European Research on Mobile Emission Sources

ERMES Plenary 2021

Meeting Summary

July 2021

This report is produced by the European Research on Mobile Emissions (ERMES) group and provides a summary of the presentations given at the on-line ERMES 2021 Plenary.

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We acknowledge the support received from the EC Joint Research Centre (JRC) to allow the JRC to continue to chair the ERMES group.

Contents

03 Non-Exhaust and Non-Road Transport Emissions

Foreword

On behalf of the ERMES board, I would like to welcome you to the 2021 ERMES plenary sessions. This summary provides the material and the critical observations made during three online events held in May 2021.

Due to the Covid-19 pandemic, the ERMES board held the plenary sessions online. To make the plenaries more inclusive and reinvigorate the ERMES group, the 2021 plenary sessions covered a spectrum of research activities and were open to other researchers and members of the ERMES community.

The plenaries highlighted the challenges that lie ahead in reducing transport emissions and the opportunities that exist. The European Union's aim to become carbon neutral will affect all transport modes. In the short term, disruptions caused by the Covid-19 pandemic and the changes to transport use will need to be investigated in the road vehicle urban transport sector. In parallel, the ongoing challenge of improving air quality and reducing pollutant emissions requires up-to-date, state-of-the-art tools and datasets that have always been at the core of the ERMES group. Our members are engaged in several ongoing research activities spanning these issues, constituting a solid basis for new future endeavours.

As part of the plenaries, we requested participants to highlight the policy relevance of their interventions and underline needs for additional research. We believe that the condensed experience of our members, a product of participation in Horizon 2020 and other research activities, makes a valuable contribution to frame future research initiatives for the decarbonisation of the European transport sector.

We hope the ERMES plenaries have been a fruitful experience for all participants and that you will find this summary an exciting trigger for further contemplation. The intention is to continue and strengthen our work in this area.

We are looking forward to seeing you at future ERMES meetings.

Georgios Fontaras

Chair of the ERMES Board

All presentations are available on the ERMES website

European Research on Mobile Emission Sources

The European Research on Mobile Emission Sources (ERMES) is a group of research institutions, competent authorities, industry associations, whose mission includes the support of cooperative research in the field of transport emission modelling. ERMES partners contribute to the development of the most up-to-date emission estimation tools for policy making and policy implementation purposes.

"UNDERSTANDING THE SCIENTIFIC AND TECHNOLOGICAL ISSUES RELATING TO THE IMPACT OF TRANSPORT EMISSIONS ON SOCIETY."

The ERMES group emerged from the collaboration since early 2000 of two groups engaged in developing the models HBEFA (DACHNL group headed by INFRAS and TUG) and COPERT (EEA/JRC/LAT/Emisia). Both groups have been active in emission measurements and modelling since the 1990s. The group, chaired by European Commission's Joint Research Centre (JRC) since 2009, strives to bring together the knowledge produced in Europe, to facilitate the exchange of information and to promote the cooperation among the actors involved in the measurement and modelling of road vehicle emissions.

ERMES partners share their experience, solve methodological issues and consolidate the knowledge in the field of transport emissions to produce the most up-to-date emission estimation tools for policy making and implementation. Measurement programmes are expensive yet indispensable for understanding the impact of technologies on emissions from mobile sources and they provide the means for validating and updating emission inventory models. The burden of measurements is shared by the funding authorities within ERMES.

The ERMES group meets regularly to share research results and discuss priorities for its annual work programme.

ERMES

Plenary

2021

01

Emission Models and Projections

1.1

Update Dutch Emission Factors for 2021 and the TNO Research Agenda

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Presentation

Emissions of nitrogen oxides (NO_x) and ammonia (NH_3) from mobile sources remain a major concern. The May 2019 verdict of the highest administrative court in the Netherlands on the level of eutrophication has blocked new developments such as building projects for housing and roads. TNO has updated the emission factors of older petrol cars (from Euro 3 to Euro 6), which show a substantial deterioration over the lifetime of the vehicle. This has also been confirmed by remote sensing. However, there has been an improvement in NO_x and NH_3 emissions in the latest diesel cars and vans compared to the first Euro-6d-temp.

For heavy-duty trucks, current legislation does not properly cover the urban use of trucks, and emissions remain much higher than for long-distance road haulage. The testing and measurement of mobile machinery show a large range in NO_x and particulate matter (PM) emissions. Some previously unknown contributors to total NO_x emissions in the Netherlands such as cooling units on trucks have been identified. The H2020 uCARe project is making such detailed emission information publicly available.

The Dutch government is concerned about the lifetime emissions of vehicles and problems with tampering. For this reason, TNO is looking into the improvement of PTI testing. The feasibility of emission monitoring of longer periods is being investigated. Finally, the Dutch vehicle taxing system, is now based on carbon dioxide (CO_2). However, TNO studies have showed the limited effectiveness of CO_2 based taxation due to the large deviation between real-world and type-approval CO_2 values, and reduced correlation between the two values.

Further Reading

Real-world emissions of non-road mobile machinery | TNO Publications
Dutch In-service emissions testing programme for heavy-duty vehicles 2019-2020 | TNO Publications
Real-world fuel consumption of passenger cars and light commercial vehicles | TNO Publications
On road emissions of 38 petrol vehicles with high mileages | TNO Publications
Effects of European emission reductions on air quality in the Netherlands and the associated health effects | TNO Publications (paper)
Emissions of five Euro 6d-Temp Light Duty diesel vehicles | TNO Publications
Petrol fuel and blending ethanol analyses | TNO Publications
Follow-up research into the PN limit value and the measurement method for checking particulate filters with a particle number counter | TNO Publications

1.2

HBEFA and Emission Measurements: Outlook and Update Plans

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Presentation

An outlook on update plans of the Handbook of Emission Factors for Road Transport (HBEFA) and the associated emission measurement activities is presented. The work programme up to the next major HBEFA update includes:

- Content updates for the “light update” HBEFA 4.2, to be released by the end of 2021
- Content updates for the major update HBEFA 5.1, to be released 2025
- The development and use of a new measurement database (DBEFA), implemented as a server-client solution with remote access for data providers and users
- The migration of the HBEFA application to a Python-based server-client solution.

