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Adapting driver behaviour for lower emissions

MODALES interim results

…on the road to improving air quality

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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 objectives:

To advance the understanding of the co-variability between **user behaviour** and **vehicle emissions** from **powertrain, brakes and tyres**.

To **modify user behaviour**, via **training** which includes a **driver assistance app** and an **awareness campaign**

To **propose and validate other solutions** to contributing to lower emissions

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

MODALES receives funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815189.

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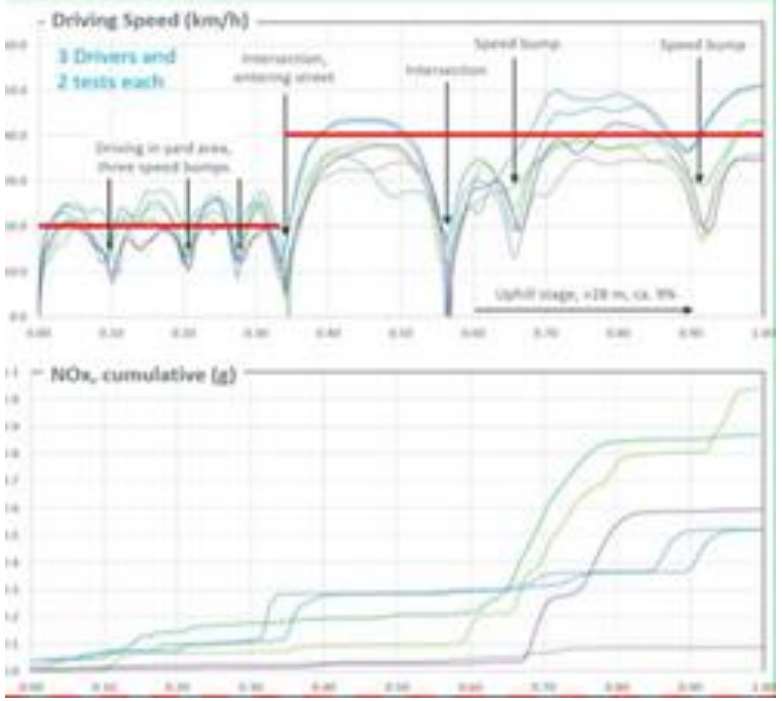
Research on emissions from ICE cars

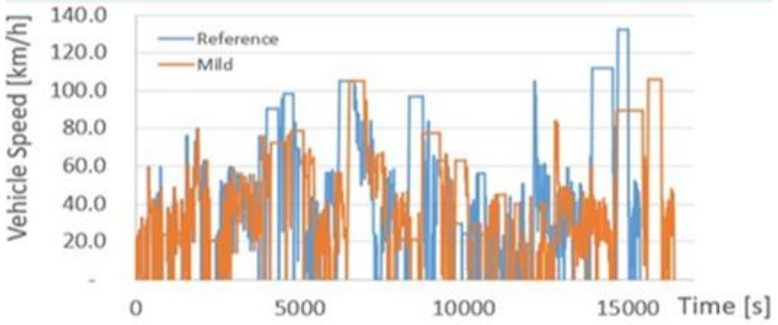
Powertrain (exhaust) emissions

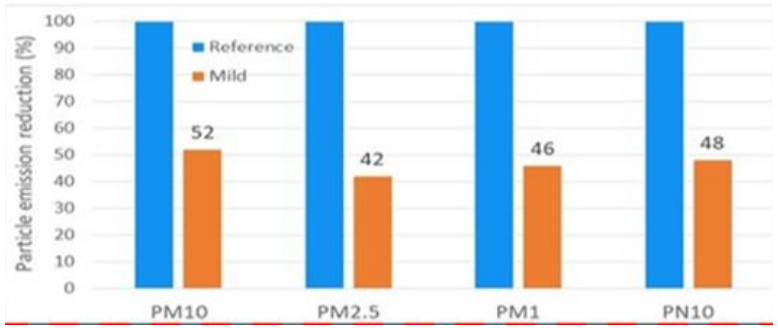
Real-world driving, 15 drivers and 6 cars



Brake wear emissions

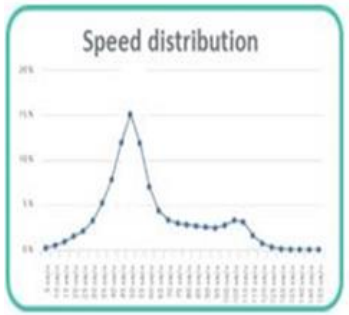
In-lab driving cycle tests

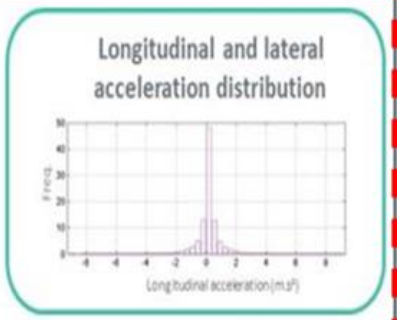


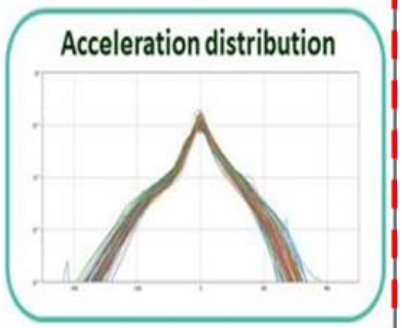


Tyre wear emissions

Real-world driving and measurements







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4 main 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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1. Driver

