Adapting driver behaviour
for lower emissions

MODALES results on effectiveness of inspections and depollution systems

Andrew Winder – MODALES Project Coordinator, ERTICO **(Speaker)**

Dimitris Margaritis – MODALES Technical Coordinator, CERTH

Rasmus Pettinen – Senior Scientist, VTT

Arno Amberla – Vice President - Technology, Proventia

Haibo Chen – Professor of Intelligent Transport Systems, University of Leeds

Sébastien Faye - Technology & Innovation Manager, Luxembourg Institute of Science and Technology

Esther Tenge – Principal Consultant, Spark Legal Network **(Speaker)**

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MODALES – Adapting driver behaviour for lower emissions

Project Vision:

To **reduce air pollution** (e.g. NOx, PM, PN) from all types of road vehicles (but especially older vehicles) by encouraging adoption of **low-emission driving behaviour** and **proper maintenance choice**

Core objective:

To advance the understanding of the co-variability between **user behaviour** and **vehicle emissions** from **powertrain, brakes and tyres**, in order to **modify user behaviour**, via **training** which includes a **driver assistance app** and an **awareness campaign**

MODALES runs from September 2019 to May 2023, with a budget of €4.72 million.

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Project innovation areas

Driver
1. Low-emission driving style & training
2. Guidelines for regular maintenance
3. Use of adaptive cruise control & navigation to avoid congestion
4. Increased awareness of emissions
5. Real time indication of emission (app)

Retrofits
6. Diesel-saving technologies for cars & vans
7. NOxBUSTER for buses and trucks
8. Diesel particulate filter servicing

On-Board Diagnostics
9. More robust & durable emission control systems
10. Enhanced OBD functionality as an anti-tampering measure

Periodic inspections
11. Enhanced inspection procedure to trap tampering
12. Roadside emissions testing

Exhaust emission
CO_2, CO, HC, NO_X, PM, PN

Brake and tyre/road wear
Fine and ultrafine particles (PM, PN)

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Effectiveness of Inspections and Depollution Systems

Proposing and validating possible solutions that will contribute to lower emissions by involving:

- **OBD logging**

  How current OBD can be used and improved with respect to lack of maintenance or deliberate tampering.

- **Periodic inspections and other anti-tampering solutions**

  Detection of tampering or malfunctions, considering technical, behavioural and legal criteria

- **Retrofits**

  Feasibility and potential of retrofit emission controls

  Starting from the commercially-existing systems (mainly for buses)

  Simulation of Ammonia Creation and Conversion Technology (ACCT) for cars

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Challenges for a broader use of OBD

OBD and poor maintenance

- At the start of MODALES, assumption that lack of service would increase tailpipe emissions
- However, lack of service could not be supported with the results of our experiments. Test results demonstrated that **within normal service intervals, excess emissions are quite negligible**. Post-service emission levels in most cases were at the same level as before service.
- Negligence of motorists regarding service must be quite severe before exhaust emissions are critically affected and could lead to the triggering of an event through the OBD data.

OBD and tampering

- Present OBD system **not robust** against actions used to circumvent the system's ability to detect/report elevated emission levels due to tampering.
- The main reasons:
  - no provision to permanently store DTCs (Diagnostic Trouble Codes)
  - no "readiness bits" implemented in OBD that indicate whether sub-system monitoring has been recently completed with success

Ref: MODALES WP4, **D4.1: Recommendations for a broader use of On-Board Diagnostics (OBD)**

https://modales-project.eu/deliverables/

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Recommendations for anti-tampering and improved mandatory vehicle inspection

Heavy Duty and NRMM (Non-Road Mobile Machinery) **tampering customers' profile:**

Current customers (on HD- and NRMM sectors) are divided typically into three categories:

1. Those who face **NRMM EATS failures** -> increased downtime -> requests that the EATS is disabled (temporarily or permanently) depending on spare parts price and delivery time.
2. Customers who **believe that the engine power is lower than rated by the manufacturer**, as engine response may be "slow" or lack power in relation to work load -> request for improvements -> more power = improvements in work efficiency -> "time is money".
3. Customers who buy a "rescue kit" -> a backup **ECU-flash** that is used if any error codes appear that increase the downtime during the work days. These customers want to get the job done in time and will then return the machinery for service after the work is complete.

