UK NH_3 emissions from road transport

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Abstract

To cover importance of NH3, large database of measurements, both top-down and bottom-up methods, estimated total UK emissions

Introduction

Ammonia in the atmosphere (particle formation, air quality, human health, nitrogen deposition). Enhancement of NPF, growth rates.

Sources of ammonia. Focus weighted onto agriculture, major source on a global scale. But ammonia can also come from vehicle emissions - TWC and SCR.

Regulation of NOx etc - project to decrease even further, whereas no regulation for NH3 (except Euro V1 HGV). NH3 becoming a more dominant component of vehicle emissions yet our understanding of it is relatively limited in comparison.

Current input to the inventories is based on limited data (UK/Europe) and is based on lab/PEMS tests? under a limited set of conditions.

In reality, there are a wide range of factors affecting NH3 emissions (spatial, temporal, vehicle characteristics) and we need comprehensive data that captures this complexity and better reflects vehicular NH3 in the real world.

One way to do this can be through the use of remote sensing data - explain why in more detail. This has proven useful/informative in other continents (US/China) - refer to previous studies and key outcomes.

If we can better understand NH3 from vehicle emissions, we can use this information to challenge and potentially improve the existing inventory. This is particularly important in the context of vehicle emissions due to the co-emission of NH3 with NOx in urban areas - efficient route to particle formation.

What are we specifically going to do in this study - use remote sensing data (2017 onwards, thousands of vehicles..) to carry out top-down and bottom-up estimation of NH3 from vehicle emissions. Help to understand existing inventories used in atmospheric chemical transport modelling. Demonstrate the importance of vehicular NH3 in UK/Europe.

Reference example[?,?]

Materials and methods

Instrumentation

Two spectroscopic remote sensing (RS) instruments were used to measure vehicle emissions: the Fuel Efficiency Automobile Test (FEAT) instrument developed by the University of Denver and the Opus AccuScan RSD 5000. The development and operation of the FEAT instrument has been described extensively in the literature.

Both instruments consist of a light source (collinear beams of IR and UV light) and a detector unit.

Principle of operation (IR/UV, wavelengths). Pollutant ratios to CO2. Calibration.

Measurement locations

Locations/site information, dates, daylight hours, dry conditions. Numbers of measurements.

Vehicle technical information

Technical information and mileage information. Information to derive VSP.

Methods to estimate vehicular NH_3 emissions

There are two main approaches used in the compilation of emission inventories, referred to as "top-down" and "bottom-up". The top-down approach typically starts with quantities such as fuel use at a national level, which is then apportioned to smaller geographic scales. In the bottom-up approach, data are generally used at a local scale and then aggregated to a national scale. For example, emission factors for individual vehicle types can be combined with activity data such as annual vehicle km to derive a total annual emission. Both approaches have merit and often the approach used is determined by the availability of data. In inventories such as the UK National Atmospheric Emissions Inventory (NAEI), the top-down approach is used to estimate emissions at finer spatial scales down to 1 km^2.

The combined use of top-down and bottom-up approaches can provide an effective means of inventory verification and a check on whether there is consistency between two different methods to estimate the same quantity. The effectiveness of using the two approaches in quantifying emissions totals depends on the pollutant and emission sector in question. In the current context, the focus is on gasoline emissions of NH_3. The top-down approach starts with an estimate of total UK gasoline fuel sales, which is a quantity known to a high degree of accuracy [say something on this]. The advantage of considering vehicular gasoline is that its use is strongly dominated by a single sector of passenger cars. Conversely, diesel fuel is used in a wide range of vehicle types (e.g. passenger cars, light commercial vehicles and heavy duty vehicles). Considering emissions from diesel vehicles therefore includes an extra step of allocating total fuel sales between types of vehicle, which introduces additional uncertainty.

Top-down estimate

UK gasoline fuel sales for 2017/2018 were obtained from the annual estimates of total consumption of road fuels produced by the Department for Business, Energy and Industrial Strategy (BEIS). Refer to ENV0101. The estimates are based on inland fuel deliveries.

Calculation of CO2 emissions from mass of fuel.

Assume that petrol is 87 percent carbon (870 g of carbon per kg of fuel). Mass CO2 emitted from kg of fuel = 870*0.99*(44/12) = 3158.1 kg CO2. 2017. 11 million tonnes of fuel consumed by petrol cars. Equates to 34.7 million tonnes of CO2.

An example equation can be found in Equation **??**.

$$EF_{gkg} = 870 \times 0.99 \times \frac{44}{12} \tag{1}$$

Bottom-up estimate

The methodology for calculating distance-based emission factors from vehicle emission remote sensing data is outlined in detail in **?** but are briefly outlined here.