Driving behaviour factors

Powertrain

Driving behaviour KPIs for exhaust emissions	Ranking (1: most important)
Aggressiveness (% of time in acceleration > 0.9 m/s$^{2)}$	1
Average acceleration	2
% of time in speed interval of 20~50 km/h	3
Average speed	4
Average driving speed without stops	5
% of time in deceleration interval of -0.9~0 m/s^2	6
Average deceleration	7
% of time in acceleration	8
% of distance in acceleration	9
% of time in deceleration	10
% of distance in deceleration	11
% of distance in speed interval 50~70 km/h	12
Gear upshift speed	13
Gear downshift speed	14

Brakes

Driving behaviour KPIs for brake emissions	Unit	Ranking (1: most important)
Deceleration rate of braking	m s^{-2}	1
Average deceleration rate of braking	m s^{-2}	2
Braking distance	m	3
Braking time	s	4
Initial speed when braking	km/h	5
Average initial speed when braking	km/h	6

Tyres

Driving behaviour KPIs for tyre emissions	Wear amount (m^3/rev)	Wear mass (g/rev)	Ranking (1: most important)
Deceleration rate when right braking	5.43E-10	6.30E-04	1
Acceleration rate when right accelerating	4.13E-10	4.80E-04	2
Initial speed when right braking	3.14E-10	3.64E-04	3
Initial speed when right accelerating	2.82E-10	3.27E-04	4
Deceleration rate when straight braking	2.51E-10	2.91E-04	5
Acceleration rate when straight accelerating	1.78E-10	2.07E-04	6
Initial speed when straight braking	1.49E-10	1.73E-04	7
Initial speed when right cruising	1.27E-10	1.47E-04	8
Initial speed when straight accelerating	1.07E-10	1.24E-04	9
Driving speed when straight cruising	4.73E-11	5.49E-05	10
Deceleration rate when left braking	4.14E-11	4.80E-05	11
Acceleration rate when left accelerating	3.79E-11	4.40E-05	12
Initial speed when left braking	2.65E-11	3.07E-05	13
Driving speed when left cruising	2.59E-11	3.00E-05	14

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MODALES training videos

Videos based on behaviour factors, created for:

- Car drivers
- Professional drivers of light vehicles (LDV/vans, taxis)
- Professional drivers of heavy vehicles (HDV)

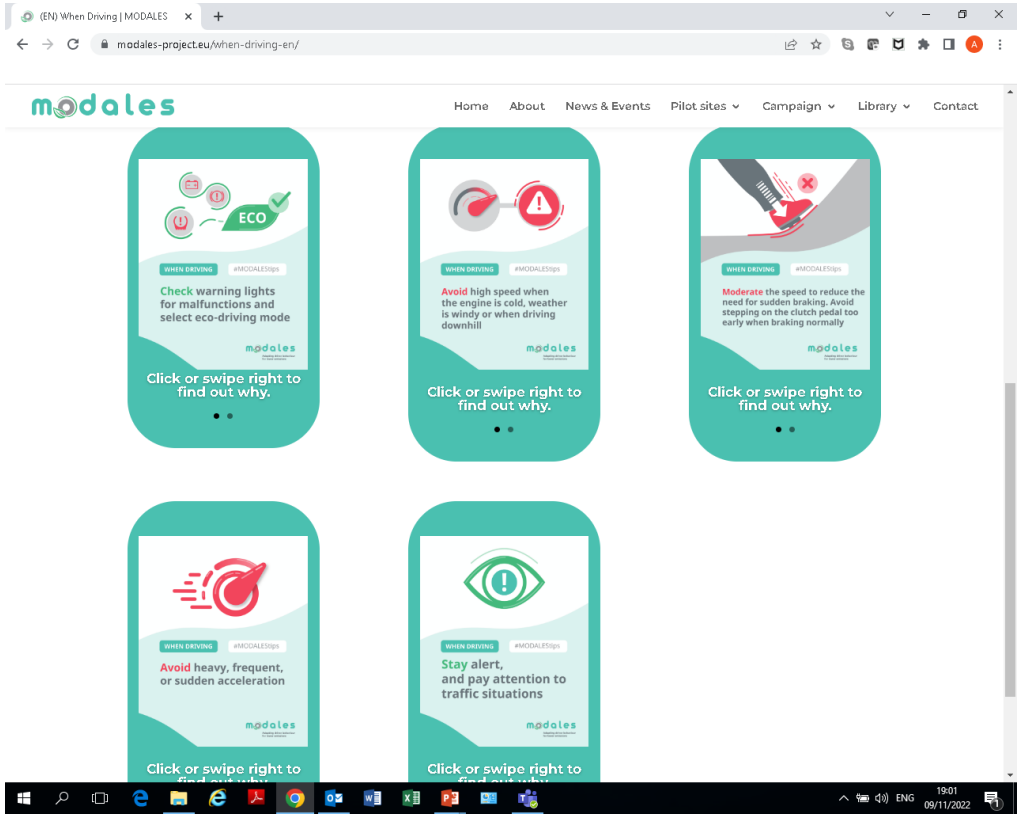
Approx. 15 minutes duration, in several language versions

Aspects covered: pre-driving, driving, maintenance

MODALES awareness campaign

Low-emission driving tips aimed at car drivers:

- 3 categories: Before driving, When driving, Car maintenance
- Simple messages with animated graphics
- Available in 11 languages also with downloadable pdf versions
- https://modales-project.eu/campaign (over 1200 views so far)



