MODALES D6.4: Impact assessment report

WORK PACKAGE	**WP6: User trials and evaluation**
TASK	T6.5 Evaluation Impact assessment
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Legal disclaimer

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Glossary, abbreviations and acronyms

EU Projects

Term	Description
Amitran	"Assessment Methodologies for ICT in multimodal transport from User Behaviour to CO_2 reduction", EU FP7 project (2011-2014), https://cordis.europa.eu/project/id/287551
CARES	"City Air Remote Emission Sensing", EU H2020 project within call MG-1-1 (parallel topic to MODALES), https://cares-project.eu
CONVERGE	EU FP4 support project to the transport sector of the Telematics Application Programme (1996-1998), https://cordis.europa.eu/project/id/TR1101
DIAS	"Diagnostic Anti-Tampering Systems", EU H2020 project (2019-2022) which developed protection and security hardware and software to detect and make tampering of environmental protection systems (EPS) impossible, https://dias-project.com
ecoDriver	EU FP7 project (2011-2016) which addressed the need to consider the human element when encouraging "green" driving, as driver behaviour is a critical element in energy efficiency. The focus of the project was on technology working with the driver. The project delivered effective feedback to drivers on green driving by optimising the driver-powertrain-environment feedback loop. https://trimis.ec.europa.eu/project/supporting-driver-conserving-energy-and-reducing-emissions
FESTA	"Field opErational teSt supporT Action", EU FP7 Support Action (2007-2008), https://trimis.ec.europa.eu/project/field-operational-tests-support-action
MODALES	This EU Horizon 2020 project: "Modify Drivers' behaviour to Adapt for Lower Emissions" (2019-2022), http:// MODALES-project.eu
uCARE	"You can also reduce emissions", EU H2020 project within call MG-1-1 (parallel topic to MODALES), www.project-ucare.eu

MODALES partners and other organisations

Abbreviation	Full partner name
ACASA	Automòbil Club Assistència SAU *(MODALES WP6 leader and an operating company of RACC)*
ACEA	Association des Constructeurs Européens d'Automobiles / European Automobile Manufacturers Association
BREMBO	Freni Brembo SpA *(MODALES partner)*
BRIDG	Bridgestone Europe NV/SA *(MODALES partner)*
CEREMA	Centre d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement *(MODALES partner)*
CERTH	Centre for Research and Technology Hellas / Ethniko Kentro Erevnas kai Technologikis Anaptyxis *(MODALES partner)*
EC	European Commission
ERTICO	ERTICO – ITS Europe *(MODALES project coordinator)*
FIA	Fédération Internationale de l'Automobile *(MODALES partner)*
INEA	Innovation and Networks Executive Agency *(agency of the European Commission)*

Abbreviation	Full partner name
IRU	International Road Union *(MODALES partner)*
LEEDS	University of Leeds *(MODALES partner)*
LIST	Luxembourg Institute of Science and Technology *(MODALES partner)*
MICH	Manufacture Française des Pneumatiques Michelin *(MODALES partner)*
OKAN	Istanbul Okan University / İstanbul Okan Üniversitesi *(MODALES partner)*
PROV	Proventia Oy *(MODALES partner)*
RACC	Real Automòbil Club de Catalunya / Royal Automobile Club of Catalonia *(Owner organisation of ACASA)*
SPARK	Spark Legal Policy and Consulting (EU) BVBA *(MODALES partner)*
VTT	Technical Research Centre of Finland Ltd / Teknologian Tutkimuskeskus VTT Oy *(MODALES partner)*

General abbreviations and acronyms

Abbreviation	Meaning
ACCT	Ammonia Creation and Conversion Technology
API	Application Programming Interface
CAN	Controller Area Network
CMT	Core Management Team (of MODALES)
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DALI	Driving Activity Load Index
DEF	Diesel Exhaust Fluid
DPF	Diesel Particulate Filter
DoA	Description of Action (part of the MODALES Grant Agreement)
EATS	Emissions After-Treatment System
EOBD	European On-Board Diagnostics
EU	European Union
FOT	Field Operational Test
FP	EU Framework Programme (FP4,FP5, FP6, FP7)
g/km	Grams per kilometre
GLMM	Generalised Linear Mixed effects Models
GPS	Global Positioning System
H2020	EU Horizon 2020 Programme
HC	Hydrocarbons
HDV	Heavy Duty Vehicle
HMI	Human-Machine Interface
ICE	Internal Combustion Engine
ICT	Information and Communication Technologies

Abbreviation	Meaning
I/M	Inspection and Maintenance
InCo	International Cooperation
IoT	Internet of Things
IPI	Impact Performance Indicator
IS	Innovation Solution
ITS	Intelligent Transport Systems
KPI	Key Performance Indicator
LDV	Light Duty Vehicle
l/km	Litres per kilometre
MID	Measurement Identification
NO_X	Nitrogen Oxides
NOxBUSTER®	Retrofit emission control system (DPF and SCR) from Proventia
NRMM	Non-Road Mobile Machinery
OBD	On-Board Diagnostics
PEMS	Portable Emissions Measurement System
PM	Particulate Matter
PN	Particle Number
PPB	Parts per Billion
PPM	Parts per Million
PROCARE™	Drive telematics system from Proventia
RDE	Real-Driving Emissions
RQ	Research Question
SCR	Selective Catalytic Reduction
SUS	System Usability Scale
TA	Type Approval
TS	Technology Solution
VPI	Validation Performance Indicators
WHVC	World Harmonized Vehicle Cycle
WP	Work Package

Executive Summary

The MODALES project worked to reduce air pollution from all types of on-road vehicles by encouraging the adoption of low-emission driving behaviour and correct maintenance choices. This deliverable is part of Work Package 6 (WP6) on user testing and evaluation, which is one of the five technical work packages of MODALES. It is an essential component in assessing the effectiveness and impact of the project's interventions and strategies.

This deliverable focuses on assessing the impact and effectiveness of the innovative solutions proposed by MODALES. It analyses the data collected locally within MODALEs experiments, in order to quantify the emission reductions achieved at the national scale in four of countries where MODALES trial sites were located (in Finland, Italy, Spain and Turkey) and two other large European countries (Germany and France).

The evaluation takes into account both quantitative data, such as emission measurements, fuel consumption, and maintenance records, and qualitative feedback from participants. In addition, the deliverable discusses the challenges and lessons learned during the evaluation process and identifies areas for improvement or further research.

MODALES developed innovation solutions to address the complex issues explained above, that are divided into four main areas: drivers and their driving behaviour, retrofits that enable emissions to be reduced, the EOBD that enables to malfunctioning to be notified, and inspections to detect poorly maintained and tampered vehicles.

The innovation solutions from MODALES could be transformed into practical solutions, ready to be implemented by European countries. All these forms of actions should affect direct or indirect emissions, but through different process. From the detailed technical studies from MODALES partners, and from studies about European national regulations, three main practical solutions are proposed, and their potential impacts tested through scenarios built upon MODALES trial tests and studies results:

The first solution consists of a regulation policy to detect poorly maintained and tampered vehicles that can be summarised by the two following measures.

- Mandatory tampering detection using OBD (On-Board Diagnostic systems) data during Periodic Technical Inspections;
- Penalties for vehicle owners when a manipulation of the vehicle data by an aftermarket software is detected.

Some recent European projects such as DIAS developed a new security software to make tampering more difficult compared to traditional OBD. The MODALES proposal was to use Periodic Technical Inspection data to provide immediate notifications or alerts of tampering attempts.

A tampered vehicle can be repaired once detected, which reduces by 80% the NOx & PM emissions. The impact of this solution is estimated based on assumptions about the average tampered vehicle prevalence in the fleet (MODALES result & literature review), and about the detection rate (lower and upper values based on MODALES lab experiments).

The second solution is to generalise retrofits for diesels whenever it is possible and relevant. MODALES lab tests proved that retrofitted vehicles could save up to 70% of NOx emissions, and more than 90% of PMs.

The impact of this solution is done by estimating the proportion of vehicles for which retrofit is relevant based on MODALES cost benefits analyses [1] .

The third solution is a mobile app for low-emission driving that aims to assist drivers throughout their journeys by providing recommendations that do not interfere with their driving. The feedback allows drivers to learn from bad driving habits and improve their emissions reduction. Together with an online training (videos available in the Media section of the MODALES website: https://modales-project.eu/media, supported by an awareness campaign with low-emission driving tips, here: https://modales-project.eu/campaign), the app is assumed to impact the driving style and generate benefits on pollutant emissions.

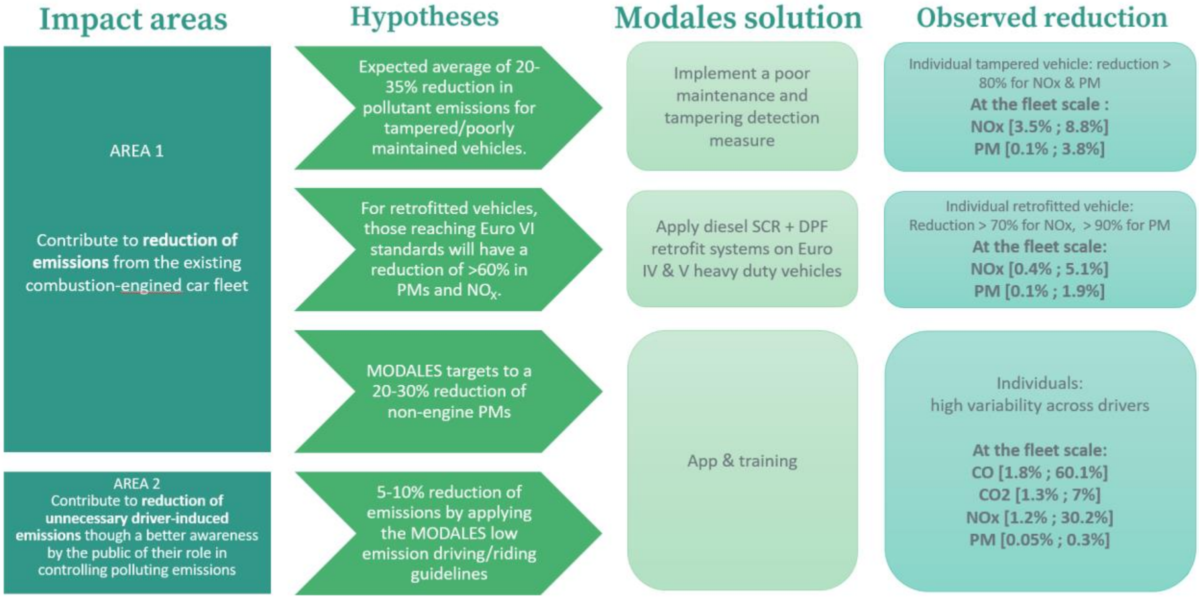
The combined impact of the app and the training is evaluated through the experimental and large scale trial tests results conducted within MODALES.

The proposed methodology for Impact assessment is based on the COPERT software, which is used to compare baseline vehicle emissions for some European countries (Finland, Italy, Spain, Turkey, Germany, and France) with the estimated emissions after the implementation of MODALES solutions. It specifically measures the emission savings by estimating air pollutant emissions and greenhouse gas emissions from road vehicles for the following pollutants: CO_2, CO, NOx, and PM.

In fact, COPERT is the EU standard vehicle emissions calculator. It requires detailed data as inputs, such as stock configuration share across EU standards, energy type and vehicle type. Such a level of precision is usually not available from EU countries, so MODALES developed an alternative estimation algorithm based on Eurostat open data sets to estimate the year 2025 situation. Among all the countries where a MODALES trial took place, only four had a sufficient amount of data to reconstruct the stock until the Euro 4 standard, starting in 2011. For the China it was difficult to find historical data from 2011 and the proposed methodology could not therefore be applied.

For each Innovation Solution, assumptions are made based on literature survey or MODALES results and experts' knowledge. These assumptions are used to build different scenarios. First, a "lower" scenario is built based on a pessimistic assumption, then an optimistic scenario is built and called "upper". These scenarios are then translated into a set of quantitative assumptions on the emissions that are suitable to be used as an input parameter into COPERT software, through the "Vehicle performance improvement" parameter box (see details Figure 11, page 31).

The baseline performances are estimated using the evolution of the vehicles fleet share across Euro standards for each studied country. A simple reconstruction method is proposed: Eurostat data is used to rebuild the share of Euro standards starting from year 2010, up to the year 2021. Missing data are extrapolated linearly when necessary, and the future evolution of the stock until 2025 is estimated by extending the linear trend over the years 2018, 2019, 2020, 2021.



Overview of the MODALES solutions and their extrapolated impacts at the European country level

A summary of the results is presented in the above figure, providing the range of emissions reductions from the lower scenario (pessimistic) to the upper one (optimistic). Also, this figure provide the estimates obtained by MODALES previous works at the individual level and already explained in previous deliverables ([1], [2]).

Results shows that the older the vehicle stock, the more savings can be expected from the MODALES proposed solutions. This is because older vehicles are often less fuel efficient and emit more pollutants than newer models. By retrofitting these vehicles with newer technology and implementing anti-tampering measures, emissions can be reduced and fuel efficiency can be significantly improved at the country level.

However, the effectiveness of these measures varies depending on the type of vehicle and the country in question. For example, countries with older vehicle stocks may see greater benefits from retrofit campaigns, while countries with newer stocks may see limited or no impact. Similarly, the potential savings from anti-tampering measures may be greater in some countries than in others.

Results also shows that there is significant potential for savings through app-based solutions and training programs 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 on 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.

The MODALES trial conducted three surveys among its participants. The final survey focused on the use of the MODALES app and the extent to which drivers felt their driving style and behaviour had changed. The survey recorded 69 responses from volunteer drivers in pilot sites across seven countries. Majority of the respondents drove combustion engine vehicles, and around one-third of them used the app every time they drove during the trial period. The survey revealed that the app successfully encouraged behavioural changes in driving, with many respondents reporting a reduction in poor driving behaviour. However, several issues were raised with the app's design and functionality, particularly in relation to real-time feedback, interference with other apps, and connection with OBD/dongle. Respondents suggested several features to remedy these issues, including integration with the vehicle dashboard and more efficient technical support. Overall, the survey showed that a better performing and more stable version of the app would be welcomed by most respondents.

Finally, this deliverable is an essential component of Work Package 6 of the MODALES project, which highlights the effectiveness of implementing low emission driving behaviours and proper vehicle maintenance practices. The results provide valuable information to decision makers, stakeholders, and researchers in their efforts to achieve zero air pollution from road vehicles.

1. Introduction

1.1. Project overview

The MODALES project works towards reducing air pollution from all types of on-road vehicles by encouraging adoption of low-emission driving behaviour and proper maintenance choice.

MODALES pursues a user-centric approach to addressing all of the challenges which on the one hand enhance low-emission practices and on the other hand suppress high-emission behaviour by researching, developing and testing a number of innovative and complementary solutions in four key areas (driver, retrofits, EOBD and inspection) in order to reduce vehicle emissions from three main sources: powertrain, brakes and tyres.

MODALES aimed to modify user (driver) behaviour via dedicated training including a driver assistance app and awareness campaigns in order to support effective air quality improvement plans and enforcement strategies to be developed by local and national authorities.

To achieve this goal, MODALES has researched, developed, and tested 13 innovation solutions (IS), of which 11 were technical innovations.

The main activities of MODALES have been the following:

- Measurement of real-world vehicle emissions and driving behaviour to produce accurate correlation between them using advanced mathematical and statistical techniques;
- Exploration of the most advanced technologies for retrofits designed to substantially reduce powertrain emissions from all types of vehicles and to validate their effectiveness under different real-world traffic and environment conditions, and by various drivers;
- Undertaking an in-depth analysis of OBDs, periodic inspection and legal issues on tampering in Europe to help regulatory authorities put in place effective anti-tampering legislation, and to help owners properly maintain their vehicles;
- Conducting low-emission user trials (with both driving and maintenance practices), supported by awareness campaigns, to enhance public engagement and help drivers better understand the impact of their driving and maintenance behaviours in all situations.

1.2. Scope

1.2.1. MODALES WP6 on User trials and evaluation

This deliverable is part of Work Package 6 on User trials and evaluation, which is one of the five technical Work Packages of MODALES (the two “non-technical” WPs are WP1 on Project Management and WP7 on Awareness, Communication and Dissemination). The four WPs whose results feed into WP6 are:

- **WP2: Defining low-emission factors**, which explored driving behaviour variability using existing available data, as well as a data collection campaign using an on-board data acquisition setup with access to powertrain data (PEMS measurements - portable emissions measurement system). This WP delivered a first approach on driving behaviour patterns and powertrain emissions. It also addressed the state-of-the-art in retrofits, inspection and maintenance (I/M) and legal issues regarding tampering in various EU Member States.

- **WP3: Impact of user behaviours**, which undertook a series of measurement campaigns to establish the interconnection between driving behaviour and powertrain exhaust emissions, as well as fine particulates from brakes and mass-loss from tyres. Measurement campaigns were also carried out to address the impact of poor maintenance and deliberate tampering of the emissions control system.
- **WP4: Effectiveness of inspections and depollution systems**, which used the findings of WPs 2 and 3 as a base to investigate and propose solutions that will contribute to emission monitoring via the EOBD protocol and systems that detect lack of maintenance and tampering. It also investigated the potential of enhancing existing retrofit systems.
- **WP5: Guidelines and tools for low-emission training**, which took into consideration results from the above WPs to define guidelines for low-emission driving and to specify the technical requirements for a smartphone application (the MODALES App). This app was developed and tested in this WP. Training courses were also designed to ensure a consistency with existing learning processes and serve as input for on-road trials and awareness campaigns.

The main **objective of WP6** was to develop an evaluation plan and to test and evaluate with real-world trials the functionality of the innovations developed in MODALES, their effects on driver acceptance and performance, and their potential wider impact (in particular their predicted overall effects on vehicle emissions).

WP6 is broken down into five tasks, with this report covering the results of Task 6.5:

- T6.1: Evaluation plan;
- T6.2: Trial ramp-up and pilot;
- T6.3: Large scale user trials;
- T6.4: Analysis of trial data;
- **T6.5: Impact assessment**.

1.2.2. Scope and intended audience of this deliverable

This deliverable is public. It summarises the main findings and conclusions from the MODALES technical studies and wrap-up the findings in the form of practical solutions. This deliverable presents the assumptions about the plausible impacts associated with such measures, then extrapolate the findings at the national level using COPERT software [3].

1.3. Deviations from the Description of Action

1.3.1. Content deviations

The content of this deliverable is slightly different from the planned actions in the evaluation plan [4] as the project faced some significant delays due to the COVID-19 pandemic. Trial tests have been shortened, the number of participants has been reduced, and therefore also the delivery of the data. New plans have been made to extrapolate the results at the national level instead of the initial plan to extrapolate at the city level. Therefore, the extrapolation of the impacts relies on the COPERT software, instead of the previously envisioned SUMI indicators (see sections below for further details about these two solutions).

2. MODALES solutions and expected impacts

The overall objective of the MODALES project is to improve air quality, but the direct impact of the project will be on the knowledge of the factors affecting emissions, and on the development of tools and communication campaigns to promote behaviour change.

On the one hand, improvement of knowledge on the factors affecting emissions will be among experts and by guidelines, while the behavioural change promoted by MODALES project will focus on the end-user, in terms of both proper vehicle maintenance (including anti-tampering and retrofitting) and the driving style for lower emissions.

Many studies found that the majority of car users are unaware of the influence of their driving habits and other actions on the emissions they create. Also, motorists in general do not pay much attention to exhaust emissions, as they are mostly not visible and easily ignored, as are brake and tyre emissions. Hence, MODALES aims to make users more aware of these issues and, at the same time, to address behaviour that can lead to higher emissions, such as careless driving habits and lack of maintenance, or even purposeful tampering of the emissions control systems. Therefore, the goal of MODALES is to address the challenges of, on one hand, enhancing low-emission practices and, on the other hand, suppressing high-emission behaviours, through two main domains of knowledge: the Vehicle domain, and the Driving domain.

2.1. MODALES innovation solutions

MODALES develops innovation solutions to address the complex issues explained above, that are divided into four main areas: drivers and their driving behaviour, retrofits that enable emissions to be reduced, the EOBD that enables to notify malfunctioning, and inspections to detect poorly maintained and tampered vehicles (Figure 1).

MODALES innovation solutions are diverse and complementary, and can be linked to the expected impacts (listed in Table 1 below):

- Tampering and poorly maintained vehicle detection algorithms & procedures: Linked with Impact 1.
- Retrofit systems to reduce emissions: Linked with Impact 1
- A smartphone app with a personal driving assistant implementing real-time recommendations to reduce emissions levels: Linked with Impacts 1 and 2.
- The training tools (videos & knowledge about emissions) developed to accompany the driving assistant app, linked with Impacts 1 and 2.

Table 1: MODALES expected impacts

Impact	Description
1	Contribute to reduction of emissions from the existing combustion-engined car fleet
2	Contribute to reduction of unnecessary driver-induced emissions though a better awareness by the public of their role in controlling polluting emissions
3	Provide technical evidence to assess gaps in current regulation of vehicles
4	International cooperation (InCo)

All these forms of actions should affect direct or indirect emissions, but through different process requiring different experimental protocol and sensors to collect field data. Fortunately, each solution area can be considered independent from each other, and so can follow different impact assessment methodologies.

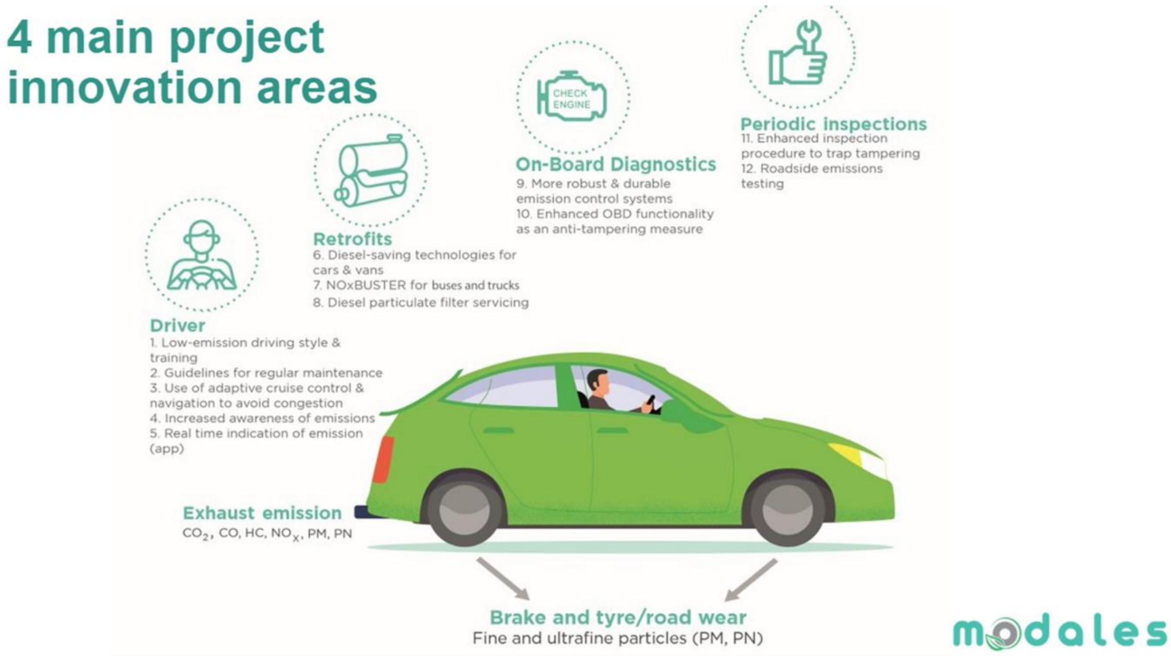


Figure 1: MODALES Innovation Solutions

2.2. MODALES solutions: the final picture

The previous innovation solutions from MODALES could be transformed into practical solutions, ready to be implemented by European countries. From the detailed technical studies from MODALES partners, and from studies about European national regulations, three main practical solutions have been proposed. The possible implementation of these solutions is described in the next sections.

2.2.1. MODALES solution 1: Regulation policy

The implementation of EATS has resulted in a noteworthy decrease in actual emission levels, however, tampering with this system is a common occurrence. This is often done to cut costs by avoiding repair expenses for malfunctions, consumables, and for performance tuning. To address this issue, MODALES partners proposed an information system, the Information System for Vehicle Anti-tampering as shown in Figure 2: Workflow of the proposed Information System for Vehicle Anti-tampering, that can identify and notify possible tampering or insufficient engine maintenance problems, as well as higher engine horsepower of a vehicle. The objective of this system is to protect the environment and improve the air quality. By detecting and addressing these issues, we can ensure that the EATS system is functioning effectively and efficiently, and that the emissions are within the acceptable limits. This will not only benefit the environment but also promote sustainable transportation practices.

The most common tampering techniques are the following:

- The most common method is to disable the EGR or DPF system;
- ECU re-flashing: Alters the ECU flash and perform checks using test drives or dyno tests;

- Emulators: Devices that attack the SCR system;
- Modifiers: Hardware solutions that are simpler to emulators and aim to alter the control state of an EATS;
- OBD Suppressors: These devices sent specific CAN-bus messages to suppress the on-board diagnostics of the vehicle.

This Information System based on OBD Data is designed to enhance the security of vehicles by leveraging data from the On-Board Diagnostics (OBD) system. The system architecture consists of a mobile phone application that receives vehicle data through an OBDLink MX+ dongle device. The data is then transmitted to a server for processing, transformation, and loading into a database. The server also implements data analytics and generates notifications based on the analysis. The website presents the aggregated data in an easy-to-understand format.

The system is designed to ensure that any tampering with the vehicle is detected and reported promptly. The OBD system provides real-time data on the vehicle's performance, which can be used to detect any anomalies that may indicate tampering. The server processes the data to identify any missing values and transforms it into a format that can be easily analysed. The data analytics component of the system uses machine learning algorithms to identify patterns in the data and generate alerts when unusual activity is detected.

Overall, the information system is a powerful tool for enhancing the security of vehicles and preventing tampering. The system provides real-time monitoring and analysis of vehicle performance, enabling prompt detection of any anomalies and ensuring that appropriate action can be taken to prevent further damage.

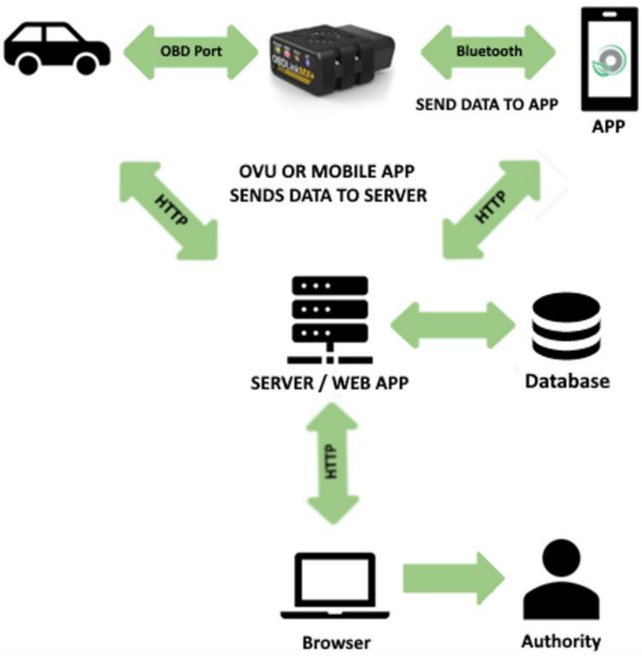


Figure 2: Workflow of the proposed Information System for Vehicle Anti-tampering

The MODALES project proposed to extrapolate the potential effects of a poor maintenance and tampering detection measure that could be summarised by the two following measures.

- Mandatory tampering detection using OBD data during the periodic inspections;

- Penalties to vehicle owners when a manipulation of the vehicle data by an aftermarket software is detected.

The way the effects of these measures are modelled to be implement into COPERT is described in section 3.5.1.

2.2.2. MODALES solution 2: Retrofit

Retrofitting for vehicles, particularly city buses and NRMM vehicles, has been proven effective in reducing emissions of PM and NOx. However, the business case for retrofitting city buses is becoming weaker due to their age and decreasing mileage, as well as the risk of emissions returning to baseline levels with poor maintenance. Retrofitting for light duty vehicles, specifically Euro 5 vehicles, can reduce NOx emissions by 50-80%, but the low value of these vehicles compared to retrofit kits and the lack of motivation for retrofits make it commercially unfeasible. Retrofitting for cars faces challenges with the approval process due to the high variation of models and emission reduction under real driving conditions. While technically possible, the political climate surrounding diesel vehicles also poses a challenge. Retrofitting is feasible when emissions exceed current emission standards and the vehicle has a long enough lifetime left.

The MODALES proposal is to generalise retrofit whenever it is possible. The way this is modelled into the COPERT software is explained in section 3.5.2.

2.2.3. MODALES solution 3: App & training

MODALES has developed a mobile app for low-emission driving that aims to assist drivers throughout their journeys by providing recommendations that do not interfere with their driving. The app adopts a modular approach, allowing several small components to be developed independently and then interact with each other to provide a unique driver experience. The app has been developed for Android and iOS, using the Flutter framework to avoid working on two code bases. To prevent breaches of privacy, most of the processes operate locally on the mobile phone, allowing the system to operate even without internet connectivity. The app is broken down into three modules: data collection, scoring, and recommendation. The data collected from the OBD-II, phone sensors, and the user is used as input to two scoring modules that distinguish different driving behaviours. Finally, the recommendation module advises the user to adopt attitudes depending on their perceived driving behaviour. Passive recommendations are given to the user after a trip, while active recommendations are presented in real-time while driving. The feedback allows drivers to learn from bad driving habits and improve their emissions reduction.

Together with online training videos (see MODALES website: https://modales-project.eu/media), the app is assumed to impact the driving style and generate benefits on pollutant emissions.