Firstly, total engine power is determined using a physics-based approach, calculating the total power demand on the vehicle engine as the sum of the power to accelerate the vehicle, overcome both rolling and air resistance, climb the gradient and power any auxiliary devices, with an appreciation for losses in the transmission. This calculation is given in Equation **??**, where m is the vehicle mass in $tonnes$, a is the vehicle acceleration in $m\ s^{-2}$, R_0 and R_1 are road load coefficients in N and $N\ (m\ s^{-1})^{-1}$ respectively, v is the vehicle velocity in $m\ s^{-1}$, C_d is the dimensionless aerodynamic drag coefficient, A is the frontal surface area of the vehicle in m^2, ρ is the density of air in $kg\ m^{-3}$, g is the acceleration due to gravity in $m\ s^{-2}$, and $Grad$ is the gradient of the road expressed as altitude divided by distance travelled.

$$P_{total} = \left[\underbrace{m \times a \times 1.04}_{P_{accel}} + \overbrace{R_0 + R_1 \times v}^{P_{roll}} + \underbrace{0.5 \times C_d \times A \times \rho \times v^2}_{P_{air}} + \overbrace{m \times g \times Grad}^{P_{grad}} \right] \times \underbrace{1.08}_{P_{trans}} \times v + \overbrace{2500}^{P_{aux}} \tag{2}$$

Vehicle mass was assumed to be the kerb weight plus an addition 150 kg, g was taken to be

9.81 $m\ s^{-2}$ and ρ was taken to be 1.2 $kg\ m^{-3}$. As none of the coefficients (R_0, R_1 or C_d) were known, the "generic", per-segment values provided in **?** were used. Vehicle segments were assigned using the classification tree provided in the same study.

Calculated engine power can then be converted into VSP through division by vehicle mass. Through a linear model relating normalised fuel consumption in $g\ hr^{-1}$ (FC_{gh}), and VSP fit through the use of the Passenger Car and Heavy Duty Emissions Model (PHEM)[?] , fuel consumption can be estimated, with negative fuel consumption values being set to zero. Per-segment "generic" parameters were once again used for the slope and intercept terms, M and C. As these parameters were based on Euro 5 and 6 vehicles, fuek consumption values for Euro 3 and 4 vehicles were increased by 5% to approximate poorer fuel efficiency. With fuel consumption, it is then facile to calculate a time-based emission factor (EF_{gs}) from a fuel-based one (EF_{gkg}). These steps are illustrated in Equations **??** and **??**.

$$FC_{gh} = (M \times VSP + C)\,/m \tag{3}$$

$$EF_{gs} = EF_{gkg} \times (FC_{gh}/3600000) \tag{4}$$

Calculating *instantaneous* distance-based emission factors by simply dividing EF_{gs} by vehicle speed would likely over-report ammonia emissions due to remote sensing requiring vehicles to be under load. Generalised Additive Models (GAMs) were fit to relate $EF_{gs}(NH_3$ to VSP in order to map remote sensing measurements over a drive cycle. The chosen drive cycle was taken from a 1Hz Real Driving Emissions (RDE) Test from Portable Emission Measurement System (PEMS) undertaken by the UK Department for Transport in 2016.[?] The maximum VSP value for this drive cycle was 36.1 $kW\ t^{-1}$, so GAMs were fitted between 0 and 37 $kW\ t^{-1}$. Emissions from negative VSPs were assumed to be zero.

With 1Hz modelled EF_gs values, one can calculate distance-based emission factors (EG_gkm) simply through summing all EF_gs values across the drive cycle and dividing by the total distance. The outcome from this is a EF_gkm value based on remote sensing measurements which includes an appreciation for conditions which remote sensing is not suited to measure – e.g. idling and braking.

Distance-based emission factors calculated for different combinations of fuel type and Euro Class can then be employed to calculate a “bottom-up” estimation. UK mileage data for... Talk about distance data Naomi found

Results and discussion

Total UK NH3 estimates

Compare the total UK estimates from the top-down and bottom-up approaches (approx 7 kt).

Discussion of differences and merits.

Top-down - fuel sales is accurate. Works best for petrol because we know that almost all of petrol sold is used in cars (small amount for LGVs). We also have accurate diesel sales, but assigning the proportion of diesel consumed by cars, LGVs, HGVs, buses/coaches introduces a level of uncertainty (NAEI estimate available). So it is good to do the comparison with the bottom-down for petrol cars initially.

Bottom-up - to obtain distance based EFs we have to make some approximation of the fuel consumption at the time of emission measurement. Distance based vary more significantly with engine load so we also have to consider if an adjustment for VSP is necessary. This approach can be useful for petrol and diesel vehicles however, because we measure both by remote sensing and have a good grasp of the annual vehicle km associated with each (from either national statistics or potentially MOT mileage information).

Comparison with NAEI

Brief description of NH3 in the NAEI e.g. proportion of total estimated to be from road transport, and the trend up to today. Show NH3 according to fuel type, vehicle type and explain how it is estimated.

How do the proportions of NAEI NH3 from fuel type / driving condition (urban, rural, motorway) compare to our estimates.

Characterisation of NH3 emissions

Key information from characteristics study that is relevant / helps explain the two approaches. Some of this might go earlier in the results (Euro standard, VSP).

Atmospheric implications

This study gives us a better insight into the absolute value of NH3 estimate and the fraction of vehicle NH3 in terms of the UK total, which is important in terms of the air quality implications.

But we can also use remote sensing to further study the characteristics of vehicle NH3 which will help to understand the spatial and temporal variation of vehicle emissions. Urban areas, seasonal patterns, existing pollution levels. Future work - input to chemical transport model to investigate impact of vehicle NH3, secondary pollutants.

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Supporting Information Available

Graphical TOC Entry