modales

Adapting driver behaviour for lower emissions

# Project Results

## Driver

**The MODALES project built a user-centric approach addressing the challenges of emissions from different sources in road vehicles.**

**It researched, developed and tested a number of innovative and complementary solutions encompassing the Driver, On-Board Diagnostics (OBD), Periodic Inspections and Retrofits.**

This results factsheet covers the 'Driver' area, focusing on how changing driving behaviour can reduce emissions. A separate factsheet 'OBD, Periodic Inspections and Retrofits' summarises the main results from these other areas of research.

Visit the MODALES website to find out more about the project and its results: modales-project.eu

The 'Driver' part of MODALES was the largest part of the project, focusing on behavioural aspects, their relation to emissions, as well as developing and testing tools and approaches to encourage drivers to adapt more environmentally friendly driving behaviour, to reduce pollutant emissions.

This work built on the results of previous research projects, as well as existing commercial products regarding eco-driving. While eco-driving focuses on saving fuel and therefore reducing greenhouse gas emissions ($CO_2$), the work in MODALES focused on reducing pollutant emissions ($NO_X$, PM and PN). As well as powertrain (exhaust) emissions, this also includes particles from the brakes and tyres.

## Research results on driver behaviour factors and correlation with emissions

MODALES measured emissions with respect to driving style for powertrain, brakes and tyres.

Powertrain (exhaust):

- Real world driving trials using PEMS (Portable Emissions Measurement System), in which 15 drivers drove 11 cars (of different makes, ages and both petrol and diesel engines) around a fixed route.
- The route, around of Espoo (west of Helsinki, Finland), was 31 km long and comprised urban, rural and motorway sections. Each driver drove each car twice on this route.
- The high-level analysis based on the main driving parameters (average speed, average engine speed, total work over trip) and the resulting fuel consumption,


*MODALES PEMS tests at VTT, Finland*

as well as measured levels of exhaust emissions, revealed that some drivers that were able to constantly drive with low emissions output, while retaining also low fuel use. On the other hand, there were also some drivers that drove with high emissions and used a lot of fuel, and whose driving was also less consistent.

- The many different driving styles and measurement of the significant variations in resulting emissions gave a good standpoint for developing the mathematical equations, based on the inter-dependencies of driving parameters and various kinds of emissions.

Brakes:

- MODALES included a novel way of accurately measuring how the way of applying the brake affects the amounts of brake particulates dissipating from the brake. This was based on the latest version of the common inter-laboratory methodology to independently measure non-exhaust brake-related emissions in terms of particle matter (PM) and particle number (PN). It was implemented in a brake dynamometer test set-up in Italy.
- Braking events were modified according to the MODALES guidelines for low emission driving and this cycle was tested in a lab for a reference drive, compared to the reference WLTP-Brake cycle (Worldwide Harmonized Light-duty Vehicles Test Procedure for brake devices).
- From this experimental activity, it was clear that a significant reduction in the emissions coming from the wear of the braking components could be achieved with a more conservative driving behaviour.

Tyres:

- Tyre wear measurements were conducted using 76 drivers in Italy (Milan and Rome) and in Greece (Athens). With the aid of an OBD (On-Board Diagnostics) dongle and associated on-board data acquisition system, characteristic driving parameters were continuously measured and recoded during driving. Tyre wear was recorded with measuring the depth of tyre grooves with three-month intervals, and the loss of material was calculated.
- A clear difference was found in tyre wear between front and rear tyres, mainly due to the fact that all participating cars were front wheel driven, which tends to put much more load on the front tyres, because they are responsible for both traction (longitudinal loads) and steering (lateral loads), whereas the rear wheels are free rolling with much less forces applied.
- Tyre wear measurements were found to vary substantially between tyre positions, vehicle types, tyre sizes as well as tyre types.

## Correlation of behaviour with emissions

To overcome the limitations on vehicle types, driver behaviours and many other factors such as road and traffic conditions in the measurement campaigns, a set of three simulation tools and models were developed: a GT-suite vehicle model to simulate exhaust emissions, a Finite Element Analysis model to simulate the brake wear resulting from the contact behaviour on a microscope size scale, and a model for the simulation of tyre wear.

