27th ITS World Congress, Hamburg, Germany, 11-15 October 2021

Paper ID #

Augmented emission maps are an essential new tool to give individualised emission feedback

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Abstract

Pollutant emissions produced by the passenger car fleet are a significant contributor to poor local air quality. Emission measurements show that these emissions can be influenced by driving behaviour. The Horizon 2020 project uCARe has developed a standard, in the form of augmented emission maps, to publish and share emission measurement data. Using these augmented emission maps, advice can be given to drivers which has been tailored to their specific vehicle and driving behaviour. By making augmented emission maps and their surrounding framework openly available we intend to allow tool-builders, researchers, and policy makers to give data-driven advice, to engage and encourage drivers to modify their behaviour, and thereby reduce pollutant emissions.

Keywords:

pollutant emissions, emission map, driver behaviour

Introduction

How people drive influences their car's emissions. However, the relationship between behaviour and emissions is dependent on the vehicle. Being able to access detailed emission data based on a driver's own vehicle and driving style allows for targeted feedback on their behaviour. This feedback can be used to engage and encourage drivers to modify their behaviour, and thereby reduce pollutant emissions.

The Horizon 2020 project uCARe has developed a standard to publish and share emission measurement data. A range of different partners active in passenger car testing have already shared measurement data using this standard in the form of augmented emission map (AEMs). These AEMs contain emission data for either a specific vehicle (as defined by a few relevant parameters) or on a more general level. Using AEMs allows for data-driven advice on the impact of behavioural change on vehicle emissions.

Why should I use an emission map?

AEMs are a standardised way of presenting measurement-based emission data; AEMs are fact-based. It was agreed within the uCARe project to fill the distributable emission map files with data-backed values only. Using the different layers within an AEM, emission calculations can be tailored to a specific individual: behaviour and vehicle. The accuracy and applicability of AEMs is ensured via the significant amount of data that is used to generate each map, which is noted in kilometres and hours in the metadata of each map.