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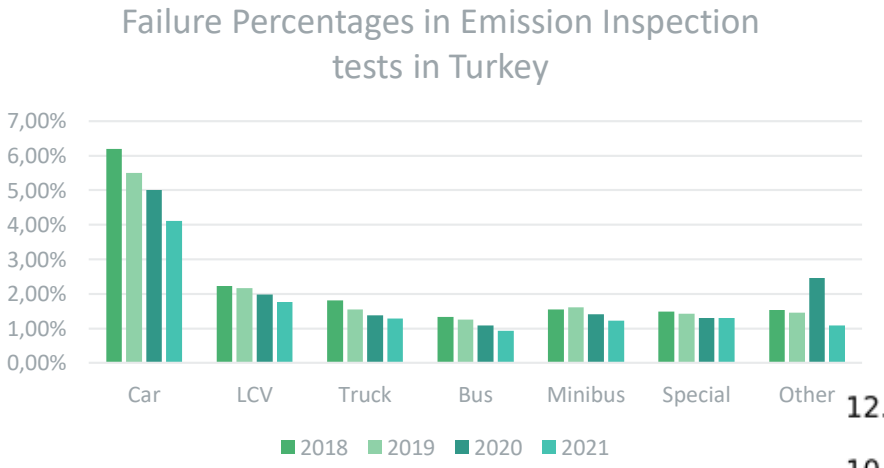
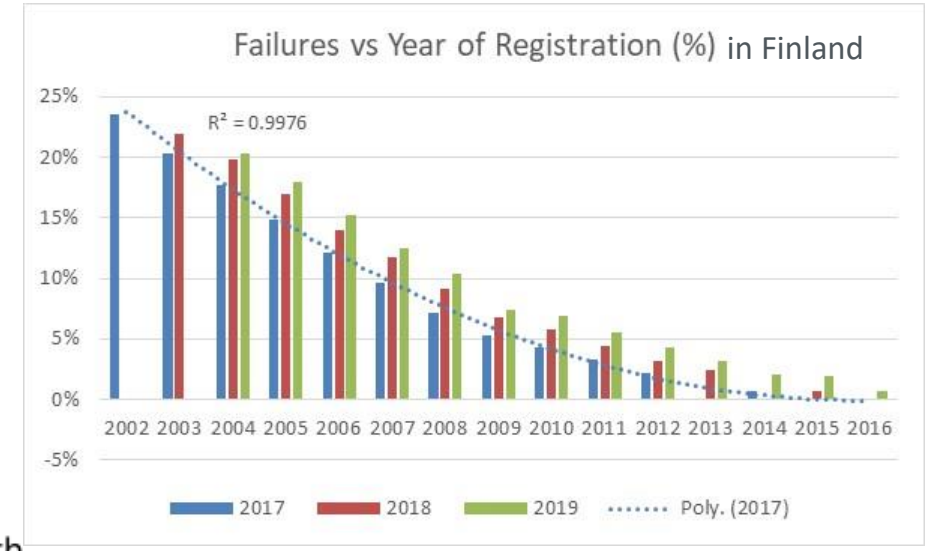
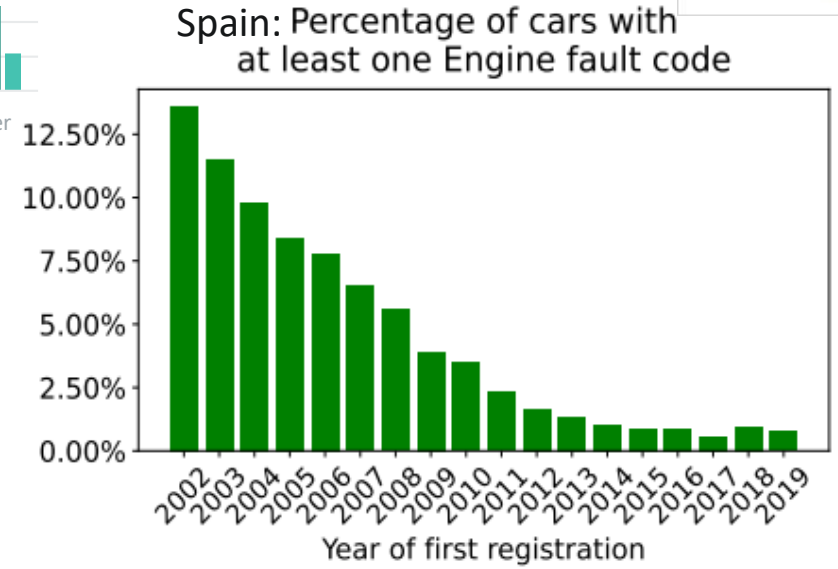
Recommendations for anti-tampering and improved mandatory vehicle inspection