Results from the MODALES test trials and experiments are used to extrapolate the observed effects of these joint solutions using the COPERT software (section 3.5.3).

2.3. Expected impacts

MODALES is expected to have a direct impact on the knowledge of the factors affecting emissions, and on the development of tools and communication campaigns to promote behaviour change. Table 1 in section 2.1 lists the expected impacts. WP6 will measure the first two of these. The third impact deals with regulation and is not part of the technical development or trials (lab or on-road); nevertheless, the outcome of the trials may be able to provide technical evidence for current regulations (although that is not their main purpose). The fourth impact, International Cooperation, is a non-technical impact, so is not included in the technical assessment.

2.3.1. Expected Impact 1: Contribute to reduction of emissions from the existing combustion-engine car fleet

Impact Performance Indicator 1: Expected average of 20-35% reduction in pollutant emissions for tampered/poorly maintained vehicles.

The hypothesis assumes there will be a significant increase in the detection rate for tampered or poorly maintained vehicles. The measurement therefore depends on both the detection rate, the accuracy of detection and the detected levels of degradation of performance of tampered/poorly maintained vehicles.

Data came from lab tests performed by VTT as well as limited controlled road tests in Finland. Also the knowledge about tampering detection includes vehicle inspection records in three countries (Finland, Greece and Turkey), although we recognise that these inspection records do not tell the full story, because mostly the problems are rectified before going into inspection. Previous results are used to estimate the most probable range of detection rates.

Impact Performance Indicator 2: For retrofitted vehicles, those reaching Euro VI standards will have a reduction of >60% in PMs and NO_X

Research question: How well does the system perform in real use cases?

MODALES partner Proventia is monitoring the effects of retrofits (NOxBUSTER) on HDVs (buses and garbage trucks) and has also retrofitted a van (Mercedes-Benz Sprinter 216, Euro5) as part of WP4 in MODALES. The results of these tests are providing ranges for emissions reductions that could be expected from a retrofitted vehicle. They are presented in [1] in details for the interested reader.

Impact Performance Indicator 3: 20-30% reduction of non-engine PMs

Research question: What is the potential reduction of brake and tyre emissions (for different vehicles and road conditions) due to MODALES?

The MODALES app together with the offline/online training, should induce driving behaviour modifications that could impact brake and tyre emissions. Long-term effects on emissions may also appear through a better care of the vehicle. Unfortunately, collecting field measures of non-engine PM emissions while adopting the MODALES App recommended driving style are not possible, as it is not feasible to distinct brake and tyre emissions from engine emissions using PEMS data.

Scaling up from experimental data is feasible at the aggregated level. The goal is to make use of internal databases and models available through industrial partners, to estimate brake and tyre emissions based on driving behaviour field data (acceleration and braking behaviour for example). Such models were settled thanks to the University of Leeds, and the obtained results have been presented in [2]. Unfortunately, these models cannot be used to estimate tyre and brakes emissions from the data collected during the trial tests. Instead, tyre and brakes emissions have been integrated in the score produced by Okan university using VTT test data. The results presented in this deliverable will use this model linking the score to aggregate emissions, which includes tyre and brakes emissions.

2.3.2. Expected Impact 2: Contribute to reduction of unnecessary driver-induced emissions though a better awareness by the public of their role in controlling polluting emissions

Among MODALES solutions, driver behaviour is only impacted by the app and online/offline training, at least for short- and medium-term effects. Increasing tampering detection can induce long term effects on driving, but this is not estimable through MODALES project and can be considered negligible at first sight.

IPI 4: 5-10% reduction of emissions by applying the MODALES low emission driving/riding guidelines

Research question: To what extent (and range) can vehicle emissions be reduced by using the MODALES app and training?

The app can be considered as a member of the "Driver behaviour and eco-driving systems family", as defined by the EU project Amitran (Assessment Methodologies for ICT in multimodal transport from User Behaviour to CO_2 reduction)[1] and described in the paper "Scaling up methodology for CO_2 emissions of ICT applications in traffic and transport in Europe" [5]. Such systems work continuously and their recommendations are applicable in all kinds of situations. According to Amitran recommendations, scaling-up is possible and straightforward when field data is collected through different road types and driving conditions.

The impact to be tested are the powertrain emissions, brake emissions and tyre emissions before and after using the MODALES app and training. As the training is to be used in conjunction with the app, they will be measured together (no analysis of app only or training only).

The large number of MODALES experiments finely captures the variability of driving behaviour across European countries. The FESTA methodology applied to MODALES research questions provides statistical evidence about the emission reduction across these various conditions, but also on the acceptance of the app and the adoption of recommendations through questionnaires. These questionnaires results are discussed at section 6.

2.4. Research Questions and Hypotheses

This chapter sets out high-level Research Questions (RQs) which the evaluation process should answer. To do this, each research question is associated with one or more hypothesis and each hypothesis will be measured by one or more performance indicator.

The impact assessment part is different from the validation, as this is not direct measurement of the output of the different technologies but involves modelling, deployment scenarios, scaling up, together with assumptions or value judgements to estimate the real effect of the different technologies and procedures together. These are mapped by means of the expected impacts given in the MODALES DoA (three main impact areas and five Impact Performance Indicators – IPIs).

[1] https://cordis.europa.eu/project/id/287551

Table 2: Impact Assessment Research Questions (by Impact Area and Impact Performance Indicator)

Impact area and Impact Performance Indicators (IPIs)		Research Question(s)	Hypotheses
Expected Impact Area 1: Contribute to reduction of emissions from the existing combustion-engined car fleet			
IPI 1	Expected average of 20-35% reduction in pollutant emissions (figures might differ depending on the types of emission: NO_X, PM, CO, HC and engine characteristics) for tampered/poorly maintained vehicles.	How much can MODALES help to increase the detection rate of tampered/poorly maintained vehicles?	MODALES solutions allow an increase in detection rate of tampered/poorly maintained vehicles Levels of degradation of performance of detected tampered/ poorly maintained vehicles are at least 20% below that of well-maintained vehicles
IPI 2	For retrofitted vehicles, those reaching Euro VI standards will have a reduction of >60% in PMs and NO_X.	How well does the system perform in real use cases?	Performance of retrofit system, in various real use cases
IPI 3	MODALES targets to a 20-30% reduction of non-engine PMs	What is the potential reduction of brake and tyre emissions (for different vehicles and road conditions) due to MODALES?	Brake and tyre emissions are reduced when following MODALES driving style compared to baseline
Expected Impact Area 2: Contribute to reduction of unnecessary driver-induced emissions though a better awareness by the public of their role in controlling polluting emissions			
IPI 4	5-10% reduction of emissions (depending on vehicle type and Euro technology) by applying the MODALES low emission driving/riding guidelines. Optimisation of the performance indicator figure will take place after running pilot studies for a more accurate reduction prediction.	To what extent can vehicle emissions be reduced by using the MODALES app and training? What is the range of impact across usage?	Driving behaviour change after the training and using the app has potentially reduced (a) Powertrain emissions; (b) Brake emissions; (c) Tyre emissions: by at least 5% across different usage[2], according to equations for emissions versus driving behaviour
Expected Impact Area 3: Provide technical evidence to assess gaps in current regulation of vehicles			
IPI 5	The adeptness of current EOBD and technical inspection procedures to detect elevated emissions levels are improved by 30 to 40%[3].	Not within the scope of this Evaluation Plan, as this is not part of the on-road trials. It will instead be covered in D4.2: "Recommendations for anti-tampering and improved mandatory vehicle inspection".	

[2] Usage refers to different road types/conditions, vehicle types and driver profiles.

[3] This targeted level of improvement comprises a combination of measures, consisting of enhanced EOBD and more rigorous technical inspections, fortified with additional legislative actions that should make tampering of emissions control a criminal act with serious consequences. MODALES estimates that each of these three

Impact area and Impact Performance Indicators (IPIs)	Research Question(s)	Hypotheses
Expected Impact 4: International cooperation		
Not within the scope of WP6 or this Evaluation Plan		

2.5. Mapping questions to solutions

Each innovation solution developed within MODALES can be associated with one or more high-level research question. Figure 3 presents graphically the information provided in section 2.3 and 2.4.

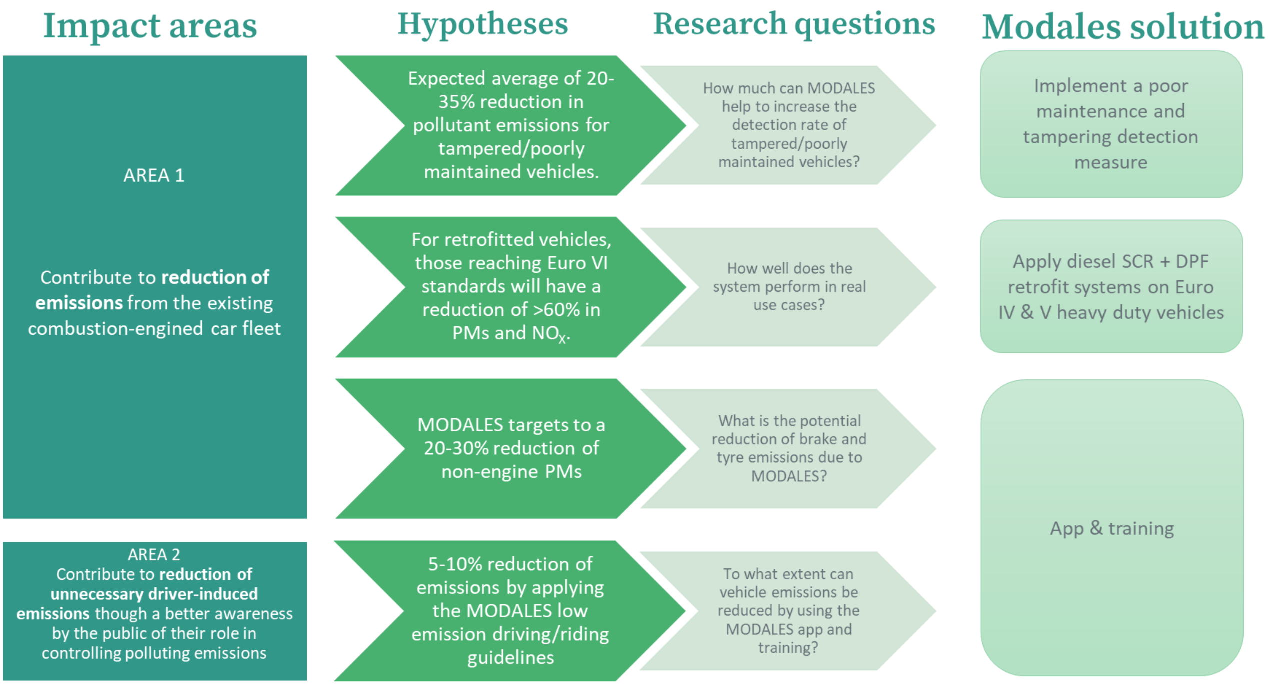


Figure 3: Overview of the links between impact areas, hypotheses and research questions, together with the associated MODALES innovative solution

measures would make some 10+ % improvement, which in aggregate make the 30 to 40% improvement in the "catch rate" of the processes to identify high emitting defected vehicles, as well as in preventing motorists from tampering their vehicles. Clearly such outcomes rely on the effectiveness of legislative measures: these should work so that they primarily deter motorists from defecting and tampering with their vehicles.

3. Evaluation Methodology

3.1. Reference methodologies

Impact assessment methodologies for the estimation of road transport emissions play a crucial role in analysing and understanding the environmental impact of transport systems [6]**.** At this level different approaches and solutions could be applied to reduce emissions. To evaluate these solutions and to calculate emissions and energy consumption for a specific country or region, the following general steps should be made:

1. Collect data on energy production and consumption: This data will include information according to the types of energy sources (diesel, gasoline or petrol, electric batteries). This data can be obtained from various sources, such as government statistical agencies, international organisations, and industry associations.

2. Determine emissions factors: Emissions factors are coefficients that relate the amount of energy consumed to the amount of greenhouse gases GHGs emitted. They are specific to each type of fuel and depend on the technology used to convert it into energy. Emissions factors can be obtained from national and international databases [3]**.**

3. Calculate emissions before and after applying of a new emission reduction approach (MODALES solution): The calculation depends on the energy consumption for each fuel, its corresponding emissions factor and the performance improvement by the proposed solution.

4. Analyse the results: Compare the results to historical data and to other countries or regions and Identify the main sources of emissions and areas where emissions reductions could be achieved.

In the literature, there are several tools available for calculating emissions and energy consumption by vehicles. These tools help evaluate the emissions generated by vehicles and provide valuable insights for policymakers, urban planners, and researchers to develop sustainable transportation strategies. Here are a couple of options:

1. Fuel Economy [7]**:** This is an online tool developed by the U.S. Environmental Protection Agency that allows users to compare the fuel economy, emissions, and energy consumption of different vehicles. The tool provides estimates of fuel costs and emissions for different driving conditions and can be used to compare the environmental impact of different vehicles.

2. Sustainable Urban Mobility Indicators (SUMI) [8]**:** is a framework developed by the European Commission to assess and measure urban mobility and transportation systems. It provides a standardised set of indicators that capture various dimensions of urban mobility, enabling cities to monitor their performance and track progress towards sustainable and efficient transportation.

3. COPERT (Computer Programme to calculate Emissions from Road Transport) [3]**:** This is a software developed and maintained by the European Environment Agency (EEA) in collaboration with the European Commission's Joint Research Centre (JRC). It focuses specifically on the estimation of air pollution emissions from road vehicles in European countries. The COPERT software is continuously updated to reflect advancements in vehicle technology, emission control measures, and scientific knowledge.

3.2. Proposed approach

The MODALES project aims to reduce air pollution from all types of road vehicles by encouraging the adoption of low-emitting driving behaviours that reduce emissions, vehicle retrofits and inspections to detect poorly maintained and tampered vehicles. To evaluate the different approaches and strategies proposed by MODALES, COPERT software is used to compare baseline vehicle emissions for some European countries with the estimated emissions after the implementation of MODALES solutions. It specifically measures the emission savings by estimating air pollutant emissions and greenhouse gas emissions from road vehicles for the following pollutants: CO_2, CO, NOx, and PM.

A simplified scheme that describes the process of assessing the impact of MODALES proposed solutions on vehicle emissions is shown in Figure 4 below.

First, baseline data (vehicle fleet composition, kilometres driven, fuel consumption, emission factors), representing current vehicle emissions without any proposed solutions, is collected by country. Second, COPERT software is used to calculate the emissions of each pollutant of interest according to the data collected and taking into account vehicle types, driving conditions and fuel types. Third, emissions are recalculated with COPERT, taking into account the potential solutions proposed by MODALES (driving behaviour, retrofits and anti-tampering). This time "vehicle performance improvement" parameter in COPERT is updated based on experimental and simulation results realised by MODALES project. Finally, the emissions calculated in the baseline scenario (without proposed solutions) to the emissions in the solution scenario (with proposed solutions) are compared. The impact of the proposed solutions in reducing emissions for some European countries (Finland, Italy, Spain, Turkey, France and Germany) is analysed and evaluated.

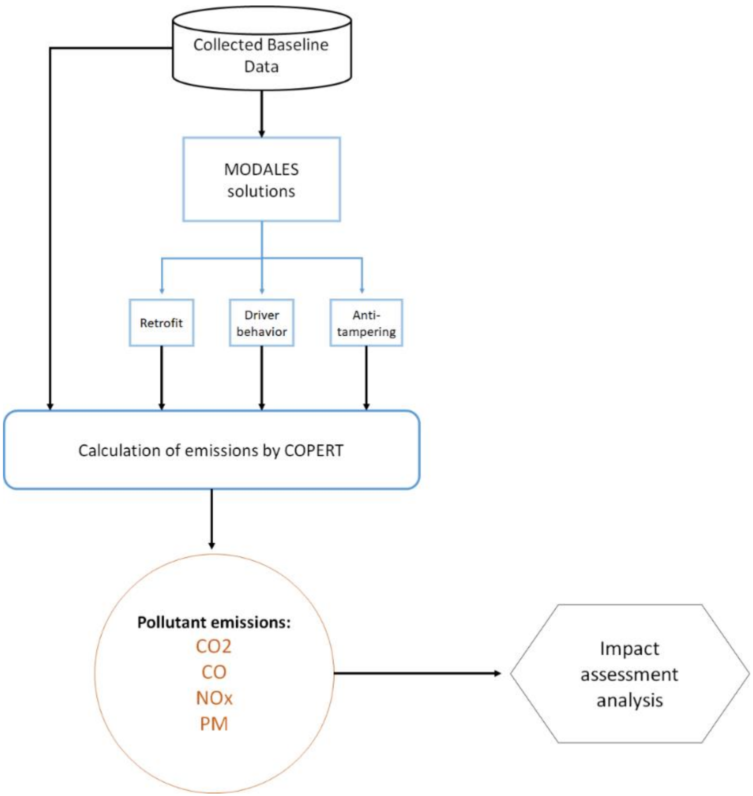


Figure 4: Flowchart that outlines the process of evaluating vehicle emissions

3.3. The COPERT methodology: A European standard

COPERT is a widely used software tool for estimating and calculating emissions from road transport. It is designed to help researchers, policymakers, and analysts assess the environmental impact of road vehicles and develop strategies to reduce emissions. COPERT is developed and maintained by the European Environment Agency (EEA) in collaboration with the European Commission's Joint Research Centre (JRC). It specifically measures air pollutant emissions and greenhouse gas emissions from road vehicles. The software utilises a range of input data, including vehicle activity data, vehicle fleet composition, vehicle emission factors, and road network characteristics, to calculate emissions on a regional or national scale. It takes into account various parameters such as vehicle types, driving conditions, fuel types, and pollutant control technologies to provide comprehensive emission estimates.

COPERT has been widely used by researchers, government agencies, and industry professionals for emission inventory development, policy analysis, and the evaluation of emission reduction measures. It helps in understanding the environmental impact of road transport and provides valuable insights for developing sustainable transportation policies and strategies.

COPERT is a stand-alone software application that uses csv or xls files mainly as input. When the user opens a database file or creates a new one with COPERT 5, automatically a temporary file is created, where all the changes that are made during the process are saved. After the user completes the necessary calculation steps and saves the changes, the input file becomes the output one that can be used again as an input file by the same or another user (Figure 5). The user can provide input data to the application either by using the application's window forms, or by importing data from Microsoft Excel files (.xls or .csv files).

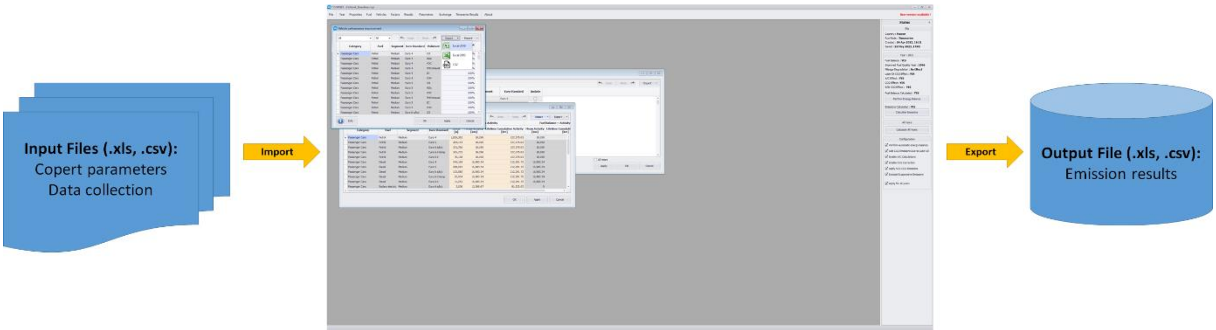


Figure 5: Visualisation of COPERT architecture

3.4. Data needs, data sources

Estimating emissions from road transport plays an important role in the analysis and understanding of the environmental impact of transport systems. The use of tools like the COPERT software helps to assess vehicle emissions and provides valuable information to policy makers and researchers to develop sustainable transport strategies.

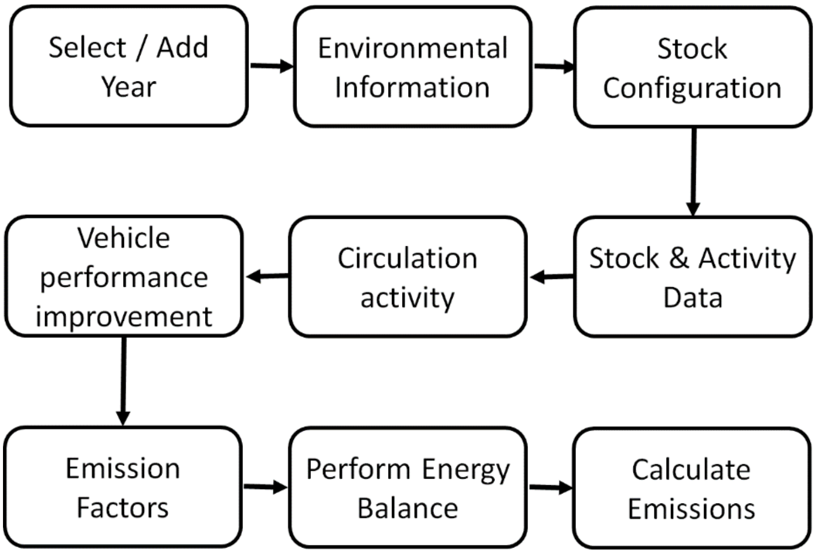
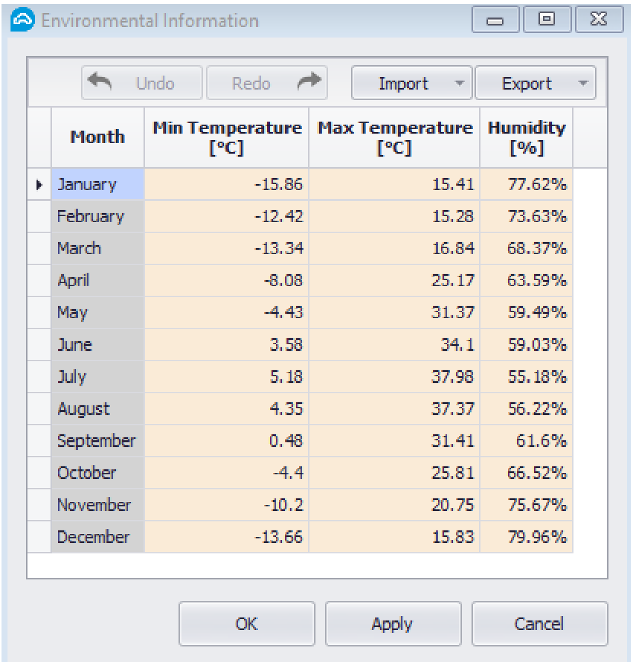


Figure 6: Procedure to estimate emissions by COPERT

Figure 6 illustrates the whole procedure of estimation with COPERT. It consists of importing, for a specific country, all information (parameters) that represent the characteristic of the source of pollutants in that region. An explanation of COPERT parameters for Spain is presented below.

1. Environmental information ([9], [10])**:** In this format, the user provides values for monthly relative humidity, minimum and maximum average temperatures for each year. This is required to calculate the load of air-conditioning (A/C) and the fuel evaporation.



Month	Min Temperature [°C]	Max Temperature [°C]	Humidity [%]
January	-15.86	15.41	77.62%
February	-12.42	15.28	73.63%
March	-13.34	16.84	68.37%
April	-8.08	25.17	63.59%
May	-4.43	31.37	59.49%
June	3.58	34.1	59.03%
July	5.18	37.98	55.18%
August	4.35	37.37	56.22%
September	0.48	31.41	61.6%
October	-4.4	25.81	66.52%
November	-10.2	20.75	75.67%
December	-13.66	15.83	79.96%

Figure 7: Environmental information COPERT parameter values for Spain

2. Stock configuration [11]**:** In this section, the user should select which types of vehicles will be in the fleet of the selected year. In our case, we have selected: four types of vehicles (Passenger cars, Light

Commercial Vehicles, Heavy Duty Trucks and buses), three type of fuels (diesel, petrol and electric) and five Euro Standard (Euro 4, Euro 5, Euro 6 a/b/c, Euro 6 d-temp and Euro 6 d).

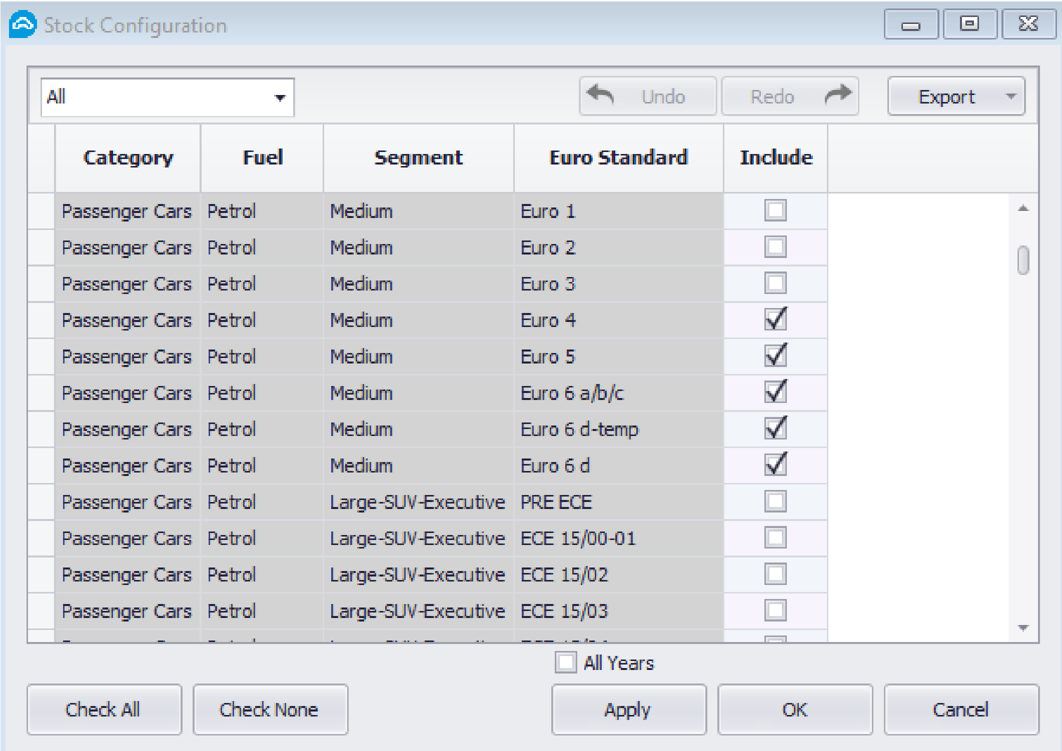


Figure 8: Vehicle stock Configuration COPERT parameter selection types for Spain

3. Stock & Activity Data ([12], [13], [14], [15], [16])**:** Accurate estimation of emissions requires detailed information about stock of vehicles, mean activity (km/year) and Lifetime Cumulative Activity (km). The Lifetime Cumulative Mileage is the mean distance travelled by each vehicle of a specific technology level since the introduction in the market. This value is then used to provide an emission degradation factor depending on vehicle age. Finally, if the user wants to carry out an energy balance, so that the calculated consumption corresponds to the statistics, COPERT calculates a new average activity.

