Response to anonymous Reviewer #1

We would like to thank the anonymous Reviewer #1 for his/her comments and suggestions for improving this manuscript. Our response to the reviewer's comments is provided below. The reviewer's comments are written in italic.

This paper has used road dust emission models to investigate the impact of studded tyre use on PM10 concentrations. The science is sound and the paper warrants publication once the following have been addressed:

Introduction In the Introduction it is mentioned that non-exhaust emissions are one of the most important causes of high roadside PM10 concentrations for several decades. However not details their overall contribution is given. Recent figures from the European Environment Agency state that ". In 2016, the non-exhaust emissions of
PM2.5 constituted 42 % of emissions from the road transport sector, compared with17 % in 2000 (for PM10, the contribution increased from 30 % in 2000 to 60 % in2016)". https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-ofair-pollutants-8/transport-emissions-of-air-pollutants-6
Answer:
The reviewer is correct. Overall contribution from the suggested source has been included in the revised manuscript with a sentence: 'Estimated relative contribution of non-exhaust emissions to the emissions of PM_{10} from road transport increased from 30 % in 2000 to 60 % in 2016.' Reference to the European Environment Agency will be included.

Traffic data It's not clear what traffic speed was used in the models. A number of mentioned (weekday daytime, night-time, weekly and monthly). Given that emissions are speed dependent this is important. If there's increased braking and accelerating) this results in additional wear of both the tyre and the road surface. As such would one solution to reduce PM10 concentrations be a lower speed limit? It is noted that it is acknowledge that the NORTRIP model does not account for congested driving conditions but what likely error does this introduce?
Answer:
In order to clarify derivation of the traffic speed for Hämeentie, we have rewritten the sentence in question in the following manner: 'The vehicle speeds for the night-time hours and weekend days were evaluated using the measured diurnal and weekly cycles of vehicle speeds in Runeberginkatu (located 2 km southwest from Hämeentie) in 2004.' Fig. 1 below shows derived average diurnal cycle of traffic volume and speed for years 2007-2009 and 2014. Modelled emissions and PM10 concentrations resemble the diurnal cycle of traffic volume.

We agree with the reviewer that the reduction of the speed limit would be a potential abatement measure for the ambient air PM10 concentrations. However, for Hämeentie where average daily vehicle speed is already very low (26 km/h), and its further reduction would not be possible in practise. We therefore considered it more important to investigating impact of studded tyre reduction and traction control measures.

The congestion could be a source of error but no measurements are available to quantify this. The treatment of the road wear in the NORTRIP model is based on vehicular speed and not on acceleration. Additionally, as acknowledged in the section 3.2.1 of the revised manuscript, the form of the dependency of road wear on vehicle speed in low speed conditions is uncertain.

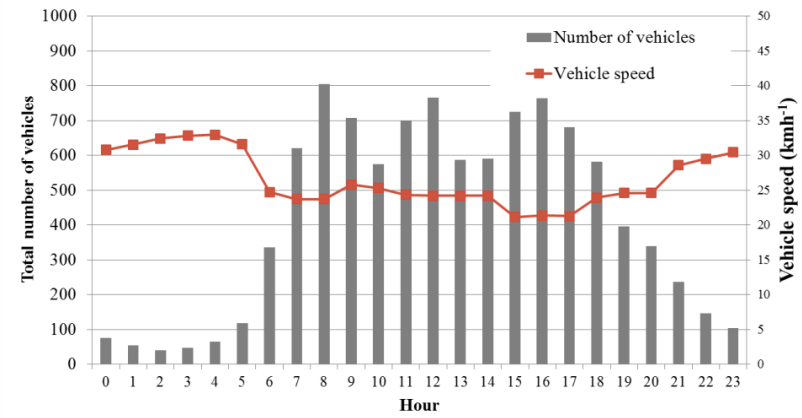

Figure 1. Diurnal cycle of traffic volume and vehicle speed at Hämeentie averaged over the four years (2007-2009 and 2014).

Meteorological data How is snowfall taken into account with total precipitation?

Answer:

In NORTRIP model input, precipitation is included as either rain (mm/h) or snow (mm/h). In case when only information about the total precipitation is available, snowfall is defined as being precipitation for atmospheric temperatures below zero. However, if data is available separately for the precipitation of rain and snow, these values can be used as such in the NORTRIP model input. The FORE model allows one input value for precipitation (mm/h), i.e., it does not separate between solid and liquid water precipitation. We will include a description of these to the revised manuscript.

Road maintenance data Are the roads washed during the summer? Street cleaning is shown in Table 3 but not Figure 3 Does snow ploughing have any impact?

Answer:

Information about the street cleaning and ploughing events will be added to the Figure 3 in the revised manuscript. Street cleaning is typically conducted after the cold season, as soon as weather permits, i.e. when freezing temperatures subside in spring. For the years considered in this study, all street cleaning activities took place from mid-March until the end of April. In the road dust emission modelling, ploughing was taken into account only by the NORTRIP model. Ploughing reduces the amount of dust on the street surface with the predefined efficiency factor, which is expected to be very low. In the NORTRIP model application for Hämeentie, this is set to be 1% and 0.1% for the non-suspendable and suspendable fraction of the road dust, respectively. The same efficiency has been assumed for the street cleaning. We have included a description of the street cleaning and ploughing efficiencies to the section 2.2.1 in the revised manuscript.