PTI (Periodical Technical Inspection) data analysis

- Sample data from 3 countries

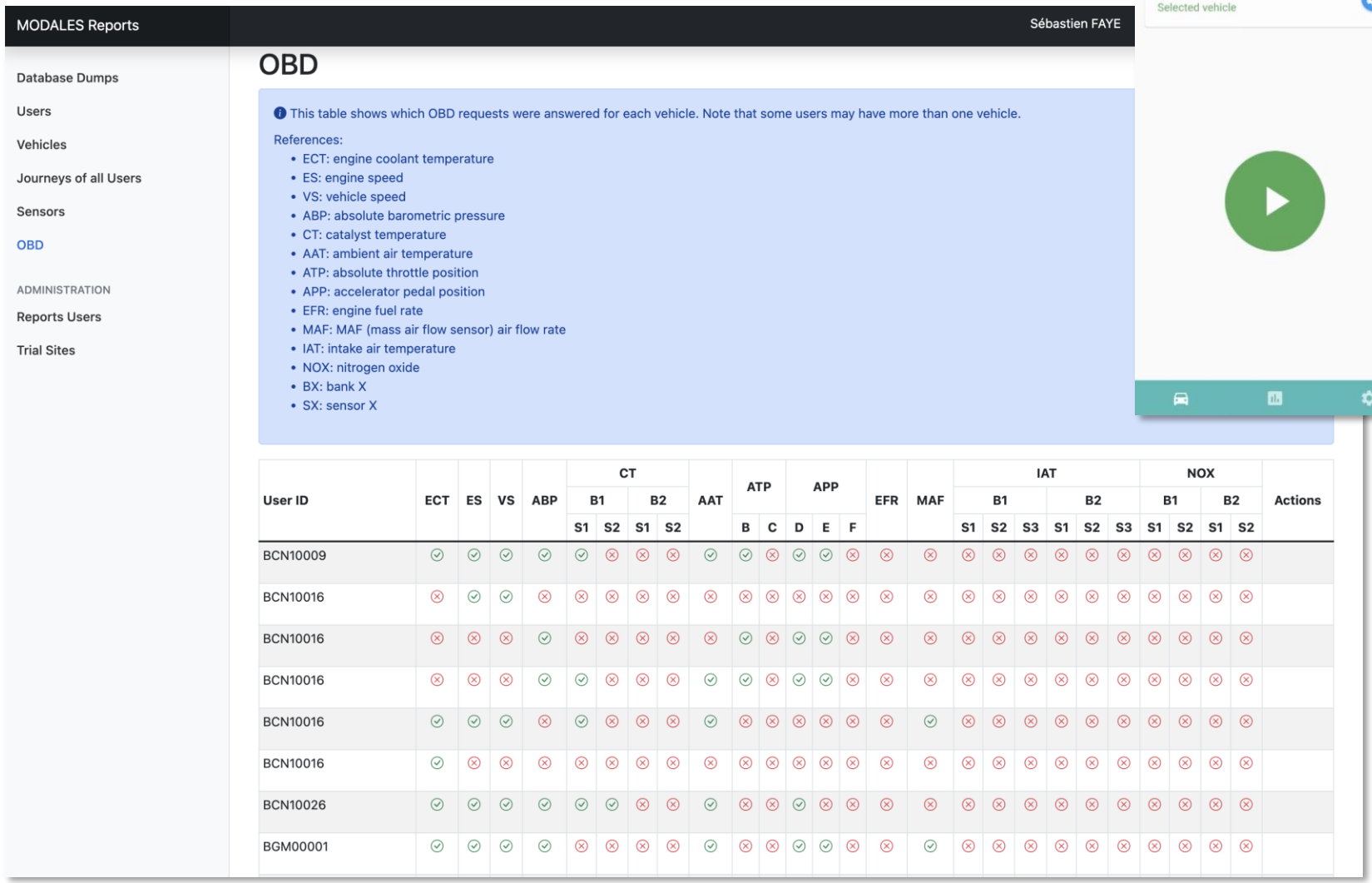






(OBD &) Trial site reporting platform for MODALES app

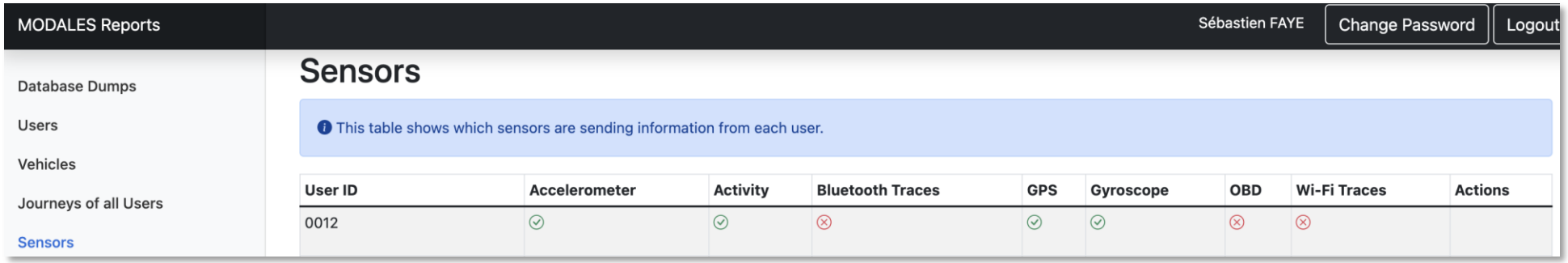
- **Internal reporting platform for aggregating the data collected through the MODALES app.**
- Management of **multiple users and trial sites**.
- Statistical information about **journeys** and **app usage**.

