Dear reviewer,

We highly appreciate your valuable feedback and comments, which help us significantly improve our MS. We would especially like to thank you for the good rating in the review criteria of scientific significance, scientific quality, and presentation quality. On your concerns regarding the reproducibility and traceability of the results, we would like to comment as follows.

As noted in the MS and discussed by Arioli et. al. 2020, data availability is a major challenge when developing traffic emission inventories. To a certain extent, our approach is tailored to the data availability in our target city, Munich. But these are not particularly specific data sources - they are also available in a similar form in numerous other cities. Most medium or larger-sized cities maintain macroscopic traffic models for road transport planning and analyzing travel demand scenarios. Additionally, vehicle-specific traffic counting data is also very common but is hardly available to the public as a harmonized data set and is usually restricted to municipal authorities. To the best of the author's knowledge, the largest, harmonized, multi-city counting dataset is UTD19 (Loder et al., 2019), which provides 2 years of traffic counting data for 40 cities globally. It demonstrates the global availability of such data and thus the reproducibility in other cities. Nevertheless, we pass the responsibility for obtaining the required data on to future users of the model. In our specific case, the comprehensive implementation required the use of city-specific, non-English data sources that cannot be shared publicly.

Finally, the HBEFA emission factor database is a well-established and commonly used emission factor database in Europe. It is used directly by several European countries (e.g., Germany, Switzerland, Austria, France, Sweden, Norway) for official reporting and indirectly through integration into other widely used tools such as COPERT. While HBEFA provides average fleet emission factors based on current national fleet statistics for some countries, users can also create custom fleet compositions representative of other countries. This, however, is outside the scope of the presented methodology. We utilized a comprehensive licensed version, which enables detailed differentiation between emission types (including hot exhaust and cold start), pollutants, model years, traffic conditions, and road categories. Due to licensing restrictions, this version cannot be made publicly available. Aggregated HBEFA emission factors are available as a free online version[1].

To support future users, we provide comprehensive documentation and a step-by-step user manual alongside the code repository, available on both GitHub and Zenodo. All computational notebooks specify the necessary procedures, and detailed README files guide users through each stage of implementation. The required data formats are explicitly defined, ensuring a streamlined model application. This MS is submitted to GMD as a model description paper. It includes the main article and a code repository; all provided with enough technical detail to enable reimplementation of the methods in other geographical regions.

We added the following paragraph in the conclusions to communicate the limitations and applicability more clearly.

502	A limitation to the application of the framework is the availability of data in the target city. The model requires a macroscopic traffic model and vehicle-specific counting data for its calculations. However, in well-developed cities, both data sets are usually

[1] https://www.hbefa.net/de/software#online-version

	available and can be requested from the city administration if they are not publicly available. In addition, the HBEFA emission factor database is specifically tailored to European cities and is best applied in countries directly supported by the database, such as Germany, Switzerland, Austria, France, Sweden, and Norway. HBEFA emission factors are based on national vehicle fleets, driving patterns, and fuel characteristics, which may not fully represent conditions in other regions. Still, users can also create custom fleet compositions representative of other countries, although this falls outside the scope of the presented methodology.

1. Reviewer comment: Moreover, the authors' approach to computing road transportation emissions is not novel. Similar methods can be found in the DARTE and Vulcan models (Gately, Hutyra and Sue Wing, 2015; Gurney et al., 2020). In their revision, I would encourage the authors to refer to previous attempts at modeling road transportation emissions and highlight how DRIVE is novel or different.

Response: Both DARTE and Vulcan v3.0 use distinct methods to estimate on-road traffic emissions, utilizing traffic counting data from the US HPMS (Highway Performance Monitoring System). While Vulcan v3.0 redistributes county-scale FFCO2 estimates based on Average Annual Daily Traffic (AADT) counts for higher-level roads and a road-length-based proxy for local roads, DARTE performs a bottom-up calculation based on road-link-level activity data. The methodology of DARTE is similar to that of DRIVE, and it was added to the introduction.