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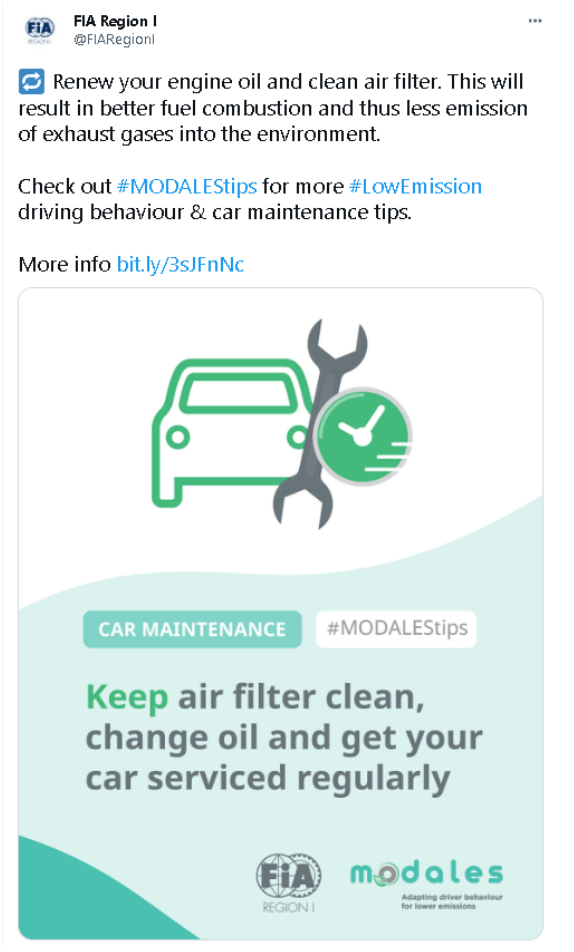
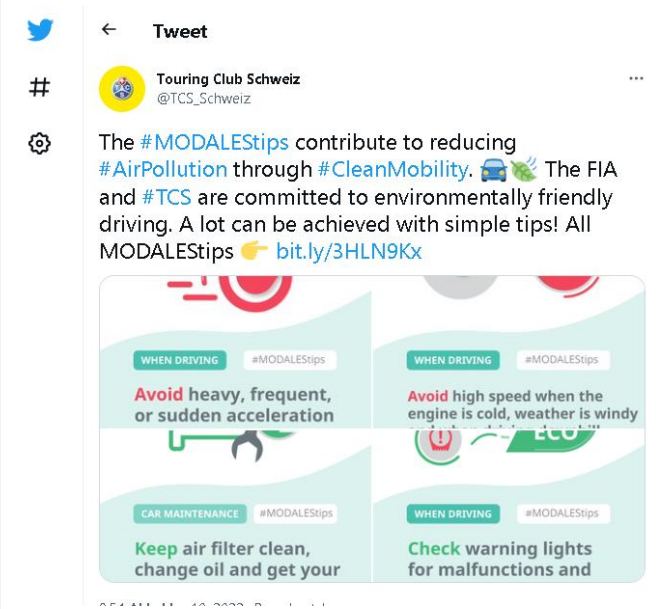
MODALES awareness campaign

Social media campaign by FIA and motoring organisations in several countries

Twitter, Facebook, LinkedIn, using hashtag #MODALEStips





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Low-emission driving smartphone app

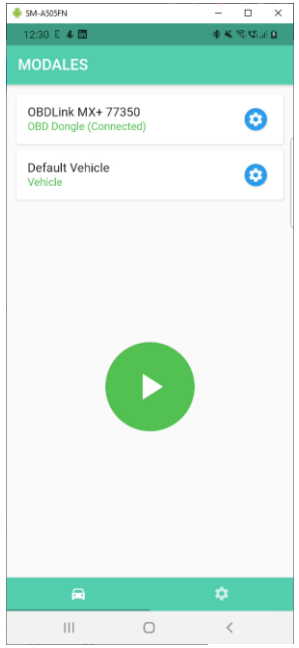
Simple interface

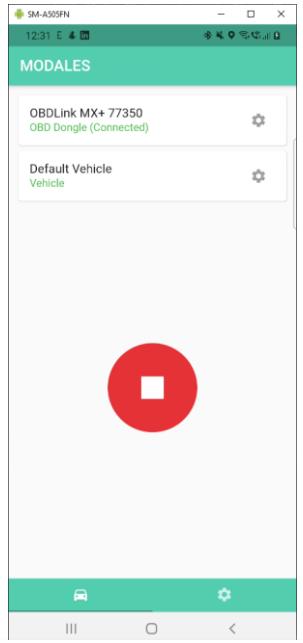
Available for Android and iOS

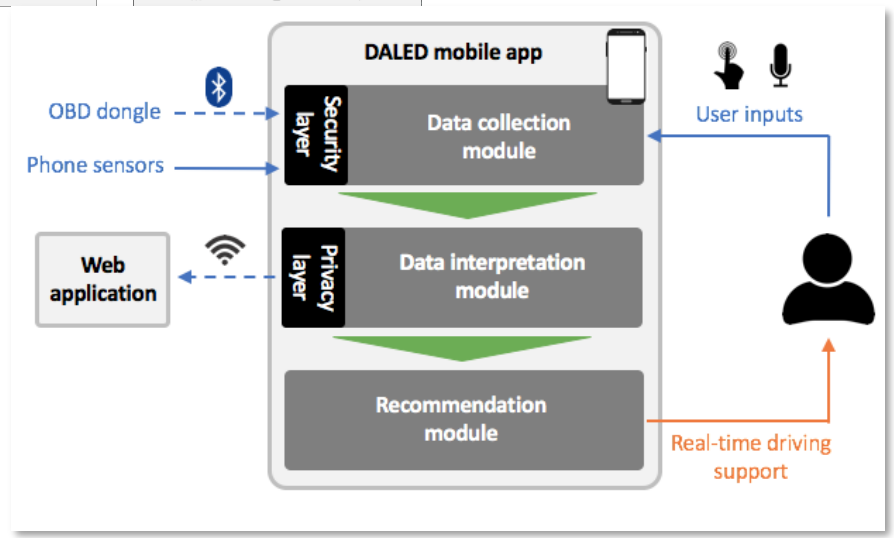
Paired with OBD dongle

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)