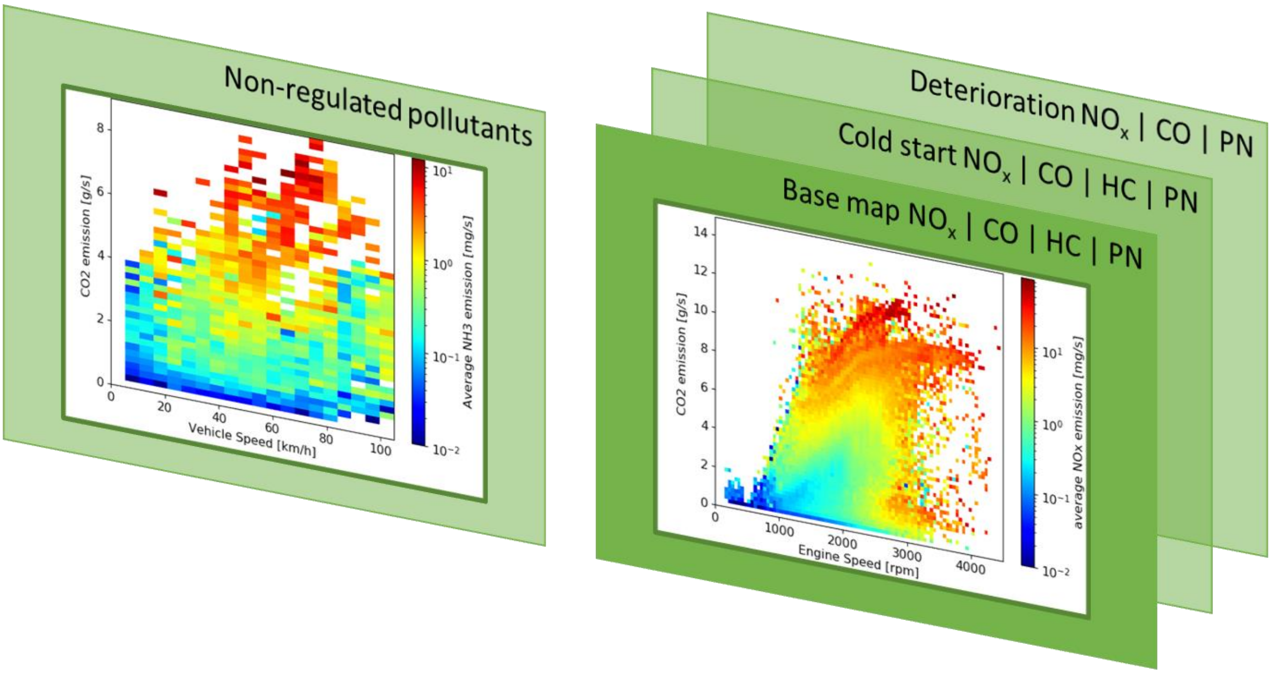

Figure 1 – Graphical representation of the different layers that can be included within an augmented emission map

For some map layers, it may be chosen to implement the emission maps as a continuous function instead. Parameter values to insert into the function are then distributed per vehicle (class). The function can then be implemented by a tool-builder or researcher. An example of this augmentation is the cold start extra emissions function.

How do I use an emission map?

Taxonomy

As discussed in detail in uCARe Deliverable D1.2,[1] a method has been developed to categorise passenger cars dependent on the main (technical) properties of the vehicle. This allows for easy categorisation of vehicles, and therefore facilitates data sharing. Using only five vehicle parameters, an engine code can be generated for each specific vehicle:

- Fuel type (e.g. petrol, electricity, ordered alphabetically in the case of bifuels)
- Emission standard (e.g. Euro 6)
- Engine displacement (e.g. 1598 cm^3)
- Engine power (e.g. 66 kW)
- Manufacturer alliance

The manufacturer alliance is intended to prevent having double entries of the same engine. The engine specifications (the combination of the first five variables) typify the alliance code in 95% of the cases.

For the other 5%, the vehicle manufacturer provides a definitive answer. Within uCARe tools have been developed to determine the alliance code.

Examples of vehicle-specific and generalised engine codes are demonstrated in Table 1. Note that engine codes can also be generalised with the use of ranges and the 'ALL' field.

Table 1 – Examples of vehicle-specific and generalised engine codes

Engine code	Explanation
P_5_898_66_RNM	Petrol, Euro 5, 898 cc, 66 kW engine belonging to the RNM (Renault-Nissan-Mitsubishi-Dacia-Datsun-Lada) alliance
D_6dT_1969_140_VOLV	Diesel, Euro 6d-Temp, 1969 cc, 140 kW engine belonging to the VOLV (Volvo) alliance
E--P_6b_1798_73_TOYO	Petrol plug-in hybrid, Euro 6b, 1793 cc, 73 kW engine belonging to the TOYO (Toyota) alliance
D_6_1968_55_VAG	Diesel, Euro 6, 1968 cc, 55 kW engine belonging to the Volkswagen Group (Volkswagen-Audi-SEAT-Skoda-Lamborghini-Porsche) alliance
D_4_ALL_ALL_ALL	Generalised code referring to all diesel Euro 4 engines
P_6_898-999_ALL_RNM3	Generalised code referring to all petrol, Euro 6 engines with engine displacements between 898 and 999 cc of the RNM3 (Renault-Nissan-Dacia-Smart) alliance

Generated engine codes can be used to access the relevant AEM for the vehicle you're interested in from the wide range of published AEMS.

Base maps

Base maps can be used to predict driver emissions. On a second-by-second basis, relevant driving parameters (e.g. engine load, speed, and/or RPM) can be used to look up the expected instantaneous emissions for a specific vehicle (see Figure 2). The instantaneous emissions can be used to approximate driver emissions over the duration of a trip. Different driving behaviour leads to different emissions. In this way, advice can be given as to the driving behaviour which can lead to lower emissions. Examples of these base maps are shown in Figure 3, for an extensive discussion see also reference 1.

