCSs have been gathered. The diurnal traffic activities profiles for the two measurement locations, provided by the Berlin City Senate for weekday (Mondays to Thursdays) and Sundays / holidays, are shown in Figure 3. The state of traffic flow is categorized using the level of service (LOS) definition under HBEFA 3.3, ranging from free flow (LOS 1), heavy (LOS 2), saturated (LOS 3), and stop-and-go (LOS 4), shown as fractions of the corresponding traffic flow in Figure 3.

The diurnal hourly profiles for Yeti emissions and LCS concentrations for NO_x for both campaigns are illustrated in Figure 4, in addition to the mean hourly urban background NO_x concentrations provided by the Berlin Air Quality Monitoring Network (BLUME). Uncertainty in LCS observational data are estimated in accordance with the process set forth by Schmitz et al (2021a). The disparity in traffic volume between the two sites can be attributed to each road type. Frankfurter Allee is a trunk (primary) road, while Kottbusser Damm serves as a distributor (secondary) road, and they are reflected by the volume of traffic and the corresponding emission levels.

On workdays, the diurnal peaks in observed concentrations roughly coincide with those in the modelled traffic emissions, influenced mainly by local variations in traffic flow and LOS distributions. This can be seen in a decrease in emissions on Frankfurter Allee on weekdays during between 10h and 14h due to a corresponding decrease in stop-and-go traffic (LOS 4). On the other hand, weekday emissions on Kotbusser Damm maintained more or less at peak levels throughout daytime period due to a consistently high level of stop-and-go traffic, representing 27% to 53% of total hourly traffic flow. However, the Sunday and holiday diurnal profiles for NO_x LCS concentrations and Yeti emissions on Frankfurter Allee exhibited highly different characteristics – where the deviation is at highest towards late evening and early morning. This reflects a deviation between the annual mean Sunday / holiday diurnal traffic profile, from which the Yeti emissions were generated, and the actual traffic conditions during the observational period, which is indicative of increase night traffic due to the summer holidays, when the Frankfurter Allee campaign was conducted. Otherwise, the concentrations and modelled emissions on Kottbusser Damm still followed generally the same trend to some degree, when such deviation in traffic activity substantially did not exist.

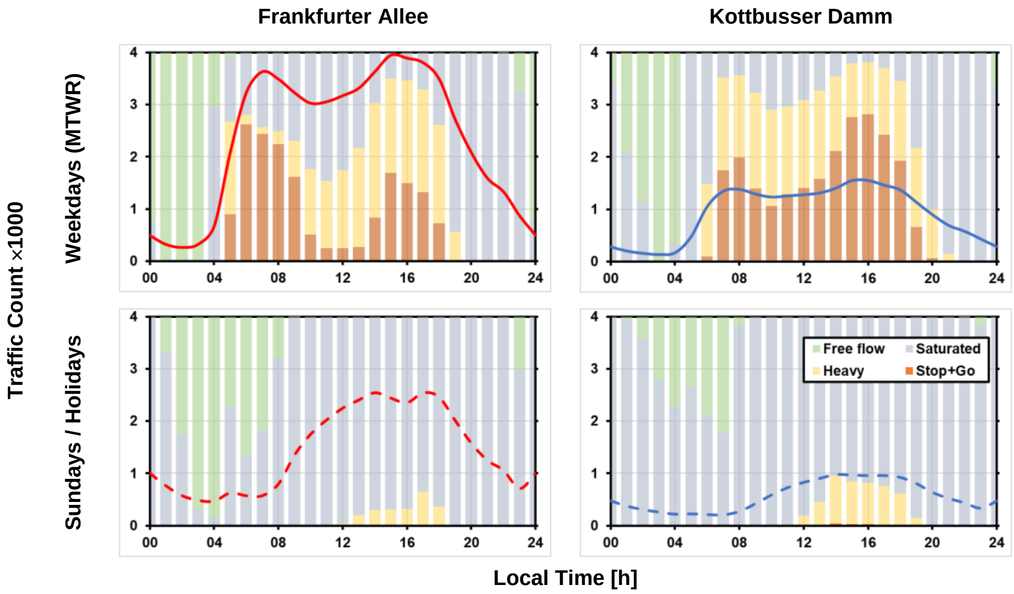

Figure 3. Mean traffic activity profiles (lines) used for calculating emissions on Frankfurter Allee and Kottbusser Damm on typical weekdays and Sundays/holidays. Colors indicate percentages of LOS.