52	DARTE provides a national on-road CO_2 inventory for the US based on average annual daily traffic counts (AADT) from highway counting stations

Furthermore, our novelty is the comprehensive use of vehicle counting data for (1) daily temporal extrapolation of the traffic model on different road types, (2) daily estimation of the vehicle shares on different road types, (3) data-based prediction of the traffic condition at a road-link level to apply traffic-related emission factors. This enables an exact temporal profile and emission calculation and facilitates real-time capability of the method. We also show a data-based uncertainty assessment of the activity data and the emission estimate. In addition, our method is based on free, anonymous data and is applicable in countries in Europe with strict data protection regulations.
We further highlighted our novelties in the introduction.

67	Our novelty is the extensive use of counting data from more than 100 individual traffic detectors across different road types within our city of interest. First, the local counting data is used to extrapolate the traffic model over time to accurately estimate the daily traffic volume on each road segment. Next, we introduce a novel method for data-based and time-resolved calculation of the vehicle share. The vehicle class-specific temporal scaling of traffic activity enables a precise and data-based prediction of traffic conditions to apply traffic-related emission factors.

2. Reviewer comment: The authors calculate emissions for Munich, Germany, using a lot of European and German data. However, they do not state whether the model they present is limited to Germany or Europe.

Response: All methods for processing traffic activity data, including temporal extrapolation, splitting of vehicle shares, and estimation of traffic conditions, can be applied wherever the necessary traffic data is available. Although data availability is a significant limitation, similar traffic models and counting data are prevalent worldwide. The HBEFA emission factor database is specifically tailored to European countries by providing average fleet compositions or average traffic situations based on national statistics. As stated in the introductory comment, users can also create custom fleet compositions representative of other countries. This, however, is outside the scope of the presented methodology. We added the following to the conclusion to communicate the limitations more clearly.

502	A limitation to the application of the framework is the availability of data in the target city. The model requires a macroscopic traffic model and vehicle-specific counting data for its calculations. However, in well-developed cities, both data sets are usually available and can be requested from the city administration if they are not publicly available. In addition, the HBEFA emission factor database is specifically tailored to European cities and is best applied in countries directly supported by the database, such as Germany, Switzerland, Austria, France, Sweden, and Norway. HBEFA emission factors are based on national vehicle fleets, driving patterns, and fuel characteristics, which may not fully represent conditions in other regions. Still, users can also create custom fleet compositions representative of other countries, although this falls outside the scope of the presented methodology.

3. Reviewer comment: The authors refer to HBEFA emission factors in multiple parts of the paper, but there is no citation or reference to a table in the paper.

Response: HBEFA is a licensed product (standard price: 250€, student version: 50€[2]) and is provided as an MS-Access database, which cannot be shared publicly. References to the latest documentation of the database were added to the introduction.

41	The activity data can be combined with a range of emission models such as HBEFA (Handbook Emission Factors for Road Transport) (Notter et al., 2019, 2022).

4. Reviewer comment: The authors use a macroscopic traffic demand model maintained by the City of Munich. Unfortunately, this model is not cited, and the source is not mentioned. It is also unclear whether the model is open source or publicly/freely available.

Response: The traffic model used in this study is not publicly available. It was provided by the city free of charge, along with the model documentation, after signing a data transfer agreement. Yet it is also not necessary for the model to be publicly available; it must exist for the targeted city, as it does for most cities. We clarified the model origin in the MS.

101	The model is not publicly available but was provided free of charge by the city administration after signing a data transfer agreement. Generally, it is

5. Reviewer comment: The authors use traffic counting data from the city administration and BASt. Citations and sources are missing. From the description provided by the authors, it appears that the data sources might be in German. If this is true, it would be an additional hindrance to reproducibility.

Response: Yes, both data sources are in German. Like the macroscopic traffic model, the traffic counting data from the city administration was provided free of charge after signing a data transfer agreement. It is city-specific and cannot be shared publicly. The BASt counting data is publicly available under the CC BY 4.0 license. We clarified the origin of both data sources in the MS.

117	Like the traffic model, the traffic counting data from the city administration is not publicly available but was provided free of charge after signing a data transfer

[2] https://www.hbefa.net/en/order-form

	agreement. Counting data from the BASt is shared publicly under the CC BY 4.0 license.

6. Reviewer comment: It was not clear how the correction factor $k_{i,vc}$ was calculated.

Response: We revised section 2.2.2 for more clarity.