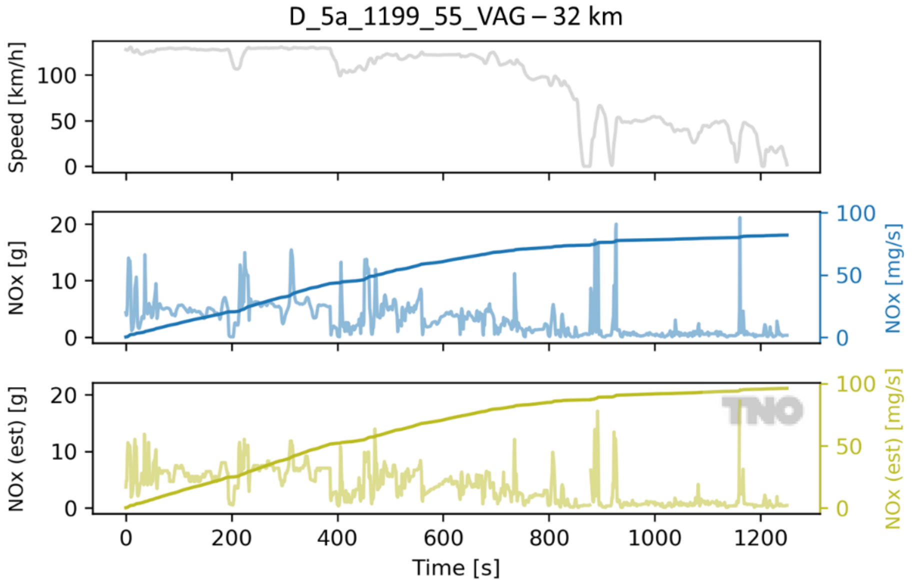

Figure 2 - Comparison of NO_x emissions from measurement data (blue, middle panel) and as estimated from an emission base map (green, bottom panel) using vehicle speed and CO_2 emission

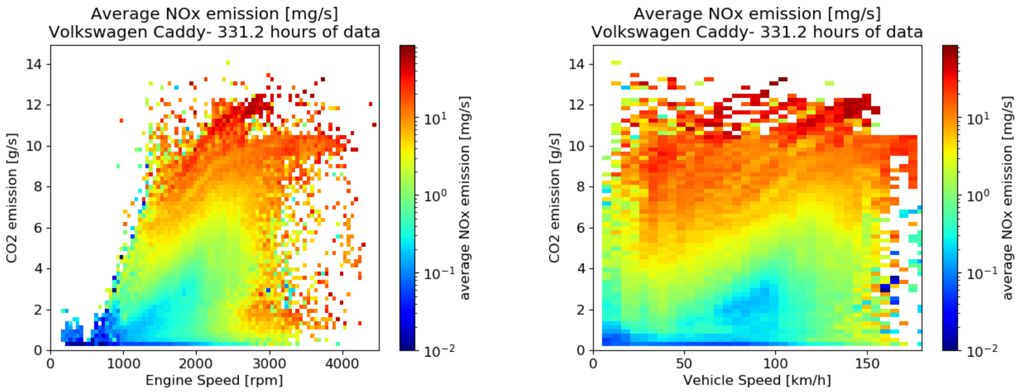

Figure 3 - Emission maps of average NO_x mass flow of a Euro 6 Volkswagen Caddy with a 1968 cc 55kW engine (D_6_1968_55_VAG), based on over 300 hours of driving data. (Left) NO_x as a function of CO_2 and engine speed, (right) NO_x as a function of CO_2 and vehicle speed .