1.3

Status of COPERT Emission Factors and Latest Changes in the Methodology

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Presentation

COPERT provides a consistent and straightforward methodology to estimate emission factors relevant for environmental and operation conditions in each European Union (EU) Member State. The emission factors distinguish between different fuels, vehicle sizes and categories, and emission control technologies. Most EU countries have used COPERT for the official submission of road transport emission inventories.

In the last version of COPERT (V5.4), more than 430 individual vehicle types are included in the model together with suitable emission factors for main pollutants (NO_x, PM, CO, VOC, NH_3, N_2O, SO_x, etc.). In addition, there are several other species which are required for air quality modelling (NMVOC speciation, heavy metals, etc.). Providing and maintaining all emission factor functions for so many individual vehicle types is a tedious procedure which requires access to robust experimental information but also solid engineering judgment on proportionality of technologies and similarities in emission performance between different vehicle types.

Two major updates on COPERT have recently taken place. The first involves the introduction of emission factors for exhaust particle numbers (PN). So far, PN emission factors were only available in tabular form in the EMEP/EEA Emissions Inventory Guidebook which has the same methodology as COPERT. Earlier PN values have been reviewed, revised and extended to Euro 6/VI vehicle technologies. The sources of the update include several recent EU projects (primarily H2020 DownToTen project) with additional measurements collected by the CLOVE consortium in the framework of the Euro 7 programme. The emission factors differ according to operational conditions and include the impact of active diesel particulate filter (DPF) regenerations on average emission levels.

In addition, emission factors for special L-category vehicles including mini-cars and all-terrain vehicles (ATVs) have now been introduced in the software. These emission factors are based on measurements conducted within the framework of the activities of introducing Euro 5 for L-category vehicles. Such vehicles are known to correspond to only a small fraction of total road transport activity, but this activity may be concentrated in urban areas. Moreover, most of the earlier models of mini cars were equipped with primitive technology diesel engines therefore disproportionally contributing to air quality issues in sensitive areas.

1.4

Fleet and Fuel Scenarios for 2050 Carbon Neutral Road Transport in the European Union

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Presentation

To meet the European Union (EU) ambition to become climate neutral by 2050, road transport greenhouse gas (GHG) emissions need to be significantly reduced. The present study uses a well-to-wheels (WtW) perspective to explore options for carbon neutral road transport by 2050.

To this aim, the European Road Transport Advisory Council's (ERTRAC) CO_2 evaluation group developed three scenarios on potential 2050 EU road-vehicle fleet composition, based on an earlier study.[1] The three scenarios vary in their fleet electrification and are complemented with measures to improve vehicle efficiency, transport flow, and transport volumes.

The fleet scenarios are combined with scenarios for deploying different alternative fuels by 2050. These four alternative fuel scenarios represent varying mixes of efuels, advanced biofuels, and remaining fossil fuel components, combined with two electricity production pathways. In total, 48 different scenarios are being investigated. Fuel pathways are based on JEC WTT v5 data,[2] with modifications to show further development throughout 2050. Scenario calculations have been carried out with the EC JRC's DIONE model. The ERTRAC CO_2 evaluation group developed the scenarios to give insights into different options ("what if" approach), without prejudice on the likelihood of different options to be implemented.

Results show that a wealth of different fleet and fuel combinations could deliver carbon neutral road transport solutions by 2050. However, the total amount of energy required in a WtW perspective varies substantially among the different scenarios.

From a tank-to wheels (TtW) perspective, all scenarios analysed reduce fuel consumption compared to today. 2050 EU27+UK road vehicle energy consumption ranges from 750 to 1900 TWh, which is 21% to 53% of 2019. The higher the share of battery electric vehicles, the lower TtW energy consumption. The fleet scenario which includes fuel cell electric vehicles performs second best, whereas the moderately electrified scenario shows the highest TtW energy consumption.

For the strongly electrified fleet scenario, well-to-tank (WtT) energy is around 20% of TtW, and 2050 EU road transport WtW energy consumption remains below 1000 TWh regardless of the fuel pathway. In the case of a moderately electrified fleet propelled with e-fuels, WtT energy is 130% of TtW energy and a WtW energy consumption of 4400 TWh results, even if electricity is assumed to be 100% renewable. Thus, fuelling moderately electrified fleets with e-fuels requires substantial additional amounts of renewable electricity.

The results further show that direct fleet electrification is the strongest driver for WtW transport energy consumption reduction among the options considered. The impact of efficiency measures can be significant but diminishes with increasing fleet electrification. The production pathways of fuels make a substantial difference for WtW fleet energy requirement if the fleet is moderately electrified (use of limited fossil and advanced biofuel volumes result in the lowest electricity needs) but become irrelevant from an energy perspective under an ambitious electrification scenario.

The ERTRAC analysis does not draw conclusions on fuel, electricity and resource availability, economic feasibility and competition with other sectors' demand, or social acceptance of different options. These aspects deserve further investigation, as do the life cycle impacts of different options. It reflects the views of the contributing authors and is not an official European Commission position.