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On-Board Diagnosis (OBD)

More reliable:

- Absolute barometric pressure
- Absolute throttle position
- Accelerator pedal position
- Air flow rate
- Ambient air temperature
- Catalyst temperature
- Engine coolant temperature
- Engine fuel rate
- Engine speed
- Vehicle speed

Less reliable:

- Intake air temperature
- NOx sensor

Image Source (OBDLinkMX+): https://www.obdlink.com/products/obdlink-mxp/

Context Information for the app

Weather:
- humidity
- temperature
- total snow
- visibility
- wind speed

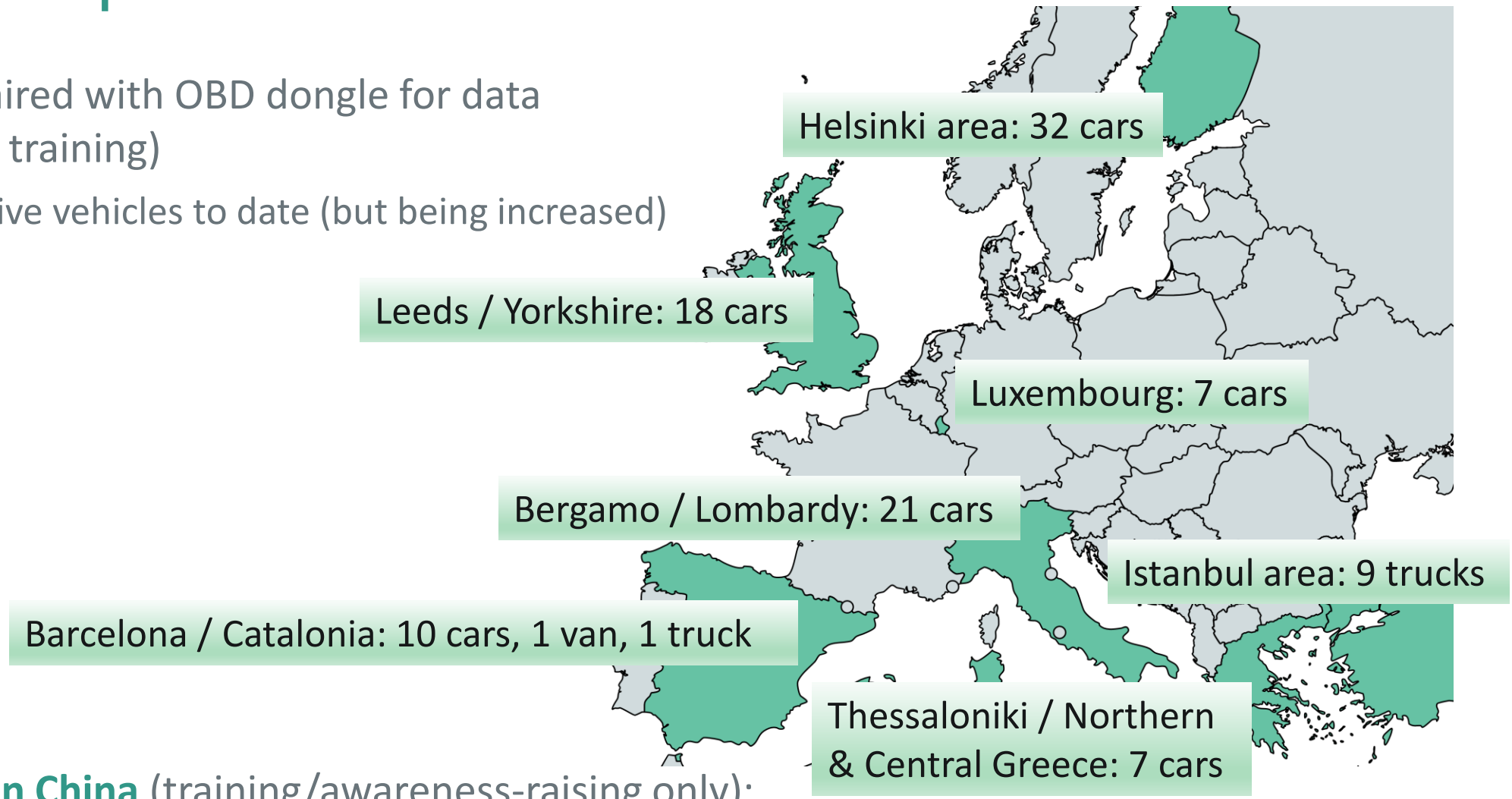
Traffic:
- historical average speed
- historical free flow speed
- historical jam factor
- historical traversability
- real-time confidence
- real-time traffic speed

Road:
- average roughness category
- curvature
- distance to intersection
- functional class
- has end of no overtaking sign
- has no overtaking sign
- has pedestrian crossing sign
- has stop sign
- has traffic signal
- has yield sign
- heading
- intersection category
- international roughness index
- is bridge
- is intersection
- is long haul
- is ramp
- is roundabout
- is tunnel
- is urban
- lane category
- radius
- road type
- slope
- speed category
- speed limit
- speed limit trucks