Base maps other pollutants

Emissions of NO_2, N_2O, PAH, CH_4, cyanides and NH_3 can be also be included in AEMs, mapped over the most suitable variables. These maps can be based on (for example) chassis dynamometer tests where more extensive analyser equipment is used (e.g. FTIR). PEMS tests usually record, additionally to NO_x, also NO and NO_2 separately. An example NH_3 map (based on CO_2 and vehicle speed) is shown in Figure 4. In this way, the behavioural influence on other non-regulated pollutants can also be investigated.

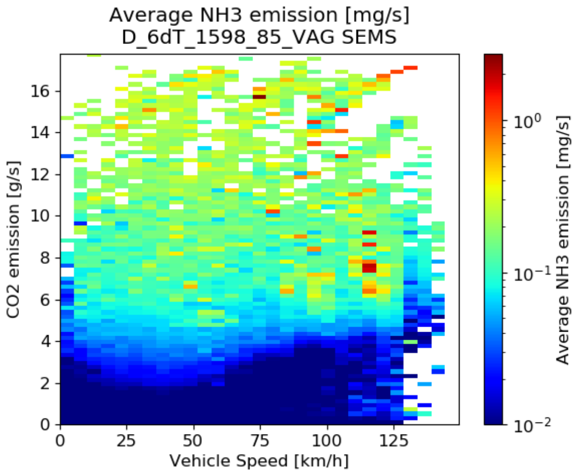

Figure 4 - Emission map of average NH_3 mass flow of a Euro 6d-Temp diesel vehicle with 1598 cc 85 kW Volkswagen AG engine, based on 67 hours of driving data

Cold start augmentation

Drivers can also influence their cold start emissions. Cold start extra emissions (CSEE) occur at engine start mostly due to the inefficient functioning of the cold after-treatment system. In AEMs we also include parameters which can be used as input for a CSEE model (described at length in uCARe Deliverable D1.2[1]) to estimate the CSEE of NOx, CO, HC and PN for any given trip (based on, e.g. engine speed, engine velocity and road gradient). The resulting CSEE are additional to the hot emissions and form a continuous function in time over the cold start period.

Just as for the so-called hot emissions, driver behaviour has a significant influence on the CSEE (see also Figure 5). However, in this case the temperature of the after-treatment system should also be considered, which depends in turn on the ambient temperature and the accumulated heating energy produced in the combustion process since the engine start. Because of these dependencies, the CSEE cannot be easily presented in a map format, and continuous functions over time are used instead to estimate the second-by-second CSEE.

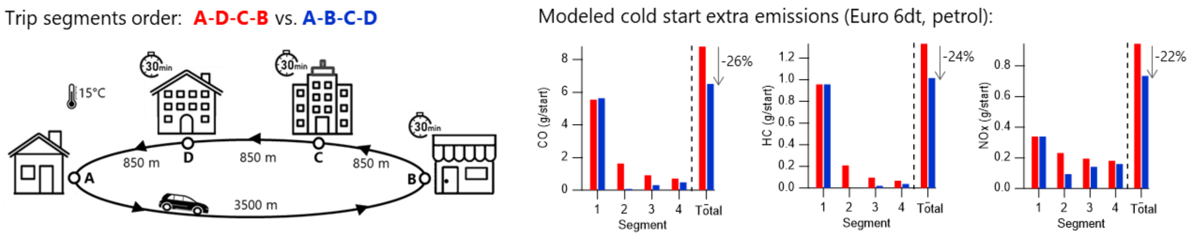

Figure 5 - Results from cold start model of inverted trip segments. The modelled cold start extra emissions are lower for the trip that starts with the longest trip segment.

Deterioration augmentation

The mileage of a car can also influence pollutant emissions. As measured emission data may not be available at the mileage of a specific car, deterioration factors have also been shared via AEMs. These factors are available for NO_x, CO, and HC emissions for both petrol and diesel vehicles from Euro 1 to Euro 6. Deterioration factors can be used to scale measured emission data from the mileage at which the data was measured, to the mileage of interest as shown in Figure 6.