Vehicle				Stock & Activity			Fuel Balance ~ Activity	
Category	Fuel	Segment	Euro Standard	Stock [n]	Mean Activity [km]	Lifetime Cumulative Activity [km]	Mean Activity [km]	Lifetime Cumulative Activity [km]
Passenger Cars	Petrol	Medium	Euro 4	12,149,737	6,348	74,906.4	6,348	74,906.4
Passenger Cars	Petrol	Medium	Euro 5	1,639,352	6,348	74,906.4	6,348	74,906.4
Passenger Cars	Petrol	Medium	Euro 6 a/b/c	2,934,917	6,348	74,906.4	6,348	74,906.4
Passenger Cars	Petrol	Medium	Euro 6 d-temp	1,103,022	6,348	74,906.4	6,348	74,906.4
Passenger Cars	Petrol	Medium	Euro 6 d	906,634	6,348	74,906.4	6,348	74,906.4
Passenger Cars	Diesel	Medium	Euro 4	8,459,915	10,580	124,844	10,580	124,844
Passenger Cars	Diesel	Medium	Euro 5	3,544,387	10,580	124,844	10,580	124,844
Passenger Cars	Diesel	Medium	Euro 6 a/b/c	4,015,041	10,580	124,844	10,580	124,844
Passenger Cars	Diesel	Medium	Euro 6 d-temp	775,151	10,580	124,844	10,580	124,844
Passenger Cars	Diesel	Medium	Euro 6 d	403,271	10,580	124,844	10,580	124,844
Passenger Cars	Battery electric	Medium	Euro 6 a/b/c	0	0	0	0	0
Passenger Cars	Battery electric	Medium	Euro 6 d-temp	0	0	0	0	0
Passenger Cars	Battery electric	Medium	Euro 6 d	0	0	0	0	0
Light Commercial Vehicles	Petrol	N1-II	Euro 4	110,699	21,609.97	298,217.6	21,609.97	298,217.6
Light Commercial Vehicles	Petrol	N1-II	Euro 5	43,187	21,609.97	298,217.6	21,609.97	298,217.6
Light Commercial Vehicles	Petrol	N1-II	Euro 6 a/b/c	6,893	21,609.97	298,217.6	21,609.97	298,217.6
Light Commercial Vehicles	Petrol	N1-II	Euro 6 d-temp	23,800	21,609.97	298,217.6	21,609.97	298,217.6
Light Commercial Vehicles	Petrol	N1-II	Euro 6 d	12,011	21,609.97	298,217.6	21,609.97	298,217.6
Light Commercial Vehicles	Diesel	N1-II	Euro 4	1,575,196	21,609.97	298,217.6	21,609.97	298,217.6
Light Commercial Vehicles	Diesel	N1-II	Euro 5	714,656	21,609.97	298,217.6	21,609.97	298,217.6
Light Commercial Vehicles	Diesel	N1-II	Euro 6 a/b/c	379,054	21,609.97	298,217.6	21,609.97	298,217.6
Light Commercial Vehicles	Diesel	N1-II	Euro 6 d-temp	596,959	21,609.97	298,217.6	21,609.97	298,217.6
Light Commercial Vehicles	Diesel	N1-II	Euro 6 d	148,011	21,609.97	298,217.6	21,609.97	298,217.6
Heavy Duty Trucks	Diesel	Rigid <=7,5 t	Euro IV	295,743	80,461.3	1,488,534.06	80,461.3	1,488,534.06
Heavy Duty Trucks	Diesel	Rigid <=7,5 t	Euro V	175,134	80,461.3	1,488,534.06	80,461.3	1,488,534.06
Heavy Duty Trucks	Diesel	Rigid <=7,5 t	Euro VI A/B/C	40,915	80,461.3	1,488,534.06	80,461.3	1,488,534.06
Buses	Diesel	Urban Buses Midi <=15 t	Euro IV	45,990	44,900	642,070	44,900	642,070
Buses	Diesel	Urban Buses Midi <=15 t	Euro V	23,332	44,900	642,070	44,900	642,070
Buses	Diesel	Urban Buses Midi <=15 t	Euro VI A/B/C	24,481	44,900	642,070	44,900	642,070

Figure 9: COPERT stock & activity data (values for Spain)

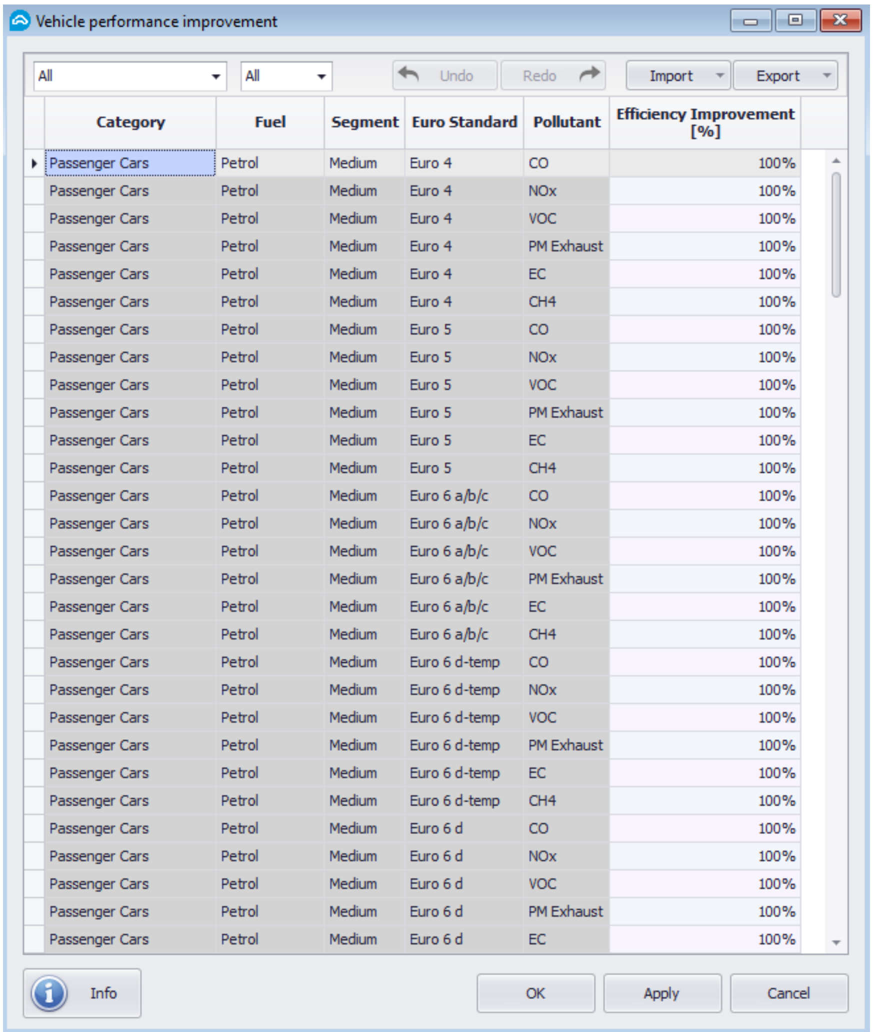
4. Circulation activity [16] [17]**:** In this form the user imports the average speed and the mileage percentage (sum should always be 100%) driven by each vehicle technology by driving mode.

Circulation activity

Vehicle				Share				Speed				
Category	Fuel	Segment	Euro Standard	Urban Peak [%]	Urban Off Peak [%]	Rural [%]	Highway [%]	Urban Peak [km/h]	Urban Off Peak [km/h]	Rural [km/h]	Highway [km/h]	Min - Max Speed [km/h]
Passenger Cars	Petrol	Medium	Euro 4	20.61%	10.31%	46.19%	22.88%	35	50	90	130	5 - 130
Passenger Cars	Petrol	Medium	Euro 5	20.61%	10.31%	46.19%	22.88%	35	50	90	130	5 - 130
Passenger Cars	Petrol	Medium	Euro 6 a/b/c	20.61%	10.31%	46.19%	22.88%	35	50	90	130	5 - 130
Passenger Cars	Petrol	Medium	Euro 6 d-temp	20.61%	10.31%	46.19%	22.88%	35	50	90	130	5 - 130
Passenger Cars	Petrol	Medium	Euro 6 d	20.61%	10.31%	46.19%	22.88%	35	50	90	130	5 - 130
Passenger Cars	Diesel	Medium	Euro 4	20.61%	10.31%	46.19%	22.88%	35	50	90	130	10 - 130
Passenger Cars	Diesel	Medium	Euro 5	20.61%	10.31%	46.19%	22.88%	35	50	90	130	10 - 130
Passenger Cars	Diesel	Medium	Euro 6 a/b/c	20.61%	10.31%	46.19%	22.88%	35	50	90	130	10 - 130
Passenger Cars	Diesel	Medium	Euro 6 d-temp	20.61%	10.31%	46.19%	22.88%	35	50	90	130	10 - 130
Passenger Cars	Diesel	Medium	Euro 6 d	20.61%	10.31%	46.19%	22.88%	35	50	90	130	10 - 130
Passenger Cars	Battery electric	Medium	Euro 6 a/b/c	20.61%	10.31%	46.19%	22.88%	35	50	90	130	5 - 130
Passenger Cars	Battery electric	Medium	Euro 6 d-temp	20.61%	10.31%	46.19%	22.88%	35	50	90	130	5 - 130
Passenger Cars	Battery electric	Medium	Euro 6 d	20.61%	10.31%	46.19%	22.88%	35	50	90	130	5 - 130
Light Commercial Vehicles	Petrol	N1-II	Euro 4	20.61%	10.31%	46.19%	22.88%	35	50	70	80	10 - 120
Light Commercial Vehicles	Petrol	N1-II	Euro 5	20.61%	10.31%	46.19%	22.88%	35	50	70	80	5 - 140
Light Commercial Vehicles	Petrol	N1-II	Euro 6 a/b/c	20.61%	10.31%	46.19%	22.88%	35	50	70	80	5 - 140
Light Commercial Vehicles	Petrol	N1-II	Euro 6 d-temp	20.61%	10.31%	46.19%	22.88%	35	50	70	80	5 - 140
Light Commercial Vehicles	Petrol	N1-II	Euro 6 d	20.61%	10.31%	46.19%	22.88%	35	50	70	80	5 - 140
Light Commercial Vehicles	Diesel	N1-II	Euro 4	20.61%	10.31%	46.19%	22.88%	35	50	70	80	10 - 110
Light Commercial Vehicles	Diesel	N1-II	Euro 5	20.61%	10.31%	46.19%	22.88%	35	50	70	80	5 - 130
Light Commercial Vehicles	Diesel	N1-II	Euro 6 a/b/c	20.61%	10.31%	46.19%	22.88%	35	50	70	80	5 - 130
Light Commercial Vehicles	Diesel	N1-II	Euro 6 d-temp	20.61%	10.31%	46.19%	22.88%	35	50	70	80	5 - 130
Light Commercial Vehicles	Diesel	N1-II	Euro 6 d	20.61%	10.31%	46.19%	22.88%	35	50	70	80	5 - 130
Heavy Duty Trucks	Diesel	Rigid <=7,5 t	Euro IV	20.61%	10.31%	46.19%	22.88%	35	50	70	80	12 - 86
Heavy Duty Trucks	Diesel	Rigid <=7,5 t	Euro V	20.61%	10.31%	46.19%	22.88%	35	50	70	80	5 - 85
Heavy Duty Trucks	Diesel	Rigid <=7,5 t	Euro VI A/B/C	20.61%	10.31%	46.19%	22.88%	35	50	70	80	5 - 85
Buses	Diesel	Urban Buses Midi <=15 t	Euro IV	20.61%	10.31%	46.19%	22.88%	35	50	80	100	11 - 86
Buses	Diesel	Urban Buses Midi <=15 t	Euro V	20.61%	10.31%	46.19%	22.88%	35	50	80	100	5 - 85
Buses	Diesel	Urban Buses Midi <=15 t	Euro VI A/B/C	20.61%	10.31%	46.19%	22.88%	35	50	80	100	5 - 85

Figure 10: COPERT circulation activity parameter window (values for Spain)

5. Vehicle performance improvement [18]**:** In this format, a vehicle performance improvement is defined which is related to the increasing fuel efficiency of the same vehicle technology type from year to year. This parameter depends on the new solutions or strategies that are implemented with MODALES project to reduce vehicle emissions.



Category	Fuel	Segment	Euro Standard	Pollutant	Efficiency Improvement [%]
Passenger Cars	Petrol	Medium	Euro 4	CO	100%
Passenger Cars	Petrol	Medium	Euro 4	NOx	100%
Passenger Cars	Petrol	Medium	Euro 4	VOC	100%
Passenger Cars	Petrol	Medium	Euro 4	PM Exhaust	100%
Passenger Cars	Petrol	Medium	Euro 4	EC	100%
Passenger Cars	Petrol	Medium	Euro 4	CH4	100%
Passenger Cars	Petrol	Medium	Euro 5	CO	100%
Passenger Cars	Petrol	Medium	Euro 5	NOx	100%
Passenger Cars	Petrol	Medium	Euro 5	VOC	100%
Passenger Cars	Petrol	Medium	Euro 5	PM Exhaust	100%
Passenger Cars	Petrol	Medium	Euro 5	EC	100%
Passenger Cars	Petrol	Medium	Euro 5	CH4	100%
Passenger Cars	Petrol	Medium	Euro 6 a/b/c	CO	100%
Passenger Cars	Petrol	Medium	Euro 6 a/b/c	NOx	100%
Passenger Cars	Petrol	Medium	Euro 6 a/b/c	VOC	100%
Passenger Cars	Petrol	Medium	Euro 6 a/b/c	PM Exhaust	100%
Passenger Cars	Petrol	Medium	Euro 6 a/b/c	EC	100%
Passenger Cars	Petrol	Medium	Euro 6 a/b/c	CH4	100%
Passenger Cars	Petrol	Medium	Euro 6 d-temp	CO	100%
Passenger Cars	Petrol	Medium	Euro 6 d-temp	NOx	100%
Passenger Cars	Petrol	Medium	Euro 6 d-temp	VOC	100%
Passenger Cars	Petrol	Medium	Euro 6 d-temp	PM Exhaust	100%
Passenger Cars	Petrol	Medium	Euro 6 d-temp	EC	100%
Passenger Cars	Petrol	Medium	Euro 6 d-temp	CH4	100%
Passenger Cars	Petrol	Medium	Euro 6 d	CO	100%
Passenger Cars	Petrol	Medium	Euro 6 d	NOx	100%
Passenger Cars	Petrol	Medium	Euro 6 d	VOC	100%
Passenger Cars	Petrol	Medium	Euro 6 d	PM Exhaust	100%
Passenger Cars	Petrol	Medium	Euro 6 d	EC	100%

Figure 11: COPERT Vehicle performance improvement parameter window

6. Emission Factors [19]**:** Emission factors represent the amount of pollutants released per unit of activity (e.g., vehicle kilometres travelled or fuel consumed). Emission factors are regularly updated with COPERT to reflect advancements in vehicle technology and emission control measures.

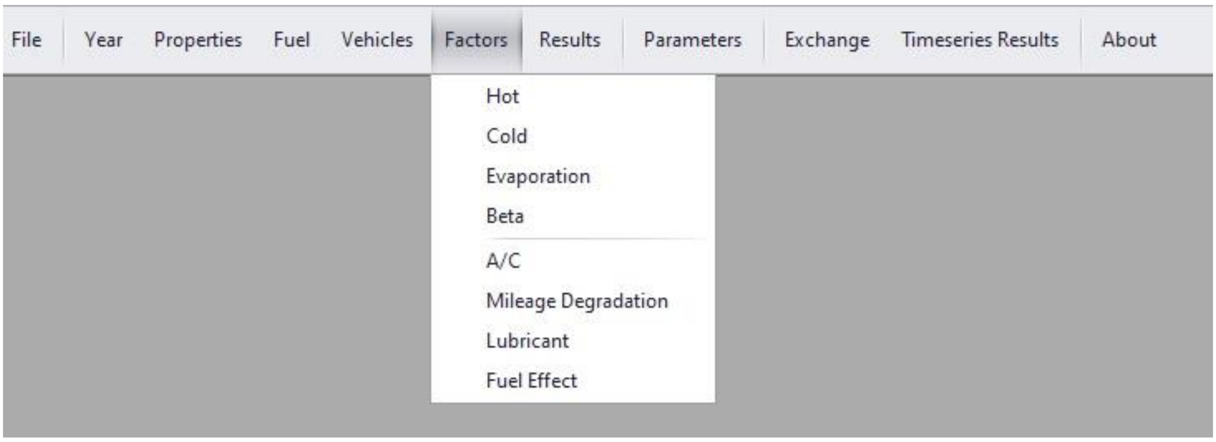
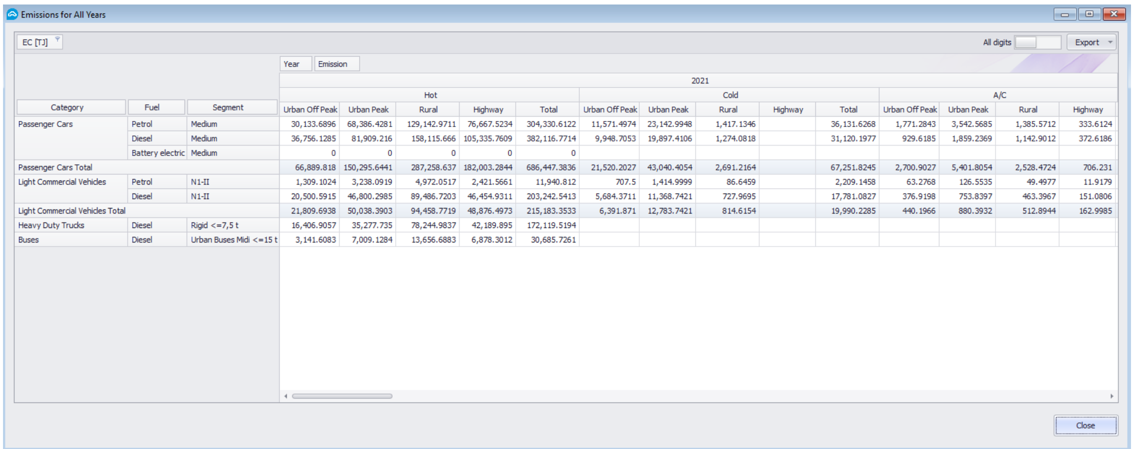


Figure 12: COPERT Emission factors window

7. Energy balance and calculate emissions: After automatic calculation by COPERT, the user can finally export and have an overview of all results.



Category	Fuel	Segment	2021 Hot Urban Off Peak	Hot Urban Peak	Hot Rural	Hot Highway	Hot Total	Cold Urban Off Peak	Cold Urban Peak	Cold Rural	Cold Highway	Cold Total	A/C Urban Off Peak	A/C Urban Peak	A/C Rural	A/C Highway
Passenger Cars	Petrol	Medium	30,133.6896	68,386.4281	129,142.9711	76,667.5234	304,330.6122	11,571.4974	23,142.9948	1,417.1346		36,131.6268	1,771.2843	3,542.5685	1,385.5712	333.6124
	Diesel	Medium	36,756.1285	81,909.216	158,115.666	105,335.7609	382,116.7714	9,948.7053	19,897.4106	1,274.0818		31,120.1977	929.6185	1,859.2369	1,142.9012	372.6186
	Battery electric	Medium	0	0	0	0	0									
Passenger Cars Total			66,889.818	150,295.6441	287,258.637	182,003.2844	686,447.3836	21,520.2027	43,040.4054	2,691.2164		67,251.8245	2,700.9027	5,401.8054	2,528.4724	706.231
Light Commercial Vehicles	Petrol	N1-II	1,309.1024	3,238.0919	4,972.0517	2,421.5661	11,940.812	707.5	1,414.9999	86.6459		2,209.1458	63.2768	126.5535	49.4977	11.9179
	Diesel	N1-II	20,500.5915	46,800.2985	89,486.7203	46,454.9311	203,242.5413	5,684.3711	11,368.7421	727.9695		17,781.0827	376.9198	753.8397	463.3967	151.0806
Light Commercial Vehicles Total			21,809.6938	50,038.3903	94,458.7719	48,876.4973	215,183.3533	6,391.871	12,783.7421	814.6154		19,990.2285	440.1966	880.3932	512.8944	162.9985
Heavy Duty Trucks	Diesel	Rigid <=7,5 t	16,406.9057	35,277.735	78,244.9837	42,189.895	172,119.5194									
Buses	Diesel	Urban Buses Midi <=15 t	3,141.6083	7,009.1284	13,656.6883	6,878.3012	30,685.7261									

Figure 13: COPERT results window

3.5. From MODALES results to COPERT parameters

This section explains how to translate MODALES innovation solutions into set of parameters suitable to be used as tuning parameters for COPERT simulations. For each Innovation Solution, assumptions are made based on literature survey or MODALES results and experts' knowledge. These assumptions are used to build different scenarios. First, a "lower" scenario is built based on a pessimistic assumption, then an optimistic scenario is built and called "upper".

In the sections below, each innovative solution is translated into assumptions and parameters, together with the explanation or the relevant source. The final parameters are gathered into tables easily readable.

3.5.1. MODALES solution 1: Regulation policy

According to the MODALES results [2], it is proposed to implement a poor maintenance and tampering detection measure with the following main aspects:

- *Mandatory tampering detection using OBD data during the periodic inspections*
- *Penalties to vehicle owners when a manipulation of the vehicle data by an aftermarket software is detected*

Under the assumption that 10% of all vehicle types are tampered on average, this solution could impact all categories of vehicles (passenger cars, light commercial vehicles, heavy duty trucks & buses) and all euro standards ([20],[21]).

In order to model this solution using COPERT software, we need to estimate its effects by making some assumptions based on a literature survey and on the MODALES experiments and studies.

The following assumptions are made:

1. **10% of the fleet of light & heavy duty vehicles is being tampered** [20]**.**
2. **For every additional 1% of tampered vehicles, we have an increase of 2% of PM and NOx emissions for the whole fleet (source icct-2022, indicating a range between 2% and 3%)**
3. **The detection rate of the proposed measure is:**

   a. **25% for the lower scenario,**
   b. **50% for the upper scenario.**
4. **Once a vehicle is detected, it is assumed that it returns to its normal emission factor before tampering.**

Under these assumptions, it is possible to estimate the effect of the proposed measure. As an example, if 50% of the 10% tampered vehicles are detected, that means the measure saves the equivalent of 5% additional tampered vehicles. From ICCT studies we could estimate these 5% tampered vehicles to be responsible for an increase of 2x5=10% for PM and NOx emissions, which is a conservative approach as it could range up to 3 times. When reasoning on the opposite way, it could calculated how much reduction is expected when decreasing the population of tampered vehicles from 10% to 7.5% (lower scenario) or to 5% (upper scenario). The calculated values are indicated in the table below.

Table 3: Parameters used for Coper simulations for the anti-tampering regulation solution[4]

passenger cars, light commercial vehicles, heavy duty trucks & buses	lower scenario (25% detection rate)	upper scenario (50% detection rate)	Targeted engine type
CO	0%	0%	diesel
CO_2	0%	0%	diesel
NOx	4.2%	9%	diesel
PM 10 & 2.5	4.2%	9%	diesel

3.5.2. MODALES solution 2: Retrofit

The second type of solution proposed by MODALES consist of generalising retrofit systems when it is relevant. The studies performed helped to evaluate the targeted population of vehicles, together with the range of proportion for which SCR + DPF is applicable.

The targeted population of vehicles are the following: light commercial vehicles, heavy-duty trucks, and buses. This solution is only applicable to diesel vehicles.

In order to build a lower and an upper scenario, we use the uncertainty associate with the estimation of the proportion of vehicles for which the solution is applicable. From the studies made by CERTH within MODALES and from expert knowledge, we can derive the following results for the proportion of vehicles with SCR + DPF applicable:

- Light commercial vehicles Euro 4 & 5: 0,5% (lower scenario) or 1% (upper scenario)
- Heavy duty trucks Euro IV: 5% (lower) or 10% (upper)
- Heavy duty trucks Euro V: 25% (lower) or 50% (upper)
- Buses Euro IV: 5% (lower) or 10% (upper)
- Buses Euro V: 12.5% (lower) or 25% (upper)

[4] The indicated values are the estimated reduction in emissions

Once a vehicle is equipped with a SCR+DPF system, the observed reductions are the following:

- CO: 50%
- NOx: 70%
- VOC: 50%
- PM: 90%

Although the VOC (Volatil Organic Components) emission is estimated using COPERT simulations, results are not displayed in this deliverable for consistency between the different solutions and because VOC are not in the scope of MODALES studies.

It is then possible to mix all these parameters to estimate the potential reduction of emissions. For example, if we consider the NOx emissions, and the light commercial vehicles fleet for the lower scenario, the proposed measure is expected to reduce by 70% the emissions for 0.5% of the fleet. This translates into a reduction 0.35% for the whole fleet (0.5x0.7). The final parameters used are indicated in the tables below.

Table 4: Parameters used for Coper simulations for the retrofit solution[5]

light commercial vehicles (Euro 4 & 5)	**lower scenario (Retrofit applicable to 0.5% of Euro 4 & 5 light commercial vehicles)**	**upper scenario (Retrofit applicable to 1% of Euro 4 & 5 light commercial vehicles)**	**Targeted engine type**
CO	0.2%	0.5%	diesel
CO_2	0%	0%	diesel
NOx	0.3%	0.7%	diesel
PM 10 & 2.5	0.4%	0.9%	diesel

Table 5: Parameters used for Coper simulations for the retrofit solution[6]

heavy duty trucks (Euro IV & V)	**lower scenario (Retrofit applicable to 5% of Euro IV trucks, 25% of Euro V trucks)**	**upper scenario (Retrofit applicable to 10% of Euro IV trucks, 50% of Euro V trucks)**	**Targeted engine type**
CO	2.5% (Euro IV), 12.5% (Euro V)	5% (Euro IV), 25% (Euro V)	diesel
CO_2	0%	0%	diesel
NOx	3.5% (Euro IV), 17.5% (Euro V)	7% (Euro IV), 35% (Euro V)	diesel
PM 10 & 2.5	4.5% (Euro IV), 22.5% (Euro V)	9%(Euro IV), 45% (Euro V)	diesel

[5] The indicated values are the estimated reduction in emissions for the fleet of light commercial vehicles
[6] The indicated values are the estimated reduction in emissions for the fleet of heavy duty trucks

Table 6: Parameters used for Coper simulations for the retrofit solution[7]

buses (Euro IV & V)	lower scenario (Retrofit applicable to 5% of Euro IV buses, 12.5% of Euro V buses)	Upper scenario (Retrofit applicable to 10% of Euro IV buses, 25% of Euro V buses)	Targeted engine type
CO	2.5% (Euro IV), 6.2% (Euro V)	5% (Euro IV), 12.5% (Euro V)	diesel
CO_2	0%	0%	diesel
NOx	3.5% (Euro IV), 8.7% (Euro V)	7% (Euro IV), 17.5% (Euro V)	diesel
PM 10 & 2.5	4.5% (Euro IV), 11.2% (Euro V)	9%(Euro IV), 22.5% (Euro V)	diesel

3.5.3. MODALES solution 3: App & training

In addition to the engine and its control policies, it is possible to act on driving behaviour by means of instant feedback or appropriate courses. MODALES has developed a dedicated app that incorporates several algorithms specifically developed within the project and used as a basis for immediate feedback. This solution combines two actions: firstly, a short training course that can be followed remotely thanks to a video, and secondly, an app companion that provides simple, immediate feedback and advice after the journey. The combination of these two features is expected to have an impact on different types of emissions.

The experimental protocol of the adopter did not allow the results to be split between these two features. The proposed impact assessment follows the same approach as the previous two solutions: a lower and an upper scenario are designed.

The extrapolation of pollutant emissions is always challenging, as their measurement requires special and expensive tools such as PEMS (Portable Emission Measurements). Only the road tests carried out by VTT (Finland) benefit from such a precise measurement tool. Although very accurate and informative, these tests suffer from a lack of representativeness for the following reasons: Firstly, only 6 drivers drove the instrumented cars, and secondly, the route was always the same, mixing traffic conditions, but certainly not representative of the average conditions of a European driver.

Despite these drawbacks, the results are the only accurate measurements available. They are available in Table 7. It can be assumed that the drivers were in an optimal condition to apply the training course carefully. The laboratory conditions, i.e. driving an instrumented car together with a technician, are known to be a favourable condition for the subjects' compliance with the experimenter's expected wishes. **Based on this knowledge, the VTT results are used as parameters for the upper scenario.**

[7] The indicated values are the estimated reduction in emissions for the fleet of buses

Table 7: Summary of the observed reduction of emissions for the tests performed by VTT

CO_2 [%]	Helsinki 1	Helsinki 2	Helsinki 3	Helsinki 6	Helsinki 16	Helsinki 26	Helsinki 27	%
Petrol	-5 %		-2 %		2 %	2 %	-8 %	-2 %
Diesel	-10 %	-9 %		-8 %		-3 %	-6 %	-7 %
Avg	-8 %	-9 %	-2 %	-8 %	2 %	-1 %	-7 %	-5 %

CO [%]	Helsinki 1	Helsinki 2	Helsinki 3	Helsinki 6	Helsinki 16	Helsinki 26	Helsinki 27	
Petrol	31 %		206 %		-68 %	41 %	-33 %	-25 %
Diesel	-100 %	-100 %		109 %		-100 %	-100 %	-99 %
Avg	-34 %	-100 %	206 %	109 %	-68 %	-29 %	-66 %	-62 %

NOx [%]	Helsinki 1	Helsinki 2	Helsinki 3	Helsinki 6	Helsinki 16	Helsinki 26	Helsinki 27	
Petrol	17 %		-18 %		10 %	15 %	-15 %	1 %
Diesel	-58 %	11 %		-31 %		-51 %	-70 %	-47 %
Avg	-20 %	11 %	-18 %	-31 %	10 %	-18 %	-43 %	-23 %

PN [%]	Helsinki 1	Helsinki 2	Helsinki 3	Helsinki 6	Helsinki 16	Helsinki 26	Helsinki 27	
Petrol	-18 %		-36 %		-46 %	-35 %	-54 %	-41 %
Diesel	-3 %	0 %		-9 %		2 %	3 %	-2 %
Avg	-10 %	0 %	-36 %	-9 %	-46 %	-17 %	-26 %	-22 %

Based on VTT results for petrol cars, Okan University developed a machine learning algorithm to produce a global driving score reflecting the emission level for various pollutants. Relations with Scores and Aggregate emission has been derived using VTT test on a Ford Fiesta Gasoline engine vehicle. This algorithm has been described in [22] in details, and the main findings useful for the impact assessment are recalled in the following figures. The results are in the form of linear relationships between the score and the aggregate emissions (a weighted combination of NOx, PMs and Carbons emissions, see Figure 14), the fuel consumption (Figure 15), and the PMs respectively (Figure 16).

These equations can be used to estimate the emissions from the road trials as the score is computed for every second of driving data. The observed reduction in scores before and after using the MODALES App gives us estimates of the emissions reduction by applying the Okan University formulas. Aggregate emissions reduction is used to estimate the reduction CO, while the dedicated formulas from Figure 15 and Figure 16 are used to estimate reductions in CO_2 and PMs respectively.