Further Reading

[1] Krause, J., Thiel, C., Tsokolis, D., Samaras, Z., Rota, C., Ward, A., Prenninger, P., Coosemans, T., Neugebauer, S. and Verhoeve, W. (2020), EU road vehicle energy consumption and CO2 emissions by 2050 – Expert-based scenarios, Energy Policy, Volume 138, 2020, https://www.sciencedirect.com/science/article/pii/S0301421519308067

[2] Prussi, M., Yugo, M., De Prada, L., Padella, M., Edwards, R. and Lonza, L. (2020), JEC Well-to-Tank report v5, EUR 30269 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-19926-7, doi:10.2760/959137, JRC119036, https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/jec-well-tank-report-v5

Presentation ERTRAC CO2 WtW Study - status April 2021, https://www.ertrac.org/uploads/documentsearch/id69/ERTRAC-PPT-Carbon%20Neutral%20Road%20Transport%202050_Workshop_April_29.pdf

1.5

Carbon Footprint of Alternative Fuelled Cars

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Presentation

The need to shift towards renewable energy in transportation is widely accepted, however, there is an ongoing debate which drivetrain concepts or fuel types are most favourable.

In this presentation, we compare the carbon footprint of a C-segment car in Germany with different drivetrains (battery- electric, hydrogen, natural gas as well as gasoline and diesel). Electricity usage as well as e-fuels (synthetic fuels generated from electricity) are considered and compared. Car manufacturing, maintenance, and disposal (including the battery for electric cars), the tailpipe emissions as well as the energy provision are included in the carbon footprint assessment.

Electric passenger vehicles (EV) have higher manufacturing emissions (mainly due to the additional emission from the car battery) than conventional ICE vehicles but offer benefits in the use phase. In contrast, EV have more than a 30% climate benefit over their entire lifecycle when compared with a conventional vehicle - even with the German electricity mix.

A car driven with a synthetic fuel needs 3 to 5 times more energy than an EV. Therefore e-fuels using a German electricity mix perform worse than the fossil fuels. Only when using additional renewable electricity can e-fuels have a benefit. If the availability of renewable electricity is limited, then an EV is always beneficial compared to a synthetic fuel. Synthetic fuels will be needed for carbon neutral transport system - but they should mainly be used in applications where no direct substitution with electricity is possible (e.g., for airplanes or long-distance transports by ship).

1.6

Probabilistic LCA: A fast and effective approach to Life-Cycle Assessment of greenhouse gas emission impacts of electric vehicles versus fossil-fuelled cars

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Presentation

To properly assess greenhouse gas (GHG) emissions performance of different vehicle technologies, all aspects of a vehicle's life (cradle-to-grave) need to be examined. Life Cycle Assessment (LCA) can clarify potential trade-offs between different environmental impacts and between different stages of the life cycle. The comprehensive scope of LCA is useful in avoiding problem-shifting from one life cycle phase to another, from one region to another, or from one environmental problem to another.

LCA studies can be set up in different ways, naturally with several underlying – and not always visible – assumptions. LCA considers processes that are complex, location specific and dynamic (vary in time, as well as over time i.e., trends). It is therefore not surprising that LCA studies have caused diverging arguments about the environmental performance of the technology that is assessed (Turconi *et al.*, 2013; Nordelöf *et al.*, 2014).

It is important that the uncertainty in LCA results is quantified and that LCA results are regularly updated and improved. Although most LCA studies have used deterministic approaches, a few recent studies have deployed a probabilistic approach to LCA (p-LCA). A p-LCA approach is useful to determine the robustness of study outcomes and to identify which aspects of the LCA are most uncertain and warrant further targeted examination.

TER (2020) conducted a p-LCA into fleet average GHG emission rates from both conventional (petrol, diesel, LPG, CNG) passenger vehicles (ICEVs) and battery electric vehicles (BEVs) in Australia. A Monte Carlo simulation was used to propagate input probability distributions and to estimate the emission factors (grams CO_2-e/km) and associated uncertainty for ICEVs and BEVs. Probability distributions were defined through statistical analysis of available data sets and in-depth review of scientific literature.

The weight of evidence suggests that BEVs will reduce GHG emission rates with 16% to 40% (28% on average) for the current (2018) Australian electricity mix, which is still largely fossil fuels based. For a 'marginal 100% fossil-fuelled electricity' scenario, BEVs will still reduce GHG emission rates between 5% and 29% (17% on average). For a 'renewable energy' scenario (90% renewables, 10% fossil fuels), BEVs will reduce GHG emission rates with 67% to 82% (74% on average). It is concluded that rapid electrification of the Australian passenger vehicle fleet is a robust and possibly the best way to substantially reduce life-cycle emissions from road transport.

Further Reading

Nordelöf, A., Messagie, M., Tillman, A.M., Söderman, M.L., Van Mierlo, J., 2014. Environmental impacts of hybrid, plug-in hybrid, and battery electric vehicles—what can we learn from life cycle assessment?, Int J Life Cycle Assess, 19, 1866–1890.

TER, 2020. *Meeting our Greenhouse Gas Emission Targets: Can Electric Vehicles Meet the Challenge? – A Probabilistic Life Cycle Assessment (LCA) for GHG Emissions from Australian Passenger Vehicles*, Robin Smit, Transport Energy/Emission Research (TER), 5 December 2020, https://www.transport-e-research.com/publications.

Turconi, R., Boldrin, A., Astrup, T., 2013. Life cycle assessment (LCA) of electricity generation technologies: overview, comparability and limitations, *Renewable and Sustainable Energy Reviews*, 28, 555–565.