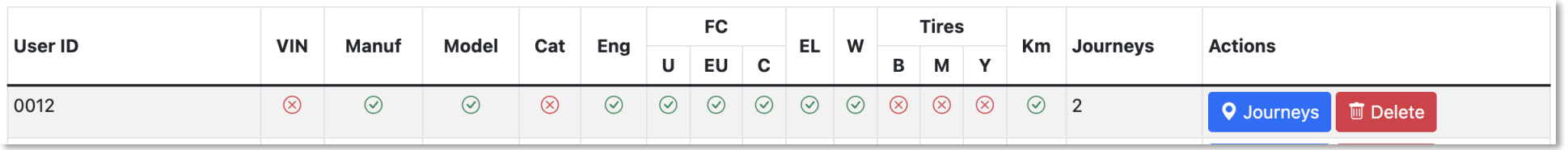


(OBD &) Trial site reporting platform for MODALES app

Anonymised datasets for analysis of driving behaviour & other indicators:

- From the **smartphones' sensors** (accelerometer, gyroscope, network traces, etc.).
- From **OBD dongles** (air flow rate, catalyst temperature, engine speed, etc.).
- From **external services** for data augmentation: identification of the vehicle based on the Vehicle Identification Number (VIN) and contextual information on a journey (traffic jams, POIs, etc.).





Demonstrating effects of Emissions After-Treatment Systems (EATS) tampering and ECU reprogramming on overall HDV performance

- This action was performed to demonstrate the **effects of different EATS tampering methods** and **reprogramming of ECU** (Engine Control Module) **software** in **HDV applications**
- The main focus was to study the **direct impact** of the modifications on **exhaust emissions** and **vehicle performance** → improve the understanding for detecting ECU/EATS modifications
- Experimental tests on VTT HDV chassis dynamometer, WHVC cold and hot cycle + drivetrain power evaluation using acceleration measurements
  - Study the change in emissions (focus on CO2, CO, NOx and particles), fuel consumption, vehicle performance
  - Demonstrate the “gains & losses”, e.g. gain in fuel consumption in relation to change in emissions
  - Evaluate the potential to detect ECU remapping and EATS tampering through changes in emissions