186	We apply additional correction factors because vehicle shares vary spatially, even on roads of the same type. For example, ring motorways have a higher HGV share than radial motorways (routes into the city center). The traffic model provides vehicle class-specific traffic volumes for HGV and LCV. They were used to infer average annual weekday shares $\delta_{i,HGV}^{model}$ and $\delta_{i,LCV}^{model}$ for each road link. Subsequently, we calculate the average weekday share of the reference year 2019 based on the counting data $\delta_{HGV,r}^{count,ref}$ and $\delta_{LCV,r}^{count,ref}$ for each road type. The quotients $\kappa_{i,HGV}$ and $\kappa_{i,LCV}$ between the vehicle share in the traffic model and at the counting stations, aggregated by road category, were used to correct the vehicle share at each road link. The correction factor $\kappa_{i,vc}$ for the remaining vehicle categories is calculated by dividing the total share left after correcting for HGV and LCV by the original, uncorrected share for these categories. This factor ensures that the sum of all shares $\delta_{vc,r}$ equals one after correction.

7. Reviewer comment: Table B2 (Appendix B) describes scaling factors for Passenger Car Units. However, a description of how or why such scaling factors were used is missing.

Response: According to another reviewer's comment, we split the table and moved the passenger car equivalent scaling factors to the related section in the MS and revised the table caption for more clarity.

<table>
<tr><td>209</td><td>The traffic volume for each vehicle class is converted into passenger car equivalents (PCE) to account for differences in vehicle size and impact on traffic flow. This conversion enables the analysis of mixed traffic streams as if they consisted solely of passenger cars. The scaling factors η_{vc} applied are shown in Table 3.

Table 3. Passenger Car Equivalent (PCE) scaling factors n_{vc}. These factors are applied to adjust the mixed traffic stream for the size and flow impact of different vehicle categories.
<table>
<tr><th>vehicle class vc</th><th>PCE factor n_{vc}</th></tr>
<tr><td>PC</td><td>1</td></tr>
<tr><td>MOT</td><td>1</td></tr>
<tr><td>LCV</td><td>1</td></tr>
<tr><td>HGV</td><td>2.5</td></tr>
<tr><td>BUS</td><td>1.75</td></tr>
</table>
</td></tr>
</table>

8. Reviewer comment: All German citations lead to reproducibility issues.

Response: We appreciate the reviewer's emphasis on reproducibility but respectfully disagree with the general statement that all German citations lead to reproducibility issues. We believe the situation is similar to all non-Englisch speaking countries. In the end, the users of our inventories are also the local governments/city authorities. The framework we propose depends on local data sources, which are often only fragmentarily available. In addition, the assessment of the model results was based on local information (e.g., the emissions assessment of the city of Munich). The German sources cited were used as a reference to local data sources, to evaluate national emission factors, and to compare the model results with local or national results. All key data, methods, and analyses are described in detail to ensure transparency and reproducibility. We think the situation is reproducible for many cities in the world.

9. Reviewer comment: In section 3.2, a citation for 'emission regulation' is missing.

Response: We reference the German National Inventory Report (IIR), which shows a similar trend and draws the same conclusion.

282	This change can be attributed to the ongoing development of emissions legislation, which improves the emissions performance of the entire fleet (Gniffke et al. (2024).

10. Reviewer comment: The authors have often used qualitative terms like "a substantial portion". I would encourage them to quantify these.

Response: We revised the MS at multiple locations.

17	Approximately 20-50 % of urban greenhouse gases and air pollutants are associated with transportation, mainly from road vehicles (Chapman, 2007; Edenhofer et al., 2014; Crippa et al., 2021).
31	A sub-kilometer spatial resolution and hourly temporal resolution become essential when inventories are used alongside observations and atmospheric transport models in cities.
310	Based on local activity data, the DRIVE inventory assigns 90 % of the total CO_2 emissions to the main road network (motorway, primary, and secondary roads), reflecting traffic volumes and congestion.

11. Reviewer comment: DRIVE is built for Munich, a city in Germany. The authors do not explain why they focused on this city and did not develop a model for Europe or even a global one.

Response: Clarifications were added to the MS.