1.7

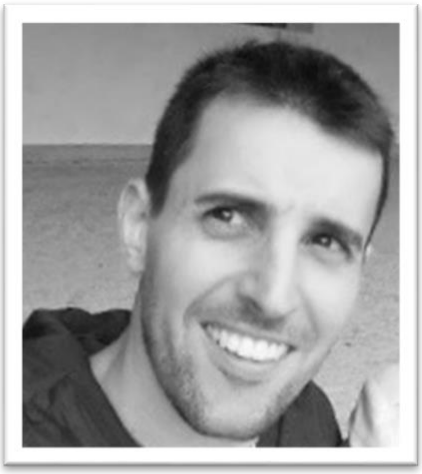
Research Gaps

In this session on *Emission Models and Projections*, research gaps identified included:

- Addressing the lack of emission factors for non-road mobile machinery, especially older machines, and inland shipping
- Emission increases from ageing and malfunctions for road vehicles should be investigated in further detail and update existing models accordingly
- More detailed information and emission factors regarding non-regulated emissions (i.e., nitrous oxide, methane, ammonia, etc.)
- Revisit issues related to particulate matter and particulate number measurement and relevance for air quality and health (i.e., toxicity)
- Improve the understanding of the environmental impacts during the vehicle lifecycle (e.g., resource usage or other relevant impacts such as acidification) including vehicle battery manufacturing as well as electricity provision.
- Retrieve more reliable data on lifetime (mileage) of cars using alternative drivetrains (e.g., electric cars).
- Data on vehicle lifetimes and lifetime mileages particularly for electric cars.
- Collect more reliable data on real world fuel/energy demand of fuel cell and electric cars.
- Improve powertrain technology: cost, range, functionality and adapting infrastructure technology.
- Efficiency improvements in vehicle, traffic conditions and traffic reduction technologies.
- Renewable electricity generation capacity and net carbon neutral hydrogen and fuel production (inside and outside of the EU).
- Investigate technologies and capacity of carbon capture and storage and direct air capture
- Availability of raw materials and sustainable feedstocks (appraised in a life-cycle analysis perspective).
- Integrate economics and societal acceptance of different road transport decarbonisation options into existing models and analyses.

02

Air Quality and Remote Sensing



2.1

Update from the European Commission on Air Quality - Revision of EU Rules

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Presentation

Air pollution continues to be a major health and environmental concern to European Union (EU) citizens. In response, the European Commission (EC) is improving the whole legislative framework to achieve health benefits, which goes beyond existing air quality limits.

The aim of the EC revision is to enhance EU air quality legislation to avoid, prevent or reduce the harmful effects of air pollution on human health and the environment. This is in line with the European Green Deal's zero pollution ambition and builds on the lessons learnt from the Fitness Check of the Ambient Air Quality Directives. The European Green Deal announced the EC will revise air quality standards to align with the World Health Organization (WHO) air quality guidelines, as well as propose to strengthen provisions on monitoring, modelling and air quality plans to help local authorities achieve cleaner air.

Future EC work will be focused on three policy areas:

- aligning the EU air quality standards with new scientific knowledge, including the latest WHO air quality recommendations;
- improving the air quality legislative framework, including provisions on penalties and public information; and
- strengthening air quality monitoring, modelling and plans.

The revision of the EU rules on air quality started in 2021 with the first round of expert consultations. There is a public consultation planned for the 3rd quarter of 2021. According to the indicative timeline, the EC will adopt the new legislative proposal by the second half of 2022, with ensuing European Council and European Parliament discussions taking place during the first half of 2023.

2.2

Progress Towards a Unified Storage Solution for Remote Emission Sensing Data

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Presentation

The City Air Remote Emission Sensing (CARES) project is carrying out multiple experiments characterising instruments and sensors. This involves city demonstration campaigns using a range of Remote Emission Sensing (RES) technologies such as commercialised instruments (both crossroad and top-down configurations), plume chasing and point sampling. The CARES project builds upon the CONOX project that developed a central repository of 1 million remote emission sensing (RES) measurements and undertook advanced statistical analysis of RES data.

The CARES project presents a series of data handling challenges, notably collating the historic database of CONOX measurements, with data from other European campaigns that use new sensors and types of data. The consistency of the technical details of measured vehicles collected in different locations in EU Member States cannot be guaranteed. The format of data collected by rapidly advancing RES technologies is also not fixed.

In the CARES project, the RES data infrastructure is moving away from database architecture with a fixed schema. The project adopts a flexible and scalable cloud computing document (NoSQL) database on the Microsoft Azure CosmosDB platform. Key to implementing this platform, is the development of a series of data input facilities that allow users to check data quality in an easy way before entering them into the database. The data architecture also includes a series of data viewing and analysis platforms that allow users to engage, analyse and visualise their data. This presentation will include a “live” demonstration of the prototype CARES cloud computing database.

2.3

Recent Studies in European Cities Using Commercial Remote Sensing Techniques

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Presentation

This presentation outlines the scope and objectives of various European campaigns undertaken by the International Council for Clean Transport (ICCT) in 2020 using commercial remote sensing instruments. The remote-sensing technique was deployed in major European cities such as Brussels and Warsaw to measure emissions from over 500,000 vehicles and, for the first time, collocated with on-road particulate number (PN) inspection and noise measurements.

The campaign objectives covered several issues such as improving the knowledge of vehicle emissions in real-world driving conditions, studying vehicle tampering and malfunctions, supporting in-service conformity and market surveillance, and identifying sources of traffic-related noise pollution.

2.4

From Roadside to Nationwide - Remote Sensing Measurements for Emission Inventory Development

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Presentation

This presentation considers how remote sensing measurements can be used for national emission inventory development. The use of such data has many attractions for inventory development; in particular, the full fleet coverage and measurements that are made under real-world driving conditions.