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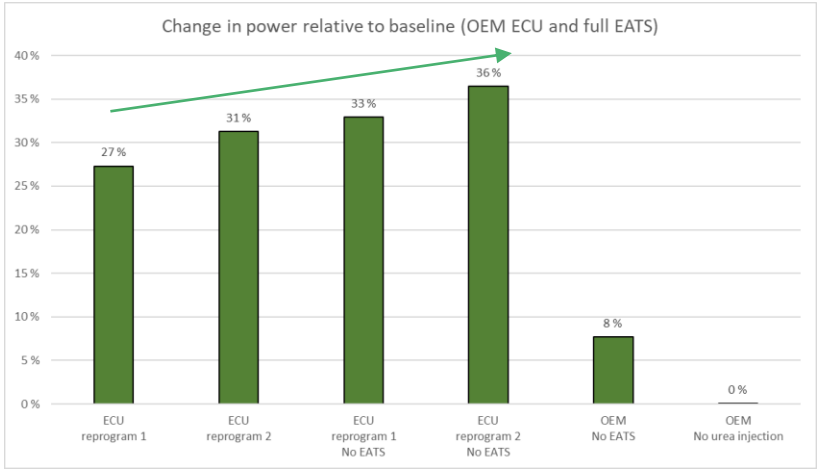
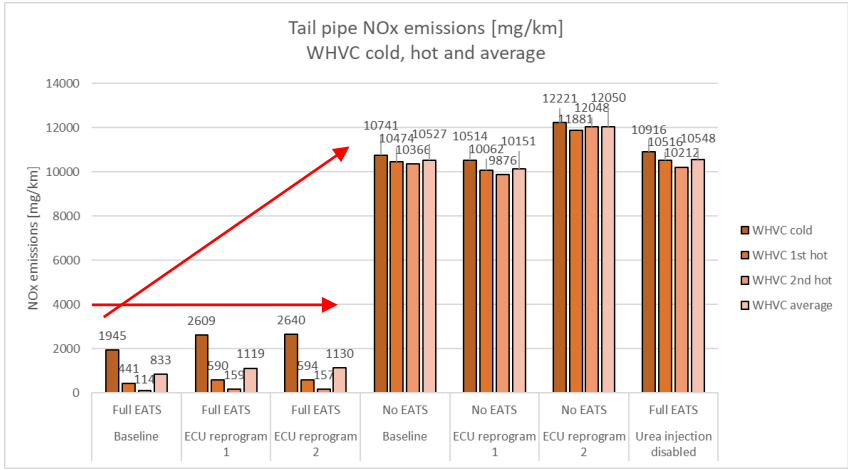
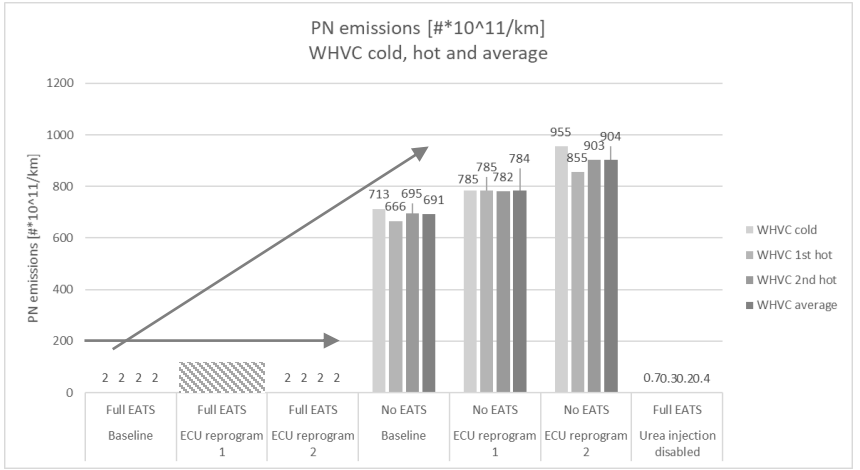
Impacts of ECU reprogramming and EATS tampering

- ECU reprogramming **increased the powertrain peak power** by 27 – 31 % with the EATS system installed, further increasing to 33 – 36 % with the EATS removed.
  - Simultaneously **reducing fuel consumption** by 2 – 6 % depending on configuration and condition.
- As expected, EATS removal produced the greatest impact on tail pipe emissions (compared to ECU reprogramming), increasing the emission levels corresponding to raw exhaust emissions
- Although it was found that ECU reprogramming has some effect on gaseous emissions even with full EATS in use, the tail pipe emissions **did not change** significantly enough, in order to distinguish ECU remapping from OEM → EATS was fairly capable of adapting with the increased engine out concentrations
- This particular ECU modification turned out to be fairly sophisticated, but this **does not necessary apply for other software modifications**

Ref: MODALES WP3, **D3.1: Emission Measurements** https://modales-project.eu/deliverables/







Real-world tests of NOx retrofits

Analysis of effectiveness of the NOxBUSTER® City Diesel Particulate Filter (DPF) + Selective Catalytic Reduction (SCR) Retrofit System by Proventia

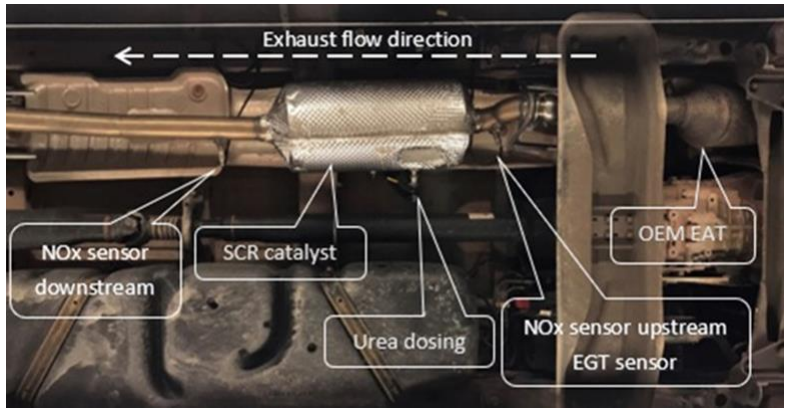
Trial retrofit to a light van; Tested on a dynamometer in Finland