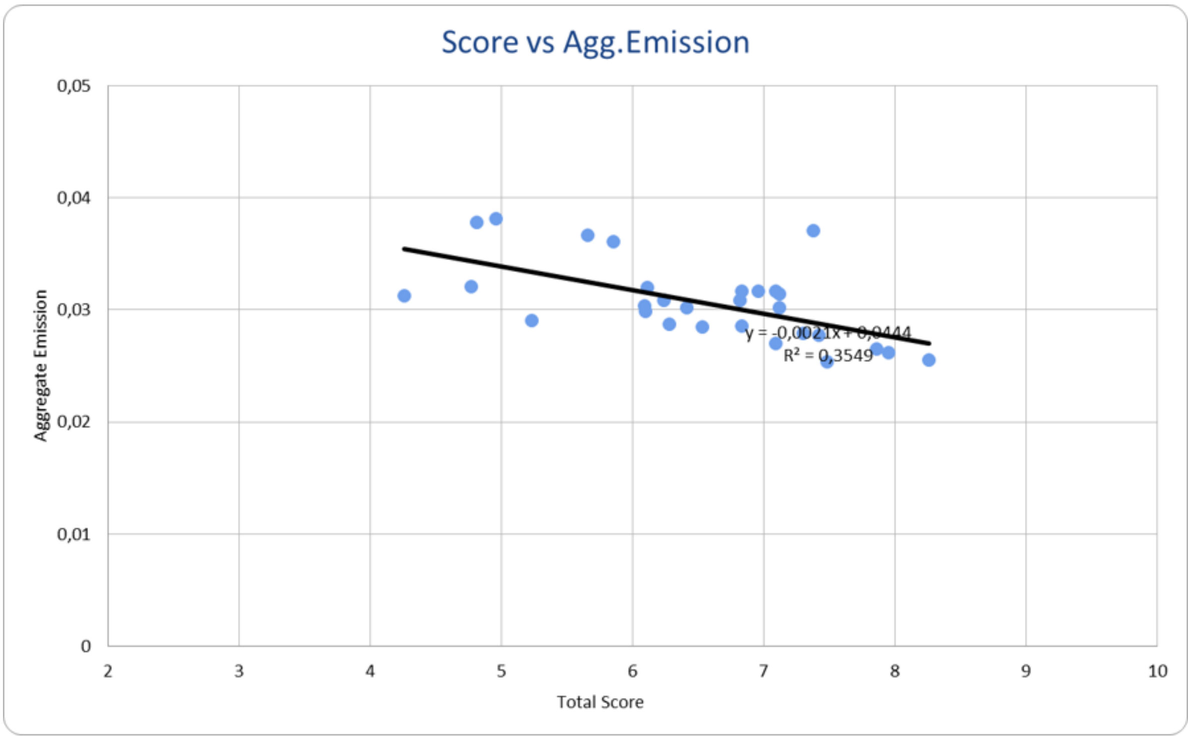


Figure 14: Okan University model, linking score with aggregate emissions

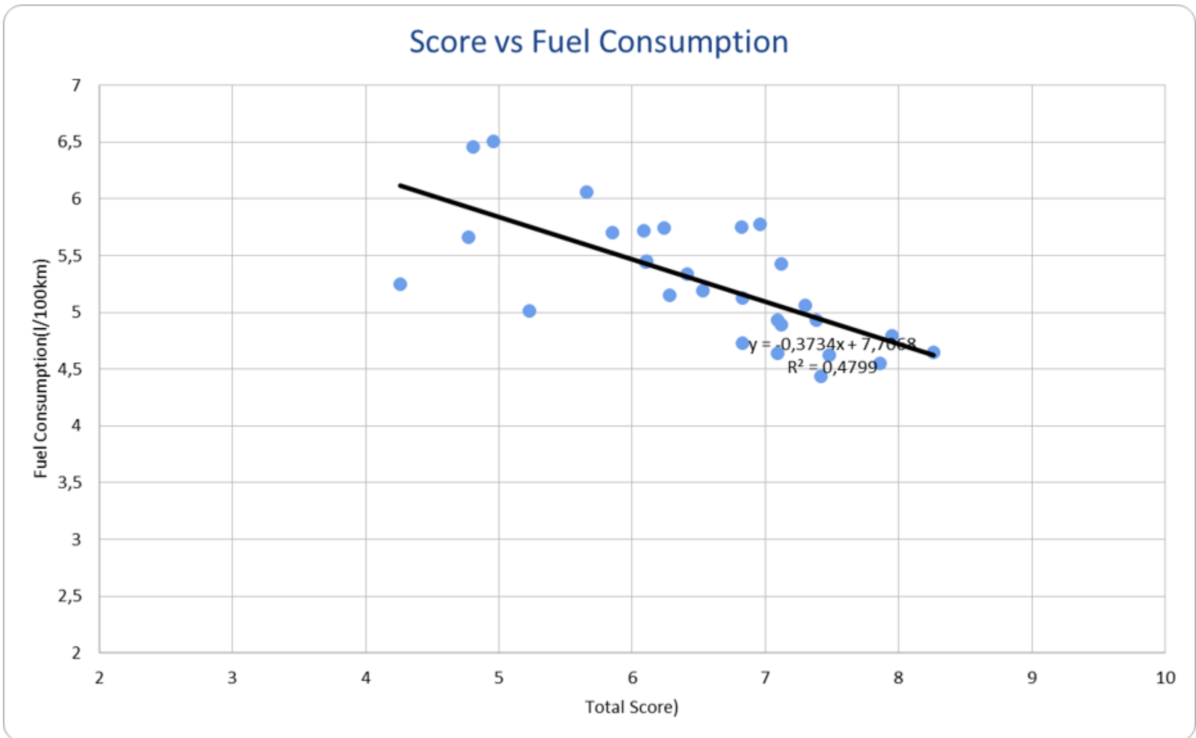


Figure 15: Okan University model, linking score with fuel consumption[8]

[8] Fuel consumption proportional to CO_2 emissions

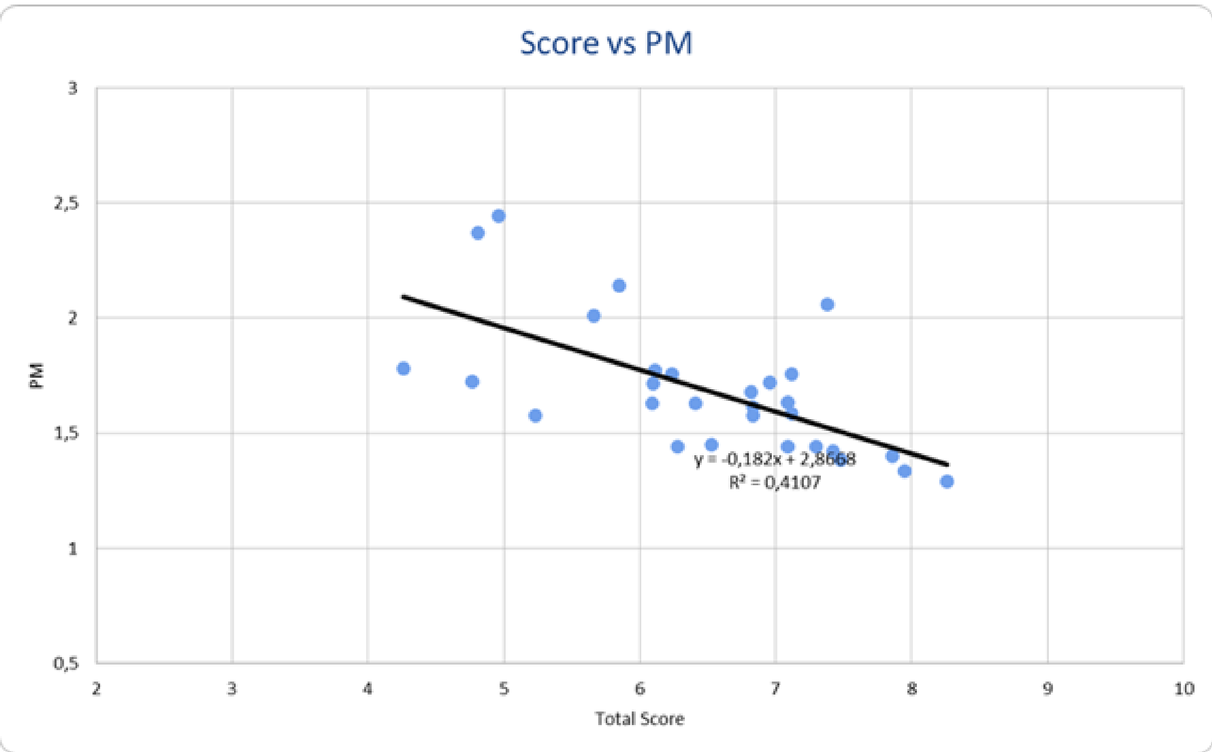


Figure 16: Okan University model, linking score with PM emissions

It must be noted that this model does not take NOx emissions into account as it has been fitted only on petrol cars' data. Therefore, it is needed to use trial test results to estimate NOx emissions changes (Figure 18). These results have been used as inputs for COPERT simulations for the following countries: Finland (Helsinki results), Spain (Barcelona results), Turkey (Istanbul results) and Italy (Bergamo results). One can note that Istanbul results are negative, which is contradictory with the trial tests from VTT which did not stated any increasing NOx emissions, even for petrol cars. The presence of a high prevalence of petrol cars in the Istanbul vehicles trial fleet may explain this increase in NOx emissions, reductions being mostly associated with diesel vehicles**. Instead of an emission increase for NOx for Turkey, it has been decided to use a null value for the lower scenario, stating that no reduction in NOx is expected for this country, even for diesel vehicles.**

For CO, CO_2, and PM emissions, the observed reduction in scores for every test sites (see Figure 17) are used as inputs for the Okan University equations. **The obtained values are used as COPERT inputs for the lower scenarios for the corresponding country where the test trials took place.**

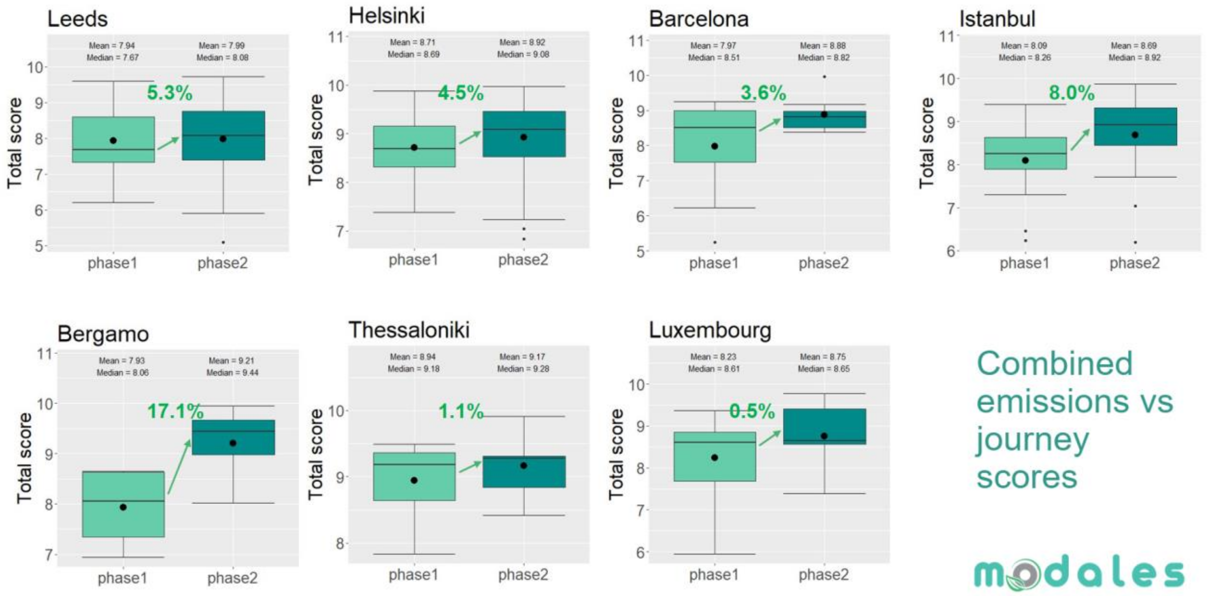


Figure 17: Observed changes in scores for the various test sites of MODALES

Results for NOx reductions (diesel vehicles):

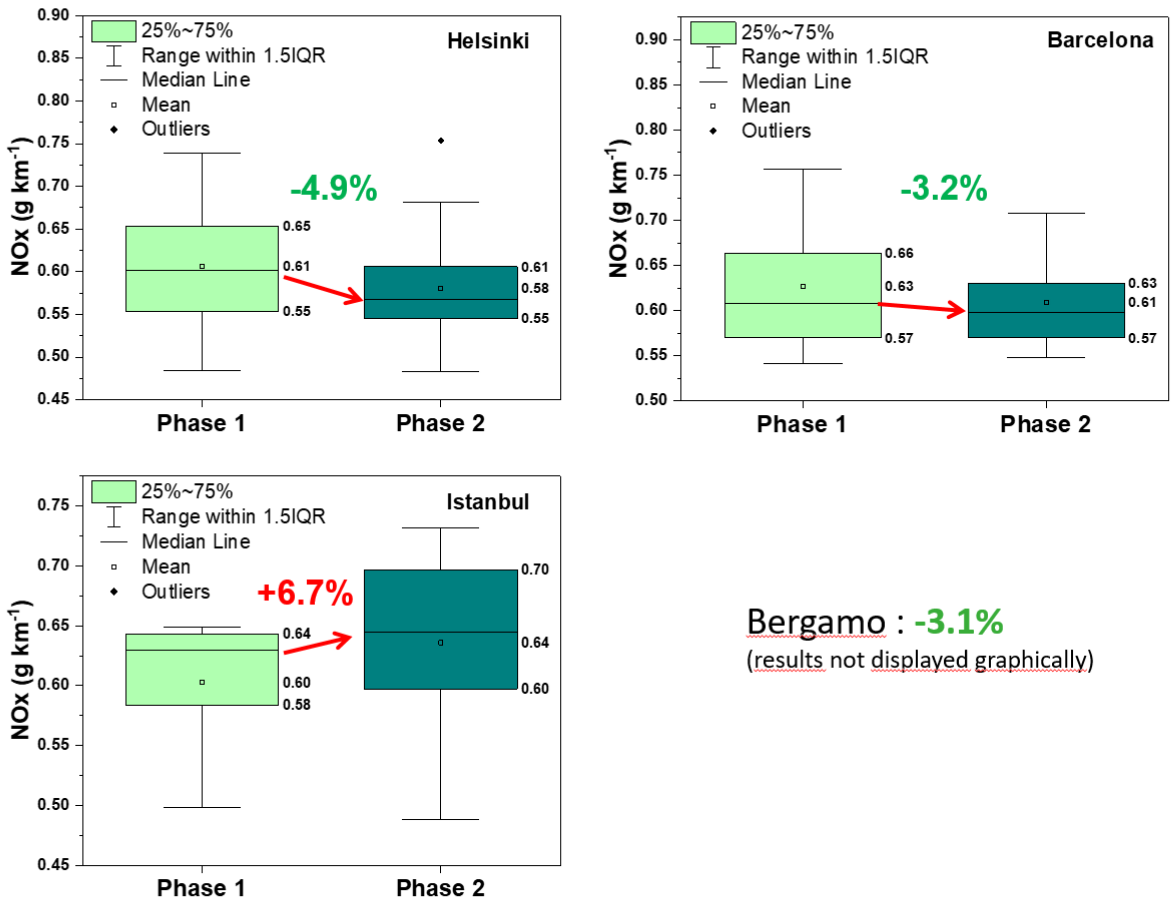


Figure 18: Observed reductions in NOx for four MODALES test sites

The following tables are summarising the parameters used to evaluate the MODALES solutions impact through the "vehicle performance improvement" window.

Finland

Table 8: Parameters used for COPERT simulations for the App & training solution (Finland)

Passenger cars	**lower scenario (Helsinki trial data)**	**upper scenario (VTT experiment)**	**target**
CO	3.1%	62%	Petrol & diesel
CO_2	3.3%	5%	Petrol & diesel
NOx	4.9%	47%	diesel
PM 10 & 2.5	5.5%	22%	Petrol

Spain

Table 9: Parameters used for COPERT simulations for the App & training solution (Spain)

Passenger cars	**lower scenario (Barcelona trial data)**	**upper scenario (VTT experiment)**	**target**
CO	2.5%	62%	Petrol & diesel
CO_2	2.6%	5%	Petrol & diesel
NOx	3.2%	47%	diesel
PM 10 & 2.5	4.3%	22%	Petrol

Italy

Table 10: Parameters used for COPERT simulations for the App & training solution (Italy)

Passenger cars	**lower scenario (Bergamo trial data)**	**upper scenario (VTT experiment)**	**target**
CO	10.5%	62%	Petrol & diesel
CO_2	11%	5%	Petrol & diesel
NOx	3.1%	47%	diesel
PM 10 & 2.5	17.9%	22%	Petrol

Turkey

Table 11: Parameters used for COPERT simulations for the App & training solution (Turkey)

Passenger cars	**lower scenario (Istambul trial data)**	**upper scenario (VTT experiment)**	**target**
CO	5.1%	62%	Petrol & diesel
CO_2	5.3%	5%	Petrol & diesel
NOx	0	47%	diesel
PM 10 & 2.5	8.8%	22%	Petrol

For Turkey, results from the trial tests are greater than the VTT results for the CO_2 emissions reduction.

China (Nanjing)

The Nanjing test site was devoted to study the impact of MODALES training on buses driving behaviour. For safety reasons, it was not possible for them to use the MODALES App while driving. The obtained results reflect only the change due to the training. It was not possible to derive a lower scenario for the buses case. Instead, 0% emissions reduction are used as inputs, which equivalent to not having the MODALES solution onboard. The observed reduction for the buses in Nanjing has been used for the upper scenario of all the 6 countries considered.

Table 12: Parameters used for COPERT simulations for the training solution and for the buses fleet (all countries)

Diesel buses	**lower scenario**	**upper scenario (Nanjing trial data)**	**target**
CO_2	0%	7.1%	Diesel trucks
NOx	0%	2.5%	Diesel trucks

France & Germany

These two countries were not covered by the trials within the MODALES project. The corresponding lower scenario is then considered to be the average of the other four countries (Finland, Spain, Italy, Turkey).

Passenger cars	**lower scenario (Istambul trial data)**	**upper scenario (VTT experiment)**	**target**
CO	5.4%	62%	Petrol & diesel
CO_2	5.6%	5%	Petrol & diesel
NOx	4.1%	47%	diesel
PM 10 & 2.5	9.3%	22%	Petrol

4. Estimating European countries vehicle's stock

Using COPERT requires several kinds of inputs already described in the previous section. Among those inputs, the main requirement is the description of the national vehicles stock, segregated by engine type (Petrol, diesel, hybrid or electric) and by European standards (Table 13). Such information can be extrapolated at the European level for a fixed year, see for example [23], but it is a more complex task to get it for every European country.

As stated by [24], only four countries (Germany, Spain, Finland and Italy) report on the combination of age class and engine type. As Euro standards are derived from the age of the vehicles, it is a challenge to obtain the needed data from any known source. Moreover, as the impact assessment needs to extrapolate the stock into the future, it is not only necessary to know the stock by engine type and euro standards, but also to know it over the past years, and in the future. Indeed, the evolution of the stock profile, segregated by Euro standard and ZEV uptake, plays a critical role in the emission reduction potential and associated health benefits [25].

After a careful analysis of the available data, authors had to face the evidence that such data is not available publicly anywhere, and that a dedicated model had to be developed.

A literature review reveals that complex models have been developed in specific cases ([26], [27]), but they are used to study long term impacts (2040-2050) of planned policies on the share of driving technologies. The MODALES solutions can be seen as transition solutions, temporarily effective until the target of a market dominated by electric vehicles is reached. Is it therefore not relevant to use such models as our target is the year 2025. Moreover, such models are developed for the national or regional level and cannot be extrapolated to other countries.

A simpler and generalisable methodology has been settled-up to tackle this issue starting from harmonised and quality checked data from the Eurostat website.

The sections below are describing in detail the proposed approach to estimate the evolution of the stock based upon the available data from Eurostat website.

4.1. Overview of the available data

Several European countries are maintaining national statistics about the stock evolution, but various drawbacks are associated with such initiatives: firstly, the data may not be accessible easily for researchers from another country, and secondly, the data may not use the reference categories as the European standards. For example, in France, such data exists but it mixes the engine type with the "Critair" segmentation (national categorisation of vehicles emissions) instead of the Euro standards, and it is not straightforward to set up the link between the two.

Several other European countries are not providing any data, and Eurostat data is likely to be the most exhaustive resource available that time. Even within Eurostat data, several parts are missing or have not been transmitted by some countries. Due to this reason, it was not possible to compute the impact of MODALES solutions to all the relevant countries in which the trial test took place.

The following countries have been considered: Finland, Spain, Italy, Turkey, France, Germany.

Luxembourg, Greece, and Great Britain have too much missing data to reconstruct the stock across the years. France and Germany have been added to the list despite the absence of test trials in these countries, but because their stock of vehicles are the biggest in Europe.

The following files from Eurostat data [28] are used as inputs to our model:

Registration data:

- Passenger cars: road_eqr_carpda
- Light commercial and heavy duty trucks: road_eqr_lormot
- Buses: road_eqr_busmot

Stock data:

- Passenger cars: road_eqs_carpda
- Light commercial and heavy duty trucks: road_eqs_lormot
- Buses: road_eqs_busmot

4.2. Vehicle stock estimation

The main idea underlying the reconstruction procedure is simple:

For each year N, the vehicle stock at the end of the year is equal to the stock at the end of year N-1, plus the newly registered vehicles at year N, minus the vehicles out of the stock. This relationship can be expressed using the following equation:

Stock(N)= stock(N-1) + registrations(N-1) – out_of_stock(N)

Historical stock data is available from Eurostat, but we would like to rebuild it until 2021 (last year of Eurostat data) step by step in order to:

1. Allocate the newly registered vehicles to the corresponding Euro standard.
    a. This is done using official Euro standard date of first registration given in Table 13.
    b. For light commercial & trucks before 2013, the following convention is adopted: 75% of vehicles are attributed to Euro IV (4), and 25% to Euro V(5). Indeed, Euro V standard started in 2008, far beyond the oldest available data from Eurostat (2013).
2. Suppress the vehicles out of the stock from the correct Euro standard.
    a. The adopted convention is that when X vehicles are out of the stock, they are subtracted first from the oldest category still in circulation, and then the following when it is empty.

Also, we would like to be able to estimate the stock for the future until year 2025.

In order to reach our goals, it is necessary to estimate the number of vehicles out of the stock every year, and estimate it for the future years. The vehicles out of the stock at year N can be estimated using the historical data, using the following equation:

Out_of_stock (N) = stock(N-1) + registrations(N-1) - stock (N)

Given the values of out_of_stock, stock & registrations are available for each year, it is straightforward to estimate the stock share of Euro standards by performing the previous steps 1 and 2.

To extrapolate the stock share across Euro standards in the future, it is needed to estimate the stock, the registrations, and the vehicles out of stock for the needed years. This is done using a simple linear model fitted over the years 2018, 2019, 2020 and 2021. Extrapolation of the trend over the years 2022, 2023, 2024, 2025 provide us with adequate average estimates.

Table 13: Euro standards dates of first registration according to vehicle types[9]

European emission standards for passenger cars (Category M),[a] g/km		European emission standards for light commercial vehicles ≤ 1,305 kg reference mass (Category N1 Class I), g/km		European emission standards for light commercial vehicles 1,305–1,760 kg reference mass (Category N1 Class II), g/km		European emission standards for light commercial vehicles > 1,760 kg reference mass max 3,500 kg. (Category N1 Class III & N2), g/km		European emission standards for heavy-duty diesel engines, g/kWh	
Tier	**Date (first registration)**	**Tier**	**Date (first registration)**	**Tier**	**Date (first registration)**	**Tier**	**Date (first registration)**	**Tier**	**Date**
Diesel		**Diesel**		**Diesel**		**Diesel**		**Diesel**	
Euro 1[c]	January 1993	Euro 1	October 1994	Euro 1	October 1994	Euro 1	October 1994	Euro I	1992, < 85 kW
Euro 2	January 1997	Euro 2	October 1997	Euro 2	October 1998	Euro 2	October 1999		1992, > 85 kW
Euro 3	January 2001	Euro 3	January 2001	Euro 3	January 2002	Euro 3	January 2002	Euro II	October 1995
Euro 4	January 2006	Euro 4	January 2006	Euro 4	January 2007	Euro 4	January 2007		October 1997
Euro 5a	January 2011	Euro 5a	January 2011	Euro 5a	January 2012	Euro 5a	January 2012	Euro III	October 1999 EEVs[e] only
Euro 5b	January 2013	Euro 5b	January 2013	Euro 5b	January 2013	Euro 5b	January 2013		October 2000
Euro 6b	September 2015	Euro 6b	September 2015	Euro 6b	September 2016	Euro 6b	September 2016	Euro IV	October 2005
Euro 6c	September 2018	Euro 6c	September 2018	Euro 6c	September 2019	Euro 6c	September 2019	Euro V	October 2008
Euro 6d-Temp	September 2019	Euro 6d-Temp	September 2019	Euro 6d-Temp	September 2020	Euro 6d-Temp	September 2020	Euro VI	31 December 2012[24]
Euro 6d	January 2021	Euro 6d	January 2021	Euro 6d	January 2022	Euro 6d	January 2022		
Petrol		**Petrol**		**Petrol**		**Petrol**			
Euro 1[c]	January 1993	Euro 1	October 1994	Euro 1	October 1994	Euro 1	October 1994		
Euro 2	January 1997	Euro 2	October 1997	Euro 2	October 1998	Euro 2	October 1999		
Euro 3	January 2001	Euro 3	January 2001	Euro 3	January 2002	Euro 3	January 2002		
Euro 4	January 2006	Euro 4	January 2006	Euro 4	January 2007	Euro 4	January 2007		
Euro 5a	January 2011	Euro 5a	January 2011	Euro 5a	January 2012	Euro 5a	January 2012		
Euro 5b	January 2013	Euro 5b	January 2013	Euro 5b	January 2013	Euro 5b	January 2013		
Euro 6b	September 2015	Euro 6b	September 2015	Euro 6b	September 2016	Euro 6b	September 2016		

[9] source: Wikipedia. Values used as parameters for the stock reconstruction algorithm are indicated in pale green

Euro 6c	September 2018	Euro 6c	September 2018	Euro 6c	September 2019	Euro 6c	September 2019
Euro 6d-Temp	September 2019	Euro 6d-Temp	September 2019	Euro 6d-Temp	September 2020	Euro 6d-Temp	September 2020
Euro 6d	January 2021	Euro 6d	January 2021	Euro 6d	January 2022	Euro 6d	January 2021

As a summary, numerous steps are needed to transform Eurostat raw data into suitable inputs for the reconstruction algorithm. The following steps have been performed:

1. Import Stock data (from 2010-2021 for passenger cars, 2013-2021 for light commercial and heavy duty) and registration data (2013-2021)
2. Exclude countries with more than 4 missing years data.
3. Extrapolate the missing values for the remaining countries, using a linear model estimated for the years 2013-2025 (all range of available data).
4. For passenger cars only:
    a. Extrapolate the registrations in the past (years 2010, 2011, 2012) in order to reconstruct the stock starting from 2011 which is the first year of Euro5 standard adoption.
    b. This is done using a linear model estimated for the years 2013-2019 (2020 & 2021 are excluded due to the covid effect).
5. For all the vehicle types:
    a. Extrapolation of the stock & the registrations for the years 2022, 2023, 2024 & 2025.
    b. This is done using a linear model fitted over the years 2018, 2019, 2020 and 2021.

All the previous steps being performed, stock and registrations are available for every years ranging from 2013 to 2025 (from 2011 to 2025 for passenger cars). The obtained values for both stock and regi

The algorithm is initialised at year 2011 for passenger cars and from 2013 for light commercial, heavy-duty vehicles and buses.

For passenger cars, all vehicles in the stock are considered to be Euro 4 standards. Indeed, it is not possible to estimate the amount of Euro 2 or 3 vehicles as historical data beyond 2011 are not available. Therefore, when we refer to Euro 4 standard, it is meant Euro 4 or less.

4.3. Aggregate results for the stock estimation

Detailed results per country are presented in the next section, together with the COPERT results. Global results aggregated per category of vehicles and energy type are presented in Figure 19 for the registration data, and in Figure 20 for the car retirement flow, denoted “out of the stock” in this deliverable.