77	The framework was developed and implemented for the City of Munich as part of the ICOS Cities project. ICOS Cities aims to develop and evaluate standardized greenhouse gas measurement and services in urban environments, with Munich as one pilot city.

12. Reviewer comment: Related to the above point, the authors do not elaborate on whether this model can be extrapolated to the rest of Europe or the globe.

Response (identical to response on comment 2): All methods for processing traffic activity data, including temporal extrapolation, splitting of vehicle shares, and estimation of traffic conditions, can be applied wherever the necessary traffic data is available. Although data availability is a limitation, similar traffic models and counting data are prevalent worldwide. The HBEFA emission factor database is specifically tailored to European countries by providing average fleet compositions or average traffic situations based on national statistics. As stated in the introductory comment, users can also create custom fleet compositions representative of other countries. This, however, is outside the scope of the presented methodology. We added the following to the conclusion to communicate the limitations more clearly.

502	A limitation to the application of the framework is the availability of data in the target city. The model requires a macroscopic traffic model and vehicle-specific counting data for its calculations. However, in well-developed cities, both data sets are usually available and can be requested from the city administration if they are not publicly available. In addition, the HBEFA emission factor database is specifically tailored to European cities and is best applied in countries directly supported by the database, such as Germany, Switzerland, Austria, France, Sweden, and Norway. HBEFA emission factors are based on national vehicle fleets, driving patterns, and fuel characteristics, which may not fully represent conditions in other regions. Still, users can also create custom fleet compositions representative of other countries, which falls outside the scope of the presented methodology.

13. Reviewer comment: The HBEFA emission factors are national-scale factors, but DRIVE is for a specific city. The authors need to address the variation of factors within a country and/or whether the national-level statistics are representative of the city of Munich.

Response: The base emission factors originate from a national-level database; their parameterization and application were localized to reflect Munich's conditions. HBEFA provides distinct fleet compositions for different area- and road-types. We select emission factors for the area type "urban" and consider the different road types available in the target region.
We fully acknowledge that uncertainty remains due to regional variability and briefly discussed it in the limitations of our uncertainty assessment and the conclusion.

442	Furthermore, on a city level, no specific information is available regarding the fleet composition, such as powertrain technologies and emission concepts, so statistical averages provided in HBEFA are used. These factors can vary significantly based on vehicle type, age, maintenance, and operating conditions, which may not be fully represented in a generalized dataset.
507	Despite the limitations in accurately modeling traffic conditions and the limited knowledge of the local fleet composition, the proposed method provides a comprehensive, data-driven, and scalable approach to exploit static travel demand models and counting data from multiple traffic counting stations to estimate road transport emissions and their uncertainty.

14. Reviewer comment: While introducing the macroscopic traffic demand model for Munich, the authors do not describe its spatial resolution.

Response: Clarifications were added to the MS.

102	The road network is split into road segments, which are represented as lines in the model. The spatial resolution ranges from several tens of meters in densely networked inner-city areas to a kilometer scale on highways.

15. Reviewer comment: In section 2.1.3, the authors need to elaborate on what "manual data curation" and "automatic preprocessing" mean and/or involve.

Response: Clarifications were added to the MS. The required steps for data curation and preprocessing are presented in section 2.1.3. In this chapter, we provide a broad overview while offering detailed comments on our implementation in the related computational notebooks and supplements.

130	The exact steps required depend on the format and quality of the available data and may differ in other cities. The basic procedure is described in the following section.

16. Reviewer comment: Section 2 of the manuscript is the ‘Methodology’ section. However, the authors include some results in this section. These should be moved to the proper section.

Response: We appreciate the observation regarding the inclusion of some results in the methodology section. However, we would like to clarify that these are not intended as final results but as intermediate outcomes to help the reader better understand the method presented. We show the temporal scaling factors applied to extrapolate the traffic model, which includes annual cycles, diurnal cycles, and the applied vehicle shares. We prefer to maintain the current structure, as it enhances comprehension for the readership.

17. Reviewer comment: The universal and/or SI system uses a dot (“.”) as a decimal point and a comma (“,”) as a separator. The authors should use these standards consistently in the manuscript and not use the German system.

Response: Thank you for this comment. We have incorporated the suggested changes.