- Tests prove that Euro 5 vehicles are optimised for NEDC and does not correlate well with WLTC results in general
- Impact of applying diesel SCR retrofit systems on Euro 5 vehicles: NOx reduction of 51 - 65 % over the whole cycle may be achieved
- When retrofit system active, NOx conversion efficiency was between 59 - 78 %
- No significant effect on CO2, CO or HC found with usage of Proventia retrofit compared to OEM configuration
- Retrofit SCR efficiency highly dependent on the engine out exhaust temperature and retrofit system operating window highly dependent of upstream EGT conditions

Real-world tests of NOx retrofits

Conclusions:

- Retrofits for buses and vans worked quite well
- But most buses are > Euro 5
- Future market:
  - HDVs (buses and trucks): some interest but potential vehicles already quite old
  - LDVs (vans): no real business. ~20% are tampered
  - Cars: No interest to install anything
  - NRMM: high variability of applications
- It is a transition technology (5 – 7 years)



Proventia NOxBUSTER City Light® SCR retrofit system installed on test vehicle (Mercedes-Benz Sprinter)

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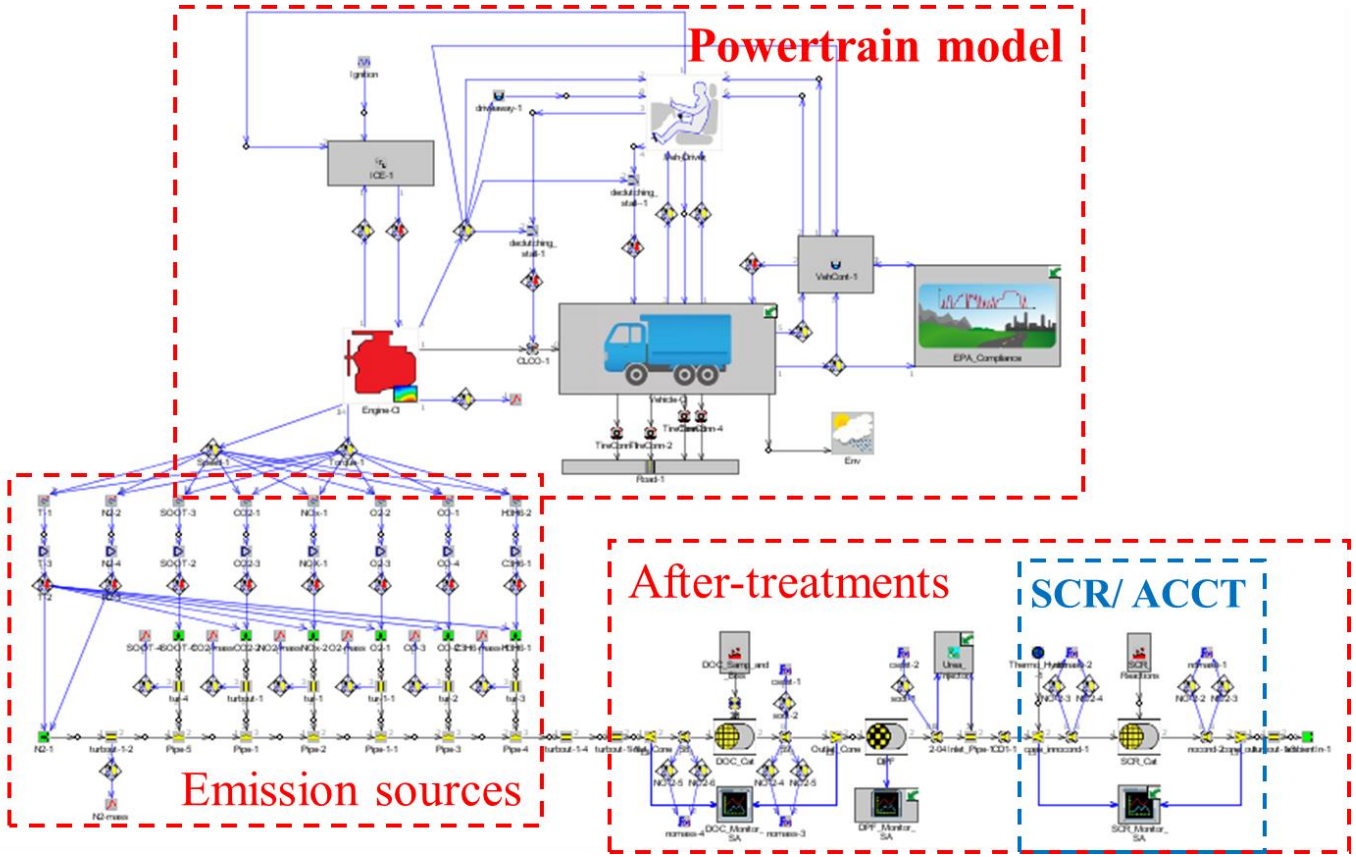
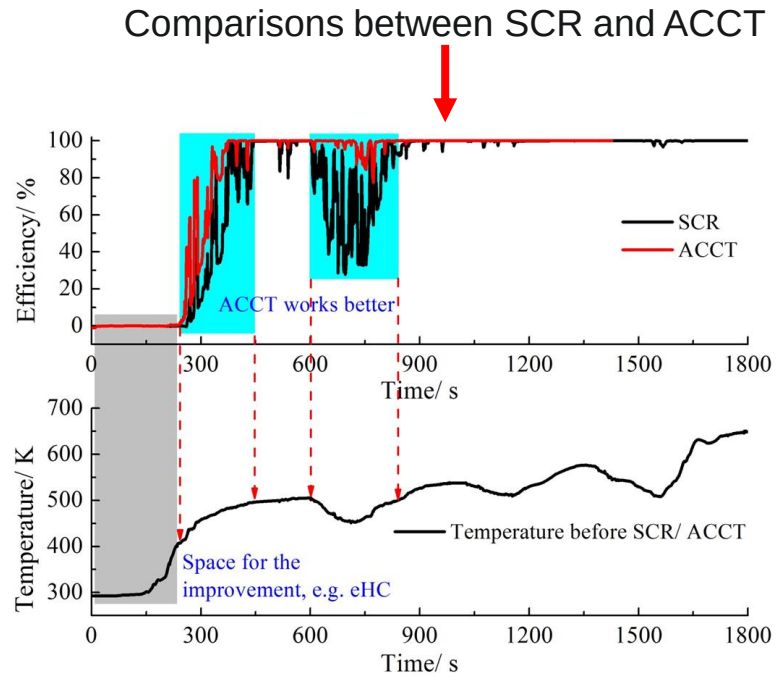
Retrofit solutions for road vehicles: Simulation of NOx retrofits under real-world driving conditions