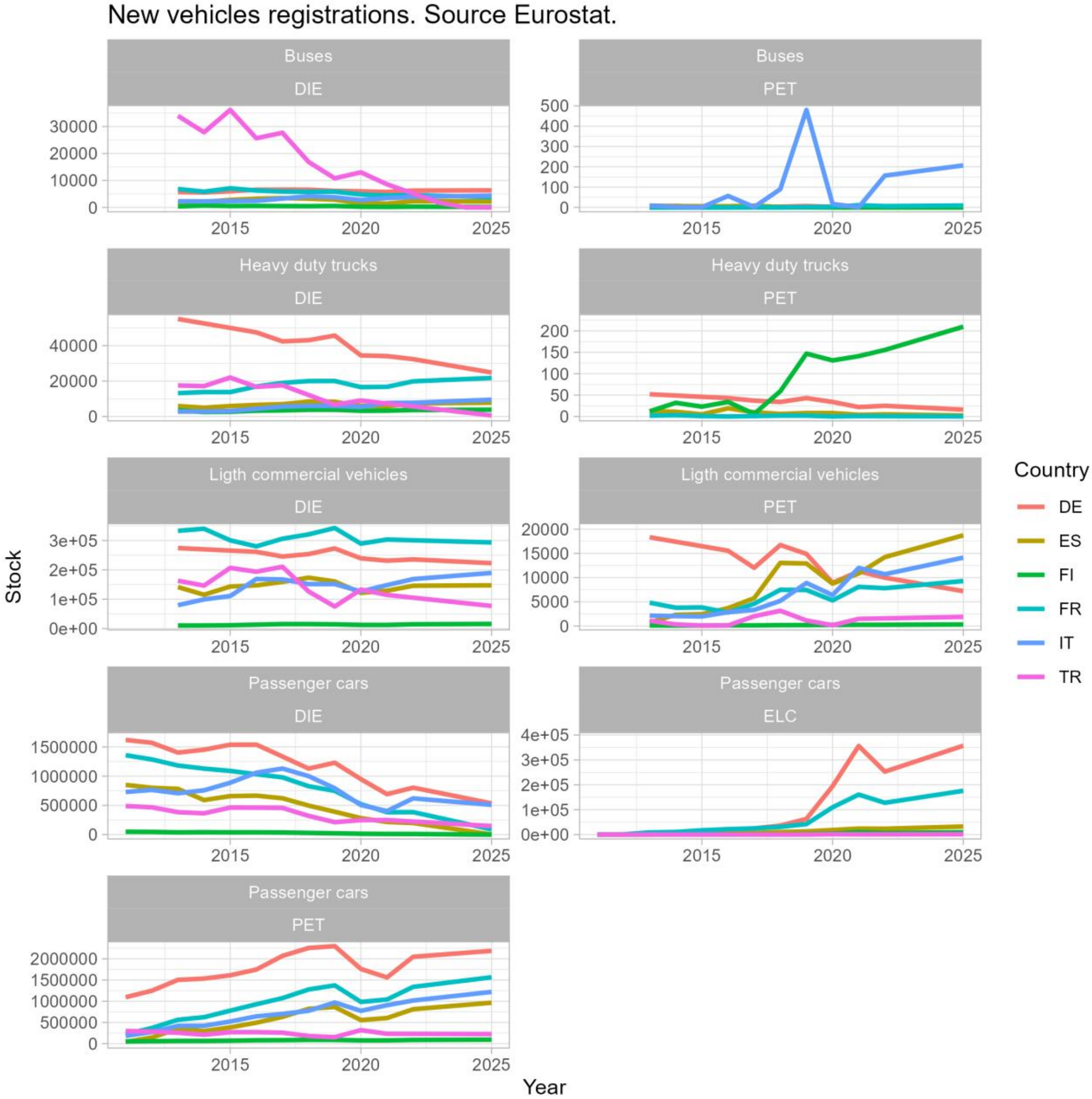


Figure 19: Vehicles registrations for the 6 considered countries[10]

[10] Years before 2013 for the passenger cars, and years from 2022 for all vehicles are estimated using linear models

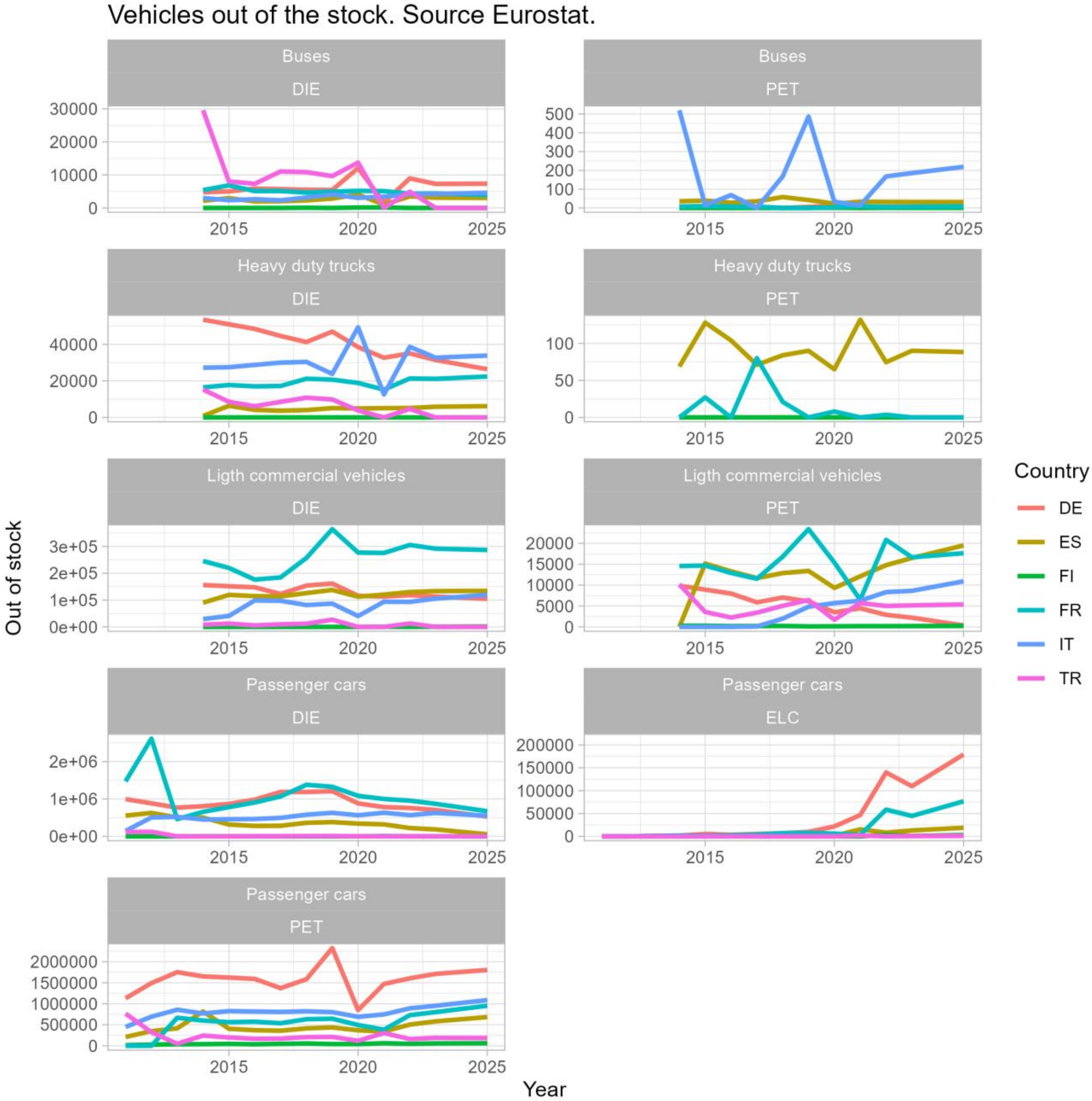


Figure 20: Vehicles out of the stock for the 6 considered countries[11]

[11] Years before 2013 for the passenger cars, and years from 2022 for all vehicles are estimated using linear models

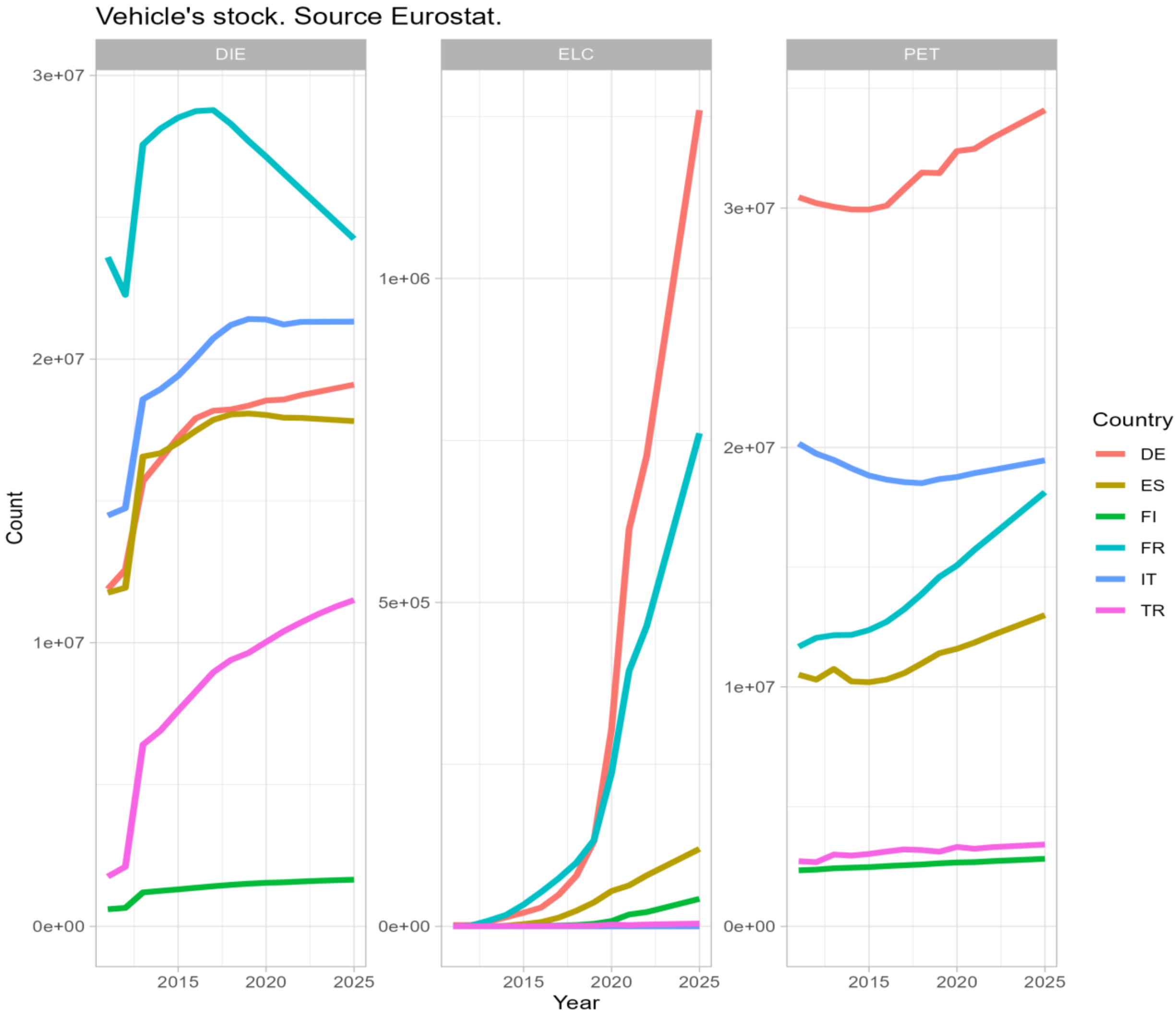


Figure 21: Vehicle's stock according to energy type for the selected countries

Registration data reflects interesting trends: diesel passenger cars are constantly decreasing for all countries, while petrol ones are still increasing. Electric passenger cars show an increasing trend for Germany and France, while their number is still low for the other countries. The differences in trend across countries reflect different policies. As an example, petrol light commercial vehicles are decreasing in Germany, while their number still increase for all the other countries.

When aggregated, it is clear that diesel vehicles stock is stable, except for France which as recent policy reducing the incentives to by such vehicles. Electric vehicles stock is increasing for all countries, but the trends are much greater for Germany and France. Petrol vehicles stock is stable, with small increases for Germany and France.

modales

5. Results of the stock estimation and the COPERT results per country

This chapter provides the results obtained for both the vehicle stock share estimation across Euro standards and the COPERT simulations before & after the MODALES solution. Apart from the inputs parameters derived from MODALES trails, the stock share across Euro standards plays a significant roles in national level emissions estimation. Various situations exist across European countries, and MODALES solutions impact is likely to be different.

For each country, the results are provided using two graphs and one table. The first graph presents the European standard share evolution from 2010 to 2025. The second graph presents the results of COPERT simulations for year 2025, together with a table containing the same results in a numerical form.

Firstly, detailed results per country are presented, then a global analysis is performed at the final section of this chapter.

5.1. Results per country

5.1.1. Finland

Finland stock of vehicles is characterised by a domination of old Euro 4 vehicles (57% in 2025, see Figure 22), with low penetration rates of most recent Euro standards.

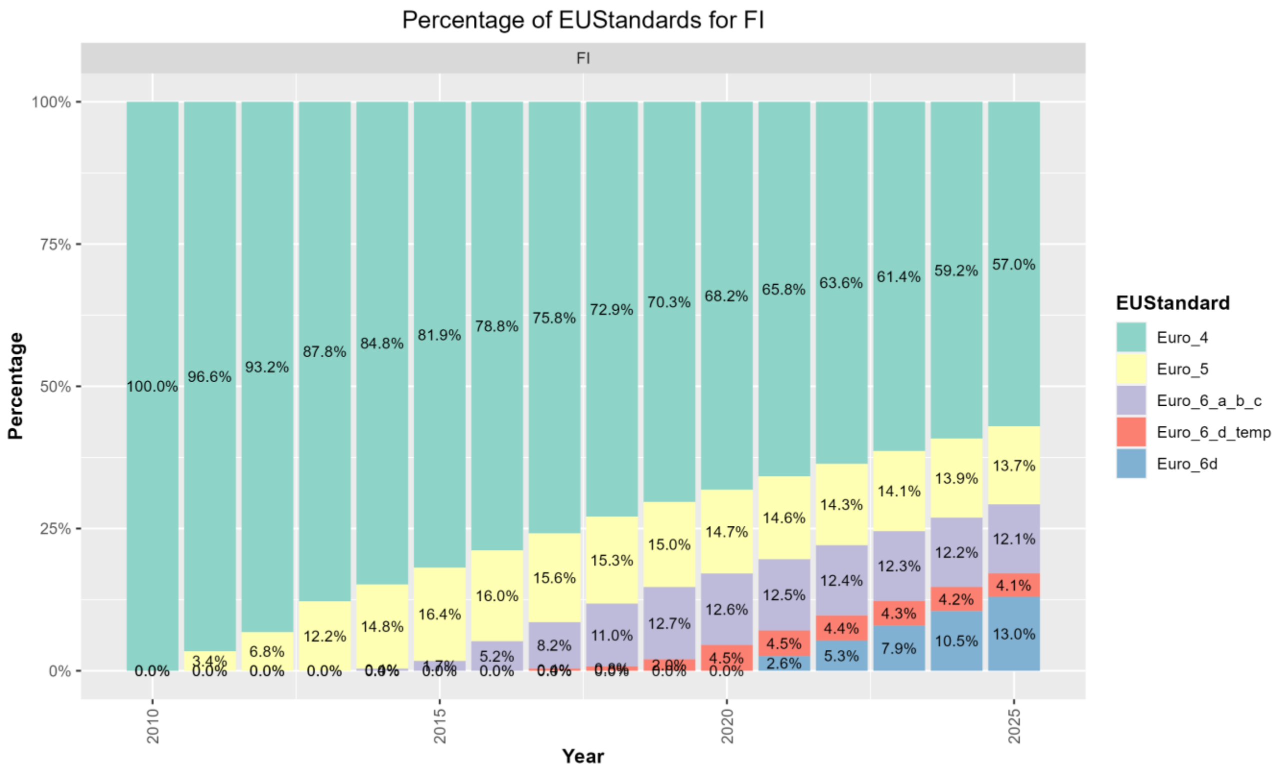


Figure 22: Evolution of the stock, segregated by Euro standards, from 2010-2025 for Finland

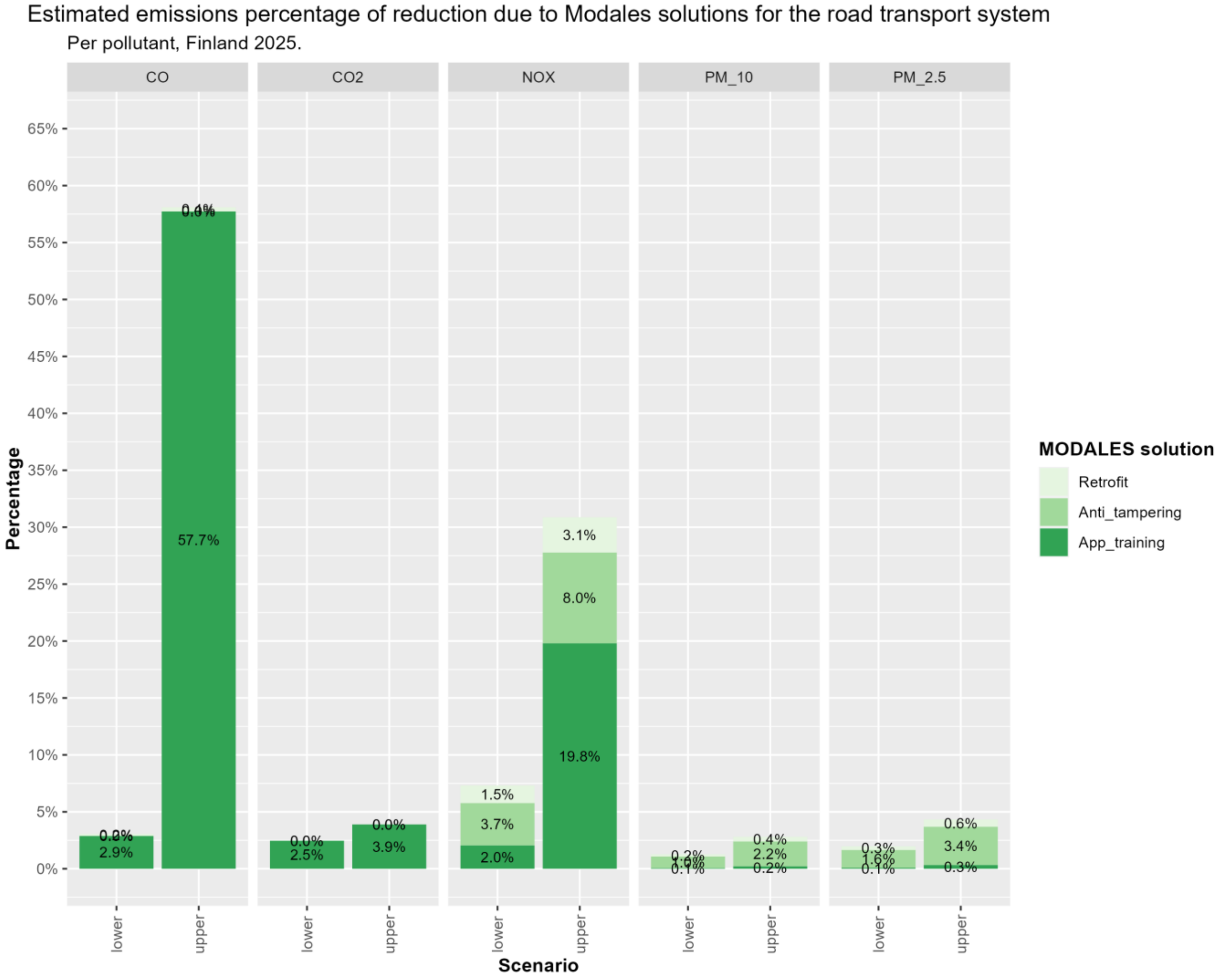


Figure 23: Estimated reduction of pollutants for year 2025 according to the scenario and the MODALES solutions, for Finland

Results of the COPERT simulations are presented graphically (Figure 23) and numerically (Table 14). Results are dominated by the upper scenario of the App & training effect, which, according to the VTT results, can have deep impact on CO and NOx emissions reduction.

For Finland, CO emissions could be reduced from 3.1% to 58.1%, mostly from the App & training effect. CO_2 emissions reduction ranges from 2.5% to 3.9%, also due to the App & training. For the other pollutants, benefits are expected from all the three MODALES solutions. PMs emissions reduction is mostly obtained from anti tampering measures, ranging from 1.3% (PM10-lower) to 4.3% (PM2.5-upper). Finally, NOx emissions are greatly reduced, from 7.2% (lower) up to 30.9% (upper).

Table 14: Detailed results obtained using COPERT software for Finland (2025), according to the MODALES solutions, pollutants, and scenario[12]

Country	Solution	Pollutant	Scenario	Emissions_Total	Emissions_Baseline	Savings	Perc.reduction
Finland	Anti_tampering	CO	lower	35979	35979	0	0,0
Finland	Anti_tampering	CO	upper	35979	35979	0	0,0
Finland	Anti_tampering	CO_2	lower	10913519	10913519	0	0,0
Finland	Anti_tampering	CO_2	upper	10913519	10913519	0	0,0
Finland	Anti_tampering	NOx	lower	18213	18917	704	3,7
Finland	Anti_tampering	NOx	upper	17408	18917	1509	8,0
Finland	Anti_tampering	PM_{10}	lower	2015	2036	21	1,0
Finland	Anti_tampering	PM_{10}	upper	1992	2036	44	2,2
Finland	Anti_tampering	$PM_{2.5}$	lower	1303	1323	20	1,5
Finland	Anti_tampering	$PM_{2.5}$	upper	1279	1323	44	3,3
Finland	App_training	CO	lower	34940	35979	1039	2,9
Finland	App_training	CO	upper	15207	35979	20772	57,7
Finland	App_training	CO_2	lower	10644769	10913519	268750	2,5
Finland	App_training	CO_2	upper	10488560	10913519	424959	3,9
Finland	App_training	NOx	lower	18530	18917	387	2,0
Finland	App_training	NOx	upper	15172	18917	3745	19,8
Finland	App_training	PM_{10}	lower	2035	2036	1	0,0
Finland	App_training	PM_{10}	upper	2032	2036	4	0,2
Finland	App_training	$PM_{2.5}$	lower	1322	1323	1	0,1
Finland	App_training	$PM_{2.5}$	upper	1319	1323	4	0,3
Finland	Retrofit	CO	lower	35914	35979	65	0,2
Finland	Retrofit	CO	upper	35849	35979	130	0,4
Finland	Retrofit	CO_2	lower	10913519	10913519	0	0,0
Finland	Retrofit	CO_2	upper	10913519	10913519	0	0,0
Finland	Retrofit	NOx	lower	18625	18917	292	1,5
Finland	Retrofit	NOx	upper	18333	18917	584	3,1
Finland	Retrofit	PM_{10}	lower	2032	2036	4	0,2
Finland	Retrofit	PM_{10}	upper	2028	2036	8	0,4
Finland	Retrofit	$PM_{2.5}$	lower	1319	1323	4	0,3
Finland	Retrofit	$PM_{2.5}$	upper	1315	1323	8	0,6

[12] Emissions are given in tonnes

5.1.2. Spain

The Spanish Euro standard (Figure 24) share in the year 2025 state that more than 60% of vehicles are Euro 5 or more, with more than 18% of vehicles being of the last Euro 6d standard. It could be considered as an intermediate situation for European countries.

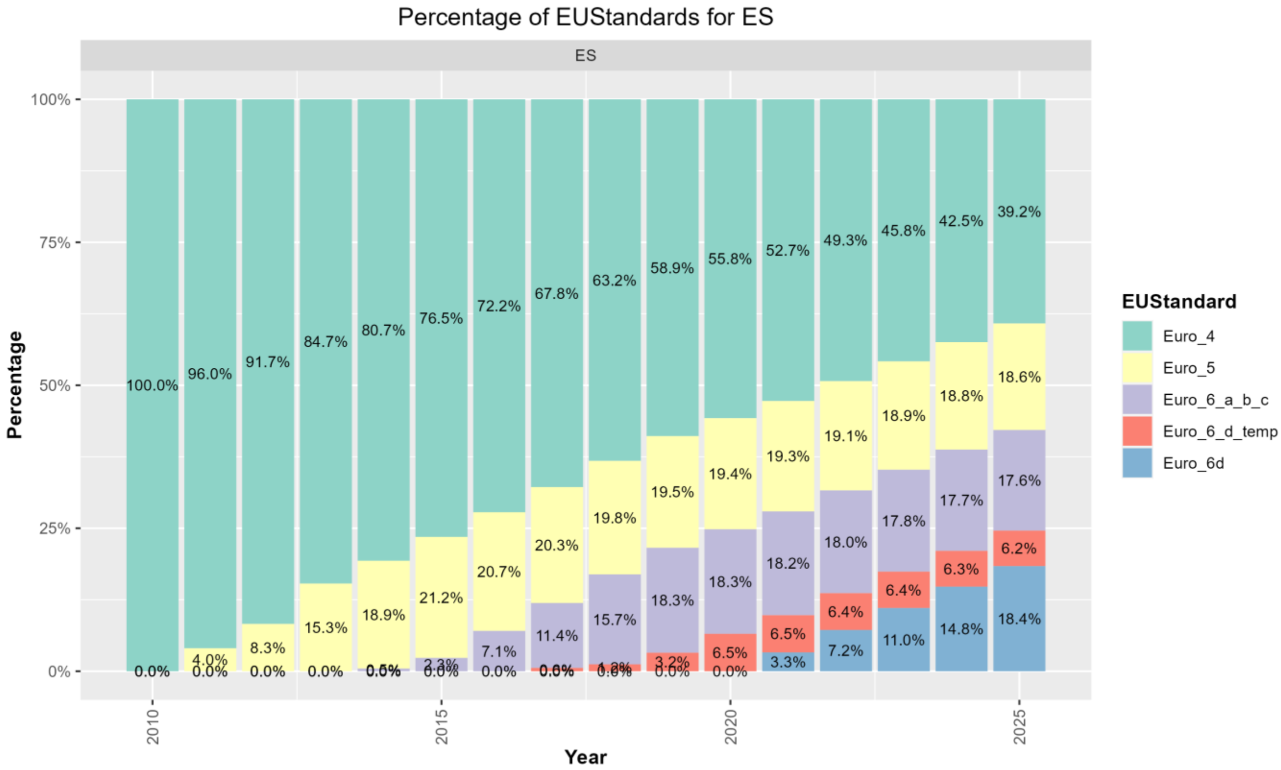


Figure 24: Evolution of the stock, segregated by Euro standards, from 2010-2025 for Spain

Results of the COPERT simulations (Figure 25) present the pattern as for Finland, with less impact for CO, CO_2 and NOx. CO reduction ranges from 2.2% to 44.4% and CO_2 from 1.3% to 2.6%, mostly from App & training impact.

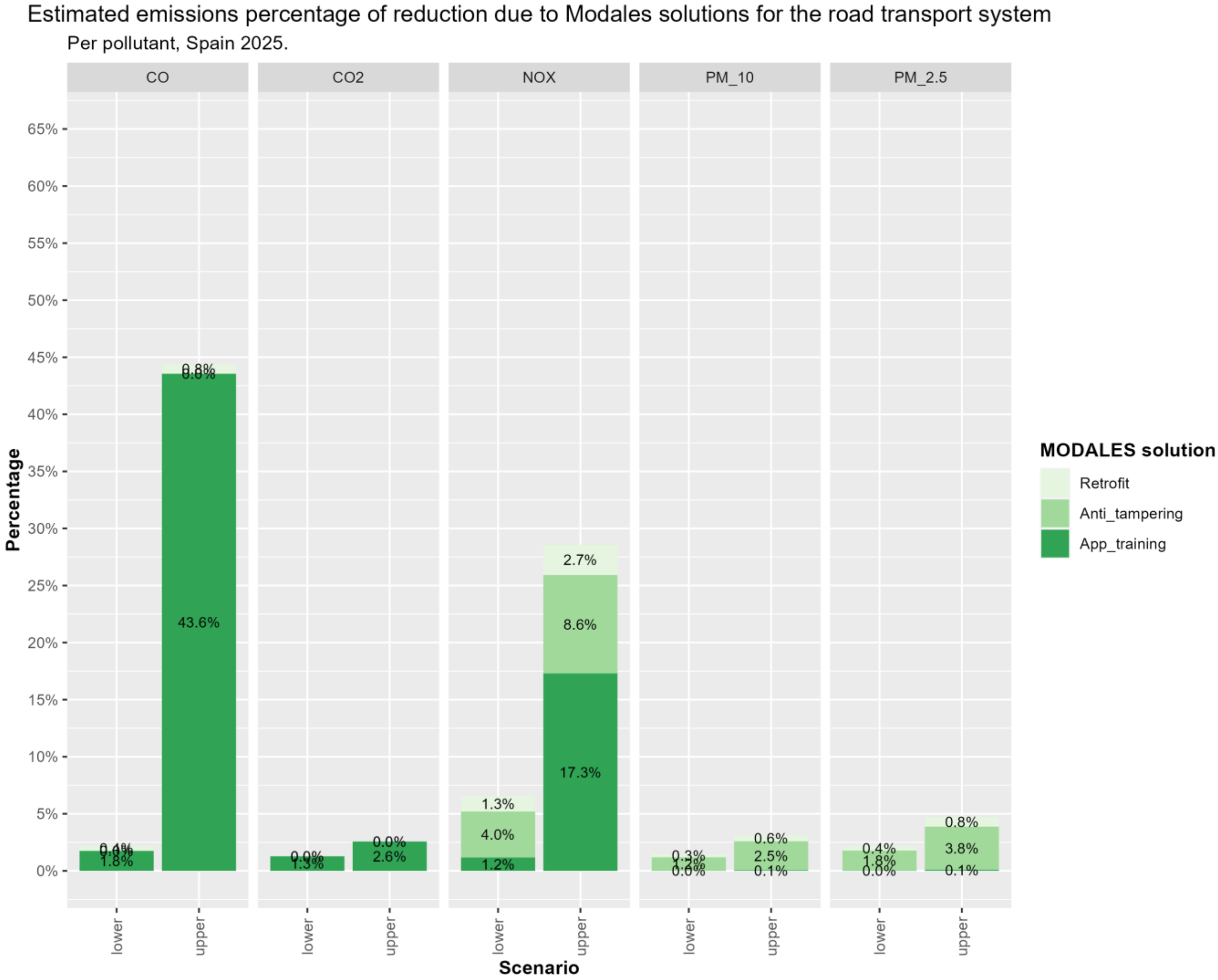


Figure 25: Estimated reduction of pollutants for year 2025 according to the scenario and the MODALES solutions, for Spain

Table 15: Detailed results obtained using COPERT software for Spain (2025), according to the MODALES solutions, pollutants, and scenario[13]

Country	Solution	Pollutant	Scenario	Emissions_Total	Emissions_Baseline	Savings	Perc.reduction
Spain	Anti_tampering	CO	lower	190944	190944	0	0
Spain	Anti_tampering	CO	upper	190944	190944	0	0
Spain	Anti_tampering	CO_2	lower	98515728	98515728	0	0
Spain	Anti_tampering	CO_2	upper	98515728	98515728	0	0
Spain	Anti_tampering	NOx	lower	248902	259334	10432	4
Spain	Anti_tampering	NOx	upper	236981	259334	22353	8,6
Spain	Anti_tampering	PM_{10}	lower	18532	18754	222	1,2
Spain	Anti_tampering	PM_{10}	upper	18278	18754	476	2,5
Spain	Anti_tampering	$PM_{2.5}$	lower	12339	12561	222	1,8
Spain	Anti_tampering	$PM_{2.5}$	upper	12086	12561	475	3,8
Spain	App_training	CO	lower	187590	190944	3354	1,8
Spain	App_training	CO	upper	107773	190944	83171	43,6
Spain	App_training	CO2	lower	97258392	98515728	1257336	1,3
Spain	App_training	CO2	upper	95984352	98515728	2531376	2,6
Spain	App_training	NOx	lower	256291	259334	3043	1,2
Spain	App_training	NOx	upper	214467	259334	44867	17,3
Spain	App_training	PM_{10}	lower	18752	18754	2	0
Spain	App_training	PM_{10}	upper	18742	18754	12	0,1
Spain	App_training	$PM_{2.5}$	lower	12559	12561	2	0
Spain	App_training	$PM_{2.5}$	upper	12550	12561	11	0,1
Spain	Retrofit	CO	lower	190136	190944	808	0,4
Spain	Retrofit	CO	upper	189327	190944	1617	0,8
Spain	Retrofit	CO_2	lower	98515728	98515728	0	0
Spain	Retrofit	CO_2	upper	98515728	98515728	0	0
Spain	Retrofit	NOx	lower	255856	259334	3478	1,3
Spain	Retrofit	NOx	upper	252379	259334	6955	2,7
Spain	Retrofit	PM_{10}	lower	18702	18754	52	0,3
Spain	Retrofit	PM_{10}	upper	18650	18754	104	0,6
Spain	Retrofit	$PM_{2.5}$	lower	12510	12561	51	0,4
Spain	Retrofit	$PM_{2.5}$	upper	12458	12561	103	0,8

[13] Emissions are given in tonnes

5.1.3. Italy

The Italian share of European standards is comparable to Spain, with a greater proportion of Euro 6d standards (22%). The stock is a bit newer than the Spanish one, and much newer than the Finnish one.

