EXTENDED ABSTRACT

Vehicle induced non-exhaust dust emissions in emission inventories and air quality modelling

Niko Karvosenoja, Finnish Environment Institute Syke

niko.karvosenoja@syke.fi

Tommi Forsberg, Ana Stojiljkovic, Finnish Environment Institute Syke

Abstract

Spatially disaggregated national emission inventories are used as input in air quality (AQ) modelling. It is crucial for AQ modelers to adequately understand the coverage and uncertainties of emission inventories for non-exhaust PM emissions from road transport, where the definition of the emission source is not unambigiuous, and the emissions are highly country specific. This study presents variable ways of estimating non-exhaust PM emissions and critically explores the sources of uncertainty. The study concentrates particularly to the Nordic and other countries where wintertime friction control methods have a remarkable impact on the emissions. An advanced method to provide with more reliable emission factors based on a road dust model is presented. Recommendations for both modelers and to improve EMEP/EEA guidebook are provided.

Introduction

National air pollution emission inventories that are reported annually to several international bodies, e.g. UNECE CLRTAP and EU NECD, quantify emissions from anthropogenic sources. The inventories give a comprehensive picture of past trends and future directions of air pollution emissions from different economic sectors and countries. In addition, spatially disaggregated national emission inventories are typically used as input in regional level AQ modelling. Therefore, it is crucial for AQ modelers to adequately understand the coverage and uncertainties of emission inventories, especially in sectors such as non-exhaust PM emissions from road transport, where the definition of the emission source is not unambigiuous, and the emissions are highly country specific. Especially in the Nordic countries, the non-exhaust emissions are high due to winter time friction control, e.g. the use of studded tyres and road sanding. Based on national emission inventory, non-exhaust emissions from road transport in Finland in 2023 account for 25% and 8% of the country total emissions of PM10 and PM2.5, respectively.

The default methodologies and emission factors for different sources, and thus the coverage of anthropogenic emissions, are defined in the EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA 2023). For non-exhaust PM emissions from road transport, it is defined to include direct wear emissions from road surface, tires and brakes. However, in real life, a fraction of PM emissions induced by road transport is

resuspension of dust from road surfaces, which particles might be a result of vehicle-induced wear or of other origin deposited on roads. EMEP/EEA guidebook is not unambiguous on how to treat resuspension emissions in emission inventories. Therefore, calculation procedures and definitions of non-exhaust PM might differ from country to country, within the definitions of the guidebook. Furthermore, there are various practices how non-exhaust emissions are treated in air quality models: including or omitting the values in emission inventories, using additional proxies or parametrizations to complement the inadequate or missing sources etc. Therefore, there is a risk of double-counting or missing important emissions in the modelling, if the understanding of emission inventories is not adequate.

In the following, we will present the variable ways of estimating non-exhaust PM emissions with measurements and modelling, and assess the methods applied in the estimates in emission inventories, particularly in the case of the Nordic countries where wintertime friction control methods greatly impact the emissions.

Description of the emission source and coverage in emission inventory

Non-exhaust PM emissions refer to (1) wear products of tires, brakes and road surface, of which a fraction is made airborne by wind and the movement of vehicles. In addition, in countries where wintertime friction control measures are applied, (2) materials spread on roads such as salt or sand, contribute to non-exhaust PM emissions (Kupiainen et al. 2004). In addition to the materials directly linked to the transport system, the wake of vehicles lifts (3) particles of other origin deposited on roads from air or other means, e.g. dust from construction sites spread upon vehicle tires.

Which of the above emissions are or should be included in the national emission inventories, and how these should be treated in AQ modelling is not unambigiuous. The EMEP/EEA emission inventory guidebook describes the source: *"The focus is on primary particles — in other words, those particles emitted directly because of the wear of surfaces — and not those resulting from the resuspension of the previously deposited material."* Obviously, the wear products category (1) is the main focus, and the resuspension, which should be excluded from the emission inventories, refers to the category (3). On the other hand, the guidebook states that while the default emission factors given are based on measurements that cannot fully distinguish between "*freshly emitted*" non-exhaust particles and resuspension, "…*a part of re-suspension is included in the proposed emissions factors.*" (more about measurements and other methods to determine emission factors in the next chapter). The guidebook does not give clear instructions on how to treat PM emissions that originate from materials linked to the friction control and maintenance of roads, i.e. category (2).

A further complication in the distinction between "*freshly emitted*" and "*resuspension of the previously deposited material*" arises from the fact that non-exhaust PM emissions are temporally highly dependent on weather parameters. When road surfaces are wet (or covered by snow or ice) the emissions into air are negligible. However, the road surface wear can be even enhanced at wet conditions compared to dry surfaces. The wear products

from rainy periods, not suspended at the time of the wear, would be partly removed from road surfaces by runoff water and partly deposited on roads and roadsides and suspended later when the surfaces dry out. In the case of snowy and icy conditions similar process can occur amplified: the road surfaces typically alternate between icy, wet and dry during winter, and the wear of the surface is intensified due to the use of studded tires and/or sanding, causing a remarkable dust load. The release of the dust load is most pronounced during spring months when the roads and roadsides totally melt and dry, and the monthly average non-exhaust PM emission factors are typically up to six times higher than the average in other times of the year. To what extent these phenomena are or should be covered in national emission inventories is not fully clear.

The EMEP/EEA emission inventory guidebook (2023, with 2024 update for the non-exhaust emissions section) provides default emission factors for two-tier emission calculation. Tier 1 assumes a linear relation between activity data (mileage driven by vehicle category) and emission factors, while Tier 2 takes speed-dependency into account for tire and brake wear. It is advised that Tier 2 must be used if non-exhaust emissions represent a key source in a country, or speed-dependent activity data are available. For now, Tier 3 method has not been developed.