The road dust emission model NORTRIP Need to justify why the amount of suspendable material in sand was set to 2%.

Answer:

Measurements of the sand size distribution are required in order to identify fraction of the sanding material that is available for suspension. The data concerning this aspect of sanding material quality is often limited, if available at all. In this study we have used information about the size distribution for sand used in Helsinki Metropolitan Area reported in Kulovuori et al. (2019) that have found amount of suspendable fraction (<200µm) to range from 0.4 % to 2.5 %. Lower suspendable fraction has been found for wet sieved sanding material and higher for the sand with unknown sieving status. We have assumed value of 2%. The reference has been added to the revised manuscript and quality of sanding material will been discussed in Section 3.3.

Evaluation of the vehicular exhaust emissions given that the paper relates to PM10 emissions why not use PM10 emissions instead of those of PM2.5?

Answer:

LIPASTO emission modelling system that was used for evaluation of the exhaust emissions does not separate PM_{10} and $PM_{2.5}$ exhaust particle emissions. These emissions are addressed as 'exhaust particulate matter emissions', i.e. 'exhaust PM emissions'. Only a very small fraction (or none) of the exhaust emissions are in the coarse particle range (larger than 2.5 micrometres). This has been corrected in the revised manuscript.

Results and discussion To save any confusion for readers specify seasons as winter (1 Jan to 14 March etc)

Answer:

The suggested correction has been included in the revised manuscript.

Comparison of predicted and measured PM10 concentrations state the statistical significance of R2 values.

Answer:

More detailed statistical analyses, and their interpretation, have been included as annex in the revised manuscript.

General discussion There should be some consideration of alternatives to road salt given the numerous papers which have highlighted the environmental impact of it.

Answer:

In Finland, sanding is considered as the main alternative traction control method in the areas with sensitive environment to the use of salt (e.g., in areas, in which the ground water supplies could be contaminated). The use of wood chips has been examined by the Finnish Transport Infrastructure Agency as an alternative traction control method but only for the bicycle lanes. This will be mentioned in the section 3.3 in the revised manuscript.

Studless winter tyres are becoming more popular – should Finland make this on option?

Answer:

The reduction of studded tyre use is a feasible option for the road dust abatement, also in Finland. However, policy measures, such as studded tyre charges in Norway or studded tyre ban in individual streets in Sweden, have not been introduced in Finland. Non-studded winter tyres have not gained a wider popularity among drivers, apart from their moderate increasing trend in the Helsinki metropolitan area. Average share of light duty vehicles with studded tyres observed between December and February (inclusive) decreased from 80% in the season2014/2015 to 75% in the season 2018/2019 in favour of the non-studded winter tyres.

In this study, we have demonstrated the potential to reduce the impact of non-exhaust traffic induced particle emissions on ambient air PM10 concentrations, with transition from studded to non-studded winter tyres (Section 3.3). In studied cases with reduced number of vehicles using studded tyres, studded tyres were reduced in favour of non-studded winter tyres. More discussion will be added on this subject to the revised manuscript.

There should be a discussion about the impact of different road surfaces onPM10 emissions (e.g. concrete, more durable asphalt). It is also important to highlight that the wear of the road surface increases with moisture level. Additionally after salting the road surface remains wet for longer periods and so road wear increases.

Answer:

The reviewer is correct. We have expanded Section 3.2.1 with more information about the wear rates used in this study in context of the road surface characteristics. At the same time, impact of road surface moisture on the wear is mentioned. Added paragraph is as follows:' In this study, we have used wear rates derived for the reference pavement type (SMA16 with porphyry from Älvdalen) in the Swedish road wear model (Jacobson and Wågberg, 2007) which is one of the most wear resistant asphalt pavements used in Sweden. The wear rates in the Swedish road wear model are based on laboratory and field experiments and provide an average under both dry and wet conditions. However, influence of surface moisture that increases the wear is not

directly considered in the model calculations. Denby et al. 2013a estimated the typical wear rates to be from 2 to 5 g km^{-1} veh^{-1} and acknowledged significantly variation of these values depending on the material used with increased wear rates for roads with the poor quality surfaces.'
Additionally, improvement of pavement quality in terms of the rock aggregate size and durability, or use of alternative pavements has been mentioned as a factor that will enhance air quality benefits along with the studded tyre reduction. Following paragraph has been added to the section 3.3: 'The effect of the studded tyres reductions can be enhanced by improving the quality of road surfaces. Larger aggregate size from rocks that are more resistant to wear in the asphalt pavements, or use of alternative pavements can reduce PM10 emissions (Gustafsson et al. 2009; Gustafsson and Johansson 2012) and therefore, have positive effect on the ambient air PM10 concentrations.'

Typographical Check the spelling of "tyres" as in some places there is "tires". I would also prefer the use of "roads" rather than "pavements"
Answer:
Suggested corrections regarding the spelling and terminology have been included in the revised manuscript, e.g. 'pavement wear' has been replaced with 'road wear'.

The road dust emission model FORE The model uses empirical reference emission factors which depend on the : : :. (note factors and depend)
Answer:
The sentence in question has been replaced with the following: 'The model uses empirical reference emission factors, which have different values depending on the time of the year, the mass fraction of particles (PM_{10} or $PM_{2.5}$), and the traffic environment (urban or highway). The reference emission factor will be higher for the time of the year when sanding and studded tyres are commonly used (referred to as 'sanding period') compared to the rest of the year ('non-sanding period').'

References:

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