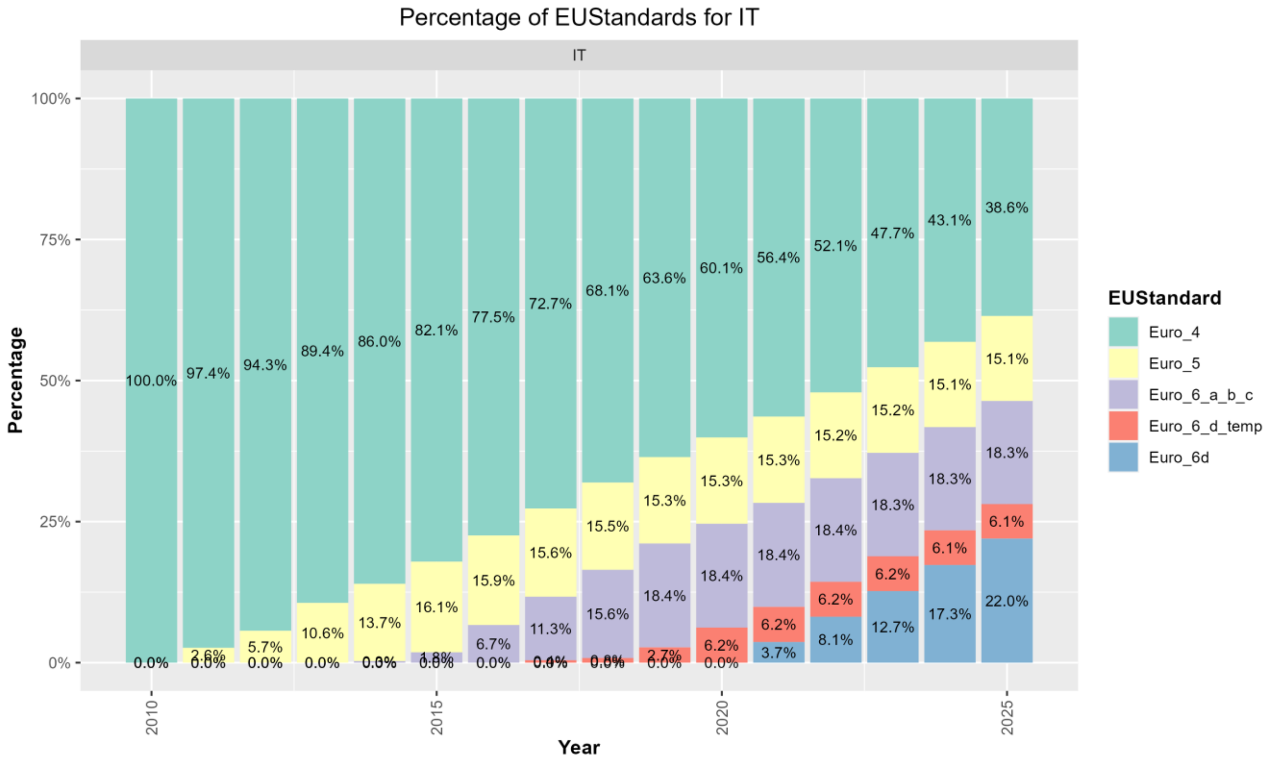


Figure 26: Evolution of the stock, segregated by Euro standards, from 2010-2025 for Italy

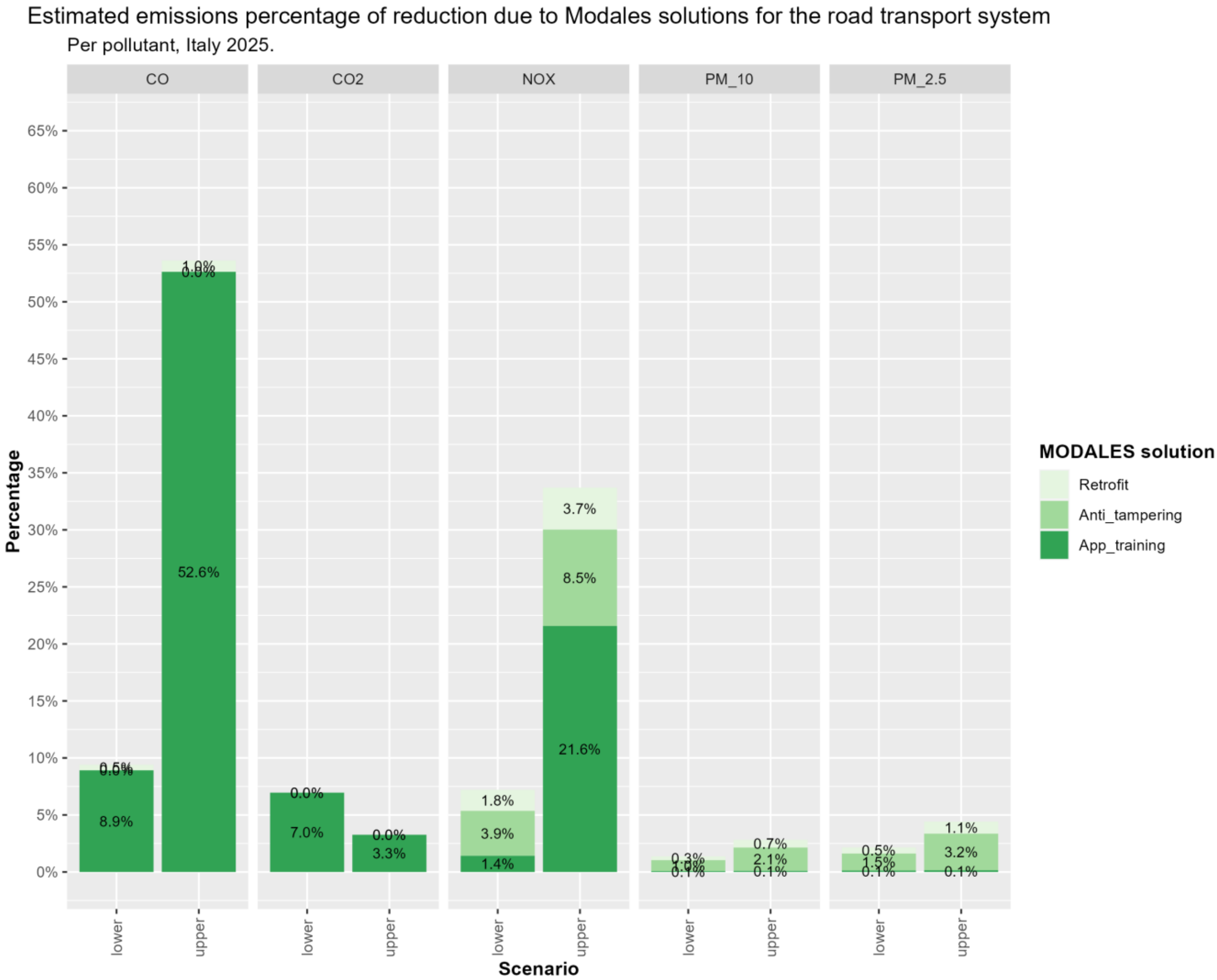


Figure 27: Estimated reduction of pollutants for year 2025 according to the scenario and the MODALES solutions, for Italy

Obtained emissions for CO are greater than Spain, ranging from 9.4% to 53.6%, while CO_2 emissions reduction are ranging from 3.3% to 7%. NOx emissions are obtained from the combination of the three MODALES solutions, from 7.1% for the lower scenario to 33.8% for the upper scenario. PMs emissions are reduced from 1.4% for the lower scenario up to 4.4% for the upper scenario.

Table 16: Detailed results obtained using COPERT software for Italy (2025), according to the MODALES solutions, pollutants, and scenario[14]

Country	Solution	Pollutant	Scenario	Emissions_Total	Emissions_Baseline	Savings	Perc.reduction
Italy	Anti_tampering	CO	lower	201182	201182	0	0
Italy	Anti_tampering	CO	upper	201182	201182	0	0
Italy	Anti_tampering	CO_2	lower	88365895	88365895	0	0
Italy	Anti_tampering	CO_2	upper	88365895	88365895	0	0
Italy	Anti_tampering	NOx	lower	186093	193742	7649	3,9
Italy	Anti_tampering	NOx	upper	177351	193742	16391	8,5
Italy	Anti_tampering	PM_{10}	lower	16864	17027	163	1
Italy	Anti_tampering	PM_{10}	upper	16677	17027	350	2,1
Italy	Anti_tampering	$PM_{2.5}$	lower	10715	10878	163	1,5
Italy	Anti_tampering	$PM_{2.5}$	upper	10529	10878	349	3,2
Italy	App_training	CO	lower	183249	201182	17933	8,9
Italy	App_training	CO	upper	95292	201182	105890	52,6
Italy	App_training	CO_2	lower	82221407	88365895	6144488	7
Italy	App_training	CO_2	upper	85483013	88365895	2882882	3,3
Italy	App_training	NOx	lower	190996	193742	2746	1,4
Italy	App_training	NOx	upper	151952	193742	41790	21,6
Italy	App_training	PM_{10}	lower	17014	17027	13	0,1
Italy	App_training	PM_{10}	upper	17011	17027	16	0,1
Italy	App_training	$PM_{2.5}$	lower	10865	10878	13	0,1
Italy	App_training	$PM_{2.5}$	upper	10862	10878	16	0,1
Italy	Retrofit	CO	lower	200186	201182	996	0,5
Italy	Retrofit	CO	upper	199190	201182	1992	1
Italy	Retrofit	CO_2	lower	88365895	88365895	0	0
Italy	Retrofit	CO_2	upper	88365895	88365895	0	0
Italy	Retrofit	NOx	lower	190190	193742	3552	1,8
Italy	Retrofit	NOx	upper	186638	193742	7104	3,7
Italy	Retrofit	PM_{10}	lower	16969	17027	58	0,3
Italy	Retrofit	PM_{10}	upper	16912	17027	115	0,7
Italy	Retrofit	$PM_{2.5}$	lower	10821	10878	57	0,5
Italy	Retrofit	$PM_{2.5}$	upper	10763	10878	115	1,1

[14] Emissions are given in tonnes

5.1.4. Turkey

Turkey share of Euro standards is different from the previous three countries, with greater proportions of Euro 5 and 6 vehicles. Euro 4 standards vehicles is about 25% of the fleet, which the less observed proportion among the countries in which a MODALES trial test took place.

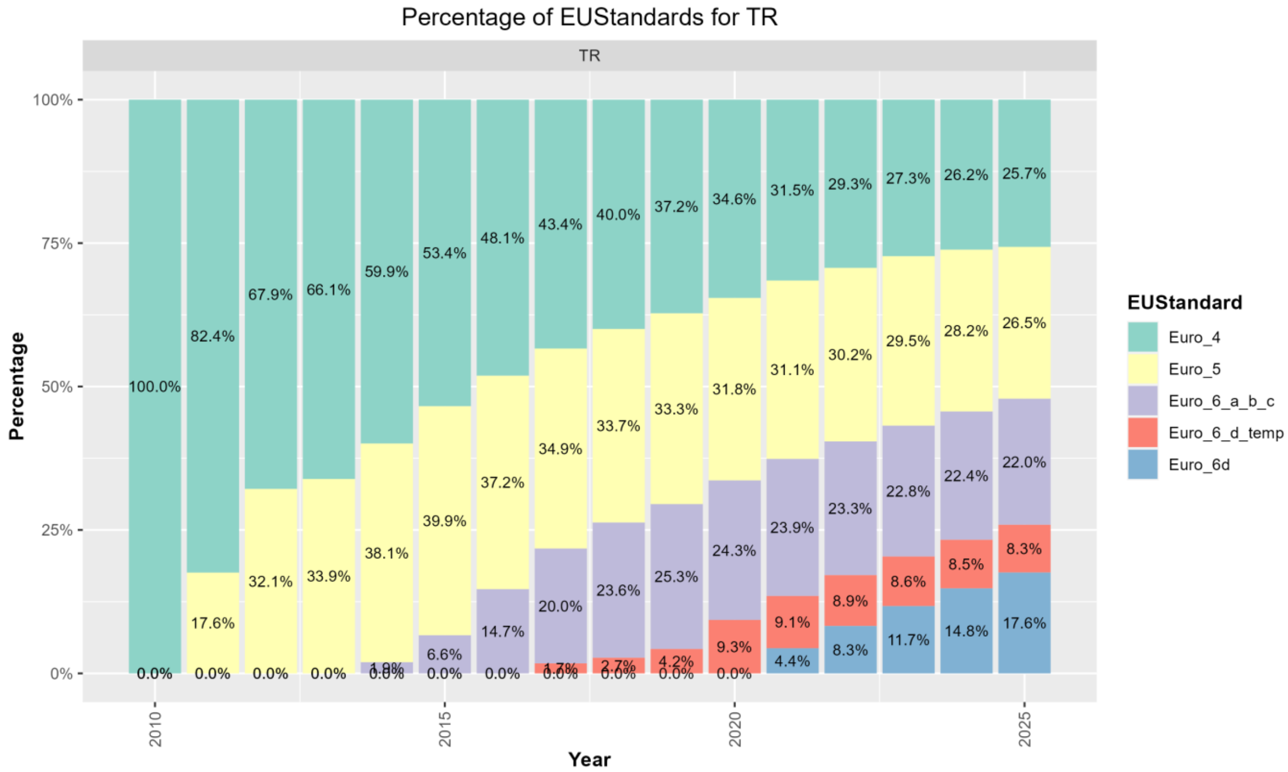


Figure 28: Evolution of the stock, segregated by Euro standards, from 2010-2025 for Turkey

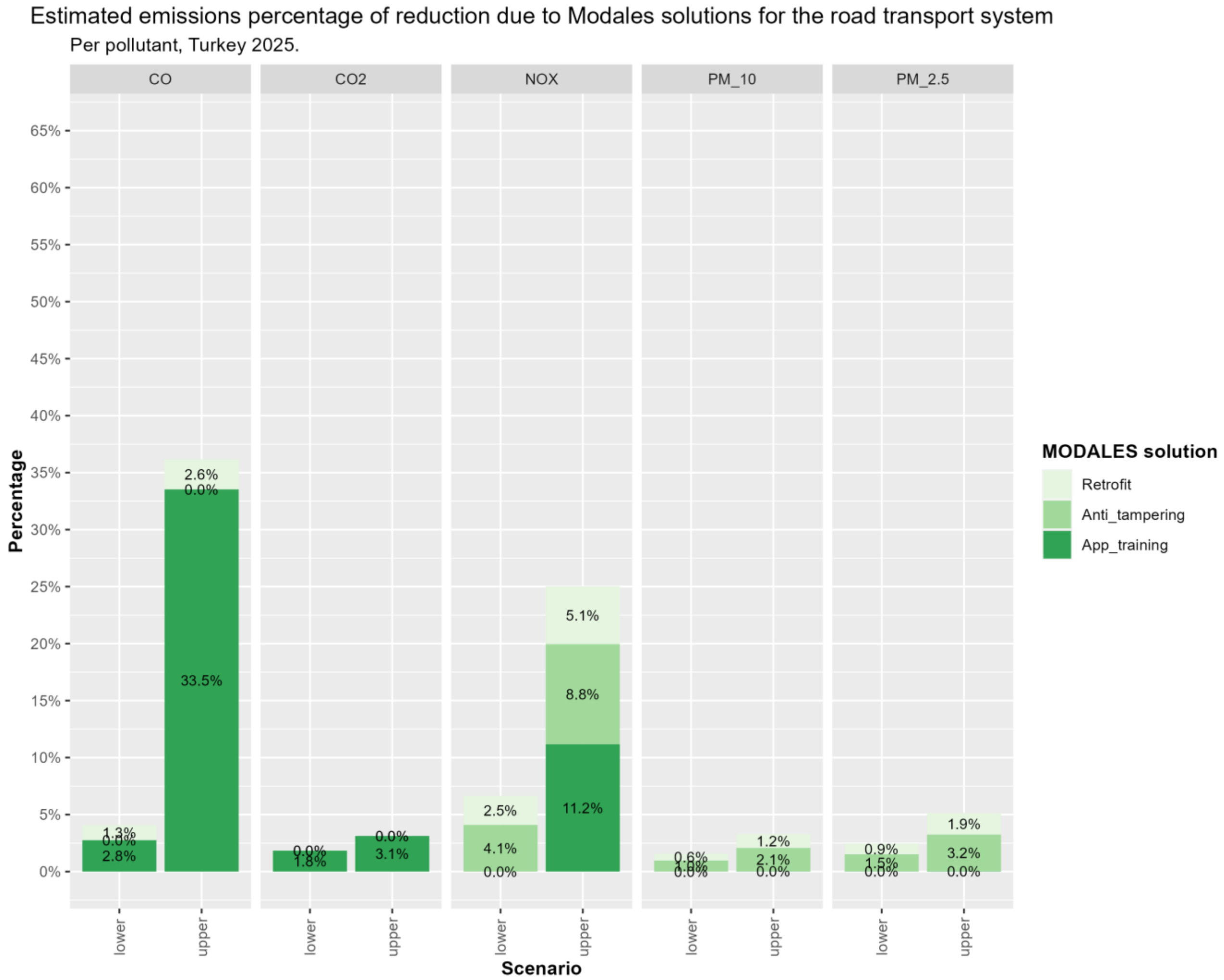


Figure 29: Estimated reduction of pollutants for year 2025 according to the scenario and the MODALES solutions, for Turkey

Due to the greater proportion of newer vehicles than for the previous countries, benefits from the App and training are less than previously observed. CO emissions range from 4.1% up to 36.1%, while CO_2 expected reduction is between 1.8% and 3.1%.

NOx reductions could be expected to lie between 6.6% and 25.1% thanks to the three MODALES solutions, with no effect of the App and training (see comments about this situation in the previous chapter).

For PMs, reductions are between 1.6% (PM_{10}, lower) and 5.1% ($PM_{2.5}$, upper).

Table 17: Detailed results obtained using COPERT software for Turkey (2025), according to the MODALES solutions, pollutants, and scenario[15]

Country	Solution	Pollutant	Scenario	Emissions_Total	Emissions_Baseline	Savings	Perc.reduction
Turkey	Anti_tampering	CO	lower	76711	76711	0	0
Turkey	Anti_tampering	CO	upper	76711	76711	0	0
Turkey	Anti_tampering	CO_2	lower	66076274	66076274	0	0
Turkey	Anti_tampering	CO_2	upper	66076274	66076274	0	0
Turkey	Anti_tampering	NOx	lower	192270	200489	8219	4,1
Turkey	Anti_tampering	NOx	upper	182876	200489	17613	8,8
Turkey	Anti_tampering	PM_{10}	lower	12642	12765	123	1
Turkey	Anti_tampering	PM_{10}	upper	12502	12765	263	2,1
Turkey	Anti_tampering	$PM_{2.5}$	lower	8035	8158	123	1,5
Turkey	Anti_tampering	$PM_{2.5}$	upper	7894	8158	264	3,2
Turkey	App_training	CO	lower	74595	76711	2116	2,8
Turkey	App_training	CO	upper	50987	76711	25724	33,5
Turkey	App_training	CO_2	lower	64863394	66076274	1212880	1,8
Turkey	App_training	CO_2	upper	64010536	66076274	2065738	3,1
Turkey	App_training	NOx	lower	200489	200489	0	0
Turkey	App_training	NOx	upper	178098	200489	22391	11,2
Turkey	App_training	PM_{10}	lower	12764	12765	1	0
Turkey	App_training	PM_{10}	upper	12763	12765	2	0
Turkey	App_training	$PM_{2.5}$	lower	8157	8158	1	0
Turkey	App_training	$PM_{2.5}$	upper	8156	8158	2	0
Turkey	Retrofit	CO	lower	75695	76711	1016	1,3
Turkey	Retrofit	CO	upper	74678	76711	2033	2,7
Turkey	Retrofit	CO_2	lower	66076274	66076274	0	0
Turkey	Retrofit	CO_2	upper	66076274	66076274	0	0
Turkey	Retrofit	NOx	lower	195403	200489	5086	2,5
Turkey	Retrofit	NOx	upper	190316	200489	10173	5,1
Turkey	Retrofit	PM_{10}	lower	12689	12765	76	0,6
Turkey	Retrofit	PM_{10}	upper	12612	12765	153	1,2
Turkey	Retrofit	$PM_{2.5}$	lower	8082	8158	76	0,9
Turkey	Retrofit	$PM_{2.5}$	upper	8005	8158	153	1,9

[15] Emissions are given in tonnes

5.1.5. France

France's share of Euro standard (Figure 30) is similar to the Turkish one, except that proportions of Euro 6d is about 24% (17.6% for Turkey). Very few benefits are expected from this category of vehicles as their emissions are already low compared to the other standards.

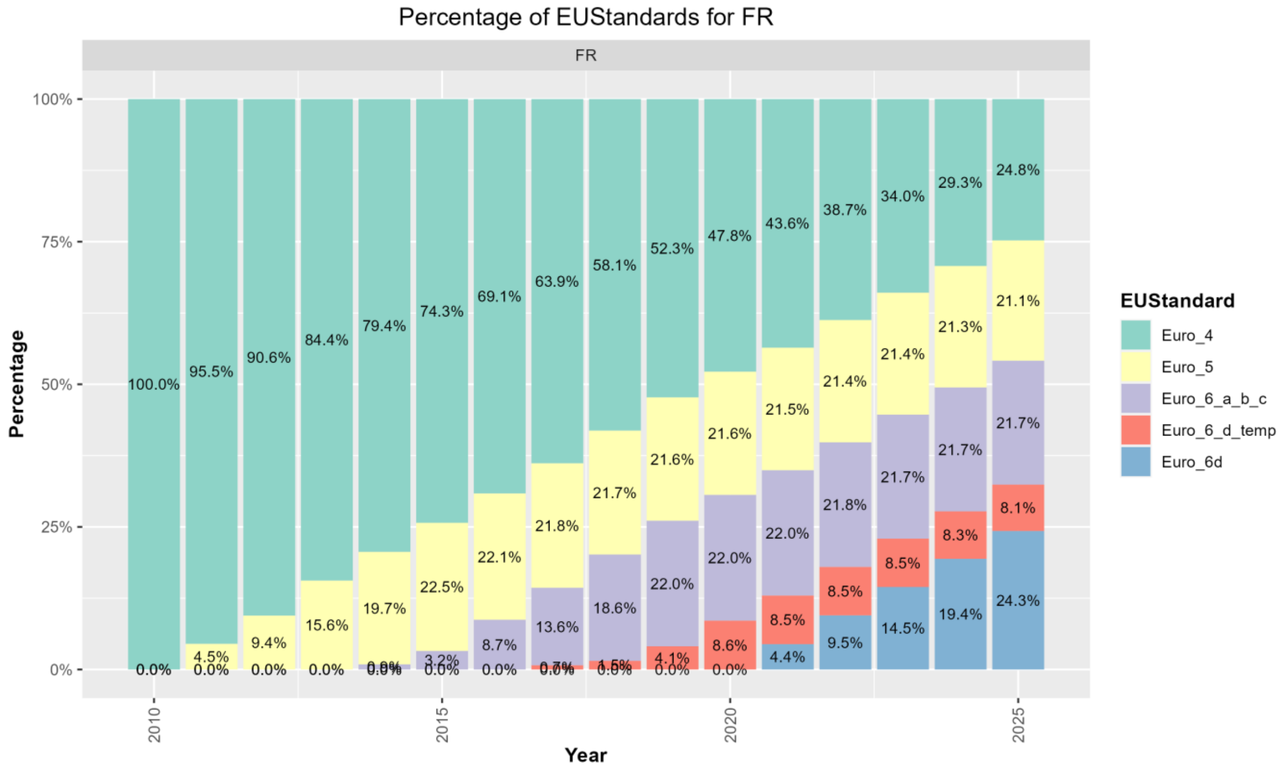


Figure 30: Evolution of the stock, segregated by Euro standards, from 2010-2025 for France

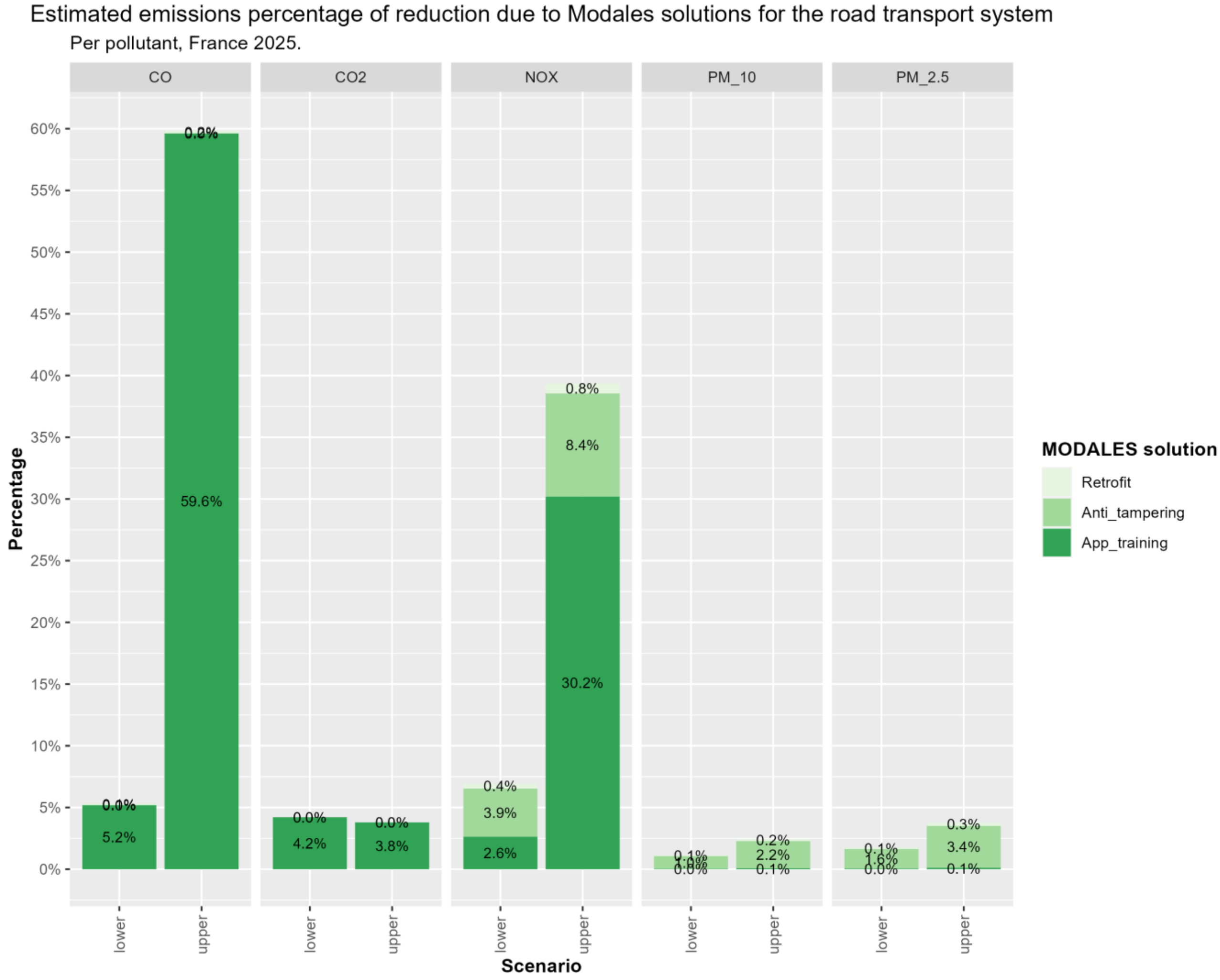


Figure 31: Estimated reduction of pollutants for year 2025 according to the scenario and the MODALES solutions, for France

For a country like France, benefits from the App and training are greater than for the previous countries, not because of a difference in the effect from the trials (input parameters are the average of the values from the MODALES trials), but probably because differences in the fleet size of passenger cars (40 million passenger cars in France in 2025, 40 million in Italy, 4.4 million in Finland, 14.4 million in Turkey, 30 million in Spain, 52 million in Germany).

Therefore, savings up to 59.6% could be expected for CO emissions, but only 5.2% in the more realistic lower scenario. CO_2 savings range from 3.8 to 4.2%, in line with other countries.

NOx emissions reductions range from 6.9% up to 39.4%. For PMs, reductions range from 1.1% (PM10, lower), up to 3.8% (PM2.5, upper). One can notice that PM reductions are mostly the result of anti-tampering measures, while retrofits have a very low impact on all the pollutants.