18. Reviewer comment: Section 3.1 starts talking about ‘LOS’ without introducing or explaining the acronym previously.

Response: We clarified the acronym in section 2.3.

203	HBEFA distinguishes 365 different traffic situations by considering the road type, road gradient, speed limit, area type (rural vs. urban), and the level-of-service (LOS) (Notter et. al., 2019). The road type, gradient, and speed limit are static for each road link, and the area type "urban" is used for the whole city area. The LOS reflects the prevailing traffic condition and is estimated for each road link using the volume-capacity ratio x_i (equation 2) and dedicated thresholds to distinguish between five classes: Freeflow, Heavy, Saturated, Stop&Go, and Stop&Go2 (gridlock with average speeds of 5-10 km/h).

19. Reviewer comment: In the same section, the authors also do not explain ‘Stop & Go’ and ‘Stop & Go 2’.

Response: We clarified the traffic conditions in section 3.1.

258	In the HBEFA, the LOS class Stop&Go describes congestion with frequent stops and slow traffic, while Stop&Go2 stands for heavy congestion or traffic jams characterized by average speeds of 5-10 km/h.

20. Reviewer comment: While describing ‘well-to-tank’ and ‘tank-to-wheel’ emissions, the authors need to explain how they avoid double-counting (e.g., oil tanker trucks can feature in both).

Response: We thank you for pointing out the issue! It should be Well-to-wheel (WTW) emissions in this case, which is the sum of well-to-tank and tank-to-wheel. Consequently, double counting does not need to be discussed in this context. We changed accordingly.

21. Reviewer comment: To scale weekday traffic volume to the weekend, the authors multiply by 0.8. The source (or citation) of this number needs to be explained.

Response: We use the traffic counting data to scale weekday traffic volume to the weekend. The factor of 0.8 is used in the method employed by the responsible department (RKU) in the city administration to account for reduced traffic on weekend days. The city's calculation method is not published, and the factor was shared during an online meeting. Therefore, a referenceable source is not available.

22. Reviewer comment: Figure 6: Different vehicular types have very different magnitudes, so I recommend using different color palettes for each map to demonstrate distinct spatial patterns better. Magnitudes can be contrasted using a simple bar plot or a pie chart.

Response: We appreciate the reviewer's suggestion. A new figure and caption have been created.

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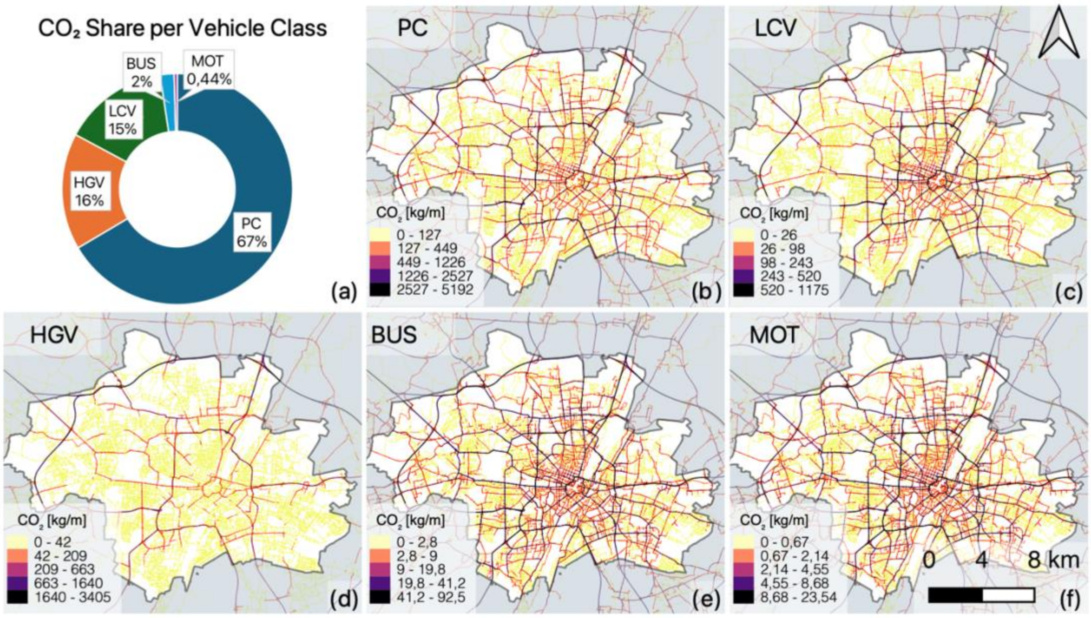