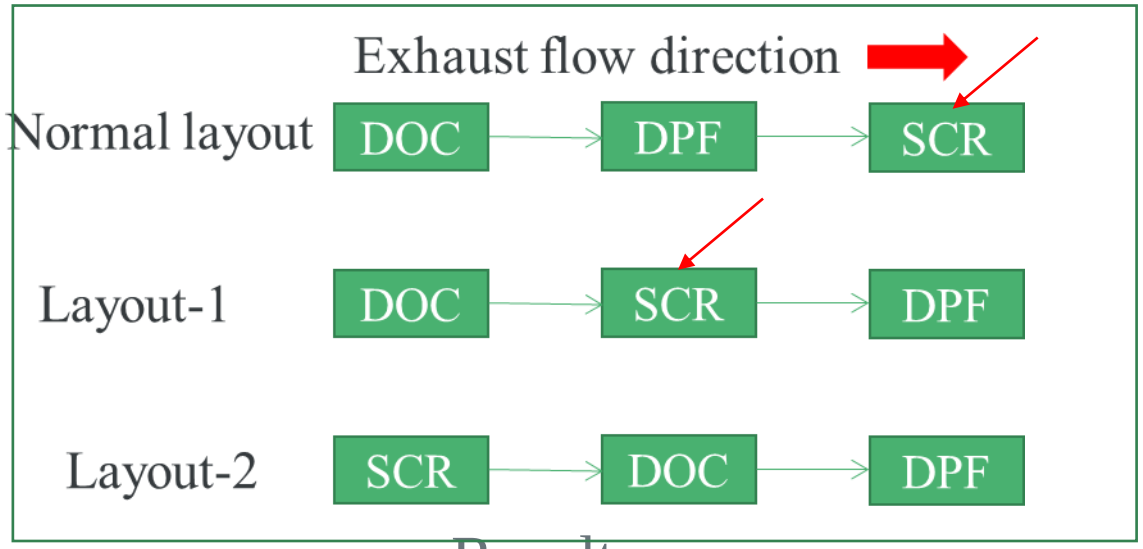
- ***Objective***: test the effectiveness of advanced NOx retrofitting technologies (e.g. ACCT), using SCR as benchmark
- ***Scenarios***: various traffic conditions were tested, such as stop-and-go, engine-off at junction, low-speed





Further information can be found in: Gao J, Chen H, Liu Y, Li Y, Li T, Tu R, Liang B & Ma C (2021), "The effect of after-treatment techniques on the correlations between driving behaviours and NOx emissions of passenger cars", Journal of Cleaner Production, 288, doi: 10.1016/j.jclepro.2020.125647.