These modelling exercises resulted in a set of top five Key Performance Indicators (KPIs) for each element:

| KPIs | Powertrain (exhaust) emissions | Brake wear emissions | Tyre wear emissions |
|---|---|---|---|
| 1 | Proportion of acceleration > 0.9 m/s2 duration in the total travel time | Deceleration rate of braking | Deceleration rate when braking on bends (curves) |
| 2 | Average acceleration in the journey | Average deceleration rate when braking | Acceleration rate when accelerating on bends |
| 3 | Proportion of speed interval of 20~50 km/h in the total travel time | Braking distance | Initial speed when braking on bends |
| 4 | Average driving speed in the journey | Braking time | Initial speed when accelerating on bends |
| 5 | Average driving speed in the journey excluding stopping (at junctions, in queues, etc.) | Initial speed when braking | Deceleration rate when braking on straight roads |

## Low-emission driving guidelines

The KPIs in the above table were translated into guidelines for use in the experimentation phase of MODALES (training, app and on-road trials) as well as in an online awareness campaign.

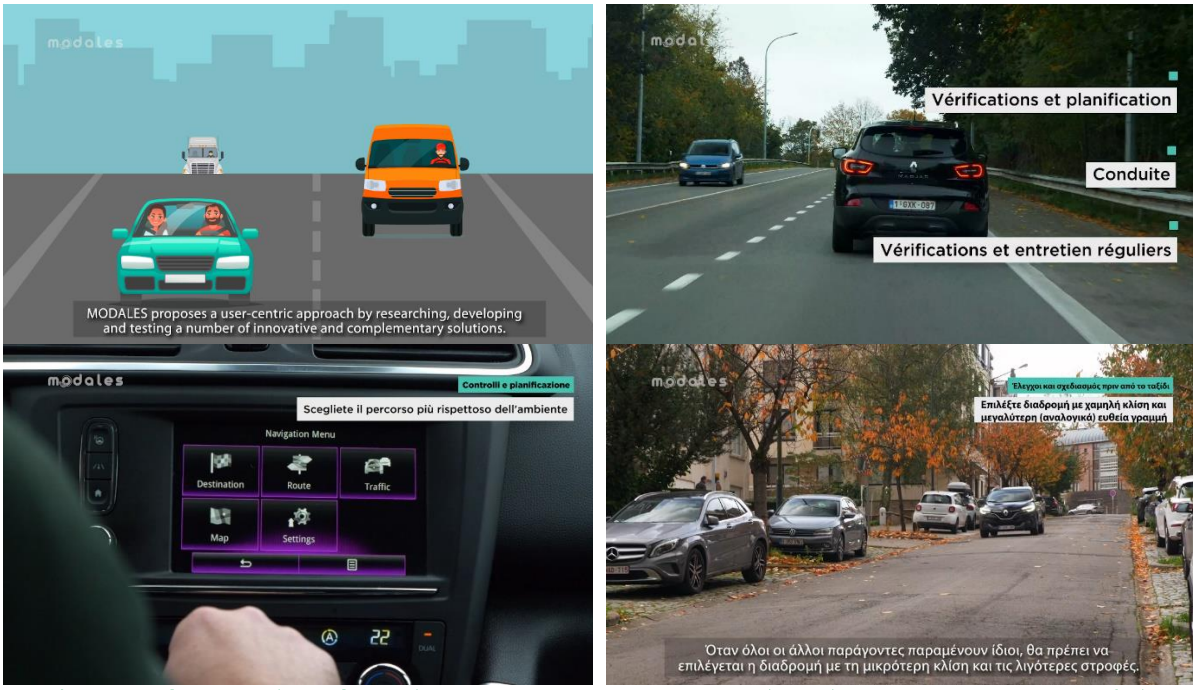
The main factor influencing emissions of all types is frequency of acceleration and deceleration. The aggressiveness of the driving style strongly related to users, and recommendations to change that style are important for reducing emissions. However, this frequency may be influenced also by factors totally unrelated to driving style, including environmental or contextual factors such as type of road and curvature, levels of congestion or weather conditions. Often, the user can do little or nothing to change these. Similarly, other factors depend on the vehicle, such as the type of engine or the weight.