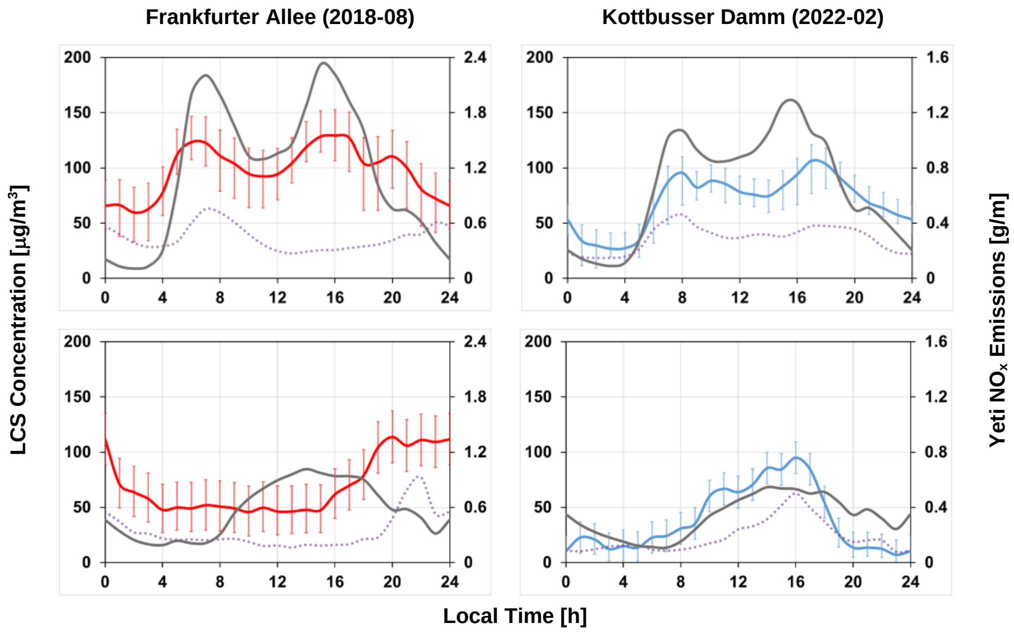

Figure 4. Hourly LCS concentrations and Yeti emissions for NO_x on (L) Frankfurter Allee and (R) Kottbusser Damm over their respective observational periods categorized by (Top) workdays and (Bottom) Sundays and holidays. Key: Colored line with error bars – LCS conentrations; Dashed line – BLUME mean observed urban background concentrations; Gray solid line – Yeti modelled emissions.

CONCLUSIONS AND FUTURE WORK

Using Berlin as the focal point, traffic emissions inventories are produced using Yeti with exhaust and non-exhaust contributions. The computed results are found to be consistent with officially reported emission inventory figures. The methodology is further applied to produce roadside emissions under meteorological conditions representative of specific measurement campaigns conducted on Frankfurter Allee and Kottbusser Damm. The calculated emissions reflect the traffic volume passing through the road, as well as the distribution of the traffic flow state (i.e., LOS) due to, in part, their corresponding functions as primary and secondary roads.

The results of this work can be applied as part of a meso- or urban scale modelling framework, where the prescribed emission profiles, in combination with local meteorological and background concentrations, can generate a concentration map that can be evaluated with observational data collected at the respective measurement campaigns. The diurnal profiles of emissions are found to match the diurnal patterns in NO_2 and O_3 pollution at each experimental site, highlighting the ability of LCS to complement and validate modelling studies. Further, a demographic based approach can be further developed on this framework for acute human pollutant exposure assessment by quantifying diurnal population movements between different microenvironments. In addition, impacts in local pollutant dispersion and transformation resulting from abrupt or continuous changes local traffic activities, can be quantified accordingly.

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