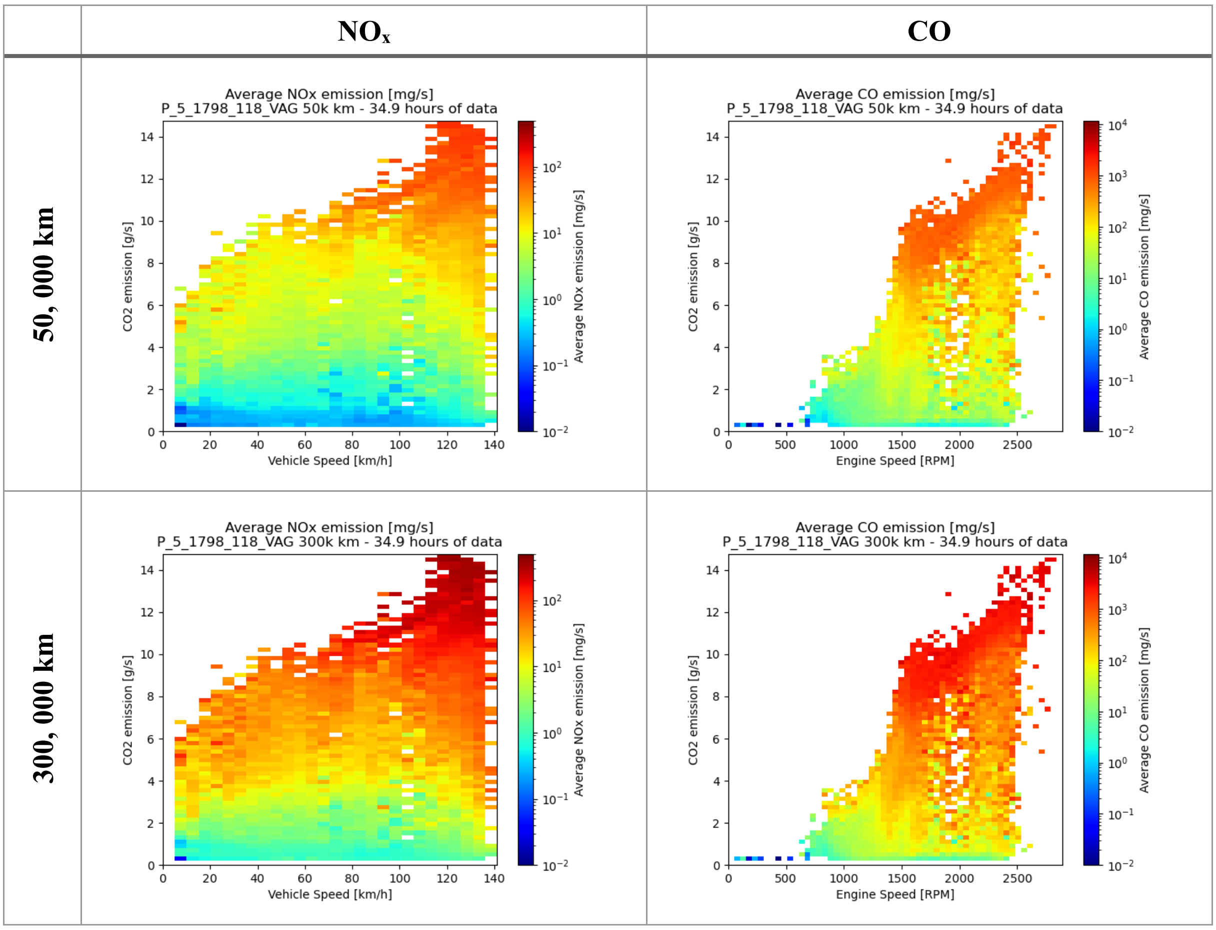

Figure 6 The effect of applying deterioration factors on a base map for NO_x (dependent on vehicle speed), and CO (dependent on engine speed), to compare emissions at mileages of 50, 000 and 300,000 km.