Methods have been developed to quantify emissions from individual vehicles to the national UK scale for carbon dioxide (CO_2), nitrogen oxides (NO_x) and ammonia (NH_3) and other pollutants. Encouragingly, we find the methods result in close to carbon-energy balance when compared with accurate UK fuel sale data. For a 2018 base year, we find that light duty vehicle NO_x and NH_3 emissions are underestimated in the UK national inventory, and especially in urban areas.

2.5

Flanders Taking Remote Sensing to the Next Level: First Deployment on Highways and Future Applications

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Presentation

Flanders has undertaken a policy study to bolster the ability of authorities to act against real-world vehicle emission issues. This included the use of remote sensing in locations with a diverse range of driving conditions.

Measurements were taken at urban and rural locations, but also at highways – the first application of remote sensing at high-volume high-speed motorways. This resulted in an extensive dataset containing 200,000 vehicles, with a considerable amount of emission data on trucks.

This presentation shows how remote sensing data on highways differs from emission measurements taken at lower speed. Based on the Flemish experience and analyses, we consider how remote sensing can surpass its academic research purpose and find large scale application.

We investigate roadside inspections to prevent tampering in trucks and into organising effective market surveillance to check compliance with the latest Euro vehicle emission standards.

2.6

Recent Remote Emission Sensing Measurements by Means of the Plume Chase Vehicle Technique

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Presentation

The plume chasing method allows the investigation of real-world driving emissions of individual vehicles while measuring pollutants in the wake of the vehicle, i.e., in the diluted emission plume. The measurement of each vehicle covers seconds to several minutes and allows an average emission value to be derived. This value is not influenced by short term fluctuations and therefore represents a more accurate emission value like that observed with a portable emissions measurement system (PEMS).

Recent technical developments allow compact plume chasing measurement setups with low maintenance and simple operation making the technique more attractive for broader real driving emissions (RDE) investigations and authority use. The current focus is on nitrogen oxide (NO_x) emissions and extensions on particles is further developed.

This presentation discusses the technique, developments and results from several campaigns compared with PEMS. In recent years, plume chasing has been used to detect the emissions from high polluting vehicles such as trucks and buses.

Several studies have shown a number of these vehicles (Euro V and Euro VI, all brands) have higher NO_x emissions due to malfunctioning of emission cleaning systems. The accuracy of the derived single vehicle emission value can determine low and high emitters.

The use of the plume chasing method by regulatory authorities has shown during vehicle inspections that high emitters have a defective or inactive emission cleaning system. Thus, plume chasing systems can assist authorities to identify reliable high emitters and optimise inspections.

2.7

Do Remote Sensing Campaigns Across Europe Give Consistent Results? The Case of Light Commercial Vehicles

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Presentation

Light commercial vehicles (LCVs) account for about 10-15% of European road traffic. However, there have been only few investigations into LCVs on-road emissions. Here, remote sensing vehicle emission measurements from eighteen locations across four European countries are combined for a comprehensive analysis of nitrogen oxides (NO_x) and smoke emission rates from diesel LCVs over the past two decades. Ambient temperature, engine load and fleet composition, particularly for Euro 4 and 5 emission classes, result in different emission levels. But controlling for these variables we find consistent results; we differentiate by emission standard, model year, curb weight, engine load, manufacturer, and vehicle age.

On-road NO_x emission rates are much higher than type approval limit values for all manufacturers, but some perform better than others. Since 2015, emission rates have been decreasing due to the introduction of Euro 6a, b emission standards. Smoke emission rates are considered as a proxy for particulate matter (PM) emissions. Their emissions decreased substantially from the year 2010 onwards for all countries measured and size classes. This is consistent with the substantial tightening of the PM emission limit value that coincided with the introduction of a diesel particulate filter.

These dependencies have already been observed earlier with diesel passenger cars; they are considered part of an abnormal emission control strategy. We compare our findings with standard emission factors used in HBEFA 4.1 and recommend some adjustments.

Further Reading

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Yuche Chen et al. On-Road NOx and Smoke Emissions of Diesel Light Commercial Vehicles– Combining Remote Sensing Measurements from across Europe Environmental Science & Technology 2020 54 (19), 11744-11752 DOI: 10.1021/acs.est.9b07856

2.8

Bus Emissions Measurements in Operational Conditions Using PEMS: A Comparison Between Euro Technologies

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Presentation

Few studies on bus emissions in real-world driving conditions have been undertaken due to buses have a specific driving cycle compared to other heavy-duty vehicles. Airparif, with the financial support of Île-de-France Mobilités, conducted a two-year study to assess bus emissions in Île-de-France (Paris region) during operational conditions (i.e., carrying passengers) over various weather and traffic situations and over different types of bus lines (e.g., urban, suburban).

Overall, 28 buses were tested over sixteen two-week campaigns: the buses were Euro IV diesel, and Euro VI diesel, hybrid and compressed natural gas (CNG). PEMS was used to measure emissions of particle number (PN), nitrogen oxides (NO and NO_2), carbon monoxide (CO) and carbon dioxide (CO_2).

More than 6,500,000 data points were collected per pollutant at a time resolution of 1 Hz, along with vehicle parameters, exhaust temperature, ambient temperature/humidity, and positioning. The uncontrolled driving conditions represented a challenge for data analysis but also a major opportunity for a first insight of real-world bus emissions on a large scale.