Ongoing testing of training and driving app in pilots across Europe and in China

Full trials (app paired with OBD dongle for data collection; online training)

- Numbers of active vehicles to date (but being increased)



Restricted trials in China (training/awareness-raising only):

Nanjing and Beijing: 20 truck drivers

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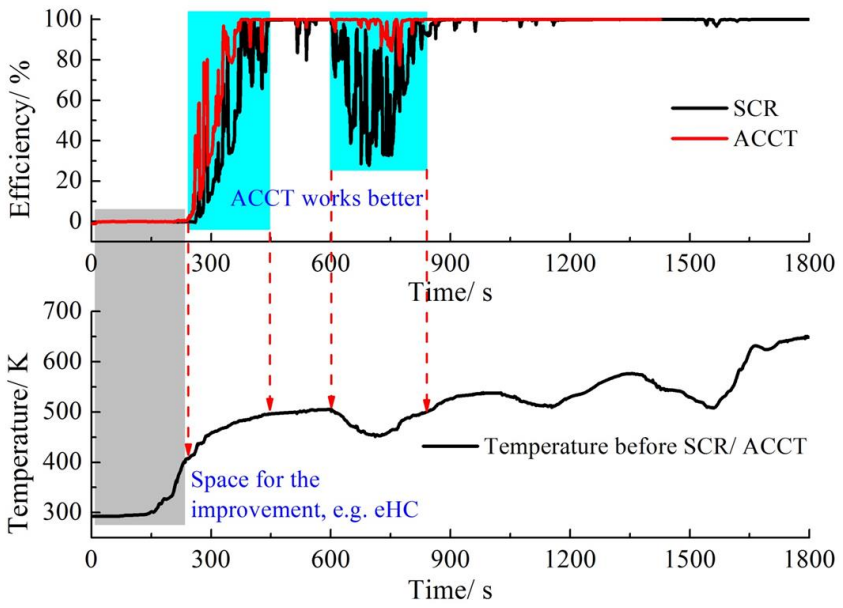
2. Retrofits

Feasibility and potential of **retrofit emission controls** for **diesel vehicles**:

- Study of results of commercially-existing systems (mainly for buses)
- Proventia retrofit carried out on a van and tested on a dynamometer
- Simulation of Ammonia Creation and Conversion Technology (ACCT) for cars



Comparisons between SCR and ACCT for diesel cars (simulation)

Potential NOx retrofit technologies

No	Technology	Efficiency	Response	Energy Penalty	Complexity/Affordability/Adaptability
1	**SCR*** (Selective Catalytic Reduction)	Medium	Medium	Low	Medium/Medium/Medium
2	**ACCT** (Ammonia Creation and Conversion Technology)	High	Fast	Medium/High	Complex/Low/Low
3	**ASDS** (Ammonia Storage and Delivery System)	High	Fast	Medium	Complex/Low/Low
4	**Thermal Insulation Technology** (Insulation materials covering SCR system)	Low	Slow	Low	Simple/High/High
5	**EHC** (Electrically Heated Catalyst)	High	Fast	High	Simple/High/High
6	**External burner**	High	Fast	High	Simple/High/High
7	**LNT** (Lean NOx Trap)	Low	Fast	Medium	Medium/Medium/Medium

Based on ammonia generation (1-3), heat loss prevention (4), exhaust temperature increase (5-6), NOx adsorber (7)

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:

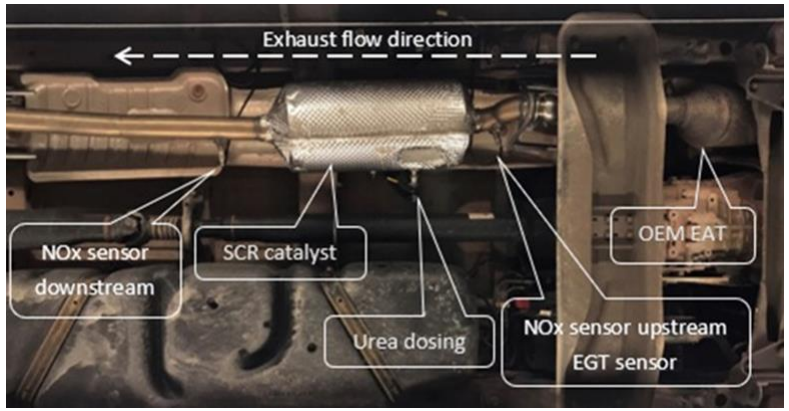
Retrofits for buses and vans worked quite well

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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3. On-Board Diagnostics (OBD)

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

OBD and poor maintenance

- We assumed that lack of service would increase tailpipe emissions. However this was not supported by 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.