Figure 6. Spatial distribution and total share of $CO_{2,ff+bf}$ emissions of different vehicle classes in 2019. Passenger cars (PC) account for the largest share in emissions (67%). Followed by heavy goods vehicles (16%) and light commercial vehicles (15%). High emission values on the main roads are visible for all vehicle classes. While the emissions from HGV concentrate on main roads and the motorway, other vehicle classes emit on all roads. No distinct spatial patterns can be observed for BUS and MOT due to the absence of spatial information in the traffic model. In total, buses and motorcycles only constitute about 3% of Munich's emissions.

23. Reviewer comment: Figure 7: The top row figures lack a color bar, and the bottom row figures need a quantitative color bar rather than a qualitative one. Moreover, I recommend plotting a percentage relative difference map to show spatial patterns of differences.

Response: Again, we appreciate the reviewer's suggestions and updated the figure and related caption.

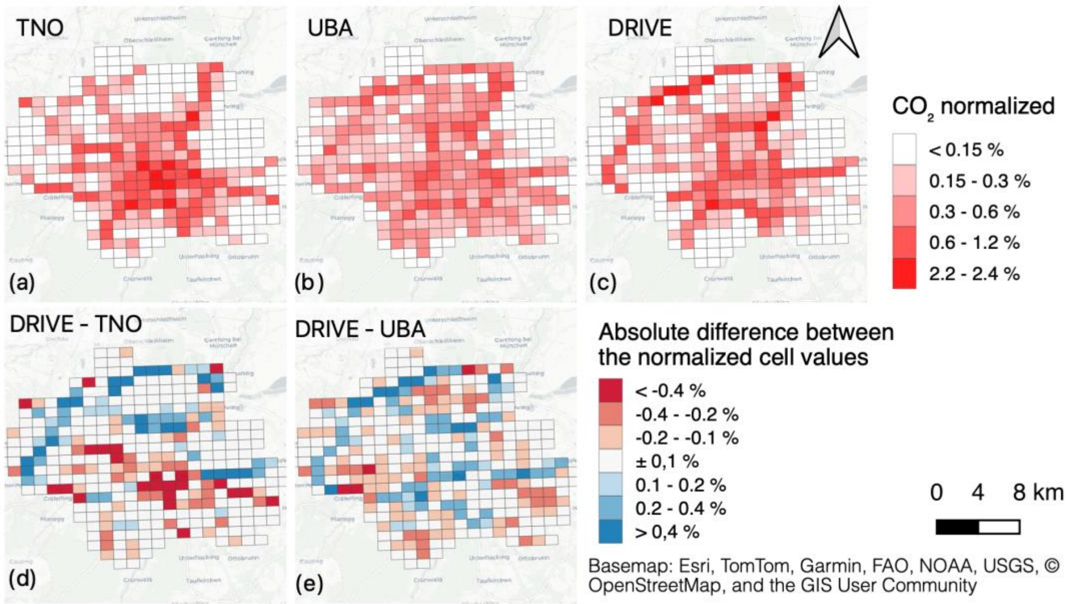
304	

Figure 7. Comparison of the spatial distribution of $CO_{2,ff+bf}$ for the traffic sector from three inventory datasets. Plots (a)-(c) are normalized to the respective total values of the city to present them on a uniform scale. Therefore, each cell value represents the fraction of the total emissions attributed to this cell. TNO (a) attributes major emissions to the city center, i.e., the place with the highest population density. The UBA shows a more homogeneous spatial distribution, and compared to the DRIVE inventory, roads with high traffic volumes are less pronounced. The difference plots in (d) and (e) show the absolute difference between the normalized cell values. They indicate that UBA and TNO attribute lower emissions (blue) to parts of the main road network and higher emissions (red) to minor roads. DRIVE uses validated local traffic activity data, more accurately representing the spatial distribution of related traffic emissions. Both downscaled inventories reflect the incorporated spatial proxies.

Sources

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