The study found a reduction in real-world driving emissions for all pollutants (PN, NO_x, CO) occurred in all bus categories from Euro IV diesel buses to Euro VI buses. On average, NO_x emissions of Euro VI buses (around 3 g/km) were 4 times lower than those of Euro IV diesel buses (around 13 g/km), and NO_x emissions of Euro VI CNG buses (around 0.4 g/km) were 7 times lower than those of Euro VI diesel buses. PN emissions of Euro VI buses of all categories (diesel, hybrid, CNG, around 10^{12} particles/km) were more than 50 times lower than those of Euro IV diesel buses (around 10^{13}-10^{14} particles/km).

PN emissions from CNG buses tended to be higher than those of Euro VI diesel buses (depending on the bus considered) but overall remained within the same range. While CO concentrations are no longer a concern for the Paris region, CO emissions were also observed to be reduced with the evolution of diesel technology (from around 7 to 0.5 g/km). For part of the CNG buses, CO emissions were higher than those of Euro VI diesel buses and part of Euro IV diesel buses. Average CO_2 emissions ranges (from tank to wheel only) of Euro VI diesel buses were 6% lower than those of Euro IV diesel buses (with an additional drop of 17% for Euro VI hybrids compared to Euro VI diesel). CO_2 emissions for Euro VI CNG buses were like those of Euro VI diesel buses.

The COPERT 5 NO_x and CO emission factors for Euro IV and Euro VI diesel buses underestimate the emission factors encountered in this study, while remaining in the first quartiles of the measured emission ranges. Some factors and events influencing emissions were also analysed: exhaust temperature, ambient temperature, cold-start, driving style, average velocity, and observed after-treatment systems failures.

2.9

Research Gaps

In this session on *Air Quality and Remote Sensing*, research gaps identified included:

- Develop more reliable inventory models that will contribute to meeting the requirements under the National Emission Reduction Directive, which will ultimately impact on air quality.
- Establish commercial point sampling instruments using lab-grade analysers.
- Research on instruments to monitor non-regulated pollutants and further diffusion for real-world measurements
- Road measurements from trucks, and at highways which pools of data from remote sensing campaigns
- Comparison and corroboration of measurements from different vehicle emission measurement methods (laboratory, PEMS, remote sensing, plume chasing, point sampling).
- Real-world ammonia emission factors because modern gasoline vehicles are potential high emitters.
- Non-exhaust PM including physical/chemical evolution of particles from exhaust exit to near-road impacts.
- Simple methods to determine on key pollutants in emission inventories.
- Statistical analyses and methods to identify thresholds to select vehicles for roadside inspection or develop reliable schemes to refer vehicles to periodic technical inspection for emissions testing.
- Research on diesel particulate filter regeneration based on multiple parameter readings (different pollutants, exhaust temperature, etc.) and potentially spatial consideration (matching volume of CO_2-plume with particulate plume for example).
- GDPR interpretations in different EU Member States and development of uniform compliant protocols for international exchange of technical vehicle data.
- Models to predict which sites are suitable to conduct remote sensing.

03

Non-Exhaust and Non-Road Transport Emissions

3.1

NRMM Emissions - Overview on Recent Measurement Data and Current Activities

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Presentation

Graz University of Technology (TUG) together with Institute for Energy Research (Ifeu) is undertaking a research study on the 2018/2019 emission standards stage V for non-road engines. The study is funded by the UBA Germany and the BMU Germany and aims to assess real-world emission behaviour of stage V machines, develop representative emission factors and evaluate the new legislation, especially the in-service monitoring (ISM) part. ISM means doing on-board measurements according to special boundary conditions. TUG undertook real-world emission measurements on 1 step IV and 1 step V excavator and plans to undertake additional measurements on another machine type.

The study highlights challenges of undertaking PEMS measurements in the NRMM category. For example, installing PEMS equipment and its power supply on the machine without limiting the real-world operations, which is common in smaller machines. Another issue is the rough test conditions. For this purpose, TUG will extend its research work on the effect of vibrations on the accuracy of PEMS measurements.

The measured real-world emissions in standard operating conditions with a hot engine are well below (stage V) or in the range of (stage IV) the specific limits. However, special events such as cold start, long idling periods or diesel particulate filter (DPF) regenerations lead to a visible emission increase. The study will also gather information on the frequency of such special events in real-world operations and evaluate the effect of them on the entire emission behaviour.

The next step will be to elaborate representative emission factors for stage IV and V machines. One possibility is to base the emission factors only on measured emissions. However, the available measurement data does not cover all combinations of working events with all machine types.

Consequently, it seems reasonable to elaborate emission factors using PHEM, - an emission map-based simulation model. This method requires enough measurement data for a good coverage of the total engine map and allows the simulation of all possible mission profiles independent of the machine category. The required data covers only engine speed and power. Of course, the number of different machines in the measurement data set influences the quality of the emission factors also in this method.

Further Reading

Vermeulen, R.J.; Ligterink, N.E.; van der Mark, P.J (2021). Real-world emissions of non-road mobile machinery, TNO report 2021 R10221

3.2

PM and PN Emissions From Light-Duty Vehicle Brakes

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Presentation

The issue of non-exhaust particle emissions is receiving significant attention due to their increasing share of traffic-induced air pollution compared to exhaust emissions. Many studies predict that the relative contribution of non-exhaust emissions to traffic related particulate matter (PM_{10}) concentrations will reach 90% by 2030.

Non-exhaust emissions comprise particles emitted mainly due to brake, tyre, and road wear. Among these sources, brakes are reported to be the higher contributor to both PM_{10} and $PM_{2.5}$ concentrations. The scientific community – including health research organisations – as well as several regulatory bodies around the world have been investigating the issue of brake emissions from different perspectives. Up to now, there is no agreement on fundamental issues, such as the contribution of brake wear to ambient PM concentrations, the quantification of real-world brake wear emission factors (EF), and the possible adverse effects of brake debris on human health. Despite these limitations, there is a consensus that future regulation should limit PM emissions from the foundation brakes.