Thus, the guidelines were complemented by the development of a scoring methodology to define what kind of recommendations the user should receive. The score calculated is related to the total emissions including the particles emitted from the brakes and tyres. The scoring methodology as selected uses an AI (Artificial Intelligence) system with a random forest algorithm.

## Training videos and tips for drivers

MODALES produced training videos for car drivers in eight languages (either with dubbed voiceovers or subtitles), covering the countries of the MODALES on-road trial sites. Separate videos for taxi/light duty commercial vehicle drivers and for heavy duty vehicle drivers were also produced.

These videos are around 15 minutes in length and were used for the on-road trials. They are now public and are available here: https://modales-project.eu/media.




*Selection of screenshots from the MODALES car training video, showing versions in English, French, Italian and Greek*

## Low-emission driving assistant (app with scoring and recommendations)

MODALES created a smartphone app (for both Android and iOS) and a backend web dashboard for data collection and analysis. The app can collect and analyse driving patterns in order to provide feedback and advice to the driver for reducing emissions. To achieve this, it collects relevant user information such as accelerometer, gyroscope, location and OBD (On-Board Diagnostics) data. Optionally, there is an OBD dongle that is connected to the vehicle using the OBD port and connected to the Smartphone via Bluetooth. The app provides two types of recommendations:

- Active recommendations, which offer straightforward recommendations during driving by providing immediate feedback using a simple colour coding system to minimise distraction.
- Passive recommendations, analysing and understanding a user's driving behaviour patterns and contextual information (e.g., on traffic jams, weather) and using a scoring algorithm to generate a post-driving report, to help encourage safer and more environmentally friendly driving.

*The MODALES app providing active (on-trip) feedback*

## Online awareness campaign

As well as the training videos and app, tested on volunteer drivers in on-road trials, the project delivered a wider driver awareness campaign on low emission driving. This gave wider visibility to MODALES and promoted the driving guidelines and training to drivers via the social media channels of motoring organisations, driving schools, road transport operators and their associations/forums.

MODALES produced a set of ten simple infographics, containing one message/guideline, for inclusion on social media sites of partners or other stakeholders (using the hashtags #MODALESproject and #MODALEStips specifically for the campaign). These are supported by short and user-friendly guidance documents (one or two pages, also available in different languages). The social media campaign ran during 2022 and early 2023, with several FIA-affiliated motoring organisations in Europe participating. Campaign materials are available in 11 languages at [modales-project.eu/campaign](modales-project.eu/campaign).

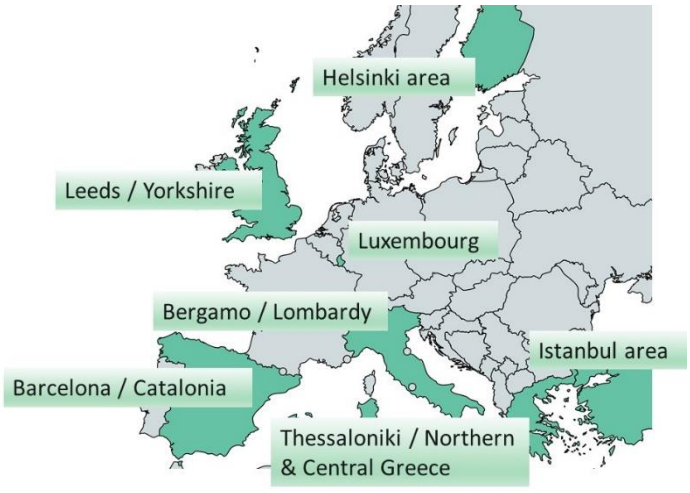

*#MODALEStips social media campaign*

## On-road trials and results

Real-world trials of the MODALES driving assistance tools (training and app) took place with 170 volunteer drivers in seven regions of Europe. This assessed the tools' functionality and effects on driver acceptance and performance.

During the initial phase, referred to as the baseline period or Phase 1, drivers did not utilise any MODALES tools except for the app for baseline data collection only. At the end of Phase 1, the participant was asked to view the training video and to download the full version of the MODALES low emission driving assistant app.