Table 2 Deterioration factors as a function of cumulated mileage used in the example in Figure 6.

Pollutant	0 km	50,000 km	100,000 km	200,000 km	300,000 km
NO_x	1.00	1.00	1.00	2.50	3.50
CO	1.00	1.00	1.30	2.00	3.00

Getting started: selecting or combining the right AEM

Over the last few years, AEMs have been created for many engines. However, given the vast number of engine types in use (including updates with newer Euro standard compliance), it has not been possible to create a vehicle-specific emission map for every single one of them. Fortunately, dependent on the map layer, there are similarities among certain maps that can be used to make extrapolations to other engines deemed similar in behaviour. Three tools were developed to help tool-builders:

A. Fallback maps
B. Selection tool
C. Combining tool

A. Fallback maps

Tailpipe emissions of vehicles are largely categorised by the Euro standard the vehicle must comply with. Without further knowledge, Euro standard-average maps give a first indication of the emission behaviour of a vehicle. These maps have been created and are available publicly.

B. Selection tool

For NOx, significant differences are visible in maps of vehicles with the same Euro standard. A flexible algorithm was developed that considers all presently available base maps. Using this algorithm, maps can be clustered along the lines of taxonomy codes. For any taxonomy code provided, the algorithm can return the five maps that are expected to be closest, i.e., the best predictors of the vehicle's emission behaviour. In this way, the tool-builder or researcher can make an educated selection.

C. Combining tool

A tool has also been developed to allow for the interpolation and combination of existing AEMs. In this way, we facilitate the comparison and contrast of different AEMs, as well as allowing for the user to combine different AEMs. By combining different AEMs, emission data can be aggregated further to the specific application of the tool-builder or researcher.

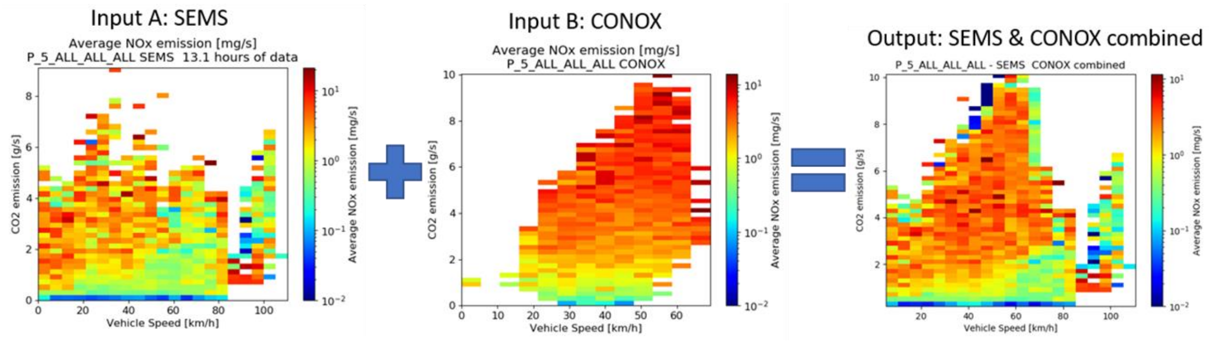

Figure 7 – Graphical representation of the AEM combining script, which allows for the combination of data from different sources

Using AEMs for additional insight into the relationship between driver behaviour and emissions

AEMs can also be used to gain additional insight into the relationship between driver behaviour and pollutant emissions, and to then give concrete advice based on that insight. An example is the advice given regarding drivers' gear choice. Conventional eco-driving instructions to reduce CO_2 suggest using a high gear to maintain low engine speeds (around 1500 RPM as demonstrated by the purple oval in Figure 8). However, we can use AEMs to see that for low NO_x driving this advice may need to be modified.