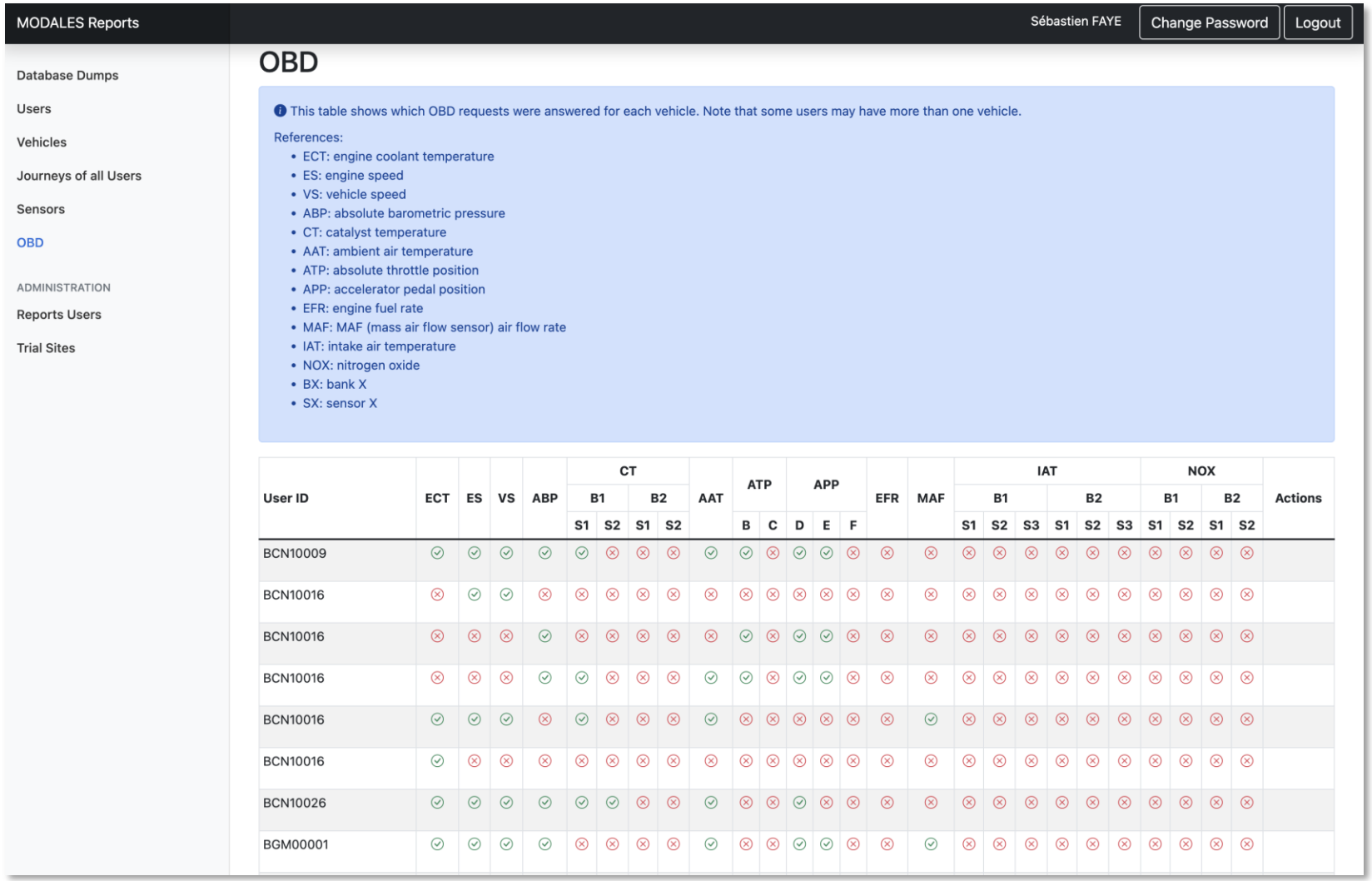
OBD and tampering

- Present OBD system is **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/

(OBD &) Trial site reporting platform for MODALES app

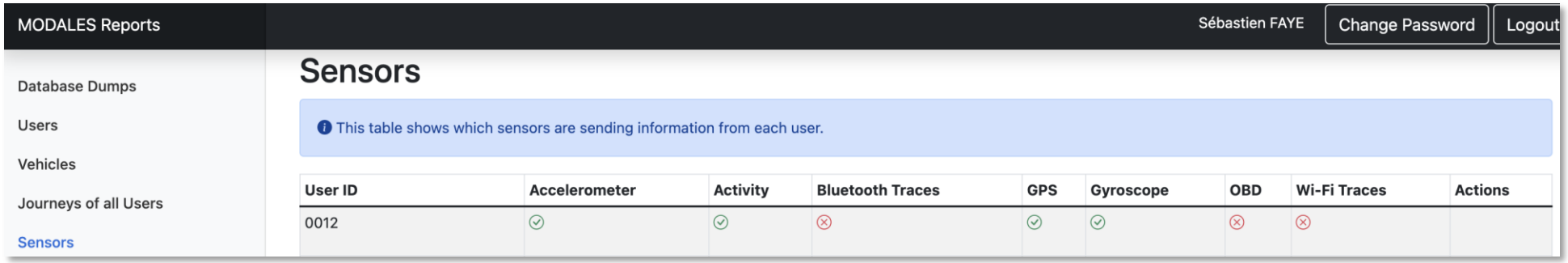
- **Internal reporting platform for aggregating the data collected through the MODALES app.**
- Management of **multiple users and trial sites**.
- Statistical information about **journeys** and **app usage**.

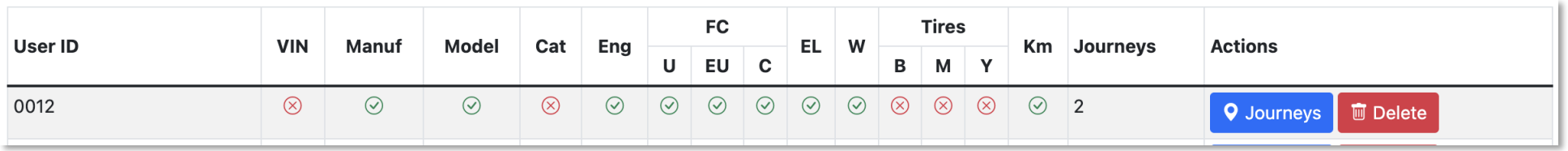


(OBD &) Trial site reporting platform for MODALES app

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.).