The results of the trials showed differential influences of driving behaviour on the three types of




***Locations of the MODALES trials in Europe. Limited trials (with the training but not the app) also took place in Nanjing, China***

vehicle emissions were studied individually and in combination. For example:

- Low-emission driving training programmes (training video and MODALES app) have shown the potential to contribute to reductions in mean values of $NO_X$ emissions from exhaust in most of the seven European cities evaluated, and despite individual variations, improvements were seen across the majority of participants and across all road types.
- The low-emission driving training programmes appeared to elicit a greater improvement (reduction in $NO_X$ emissions) for women than for men.
- There were significant reductions in brake wear emissions in almost all cities.
- Motorways exhibited the highest mean values of brake wear $PM_{2.5}$ and $PM_{10}$ emissions per stop, followed by rural and urban roads.
- The low-emission driving training effectively reduced brake wear $PM_{2.5}$ and $PM_{10}$ emissions for both female and male drivers. However, male drivers experienced greater reductions compared to female drivers.
- Experienced drivers had lower initial brake wear emissions compared to novice drivers. After participating in low-emission driving training, both groups showed improvements, but novice drivers experienced a greater reduction in brake wear emissions.
- The results revealed a difference ranging from 4-10% in the total concentration of 0.3-10.0 μm size particles emitted from the brakes when using the App. The reduction in brake particle emissions is strongly related to the smoother driving style that the driver has adopted following the MODALES recommendations (42% - 140% reduced median deceleration with the App activated).
- Generally, low-emission driving training programmes can contribute to reductions in tyre wear emissions.
- The mean values of tyre wear emissions were highest on motorway roads, followed by rural and urban roads.
- There were variations among individual drivers in terms of their influence on tyre wear emissions. However, the training demonstrated overall effectiveness in reducing tyre wear emissions for the majority of users across all road types.
- The training and app successfully decreased tyre wear emissions for both female and male drivers. However, male drivers experienced more significant reductions compared to their female counterparts.
- Following the training, novice drivers experienced a more substantial reduction in tyre wear emissions compared to experienced drivers.
- Overall, total scores have improved in Phase 2 of the trials as a result of the training intervention, while the level of improvement varies from site to site.

## Impact assessment

An impact assessment on the app and training was conducted for four of the countries which had trial sites (Finland, Italy, Spain and Turkey) as well as two other major European countries (France and Germany). COPERT software was used to estimate emissions after the implementation of the MODALES solutions. It measured

the emission savings by estimating air pollutant emissions and greenhouse gas emissions from road vehicles for the pollutants $CO_2$, CO, $NO_x$, and PM.

Scaled up results showed that there is significant potential for savings through app-based solutions and training programmes that encourage more efficient driving. However, these solutions may not be as effective as OEM embedded systems, which are typically more expensive but also more efficient, particularly in the long term.

Overall, the research suggests that there is significant potential for reducing emissions in the transportation sector through a combination of anti-tampering measures, retrofit campaigns, and behaviour-related changes. However, the effectiveness of these measures will depend on a variety of factors, including the type of vehicle, the country in question, and the specific technology used. As such, a targeted and nuanced approach will be necessary to achieve meaningful reductions in emissions.

## For more information

In-depth results are available in the following reports, available in the Deliverables Library area of the project website (modales-project.eu/deliverables):

- D2.1: Variability of driving behaviours and Low-emission driving requirements (March 2020, public)
- D2.2: Real effectiveness of OBD inspection and maintenance, and retrofits (August 2020, public)
- D3.1: Emission measurements (October 2021, public)
- D3.2: Correlation of user behaviour variability with emissions (August 2021, public)
- D5.1: Guidelines for low emission driving (December 2020, public)
- D5.2: Functional specification (December 2020, confidential but Executive Summary available)
- D5.3: Low-emission driving assistance tools (support document) (December 2022, public)
- D5.4: Experimental Test Results and Initial Feedback on User Acceptance (December 2022, public)
- D5.5: Training courses manual for low emission driving (November 2020, confidential but Executive Summary available)
- D6.1: Evaluation plan (September 2020, confidential but Executive Summary available)
- D6.2: Trial management (June 2023, public)
- D6.3: Trial data integration and analysis (June 2023, public)
- D6.4: Impact assessment (June 2023, public).

In addition, several scientific and technical papers have been published as a result of MODALES, and are available at https://modales-project.eu/publications

## MODALES partners contributing to this set of results













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For further information, visit modales-project.eu or contact info@modales-project.eu