Table 18: Detailed results obtained using COPERT software for France (2025), according to the MODALES solutions, pollutants, and scenario[16]

Country	Solution	Pollutant	Scenario	Emissions_Total	Emissions_Baseline	Savings	Perc.reduction
France	Anti_tampering	CO	lower	199944	199944	0	0
France	Anti_tampering	CO	upper	199944	199944	0	0
France	Anti_tampering	CO_2	lower	87164049	87164049	0	0
France	Anti_tampering	CO_2	upper	87164049	87164049	0	0
France	Anti_tampering	NOx	lower	179185	186464	7279	3,9
France	Anti_tampering	NOx	upper	170866	186464	15598	8,4
France	Anti_tampering	PM_{10}	lower	15525	15687	162	1
France	Anti_tampering	PM_{10}	upper	15341	15687	346	2,2
France	Anti_tampering	$PM_{2.5}$	lower	10004	10165	161	1,6
France	Anti_tampering	$PM_{2.5}$	upper	9819	10165	346	3,4
France	App_training	CO	lower	189561	199944	10383	5,2
France	App_training	CO	upper	80728	199944	119216	59,6
France	App_training	CO_2	lower	83488263	87164049	3675786	4,2
France	App_training	CO_2	upper	83857918	87164049	3306131	3,8
France	App_training	NOx	lower	181557	186464	4907	2,6
France	App_training	NOx	upper	130171	186464	56293	30,2
France	App_training	PM_{10}	lower	15682	15687	5	0
France	App_training	PM_{10}	upper	15675	15687	12	0,1
France	App_training	$PM_{2.5}$	lower	10160	10165	5	0
France	App_training	$PM_{2.5}$	upper	10154	10165	11	0,1
France	Retrofit	CO	lower	199722	199944	222	0,1
France	Retrofit	CO	upper	199500	199944	444	0,2
France	Retrofit	CO_2	lower	87164049	87164049	0	0
France	Retrofit	CO_2	upper	87164049	87164049	0	0
France	Retrofit	NOx	lower	185714	186464	750	0,4
France	Retrofit	NOx	upper	184964	186464	1500	0,8
France	Retrofit	PM_{10}	lower	15674	15687	13	0,1
France	Retrofit	PM_{10}	upper	15661	15687	26	0,2
France	Retrofit	$PM_{2.5}$	lower	10152	10165	13	0,1
France	Retrofit	$PM_{2.5}$	upper	10139	10165	26	0,3

[16] Emissions are given in tonnes

5.1.6. Germany

Euro standards share for Germany show that it is the European country with the newest vehicles, with a very low proportion of Euro 4 (or below) vehicles. Euro 6 vehicles (all letters) represent more than 66% of the vehicles in 2025.

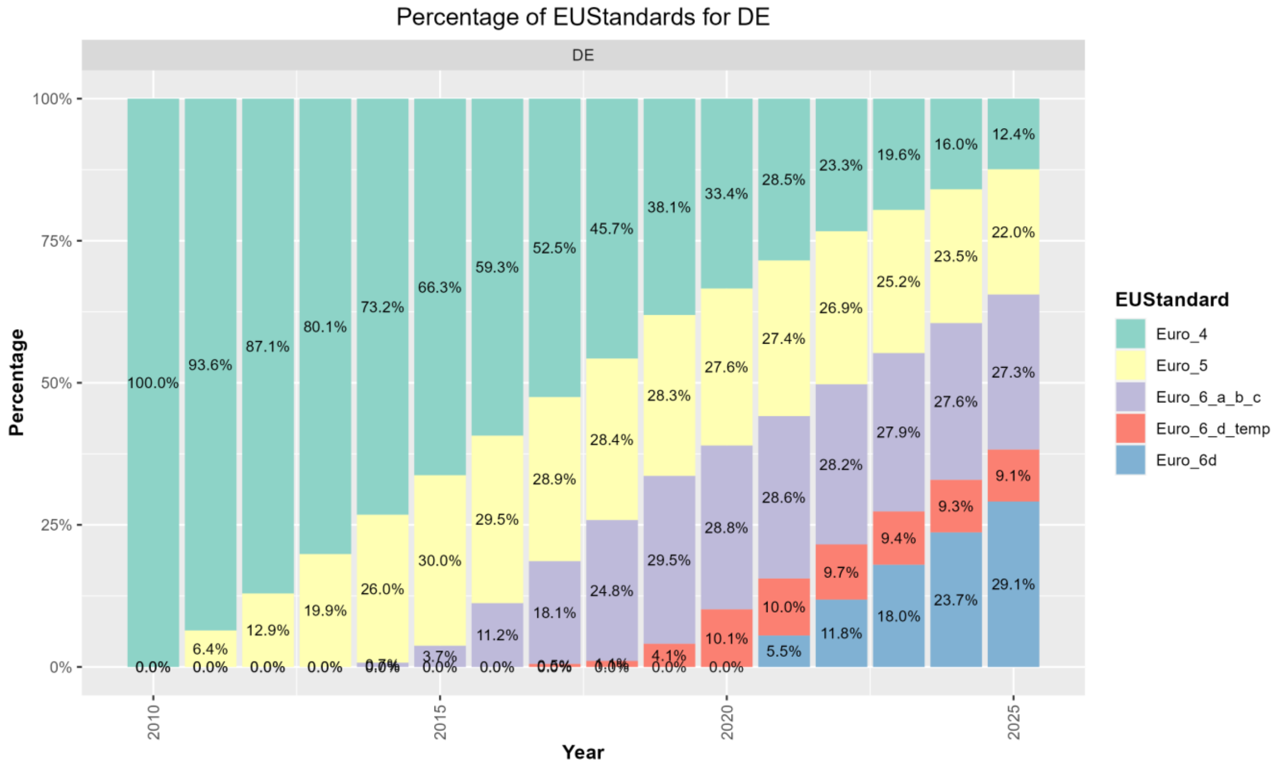


Figure 32: Evolution of the stock, segregated by Euro standards, from 2010-2025 for Germany

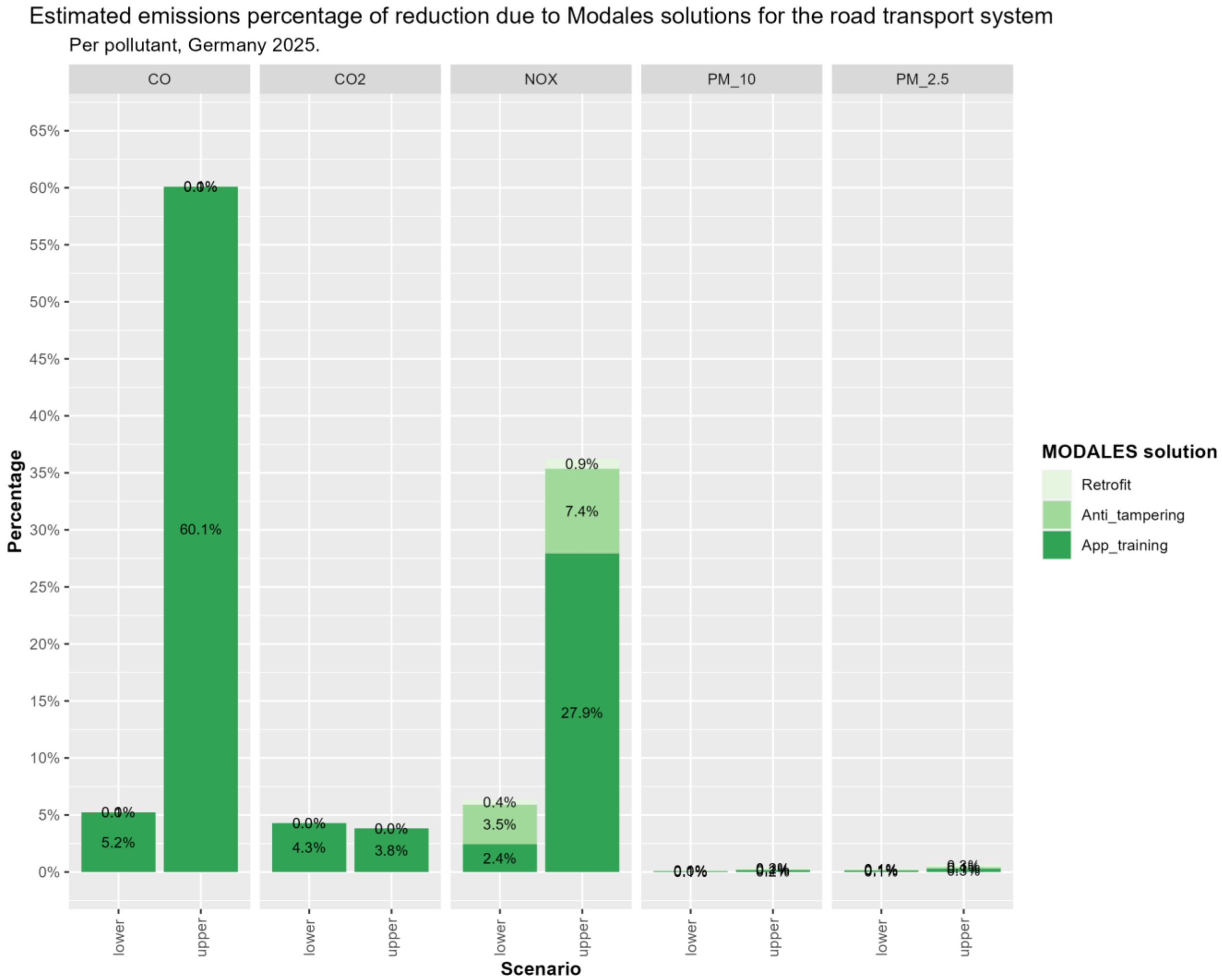


Figure 33: Estimated reduction of pollutants for year 2025 according to the scenario and the MODALES solutions, for Germany

Germany's results (Figure 33) are similar to France, in the sense that benefits from the App and training could reach very high levels due to the large fleet of passenger cars. CO emissions reduction ranges from 5.3% to 60.2%, the upper reduction among all the studied countries. CO_2 reductions are consistent with previous results, ranging from 4.3% to 3.8%.

It could be noticed that the MODALES impacts on PM emissions are under 1%, which is the minimum observed among the studied countries. This is due to the very low penetration rate of Euro 4 vehicles in Germany, which is the category of vehicles for which the impacts of retrofit is greatest.

Finally, NOx emissions show great potential for reduction, as they range from 6.3% up to 36.2%, with an important impact from anti tampering measures (between 3.5% and 7.4%).

Table 19: Detailed results obtained using COPERT software for Germany (2025), according to the MODALES solutions, pollutants, and scenario[17]

Country	Solution	Pollutant	Scenario	Emissions_Total	Emissions_Baseline	Savings	Perc.reduction
Germany	Anti_tampering	CO	lower	597660	597660	0	0
Germany	Anti_tampering	CO	upper	597660	597660	0	0
Germany	Anti_tampering	CO_2	lower	169760581	169760581	0	0
Germany	Anti_tampering	CO_2	upper	169760581	169760581	0	0
Germany	Anti_tampering	NOx	lower	198254	205386	7132	3,5
Germany	Anti_tampering	NOx	upper	190103	205386	15283	7,4
Germany	Anti_tampering	PM_{10}	lower	22087	22095	8	0
Germany	Anti_tampering	PM_{10}	upper	22078	22095	17	0,1
Germany	Anti_tampering	$PM_{2.5}$	lower	12034	12042	8	0,1
Germany	Anti_tampering	$PM_{2.5}$	upper	12024	12042	18	0,1
Germany	App_training	CO	lower	566375	597660	31285	5,2
Germany	App_training	CO	upper	238464	597660	359196	60,1
Germany	App_training	CO_2	lower	162479646	169760581	7280935	4,3
Germany	App_training	CO_2	upper	163259746	169760581	6500835	3,8
Germany	App_training	NOx	lower	200381	205386	5005	2,4
Germany	App_training	NOx	upper	148019	205386	57367	27,9
Germany	App_training	PM_{10}	lower	22081	22095	14	0,1
Germany	App_training	PM_{10}	upper	22061	22095	34	0,2
Germany	App_training	$PM_{2.5}$	lower	12027	12042	15	0,1
Germany	App_training	$PM_{2.5}$	upper	12007	12042	35	0,3
Germany	Retrofit	CO	lower	597350	597660	310	0,1
Germany	Retrofit	CO	upper	597040	597660	620	0,1
Germany	Retrofit	CO_2	lower	169760581	169760581	0	0
Germany	Retrofit	CO_2	upper	169760581	169760581	0	0
Germany	Retrofit	NOx	lower	204487	205386	899	0,4
Germany	Retrofit	NOx	upper	203589	205386	1797	0,9
Germany	Retrofit	PM_{10}	lower	22079	22095	16	0,1
Germany	Retrofit	PM_{10}	upper	22062	22095	33	0,1
Germany	Retrofit	$PM_{2.5}$	lower	12025	12042	17	0,1
Germany	Retrofit	$PM_{2.5}$	upper	12008	12042	34	0,3

[17] Emissions are given in tonnes

5.2. Results overview

It is important to extract the deep tendencies of the previous national results, as it helps understanding the underlying process of emissions reduction and how it could be influenced by individual country situations, the actual and predicted stock of vehicles for example.

A summary of the results is presented in Figure 34 below. This provides, in the same form as Figure 3 in section 2.5, the range of emissions reductions from the lower scenario (pessimistic) to the upper one (optimistic). Also, this figure provide the estimates obtained by MODALES previous works at the individual level and already explained in previous deliverables ([1], [2]).

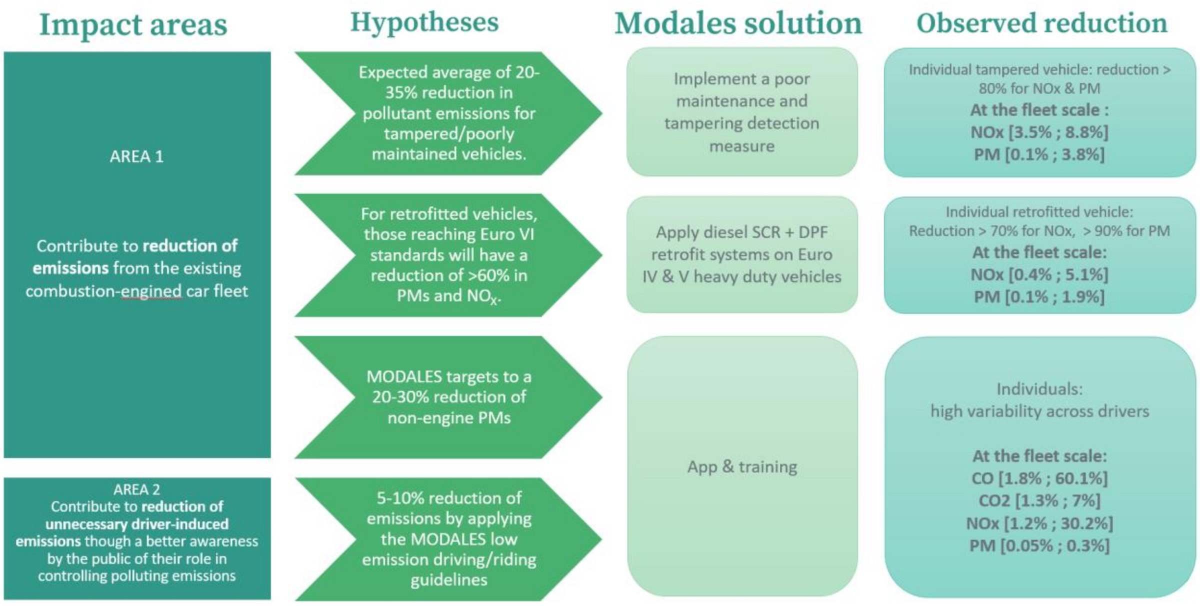


Figure 34: Overview of the obtained results range for each MODALES Innovative Solution

For the reader interested in tonnes of pollutants saved according to the MODALES solutions, for every pollutant and for every scenario, a table summarising the savings in tonnes and the corresponding percentage of reduction is provided (Table 20).

For a global analysis of the results, please refer to chapter 7.

Table 20: Summary of the results across the 6 countries studied, providing savings (tonnes of pollutant) together with the percentage reduction

			Savings			Percentage		
Solution	Pollutant	Scenario	Total[1]	Min[2]	Max[3]	Avg[4]	Min[2]	Max[3]
Anti_tampering	CO	lower	0.0	0.0	0.0	0.0	0.0	0.0
	CO	upper	0.0	0.0	0.0	0.0	0.0	0.0
	CO2	lower	0.0	0.0	0.0	0.0	0.0	0.0
	CO2	upper	0.0	0.0	0.0	0.0	0.0	0.0
	NOx	lower	41,415.0	704.0	10,432.0	3.9	3.5	4.1
	NOx	upper	88,747.0	1,509.0	22,353.0	8.3	7.4	8.8
	PM 10	lower	699.0	8.0	222.0	0.9	0.0	1.2
	PM 10	upper	1,496.0	17.0	476.0	1.8	0.1	2.5
	PM 2.5	lower	697.0	8.0	222.0	1.3	0.1	1.8
	PM 2.5	upper	1,496.0	18.0	475.0	2.9	0.1	3.8
App_training	CO	lower	66,110.0	1,039.0	31,285.0	4.5	1.8	8.9
	CO	upper	713,969.0	20,772.0	359,196.0	51.2	33.5	60.1
	CO2	lower	19,840,175.0	268,750.0	7,280,935.0	3.5	1.3	7.0
	CO2	upper	17,711,921.0	424,959.0	6,500,835.0	3.4	2.6	3.9
	NOx	lower	16,088.0	387.0	5,005.0	1.6	1.2	2.6
	NOx	upper	226,453.0	3,745.0	57,367.0	21.3	11.2	30.2
	PM 10	lower	36.0	1.0	14.0	0.0	0.0	0.1
	PM 10	upper	80.0	2.0	34.0	0.1	0.0	0.2
	PM 2.5	lower	37.0	1.0	15.0	0.1	0.0	0.1
	PM 2.5	upper	79.0	2.0	35.0	0.2	0.0	0.3
Retrofit	CO	lower	3,417.0	65.0	1,016.0	0.4	0.1	1.3
	CO	upper	6,836.0	130.0	2,033.0	0.9	0.1	2.7
	CO2	lower	0.0	0.0	0.0	0.0	0.0	0.0
	CO2	upper	0.0	0.0	0.0	0.0	0.0	0.0
	NOx	lower	14,057.0	292.0	5,086.0	1.3	0.4	2.5
	NOx	upper	28,113.0	584.0	10,173.0	2.7	0.8	5.1
	PM 10	lower	219.0	4.0	76.0	0.3	0.1	0.6
	PM 10	upper	439.0	8.0	153.0	0.5	0.1	1.2
	PM 2.5	lower	218.0	4.0	76.0	0.4	0.1	0.9
	PM 2.5	upper	439.0	8.0	153.0	0.8	0.3	1.9

[1]Total savings (tons)

[2]Mininimal value observed among the considered countries

[3]Maximal value observed among the considered countries

[4]Average percentage reduction in emissions (0 excluded)

6. Feedback questionnaire analysis

This chapter presents the results of the three surveys conducted among trial participants. First, the app built for the MODALES needs is presented, together with its functionalities. Then, the questionnaire itself is detailed, together with the choices made in order to improve response rate. Finally, the results are discussed in a later section.

6.1. Background

Guidelines for low-emission driving and technical requirements for a smartphone application were developed under the MODALES WP5 [22], taking into consideration the results from WP2, WP3 and WP4 activities. The MODALES app, a personal driving assistant implementing both real-time (active) and passive (report after each trip) recommendations to reduce emissions levels (linked to the MODALES impact 1 and 2), was developed and tested in WP6.

Together with an online video training, its aim was to impact driving style and reduce pollutant emissions (MODALES solution 2: app and training). Impacts on the powertrain emissions, brake emissions and tyre emissions before and after using the MODALES app and training were tested. Because the app was used in conjunction with the training their impacts were measured together during the pilot trials.

The MODALES app aimed to assist drivers throughout their journeys by providing recommendations that do not interfere with their driving (e.g., when stationary at a traffic light or in the form of sound notifications). The app had three separate modules:

- A **data collection module**, which considered data from *(a)* OBD-II (e.g., engine rpm, vehicle speed), *(b)* phone sensors (e.g., accelerometer, wireless traces) and *(c)* the user. Using an OBD dongle was optional, this allowed end-users to use either a standalone application or one which relied on additional data. The lack of data induced by the absence of OBD lead to less data collected for the project's impact analysis, but still valid. Phones were, if possible, fixed in the car using a car holder, allowing the user to have a comfortable view of the phone's interface and for the proper recording of accelerometric data, i.e., using a stable reference in space. Ideally, the phones should have been positioned vertically, but the system also worked horizontally.
- The data mentioned above was used as input to two **scoring modules**, enabling the creation of a local representation of the user's profile and distinguishing of different driving behaviours previously identified via laboratory tests and state-of-the-art reviews. These scoring modules computed, on one side, a real-time acceleration profile, and on the other side, a time series of scores, using a classification approach. Input data came from OBD dongle and phone sensors, while ground truth data was provided by the user and independent data such as GPS.
- Finally, a **recommendation module** advised the user to adopt attitudes depending on their perceived driving behaviour. Based on the two sub-scores explained above, the mobile app generated two types of recommendations:
  - **Active recommendations** were presented to the user while driving. The user's driving style was analysed in real-time and transcribed into an acceleration score. Active recommendations required local data processing and storage. The user interface and possible interactions actions needed to be limited to preserve the user's safety. It was aimed to keep these recommendations simple.
  - **Passive recommendations** were given to the user after a trip. An end of trip report was generated, including textual recommendations, statistical analyses, and

contextual elements. This feedback aimed to allow drivers to learn from bad driving habits and improve their emissions reduction. Passive recommendations meant that data processing and storage was outsourced to an external server.

The mobile app was developed in two different versions: the first only for data collection and the second with the full scoring and recommendation systems.

6.2. Questionnaire overview

Three surveys were conducted among the MODALES trial participants. The first was the driver selection survey (included as an annex to MODALES D6.2 – Trial Management), which was administered individually by each participating project partner (site leader) to collect basic information such as vehicle type, age group, gender, driving experience and typical driving intensity (annual mileage, main trip purposes). These allowed the volunteer drivers to be selected, and this data provides context to the data analysis which is reported in Deliverable D6.3.

The second survey followed the viewing of the training video by each participant and their move to Phase 2 of the trial. This focused on their understanding and acceptance of the video, the extent to which they learnt things and any other feedback. This is reported in MODALES D6.2 – Trial Management.

This chapter reports on the **final survey**, after the end of Phase 2 of the trials, which covered the **use of the MODALES app** and the **extent to which drivers felt their driving style and behaviour had changed** as a result of the MODALES training video and the MODALES app advice and feedback. This survey used the EUSurvey online tool[18], for consistency with the second survey and to enable different language versions of the questionnaire. It was kept as short as possible (average response time 5-10 minutes) in order to elicit a satisfactory response rate.

For two types of poor (high emitting) driving behaviour, it asked whether the user carried out this behaviour before taking the training and whether they now carry on with the same behaviour, they have modified (improved) a little, or have improved a lot (avoiding almost always this kind of poor behaviour). Alternatively, they already avoided poor behaviour and continue to do so after the training and using the app. The situations were:

- Speeding up when the engine is cold;
- Rapid accelerations, which might lead to a need for sudden braking.

The questionnaire asked how regularly the driver used the app during the trial period (most or all trips, around half of trips, or only a few). For occasions when the driver did not use the app, they were asked why not (e.g. in a hurry, only a short trip, did not like the app or did not find it useful, had technical/connection problems with the app).

It asked how the user reacted to real-time on-trip feedback from the app (simple colour changes), and also how they reacted to the post-trip feedback.

Finally, this questionnaire recognised that some drivers had experienced difficulties such as getting the app to connect with the dongle, getting the app to send data, etc., and also reminded them that MODALES is a research project and not a commercial product. However, if this project led to a better performing and more stable version of this app being available, and available for free, it asked whether

[18] https://ec.europa.eu/eusurvey

they would use it. They were also asked for any other suggestions for improvements to the MODALES app.

6.3. User feedback on the application

The MODALES app was trialled by approximately 200 volunteer drivers at 8 pilot sites in the following cities: Barcelona, Spain; Bergamo, Italy; Helsinki, Finland; Istanbul, Turkey; Leeds, United Kingdom; Luxembourg, Luxembourg; Thessaloniki, Greece and Nanjing, China.

An anonymised feedback questionnaire on the MODALES app was sent to the volunteer drivers. A total of 69 responses were recorded from drivers in pilot sites in Finland, Italy, Greece, Luxembourg, Spain, Turkey, and the United Kingdom. These responses are the subject of the following analysis.

6.3.1. Demographics

All the pilot site countries (except for China which performed a different analysis) were represented in the questionnaire responses. Turkey and the UK had the most responses whereas Italy and Luxemburg had the least. If we consider 69 respondents from the 7 countries, an average of 10 responses per country was received.

Close to three-quarters of respondents were male (51), 16 were female, 2 n/a (see Figure 35). The age group most represented among respondents was the 30–49-year-old bracket (40), followed by the 50–64-year-old bracket (16), the 21–29-year-old bracket (11) and finally the 65–74-year-old bracket (2) (see Figure 36).

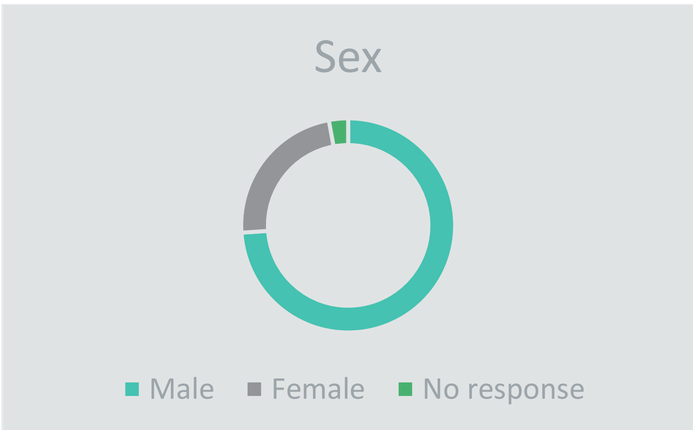


Figure 35: Final questionnaire respondent breakdown by gender

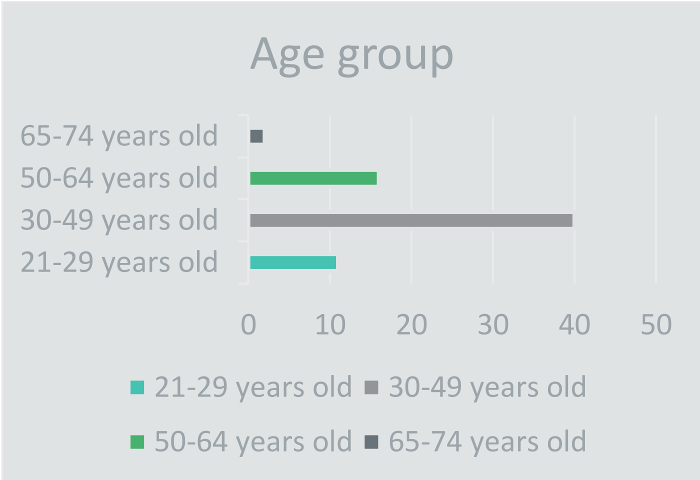


Figure 36: Final questionnaire respondent breakdown by age

Participants were asked what type of vehicle they mostly drove in the MODALES trial. The majority of respondents (58) drove combustion engine vehicles (see Figure 37), with 31 respondents driving a diesel fuelled vehicle and 27 driving a petrol fuelled vehicle. A smaller proportion, 10 respondents out of 69, reported driving electric or hybrid.

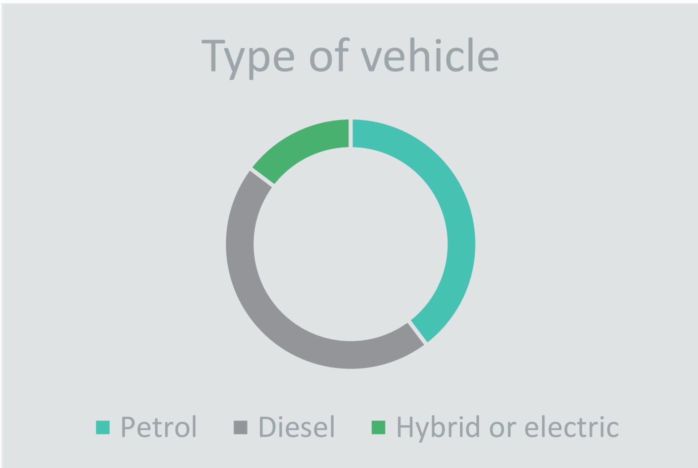


Figure 37: Type of vehicle driven by questionnaire respondents during the MODALES trials

6.3.2. (Frequency of) MODALES app use

32 respondents used the MODALES app every time or most times they drove during the trial period. 22 respondents used the app around half the time they drove during the trial period. 15 respondents used the app only a few times during the trial period (see Figure 38).