Despite the efforts of the scientific community to update the current knowledge on brake particle emissions, existing EFs are outdated – and to a certain extent – unrepresentative of real-world applications. Brake wear EFs either derive from direct measurements carried out in the laboratory or calculated through modelling using various methodologies.

Brake wear EFs depend on various parameters with the most important being the type of vehicle and featured brake, the friction couple and materials, and the applied driving conditions. Experimentally derived brake PM_{10} EFs of passenger cars have been reported to vary from 0.1 mg km^{-1} to 15 mg km^{-1} per vehicle. Similarly, reported brake $PM_{2.5}$ EFs vary from 0.1 mg km^{-1} to 5 mg km^{-1} per vehicle. Following the development of the worldwide harmonised light duty test procedure (WLTP) brake cycle, most studies focused on the application of realistic braking patterns; however, the range of reported EFs remains relatively broad. This is due to the lack of a standardised method for characterising brake particle emissions in the laboratory.

To overcome this limitation, the United Nations Working Party on Pollution and Energy (UNECE GRPE) has mandated the Particle Measurement Programme informal working group (PMP-IWG) to develop a standardised method for sampling measuring brake particle emissions. The method is expected to be the backbone of the – under development – Global Technical Regulation (GTR) on brake emissions which is expected to be finalised by June 2022.

Additionally, the development of such a methodology will allow the accurate calculation of updated brake PM and particulate number (PN) EFs and contribute to reducing particle emissions from road transport. Finally, a wide range of applications aiming in reducing brake particle emissions are being discussed.

Further Reading

T. Grigoratos and G. Martini; **Brake wear particle emissions: a review;** Environmental Science and Pollution Research 22 (2015) 2491–2504

A. Stanard, T. DeFries, C. Palacios, S. Kishan; **Brake and Tire Wear Emissions - Project 17RD016 Final Report**; Available at https://ww2.arb.ca.gov/resources/documents/brake-tire-wear-emissions

PMP Workshop on Brake Emissions Regulation; Brake Regulations Workshop MoM Final; Available at https://wiki.unece.org/display/trans/PMP+Workshop+on+Brake+Emissions++Regulation

3.3

Emission of Particles from the Tyre and Road Interface

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Presentation

Vehicle exhaust particle emissions have been successively reduced due to stricter Euro vehicle emission standards. However, the electrification of road transport means unregulated non-exhaust particles from tyres, roads and brakes will rise. Ongoing trends, such as stronger engines and heavier passenger cars could further increase unregulated non-exhaust particles emissions.

Particles emitted from the tyre and road interface result from the direct wear of both surfaces and the suspension of road dust accumulated on the road surface. The direct wear products and the road dust mix to form aggregates. This is because tyre wear particles tend to be soft and sticky causing mineral and metal dust to easily stick to them to form tyre and road wear particles (TRWP). TRWP has been identified as an air quality issue but is also a main source of microplastics.

Emissions of TRWP depends on several factors related to material and surface properties of tyres and pavements, vehicle properties, driving behaviour as well as road surface conditions, which are influenced by the weather.

To investigate how different factors affect emissions is a challenge due to representative sampling and numerous influencing factors in real-world driving conditions. In addition, the difficulty in replicating representative conditions in a laboratory.

This presentation describes the current state of knowledge regarding TRWP emissions, including examples from previous and ongoing research projects.

3.4

Maritime Air Emissions and Enforcement: The SCIPPER and EMERGE Projects

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Presentation

Maritime emissions contribute to up to 30% of ambient concentrations of pollutants in coastal and port cities. However, emission factors from vessels require constant updates and maintenance as new emission control technologies (e.g., scrubbers, SCR, EGR, etc.) and fuels (e.g., VLSFO, LNG, Methanol, etc.) become available.

In the framework of the SCIPPER project, a new set of emission factors has been proposed based on an extensive literature review and new measurements. The emission factors distinguish between fuel and engine type, as well as operating mode and load conditions. These emission factors will contribute to the EMEP/EEA Emissions Inventory Guidebook and the STEAM model and will improve EU maritime emissions inventories.

Although these emission factors reflect the best available knowledge in terms of levels and influential factors on vessel emissions, several uncertainties exist. These include emission rates for in-port activities, performance of auxiliary engines, boiler emissions, and scrubber performance with different sea water properties, etc.

The SCIPPER and EMERGE projects will collect additional experimental information by undertaking measurement campaigns involving several techniques, including on-board measurements, ground or airborne sniffer systems and optical remote sensing, including satellite observations. Within the SCIPPER project, three campaigns have been undertaken and a further three are planned in 2021.

This presentation outlines the new set of emission factors and how these have been derived and shows the main findings of the SCIPPER and EMERGE projects in terms of new emission measurements. It compares available measurement techniques in terms of deployment capacity in the field and provides recommendations on future testing to improve capacity in developing maritime emissions inventories.

3.5

Assessing Aviation Emission Impacts on Local Air Quality at Airports and Routes Towards Regulation

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Presentation

Aircraft emissions have adverse effects on air quality in and around airports which can contribute to public health concerns within neighbouring communities. The AVIATOR project[1] has adopted a multi-level measurement, modelling and assessment approach to develop an improved description and quantification of the relevant aircraft engine emissions and their impact under different climatic conditions.

Engine particulate matter (PM) and gaseous emissions at increasing distance scales from engine exit plane to several hundred metres downstream will be characterised using a combination of test cell and on-wing in-service aircraft to measure pollutant plume evolution. This will provide an enhanced understanding of primary emitted pollutants, specifically the non-volatile PM (nvPM) and volatile PM (vPM) (down to 10 nm), as well as the scalability between the regulatory test cell measurements and real ambient environments.