As mentioned, non-exhaust emissions can be highly country specific. The inventory guidebook's non-exhaust section does not give advice for the use of national methods. However, in the general sections in the guidebook, Tier 2 method is defined to "*apply country-specific emission factors which need to be developed, using country-specific information*". In the Nordic countries, different national methods are applied. In Finland, a crude method is applied at the moment for road wear that assumes a 50-fold emission factor for studded tires compared to friction or summer tires. As the current national method has been assessed to be too simplified, a new methodology is in the development to derive country- and area-specific emission factors based on a detailed road dust model NORTRIP (more details about the model in the next chapter).

Methods to determine emission factors and future improvements

The non-exhaust emission factors in the EMEP/EEA guidebook are defined based on a literature review, where the two main methods to determine emission factors have been (1) roadside receptor modelling and (2) estimates of total wear of tires, brakes and roads together with size distributions to derive the airborne fraction, the second one providing mainly a point for comparing and cross-checking the highly variable emission factors from receptor modelling. The methods were stated to entail considerable uncertainties both in the absolute values of emission factors and in the distinction between "direct" and "resuspended" emissions.

As a measure for future improvement the guidebook mentions on-road measurements using instrumented vehicles under real world driving conditions. Such mobile laboratories have been used in Finland and, to lesser extent, other Nordic countries since 2005 (Figure 1). The vehicles contain PM10 and PM2.5 mass concentration

measurements using TEOM and DustTrak devices and Optical Particle Sizer from 300 nm to 10 µm for particle size distribution.

The long-term measurements and other expertise on road dust in Finland and other Nordic countries have been exploited to develop NORTRIP (NOn-exhaust Road TRaffic Induced Particle emissions) model (Figure 2). NORTRIP is a process-based emission model developed by the Norwegian Institute for Air Research (NILU) with collaborators from Finland, Sweden and Denmark to simulate emissions from road, brake, and tyre wear. It accounts for the accumulation and suspension of particulate matter on road surfaces, influenced by meteorological conditions, road maintenance activities (e.g., salting, sanding), and surface moisture. The model integrates traffic data, weather forecasts, and road surface conditions to estimate PM emissions. NORTRIP model was used to aggregate non-exhaust emission factors for different meteorological zones in Finland for the modelling use in the FRES model of Syke (Paunu et al. 2024), and there is a process going on to extract emission factors to be used in national emission inventories in all the Nordic countries in the future.

Conclusions and recommendations

Vehicle induced non-exhaust dust is a major source of PM emissions that can account for up to 25 and 8% of the total PM10 and PM2.5, respectively, in countries where wintertime friction control methods such as use of studded tires and road sanding are applied.

When spatially and temporally defined emission fields are used as input in AQ modelling, the anthropogenic emission input is typically taken from emission inventories that can be modified or supplemented with model parametrizations. In the case of vehicle induced non-exhaust PM emissions that are highly country specific, not unambiguously defined and not fully covered by national emission inventories, there is a risk of omitting (or double counting) remarkable quantities of the emissions. To avoid these risks, AQ modelers should be aware, at least, of the fact that resuspension emissions are not fully covered by national emission inventories. Possibly, the resuspension caused by vehicle flows could be considered by, e.g., parametrizations within the AQ model. Another option could be to calculate all vehicle induced dust emissions within the AQ modeling system and exclude the emissions from the national emission inventory data set. In this case, however, important national knowledge from the inventories might be lost.

The temporal profiles of non-exhaust emissions from road transport are highly dependent on meteorology and may vastly differ from the temporal profiles of exhaust emissions. This should be considered in modelling when applying hourly and daily profiles, but also in monthly profiles in the case of countries with icy winter conditions.

To help AQ modelers to avoid these pitfalls, emission inventory guidebook should pay attention to unambiguous definition and adequate coverage of the non-exhaust dust sources. Concise and easily accessible meta-data about the coverage and shortcomings of the source should be provided within each of the country emission inventories. To help national emission inventory experts to develop more advanced country-specific methods, the guidebook should encourage this by providing guidelines, possibly as Tier 3 method.

Figure 1. Mobile laboratories by Metropolia University of Applied Sciences to measure road transport emissions in real world driving conditions.

Figure 2. Modelling of road dust emissions and source contributions using NOn-exhaust Road TRaffic Induced Particle emissions model NORTRIP (Denby et al. 2013a,b).

Acknowledgements

References

Denby, B. R. et al. 2013a. A coupled road dust and surface moisture model to predict non-exhaust road traffic induced particle emissions (NORTRIP). Part 1: Road dust loading and suspension modelling, Atmos. Environ., 77, 283–300, https://doi.org/10.1016/j.atmosenv.2013.04.069.

Denby, B. R. et al. 2013b. A coupled road dust and surface moisture model to predict non-exhaust road traffic induced particle emissions (NORTRIP). Part 2: Surface moisture and salt impact modelling. Atmospheric Environment, 81, 485-503, https://doi.org/10.1016/j.atmosenv.2013.09.003.

EMEP/EEA 2023. EMEP/EEA air pollutant emission inventory guidebook 2023. EEA Report 06/2023. (with 2024 update for the 1.A.3.b.vi-vii Road tyre and brake wear section) https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2023

Kupiainen, K. et al. 2004. The Effect of Traction Sanding on Urban Suspended Particles in Finland. Environ Monit Assess 93, 287–300. https://doi.org/10.1023/B:EMAS.0000016799.19441.0e

Paunu et al. 2024. Air pollution emission inventory using national high-resolution spatial parameters for the Nordic countries and analysis of PM2.5 spatial distribution for road transport and machinery and off-road sectors, Earth Syst. Sci. Data, 16, 1453–1474, https://doi.org/10.5194/essd-16-1453-2024.