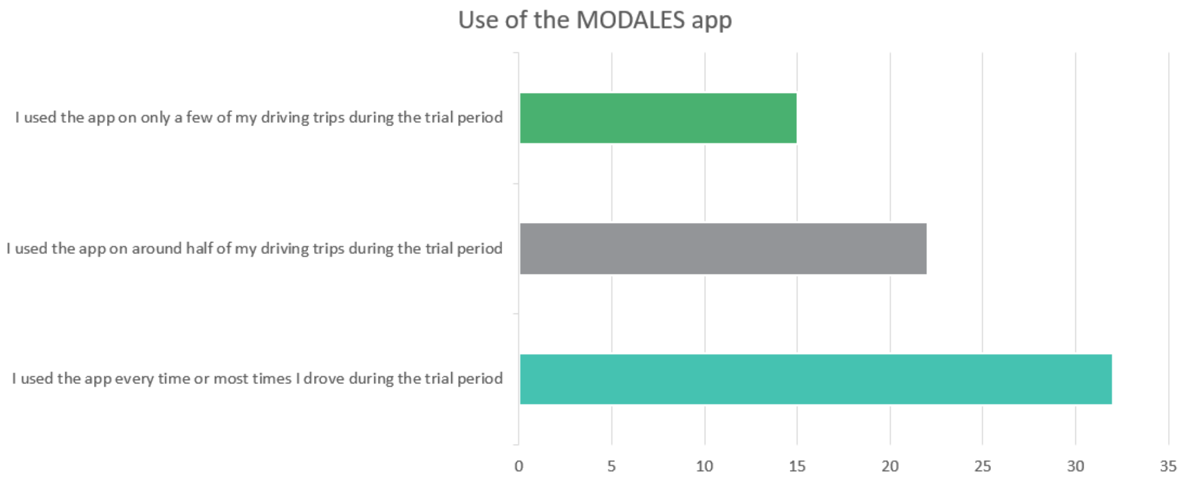


Figure 38: Frequency of MODALES app use

Respondents were asked for what reasons they may have not used the MODALES app. The most cited reason was that respondents forgot to use the app. A significant number, 29 out of 69 respondents, reported application malfunctions as a reason why they did not use it on certain trips during the trial period.

6.3.3. Driver behaviour:

Several behavioural changes were encouraged by the MODALES app and training. Respondents were therefore asked about changes in their driving behaviour before and after the use of the MODALES app.

One behaviour being targeted was the act of speeding up when the engine is cold. A total of 45 respondents reported no change in behaviour following the use of the MODALES app (see Figure 39). Of those 45, 40 respondents were already avoiding strong acceleration or high speeds with a cold engine and continued to do so. The remaining 5 respondents continued to accelerate or drive fast with a cold engine.

Importantly, 24 out of the 29 respondents who used to accelerate or drive fast with a cold engine reported behaviour change, with 18 respondents doing so less often after the trial, and 6 respondents avoiding doing so altogether.

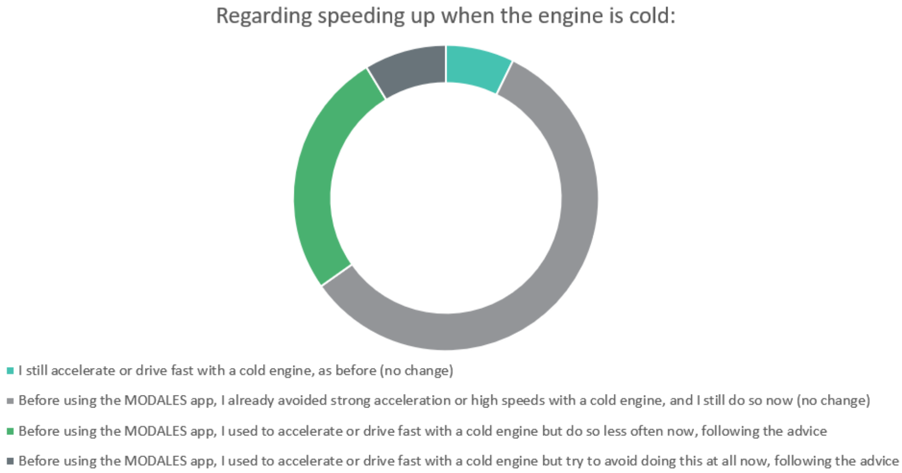


Figure 39: Respondent's driving behaviour with regards to speeding up when the engine is cold

Reports of behaviour change with regards to rapid acceleration which might lead to a sudden need for breaking was roughly similar as the above (see Figure 40). 44 respondents reported no change in behaviour, with 43 of them paying attention to traffic situations to avoid rapid or sudden acceleration prior to using the MODALES app. 18 respondents reported a change in behaviour resulting from the use of the MODALES app, stating that they now consider certain traffic situations and accelerate less, to avoid breaking suddenly.

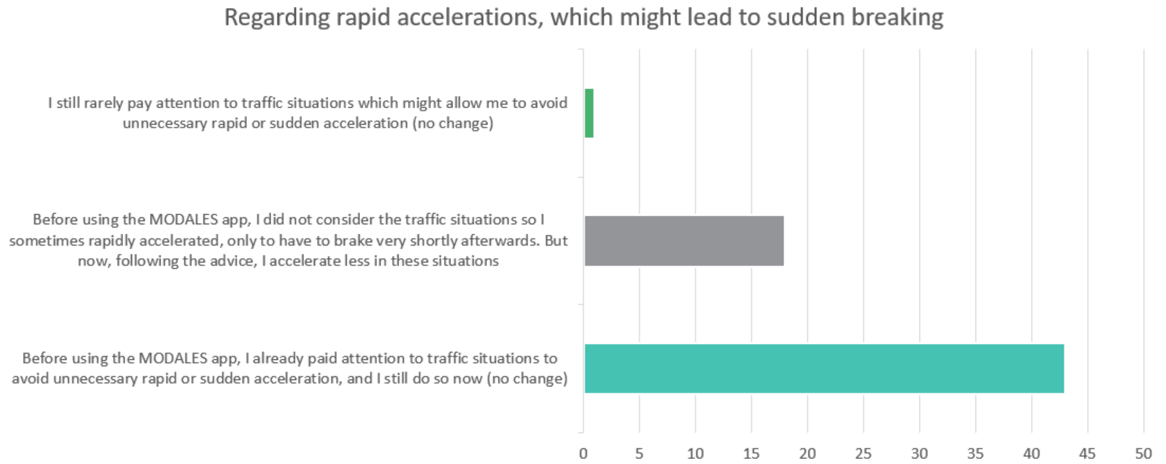


Figure 40: Respondent's driving behaviour with regards to rapid acceleration

6.3.4. Reaction to MODALES app feedback

Reaction to **real-time on-trip feedback** from the app (simple colour changes from green to yellow, orange, or red): 24 (more than one third) reduced acceleration or drove more slowly in some cases, 17 (one fourth) either reduced acceleration or drove more slowly in most or all cases, 16 (one fourth) reported not reacting or change driving style as a result of the on-trip feedback from the app (see Figure 41). Finally, 11 respondents reported having another reaction that the three options provided (reduced acceleration in some or all cases, or no change).

The comments provided by respondents in relation to the real-time on-trip feedback are very informative. A number reported that this function of the app did not work for them – that they did not see any colour changes for example. A number did not understand why the colour changed and as a result did not know how to adapt behaviour to respond to the prompt. A number thought the feedback was slow. A significant number reported that the feedback often seemed linked to irregularities in the road surface or obstacles on the road (such as traffic lights, zebra crossings or speed bumps) rather than their driving. Thought the app barely reacted to acceleration or aggressive driving. A number are reporting that the app did not work.

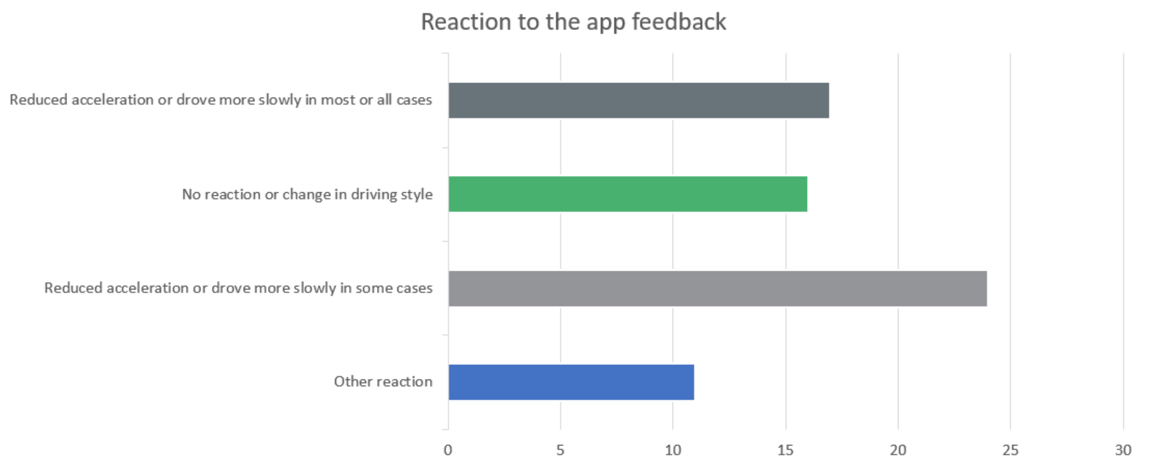


Figure 41: Respondent's reaction to the MODALES app real-time on-trip feedback

Reaction to **post-trip feedback** from the app: 26 reported adapting their driver behaviour according to the post-trip recommendations in some cases, 18 reported doing so in most or all cases (see Figure 42). 15 reported no reaction or change in driving style resulting from the post-trip feedback. 9 respondents gave another reaction, 8 of whom stated they did not receive any post-trip feedback and one stating that they did not have time to consult the post-trip feedback.

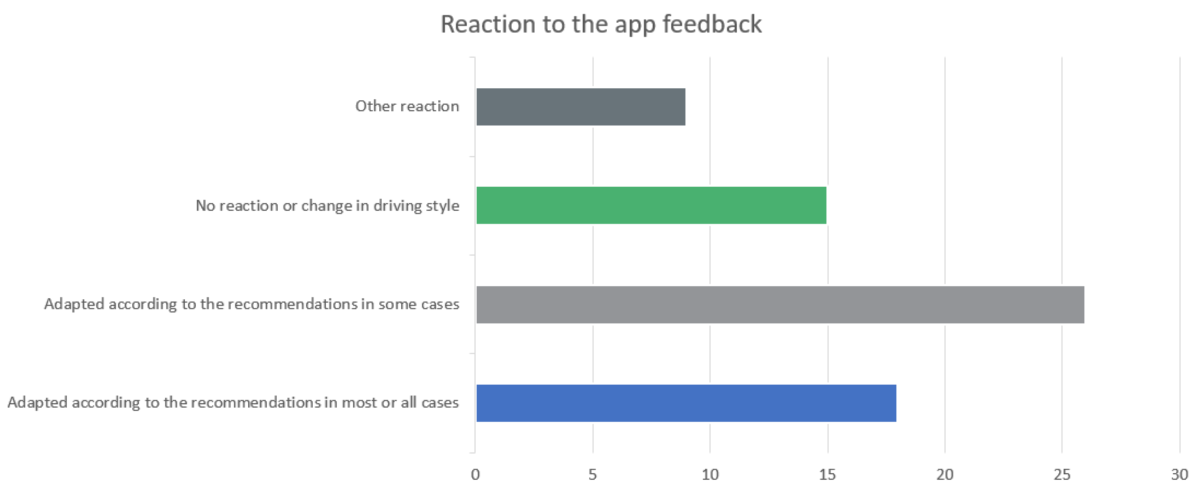


Figure 42: Respondent's reaction to the MODALES app post-trip feedback

6.4. Conclusions and recommendations for future improvements

Drivers were asked if a better performing and more stable version of the app were available for free if they would use it (see Figure 43). 63 out of 69 respondents were willing to use the app in some of the following ways: 35 respondents mentioned they would install and use it with a dongle, 19 of which said they would use it on most or all journeys, 16 of which said they would only on some occasions (such as long journeys). 9 respondents stated they would use the app but would not use the dongle.

18 respondents would only use it if the system were integrated into the dashboard of the vehicle and not on the phone. Finally, six respondents were not interested in using such an application, even if it were integrated into the vehicle and worked perfectly.

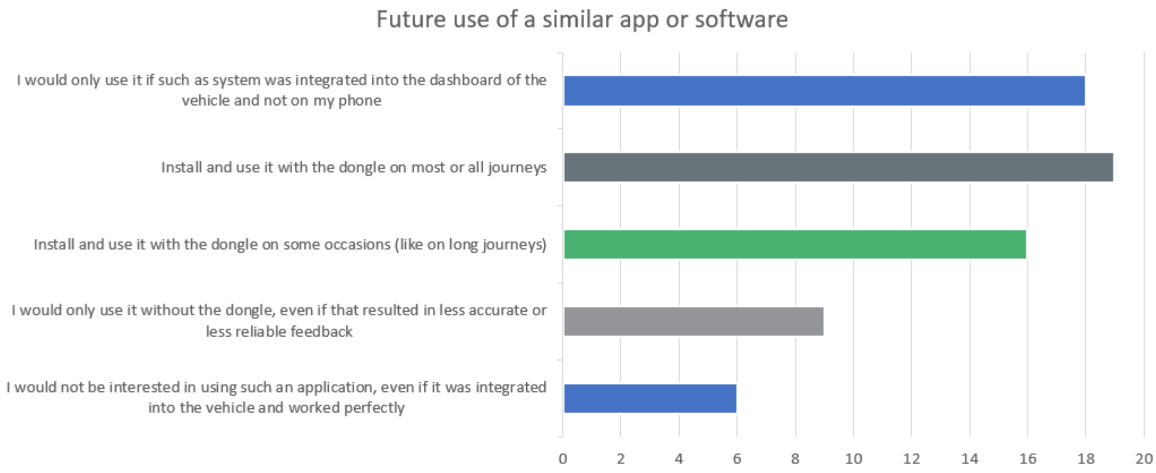


Figure 43: Respondent's views on using a driving assistance app or software in the future

A significant number of other responses and feedback was provided to this question of future use. These responses raised several important issues with the design and functionality of the app (such as its distractive qualities and its lack of clarity). Respondents highlighted mainly three categories of issues relating to: the real-time feedback feature, the interference of the MODALES app with their use of other apps (such as a maps or GPS app), the connection of the app with the OBD or dongle.

With regards to issues with real time feedback, some respondents suggested that in addition to the colour change that there be hints towards to reason for the colour change to better understand the reason for the change. A few commented on the distractive nature of real-time feedback, with one respondent suggesting that only post-trip feedback be provided. Another respondent suggested that MODALES app features be integrated into the dashboard of the vehicle.

With regards to the use of the MODALES app conflicting with the use of other apps, respondents suggested features to remedy this, such as: a floating window or widget, notification pop-ups, split screen.

With regards to issues with the connection of the app to the OBD/dongle, a respondent suggested to include an indicator for the dongle/OBD connection in the active display. Another respondent suggested that the app (working with the dongle) provide a failure code explanation to the driver. Finally, a respondent asked that there be a more efficient delivery of technical support for issues relating to the application.

7. Conclusions

The transportation sector is responsible for a significant portion of global greenhouse gas emissions, and reducing these emissions has become a priority for many governments and organisations. One approach to reducing emissions is through the use of anti-tampering regulation measures and retrofit campaigns for older vehicles.

MODALES impact assessment results have shown that the older the vehicle stock, the more savings can be expected from these measures. This is because older vehicles are often less fuel efficient and emit more pollutants than newer models. By retrofitting these vehicles with newer technology and implementing anti-tampering measures, emissions can be reduced and fuel efficiency can be improved.

However, the effectiveness of these measures varies depending on the type of vehicle and the country in question. For example, countries with older vehicle stocks may see greater benefits from retrofit campaigns, while countries with newer stocks may see limited or no impact. Similarly, the potential savings from anti-tampering measures may be greater in some countries than in others.

Another approach to reducing emissions is through behaviour-related changes, such as improving driving habits. MODALES impact assessment results have shown that there is significant potential for savings through app-based solutions and training programs 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.

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.

Considering the feedback questionnaire analysis conducted among MODALES trial participants, the final survey focused on the use of the MODALES app and the extent to which drivers felt their driving style and behaviour had changed. The survey recorded 69 responses from volunteer drivers in pilot sites across seven countries. The majority of the respondents drove combustion engine vehicles, and around one-third of them used the app every time they drove during the trial period. The survey revealed that the app successfully encouraged behavioural changes in driving, with many respondents reporting a reduction in poor driving behaviour. However, several issues were raised with the app's design and functionality, particularly in relation to real-time feedback, interference with other apps, and connection with the OBD dongle. Respondents suggested several features to remedy these issues, including integration with the vehicle dashboard and more efficient technical support. Overall, the survey showed that a better performing and more stable version of the app would be welcomed by most respondents.

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9. Annex

The table below aggregates all the results presented in this deliverable in a detailed form. Emissions are in tonnes of pollutant.

Country	Solution	Pollutant	Scenario	Emissions_Total	Emissions_Baseline	Savings	Perc.reduction
Turkey	Anti_tampering	CO	lower	76711	76711	0	0,0
Turkey	Anti_tampering	CO	upper	76711	76711	0	0,0
Turkey	Anti_tampering	CO_2	lower	66076274	66076274	0	0,0
Turkey	Anti_tampering	CO_2	upper	66076274	66076274	0	0,0
Turkey	Anti_tampering	NOx	lower	192270	200489	8219	4,1
Turkey	Anti_tampering	NOx	upper	182876	200489	17613	8,8
Turkey	Anti_tampering	PM_{10}	lower	12642	12765	123	1,0
Turkey	Anti_tampering	PM_{10}	upper	12502	12765	263	2,1
Turkey	Anti_tampering	$PM_{2.5}$	lower	8035	8158	123	1,5
Turkey	Anti_tampering	$PM_{2.5}$	upper	7894	8158	264	3,2
Turkey	App_training	CO	lower	74595	76711	2116	2,8
Turkey	App_training	CO	upper	50987	76711	25724	33,5
Turkey	App_training	CO_2	lower	64863394	66076274	1212880	1,8
Turkey	App_training	CO_2	upper	64010536	66076274	2065738	3,1
Turkey	App_training	NOx	lower	200489	200489	0	0,0
Turkey	App_training	NOx	upper	178098	200489	22391	11,2
Turkey	App_training	PM_{10}	lower	12764	12765	1	0,0
Turkey	App_training	PM_{10}	upper	12763	12765	2	0,0
Turkey	App_training	$PM_{2.5}$	lower	8157	8158	1	0,0
Turkey	App_training	$PM_{2.5}$	upper	8156	8158	2	0,0
Turkey	Retrofit	CO	lower	75695	76711	1016	1,3
Turkey	Retrofit	CO	upper	74678	76711	2033	2,7
Turkey	Retrofit	CO_2	lower	66076274	66076274	0	0,0
Turkey	Retrofit	CO_2	upper	66076274	66076274	0	0,0
Turkey	Retrofit	NOx	lower	195403	200489	5086	2,5
Turkey	Retrofit	NOx	upper	190316	200489	10173	5,1
Turkey	Retrofit	PM_{10}	lower	12689	12765	76	0,6
Turkey	Retrofit	PM_{10}	upper	12612	12765	153	1,2
Turkey	Retrofit	$PM_{2.5}$	lower	8082	8158	76	0,9
Turkey	Retrofit	$PM_{2.5}$	upper	8005	8158	153	1,9
Spain	Anti_tampering	CO	lower	190944	190944	0	0,0
Spain	Anti_tampering	CO	upper	190944	190944	0	0,0
Spain	Anti_tampering	CO_2	lower	98515728	98515728	0	0,0
Spain	Anti_tampering	CO_2	upper	98515728	98515728	0	0,0
Spain	Anti_tampering	NOx	lower	248902	259334	10432	4,0
Spain	Anti_tampering	NOx	upper	236981	259334	22353	8,6
Spain	Anti_tampering	PM_{10}	lower	18532	18754	222	1,2
Spain	Anti_tampering	PM_{10}	upper	18278	18754	476	2,5
Spain	Anti_tampering	$PM_{2.5}$	lower	12339	12561	222	1,8

Spain	Anti_tampering	$PM_{2.5}$	upper	12086	12561	475	3,8
Spain	App_training	CO	lower	187590	190944	3354	1,8
Spain	App_training	CO	upper	107773	190944	83171	43,6
Spain	App_training	CO_2	lower	97258392	98515728	1257336	1,3
Spain	App_training	CO_2	upper	95984352	98515728	2531376	2,6
Spain	App_training	NOx	lower	256291	259334	3043	1,2
Spain	App_training	NOx	upper	214467	259334	44867	17,3
Spain	App_training	PM_{10}	lower	18752	18754	2	0,0
Spain	App_training	PM_{10}	upper	18742	18754	12	0,1
Spain	App_training	$PM_{2.5}$	lower	12559	12561	2	0,0
Spain	App_training	$PM_{2.5}$	upper	12550	12561	11	0,1
Spain	Retrofit	CO	lower	190136	190944	808	0,4
Spain	Retrofit	CO	upper	189327	190944	1617	0,8
Spain	Retrofit	CO_2	lower	98515728	98515728	0	0,0
Spain	Retrofit	CO_2	upper	98515728	98515728	0	0,0
Spain	Retrofit	NOx	lower	255856	259334	3478	1,3
Spain	Retrofit	NOx	upper	252379	259334	6955	2,7
Spain	Retrofit	PM_{10}	lower	18702	18754	52	0,3
Spain	Retrofit	PM_{10}	upper	18650	18754	104	0,6
Spain	Retrofit	$PM_{2.5}$	lower	12510	12561	51	0,4
Spain	Retrofit	$PM_{2.5}$	upper	12458	12561	103	0,8
Italy	Anti_tampering	CO	lower	201182	201182	0	0,0
Italy	Anti_tampering	CO	upper	201182	201182	0	0,0
Italy	Anti_tampering	CO_2	lower	88365895	88365895	0	0,0
Italy	Anti_tampering	CO_2	upper	88365895	88365895	0	0,0
Italy	Anti_tampering	NOx	lower	186093	193742	7649	3,9
Italy	Anti_tampering	NOx	upper	177351	193742	16391	8,5
Italy	Anti_tampering	PM_{10}	lower	16864	17027	163	1,0
Italy	Anti_tampering	PM_{10}	upper	16677	17027	350	2,1
Italy	Anti_tampering	$PM_{2.5}$	lower	10715	10878	163	1,5
Italy	Anti_tampering	$PM_{2.5}$	upper	10529	10878	349	3,2
Italy	App_training	CO	lower	183249	201182	17933	8,9
Italy	App_training	CO	upper	95292	201182	105890	52,6
Italy	App_training	CO_2	lower	82221407	88365895	6144488	7,0
Italy	App_training	CO_2	upper	85483013	88365895	2882882	3,3
Italy	App_training	NOx	lower	190996	193742	2746	1,4
Italy	App_training	NOx	upper	151952	193742	41790	21,6
Italy	App_training	PM_{10}	lower	17014	17027	13	0,1
Italy	App_training	PM_{10}	upper	17011	17027	16	0,1
Italy	App_training	$PM_{2.5}$	lower	10865	10878	13	0,1
Italy	App_training	$PM_{2.5}$	upper	10862	10878	16	0,1
Italy	Retrofit	CO	lower	200186	201182	996	0,5
Italy	Retrofit	CO	upper	199190	201182	1992	1,0
Italy	Retrofit	CO_2	lower	88365895	88365895	0	0,0

Italy	Retrofit	CO_2	upper	88365895	88365895	0	0,0
Italy	Retrofit	NOx	lower	190190	193742	3552	1,8
Italy	Retrofit	NOx	upper	186638	193742	7104	3,7
Italy	Retrofit	PM_{10}	lower	16969	17027	58	0,3
Italy	Retrofit	PM_{10}	upper	16912	17027	115	0,7
Italy	Retrofit	$PM_{2.5}$	lower	10821	10878	57	0,5
Italy	Retrofit	$PM_{2.5}$	upper	10763	10878	115	1,1
Germany	Anti_tampering	CO	lower	597660	597660	0	0,0
Germany	Anti_tampering	CO	upper	597660	597660	0	0,0
Germany	Anti_tampering	CO_2	lower	169760581	169760581	0	0,0
Germany	Anti_tampering	CO_2	upper	169760581	169760581	0	0,0
Germany	Anti_tampering	NOx	lower	198254	205386	7132	3,5
Germany	Anti_tampering	NOx	upper	190103	205386	15283	7,4
Germany	Anti_tampering	PM_{10}	lower	22087	22095	8	0,0
Germany	Anti_tampering	PM_{10}	upper	22078	22095	17	0,1
Germany	Anti_tampering	$PM_{2.5}$	lower	12034	12042	8	0,1
Germany	Anti_tampering	$PM_{2.5}$	upper	12024	12042	18	0,1
Germany	App_training	CO	lower	566375	597660	31285	5,2
Germany	App_training	CO	upper	238464	597660	359196	60,1
Germany	App_training	CO_2	lower	162479646	169760581	7280935	4,3
Germany	App_training	CO_2	upper	163259746	169760581	6500835	3,8
Germany	App_training	NOx	lower	200381	205386	5005	2,4
Germany	App_training	NOx	upper	148019	205386	57367	27,9
Germany	App_training	PM_{10}	lower	22081	22095	14	0,1
Germany	App_training	PM_{10}	upper	22061	22095	34	0,2
Germany	App_training	$PM_{2.5}$	lower	12027	12042	15	0,1
Germany	App_training	$PM_{2.5}$	upper	12007	12042	35	0,3
Germany	Retrofit	CO	lower	597350	597660	310	0,1
Germany	Retrofit	CO	upper	597040	597660	620	0,1
Germany	Retrofit	CO_2	lower	169760581	169760581	0	0,0
Germany	Retrofit	CO_2	upper	169760581	169760581	0	0,0
Germany	Retrofit	NOx	lower	204487	205386	899	0,4
Germany	Retrofit	NOx	upper	203589	205386	1797	0,9
Germany	Retrofit	PM_{10}	lower	22079	22095	16	0,1
Germany	Retrofit	PM_{10}	upper	22062	22095	33	0,1
Germany	Retrofit	$PM_{2.5}$	lower	12025	12042	17	0,1
Germany	Retrofit	$PM_{2.5}$	upper	12008	12042	34	0,3
France	Anti_tampering	CO	lower	199944	199944	0	0,0
France	Anti_tampering	CO	upper	199944	199944	0	0,0
France	Anti_tampering	CO_2	lower	87164049	87164049	0	0,0
France	Anti_tampering	CO_2	upper	87164049	87164049	0	0,0
France	Anti_tampering	NOx	lower	179185	186464	7279	3,9
France	Anti_tampering	NOx	upper	170866	186464	15598	8,4
France	Anti_tampering	PM_{10}	lower	15525	15687	162	1,0

France	Anti_tampering	PM_{10}	upper	15341	15687	346	2,2
France	Anti_tampering	$PM_{2.5}$	lower	10004	10165	161	1,6
France	Anti_tampering	$PM_{2.5}$	upper	9819	10165	346	3,4
France	App_training	CO	lower	189561	199944	10383	5,2
France	App_training	CO	upper	80728	199944	119216	59,6
France	App_training	CO_2	lower	83488263	87164049	3675786	4,2
France	App_training	CO_2	upper	83857918	87164049	3306131	3,8
France	App_training	NOx	lower	181557	186464	4907	2,6
France	App_training	NOx	upper	130171	186464	56293	30,2
France	App_training	PM_{10}	lower	15682	15687	5	0,0
France	App_training	PM_{10}	upper	15675	15687	12	0,1
France	App_training	$PM_{2.5}$	lower	10160	10165	5	0,0
France	App_training	$PM_{2.5}$	upper	10154	10165	11	0,1
France	Retrofit	CO	lower	199722	199944	222	0,1
France	Retrofit	CO	upper	199500	199944	444	0,2
France	Retrofit	CO_2	lower	87164049	87164049	0	0,0
France	Retrofit	CO_2	upper	87164049	87164049	0	0,0
France	Retrofit	NOx	lower	185714	186464	750	0,4
France	Retrofit	NOx	upper	184964	186464	1500	0,8
France	Retrofit	PM_{10}	lower	15674	15687	13	0,1
France	Retrofit	PM_{10}	upper	15661	15687	26	0,2
France	Retrofit	$PM_{2.5}$	lower	10152	10165	13	0,1
France	Retrofit	$PM_{2.5}$	upper	10139	10165	26	0,3
Finland	Anti_tampering	CO	lower	35979	35979	0	0,0
Finland	Anti_tampering	CO	upper	35979	35979	0	0,0
Finland	Anti_tampering	CO_2	lower	10913519	10913519	0	0,0
Finland	Anti_tampering	CO_2	upper	10913519	10913519	0	0,0
Finland	Anti_tampering	NOx	lower	18213	18917	704	3,7
Finland	Anti_tampering	NOx	upper	17408	18917	1509	8,0
Finland	Anti_tampering	PM_{10}	lower	2015	2036	21	1,0
Finland	Anti_tampering	PM_{10}	upper	1992	2036	44	2,2
Finland	Anti_tampering	$PM_{2.5}$	lower	1303	1323	20	1,5
Finland	Anti_tampering	$PM_{2.5}$	upper	1279	1323	44	3,3
Finland	App_training	CO	lower	34940	35979	1039	2,9
Finland	App_training	CO	upper	15207	35979	20772	57,7
Finland	App_training	CO_2	lower	10644769	10913519	268750	2,5
Finland	App_training	CO_2	upper	10488560	10913519	424959	3,9
Finland	App_training	NOx	lower	18530	18917	387	2,0
Finland	App_training	NOx	upper	15172	18917	3745	19,8
Finland	App_training	PM_{10}	lower	2035	2036	1	0,0
Finland	App_training	PM_{10}	upper	2032	2036	4	0,2
Finland	App_training	$PM_{2.5}$	lower	1322	1323	1	0,1
Finland	App_training	$PM_{2.5}$	upper	1319	1323	4	0,3
Finland	Retrofit	CO	lower	35914	35979	65	0,2

Finland	Retrofit	CO	upper	35849	35979	130	0,4
Finland	Retrofit	CO_2	lower	10913519	10913519	0	0,0
Finland	Retrofit	CO_2	upper	10913519	10913519	0	0,0
Finland	Retrofit	NOx	lower	18625	18917	292	1,5
Finland	Retrofit	NOx	upper	18333	18917	584	3,1
Finland	Retrofit	PM_{10}	lower	2032	2036	4	0,2
Finland	Retrofit	PM_{10}	upper	2028	2036	8	0,4
Finland	Retrofit	$PM_{2.5}$	lower	1319	1323	4	0,3
Finland	Retrofit	$PM_{2.5}$	upper	1315	1323	8	0,6

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