4. Periodic Inspections

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

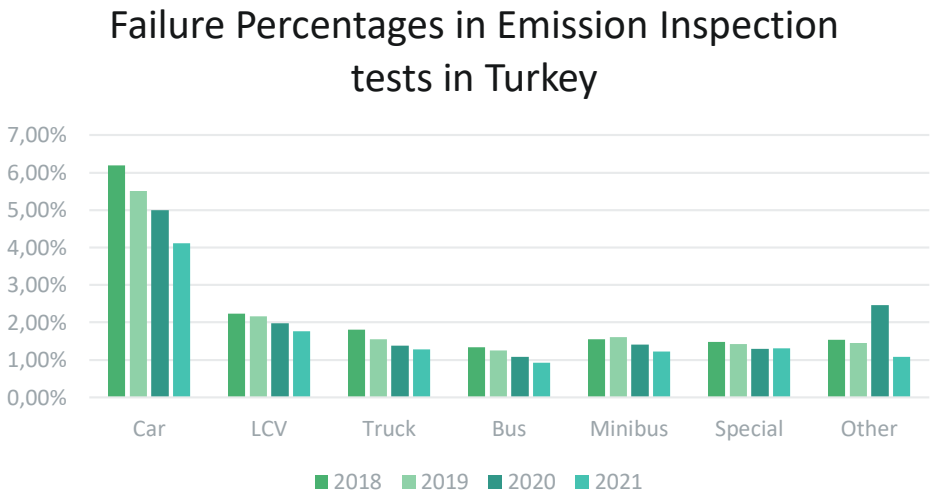
Heavy Duty and NRMM (Non-Road Mobile Machinery) **tampering customers' profile:**

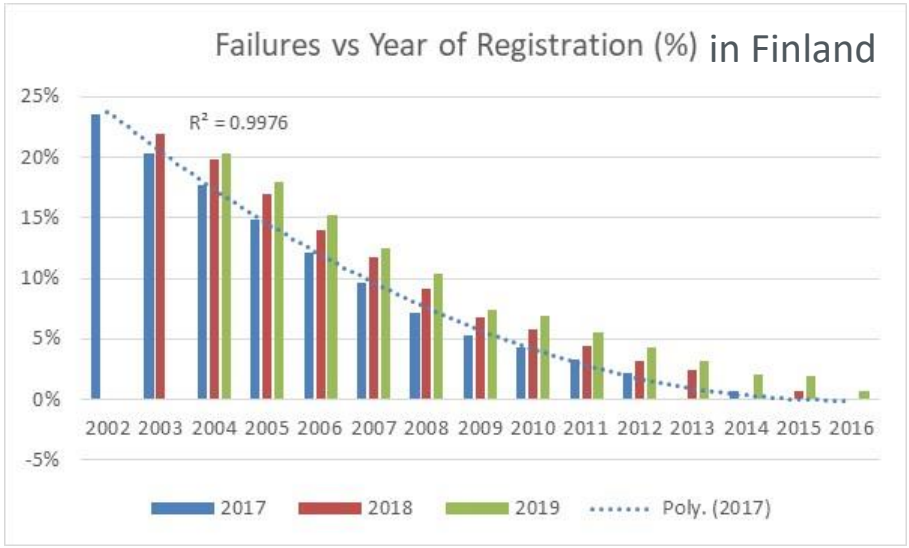
Current customers (on HD- and NRMM sectors) are divided typically into three categories:

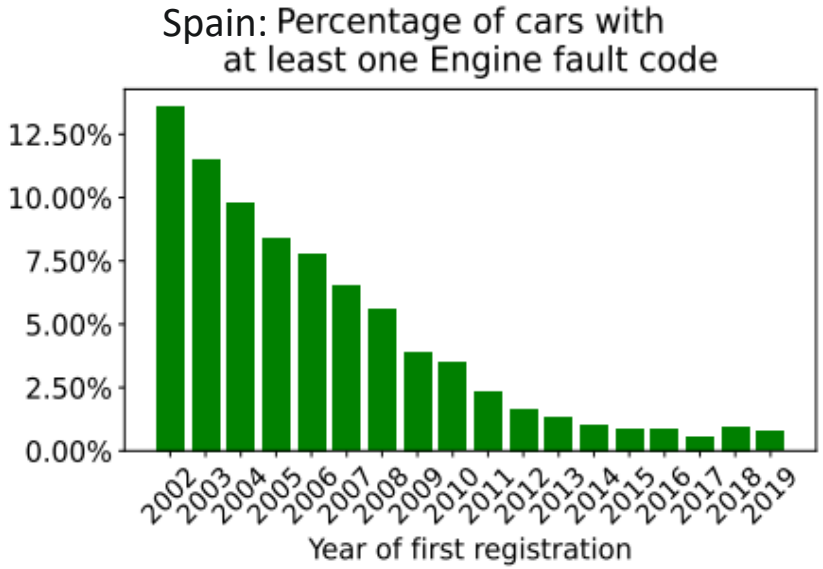
1. Those who face **NRMM EATS failures** -> increased downtime -> requests that the EATS is disabled (temporarily or permanently) depending on spare parts price and delivery time.
2. Customers who **believe that the engine power is lower than rated by the manufacturer**, as engine response may be "slow" 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.