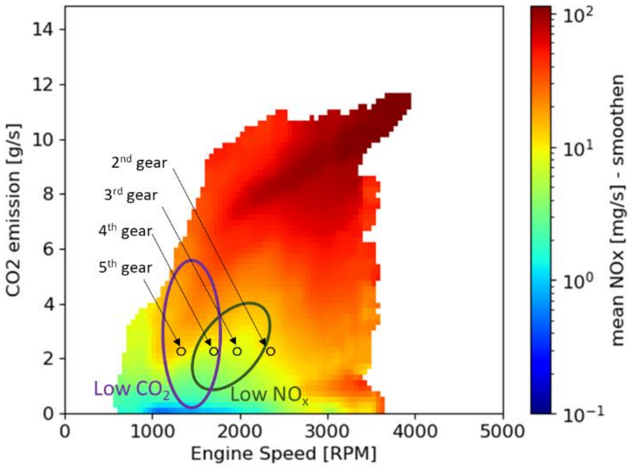

Figure 8 – Annotated NO_x base map of a Euro 5 Volkswagen Polo with a 1199 cc 55 kW engine (D_5a_1199_55_VAG), based on over 400 hours of data. Annotations indicate the engine speed range recommended for low CO_2 emissions (purple), as well as the area of the base map with lower NO_x (green). An indication is also given of where on the emission map driving at different gears would be while driving around 50 km/h with an CO_2 emission of approx. 150 g/km.

Euro 5 diesel vehicles have high NO_x emissions, which make them an excellent candidate for emission-decreasing behaviour-based advice. The base map in Figure 8 shows NO_x emissions of a Euro 5 diesel vehicle, dependent on CO_2 and engine speed. If we compare the NO_x emissions for different gears (as annotated in Figure 8) we see that for a CO_2 emission around 2 g/s, a lower gear would produce lower NO_x emissions: 3rd gear has lower NO_x emissions than 5th. Looking at the area in the map with lower NO_x (the green oval in Figure 8), this advice for low NO_x driving particularly holds when accelerating (i.e. when CO_2 emissions are higher).

How 'accurate' are AEMs?

AEMs are a standard with which organisations can share detailed pollutant emission measurement data. All data that is used to produce base maps is data that has been measured for a vehicle with that specific engine code. To generate the emission base map, the second-by-second tailpipe emission measurement data are allocated according to the x-axis variable and y-axis variable. For each bin in the emission base map, the average of the tailpipe emission is calculated and used as representative value per bin.

Because base maps only contain measured data, this data will reflect the circumstances in which it has been collected. If the measurement data was collected in limited circumstances, then the generated base map would be biased towards these circumstances, giving a narrower scope. This can lead to deviations when trying to predict emissions in other, highly different, situations. However, if the data in a base map has been collected in diverse driving situations, and with significant amounts of measurement data, the emission base map will sufficiently represent the average emission performance of the vehicle across driving conditions.

We do note that instances of incidentally high emissions remain difficult to predict, as their cause is often not discernible. Metadata such as notes, the number of vehicles, amount of data, and average mileages used to generate the base maps are included in the AEM file to give an indication of the statistical significance of the data in the emission base maps. Although AEMs are not yet able to predict emission outliers they can still offer insights at a more detailed level than generalised emission factors.

Conclusion

Via AEMs and their surrounding framework, we facilitate easy data sharing of emission measurements. The ready availability of vehicle-specific and generalised AEMs, as well as the supporting tools make this a solution that is ready for tool-builders to implement. Data is available via the OpenAire platform Zenodo to which new data can and will continually be added to as new measurements become available. By openly sharing AEMs and their surrounding framework we intend to allow tool-builders, researchers, and policy makers to give data-driven advice, to engage and encourage drivers to modify their behaviour, and thereby reduce pollutant emissions

References

1. Elstgeest, M., A. Indrajuana, J. de Ruiter, R. van Gijlswijk, N. Ligterink, P. Tilanus, M. Elser, S. Hausberger, M. Gustafsson, A. Dimaratos (2020). *uCARe Deliverable D1.2 Augmented Emission Maps,* DOI: 10.5281/zenodo.4268034.