The project will deploy across multiple airports, a proof-of-concept low-cost sensor network for the monitoring of ultra-fine particles (UFP), PM and gaseous species such as nitrogen oxides (NO_x) and sulphur oxides (SO_x), across airport and surrounding communities. The transport and impact of emissions from aircraft engines and Auxiliary Power Units will be monitored in this more complex environment with supporting validation from high fidelity measurements.

The experimental measurement campaigns will be complemented by high-fidelity modelling of aircraft exhaust dynamics, microphysical and chemical processes within the plume. Computational fluid dynamics, chemical box, and airport air quality models will be applied, providing validated parameterisations of the relevant processes, applicable to standard dispersion modelling on the local scale.

Working with the regulatory communities, the AVIATOR project will develop improved guidance on measuring and modelling the impact of aircraft emissions on air quality with specific reference to UFP. Acknowledging the uncertainty surrounding the health impacts of UFP, the AVIATOR project is also working with the TUBE project [2] as well as public health communities to develop methodologies for the representative sampling of aircraft emissions.

[1] The AVIATOR Project: https://aviatorproject.eu/

[2] The TUBE Project: https://www.tube-project.eu

3.6

Alternative Fuels For Aviation: Expected Environmental Benefits Supporting the Policy Landscape

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Presentation

Before the Covid-19 pandemic, international civil aviation was using 160 megatons (Mt) of fuel, corresponding to approximately 2.6% of whole greenhouse gas (GHG) emissions from fossil fuel combustion. The aviation sector was growing at a significant pace: before the Covid-19 crisis, International Civil Aviation Organization (ICAO/CAEP) forecasted that by 2050 international aviation emissions could triple compared with 2015. Despite this disruptive event, all the analysts are positive there will be a rapid recovery of the aviation sector.

In 2016, CAO/CAEP launched the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) initiative to reduce the impact of aviation. Under CORSIA, an airline operator is required to offset GHG emissions. Sustainable aviation fuels (SAF) are considered an effective tool for the decarbonisation of the aviation sector. SAF are renewable or waste-derived aviation fuel that meet CORSIA Sustainability Criteria.

Under CORSIA, for the first time a methodology to calculate potential GHG savings has been internationally agreed and adopted. Four elements proved fundamental to the agreed LCA method for CORSIA: (1) use of life-cycle accounting for GHG emissions; (2) inclusion of induced land use change (ILUC); (3) safeguards to prevent deforestation; and (4) crediting of practices that mitigate the risk of land use change (LUC). These elements enabled a wide range of stakeholders to pursue different measures for SAF to reduce carbon dioxide equivalent (CO_{2e}) emissions on a life-cycle basis reducing the risks of unintended consequences.

A fundamental characteristic of SAF is compliance with ASTM standards. As of writing, eight conversion processes and renewable feedstock types to produce SAFs have been approved by ASTM and included in annexes to ASTM D1655 and D7566. However, only HEFA[1] process can be considered fully developed at a commercial scale.

SAF as defined in CORSIA can reduce life cycle GHG emissions by over 90%. However, while SAF could play a major role in contributing to reducing aviation sector's GHG emissions based on their per-MJ GHG

[1] Hydroprocessed Esters and Fatty Acids

reduction potential, caution is needed as cost barriers must be overcome in order to ensure the large-scale deployment of SAF, and the corresponding GHG emissions benefits.

At the European level, many legislative acts and initiatives are supporting the uptake of SAF. The 2019 European Green Deal (EGD) provides the overarching policy framework to achieve a climate neutral continent by 2050. The 2030 Climate Target Plan, adopted in September 2020, calls for the scaling up of efforts to improve the efficiency of aircraft, ships, and their operations and to increase the use of sustainably produced renewable and low-carbon fuels.

The revised Renewable Energy Directive (REDII) pursued the decarbonisation of the economy, including the transport sector. Specific multipliers (1.2X) were defined for aviation and maritime. Since 2012, the EU emission trading system (EU ETS) has included CO_2 emissions from aviation. The EU decided to limit the scope of the EU ETS to flights within the European Economic Area until 2016 to support the development of CORSIA. Currently, European Commission is working on the ReFuelEU Aviation legislative initiative, with the specific goal of increasing the use of SAF in the EU.

Further Reading

https://www.easa.europa.eu/eaer/

Prussi, M., O'Connell, A., & Lonza, L. (2019). Analysis of current aviation biofuel technical production potential in EU28. *Biomass and Bioenergy*, *130*, 105371.

CORSIA: The First Internationally Adopted Approach to Calculate Life-cycle GHG Emissions for Aviation Fuels Renewable and Sustainable Energy Reviews. Renewable & Sustainable Energy Reviews. *Under Publication*

3.6

Research Gaps

In this session on *Non-Exhaust and Non-Road Transport Emissions*, research gaps identified included:

- Need to understand marine vessel emissions at low load conditions.
- Research on emission level degradation with vehicle ageing (including tampering and malfunctions).
- Improving emission factors for unregulated pollutants.
- Robust methodologies for the measurement of volatile and semi-volatile particulate matter measurement.
- Understanding of the impact of fuel chemistry on incomplete combustion emissions products (i.e., fuels).
- Improve knowledge of the microphysics and chemistry in the formation and evolution of secondary particulate matter from atmospheric precursors.
- Real-world measurement data of different machine types to assess the real-world emission behaviour and elaborate emission factors.
- On-road measurements from trucks, and on the highway, by pooling of data from remote sensing campaigns.
- Use of plume chasing emission values in an emission inventory (e.g., Guidebook, HBEFA).