Periodic Technical Inspection analysis

- Sample data from 3 countries







Demonstrating effects of EATS tampering and ECU reprogramming on overall HDV performance

Action to demonstrate the **effects of different EATS** (Emission After-Treatment Systems) **tampering methods** and **reprogramming of ECU** (Engine Control Module) **software** in **Heavy Duty Vehicle applications**

- Main focus: 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 CO_2, CO, NO_X 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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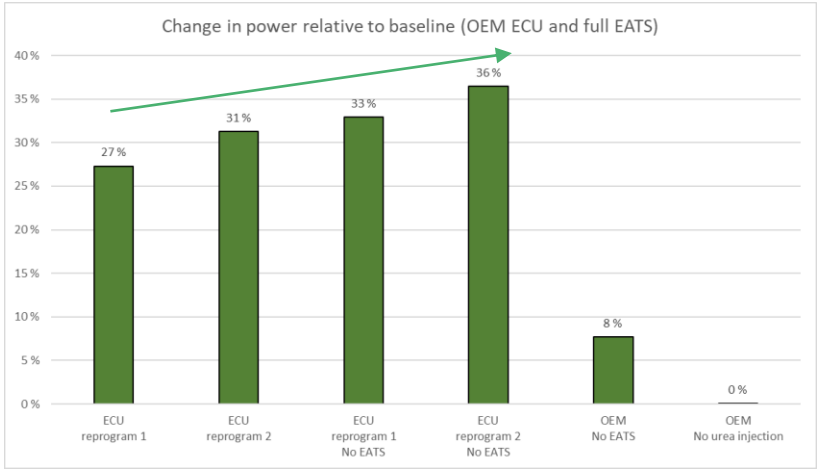
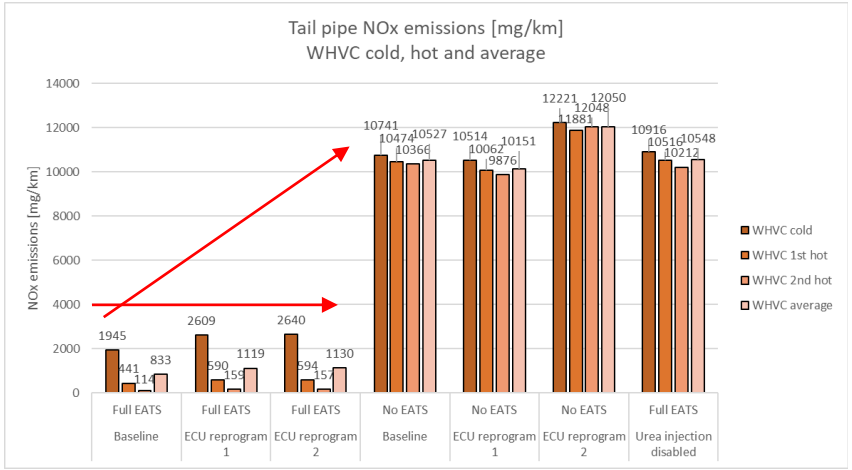
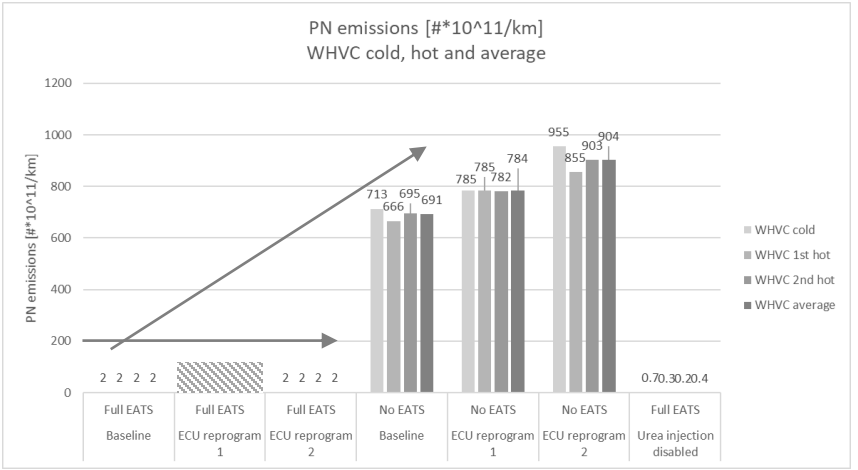
Impacts of ECU reprogramming and EATS tampering

- 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







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

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 penalties applicable to violations of rules on vehicle tampering may be considered.
- Increased **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.

Next steps and expected impacts of MODALES

- Test user acceptance of **MODALES app & training**; Validate their capacity to change behaviour:
  - Complete trials in 8 countries with approx. 200 drivers
  - Identify user groups for which MODALES has the greatest impact.
- Quantify **effects of reducing vehicle induced emissions** by the MODALES app and training:
  - Target: 5-10% reduction of emissions (depending on vehicle type and Euro technology) by applying the MODALES low emission driving guidelines
  - Trial data evaluation, scaling-up and impact assessment.
- Quantify **potential reductions** in emissions through **OBD optimisation, retrofits, enhanced periodic inspections and legal measures**:
  - Target 20% reduction in pollutant emissions for tampered/poorly maintained vehicles.
  - Retrofitted vehicles reaching Euro VI standards will have a reduction of >60% in PMs & NOx
  - Target 20% reduction in non-engine PMs.

MODALES partners

EU-funded partners

Associations

Universities

Research institutes

Industry and technology providers

Legal experts

International Partners

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Adapting driver behaviour for lower emissions

www.modales-project.eu

LinkedIn MODALES project

Thank you

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