Retrofit solutions for road vehicles: Effect of after-treatments layout on emissions



Results:

g/km	SCR			ACCT		
Layout	CO	HC+NOx	NOx	CO	HC+NOx	NOx
Normal	0.012	0.076	0.069	0.012	0.053	0.046
Layout-1	0.012	0.054	0.047	0.012	0.030	0.023
Layout-2	0.024	0.057	**0.034**	0.024	0.032	**0.008**

Main findings:

- Layout-2 has the best performance for NOx.
- ACCT performs better, compared to SCR.
- All layouts have met the Euro 6 emission standards.
- Further information can be found in:
  - Gao J, Chen H, Liu Y & Li Y (2021), "Impacts of De-NOx system layouts of a diesel passenger car on exhaust emission factors and monetary penalty", Energy Science & Engineering, doi: 10.1002/ese3.1001.

Euro 6 emission regulations	
Emissions	Limits (g/km)
CO	0.5
HC+NOx	0.17
NOx	0.08

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Legal situation on tampering

Legal desk research in 14 countries (13 EU Member States + UK) carried out by national legal experts

Stakeholder survey (EU Survey) sent out to more than 300 governmental and industry stakeholders as well as to associations

Comparative analysis aimed at identifying the commonalities and contrasts in legislation on vehicle tampering across EU Member States (e.g. no specific legal provisions on vehicle tampering beyond legislation on type approval processes, lack of severity of the sanctions)

Identification of **legal recommendations** (and best practices)

Verification survey (EU Survey) sent out to the same stakeholders that were involved in the data collection phase

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Examples of legal recommendations

- Ensure alignment of the legislation on heavy and light duty vehicles on tampering activities - a definition of tampering corresponding to the one in legislation on heavy duty vehicles could be incorporated into legislation on light duty vehicles.
- Adopting rules prohibiting vehicle tampering will enable authorities to apply anti-tampering measures outside of the context of the type approval process.
- In order to increase the dissuasiveness of the sanctions, raising the amounts of the fines or punishments applicable to violations of rules on vehicle tampering may be considered.
- Harmonisation of sanctions across Member States could contribute to effectively tackling conducts where tampered vehicles or their parts are sold in Member States with lower sanctions.

A Low-emission driving app has been developed

The smartphone app creates two types of recommendations:

- **Active recommendations**:
  - When the user is driving
  - Research prototype → simplified recommendations and HMI, using only the phone sensors
- **Passive recommendations**:
  - After a trip
  - Complete report, using the phone sensors, OBD data and external web services (e.g., weather, traffic index)

Training videos have been developed by MODALES covering:

Driving behaviour

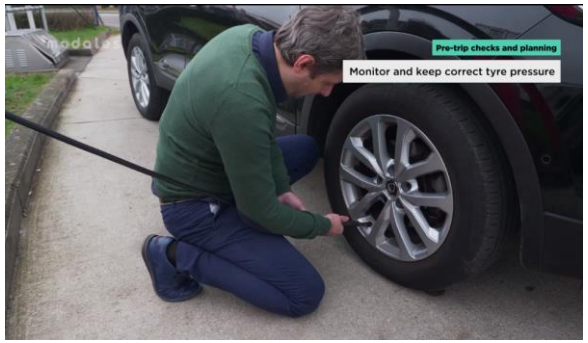
Training will be delivered on emissions savings by changing behaviour (idling, gears, breaking, accelerating etc.)

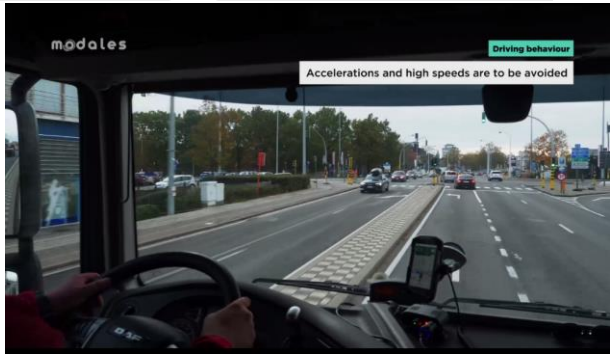
Proper maintenance

By maintaining the vehicle properly, emissions savings can be achieved

Use of the MODALES app

The MODALES app will assist drivers consulting them to drive environmentally friendly





Testing of app + video underway with volunteer drivers in 7 European city-regions (in ES, FI, IT, LU, GR, TR, UK) and in China

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MODALES partners

EU-funded partners

Associations

Universities

Research institutes

Industry and technology providers

Legal experts

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Thank you

Contacts:

Andrew Winder
Project Coordinator
a.winder@mail.ertico.com

Dimitris Margaritis
Technical Coordinator
dmarg@certh.gr

Esther Tenge
Legal Expert
esther@sparklegalnetwork.eu

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