uCARe

You Can Always Reduce Emissions

because you care

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uCARe consortium

Document information

Additional author(s) and contributing partners

Name	Organisation
Michal Vojtíšek	CVUT
Joep van den Meiracker	TNO
Declan van Heesen	TNO

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Executive summary

Beyond conventional (PEMS/SEMS) and cheap (OBD/CAN/sensor-based) measurements, uCARe also offers easy-to use tests and tricks to monitor the state of a vehicle, with respect to environmental performance, by making use of looking, smelling, and touching, and simple household and do-it-yourself (DIY) products: Citizen Science. The tests and tricks are illustrated, filmed and documented for later use in social media channels and public performance in for instance a fairground setting (relevant for WP3). Low-cost assessment methods are intended to be used to create awareness for a broad public, by enabling anybody to get an indication of the performance of a vehicle.

These results are clustered in two categories.

- Do-it-yourself emission test methods with simple household products
- Emission test methods with simple lab-grade equipment

Several DIY test methods have been developed and performed and five of them have been filmed. First the CO meter test, which provides measuring carbon monoxide (CO) emissions while the vehicle is idling using a household CO meter. Second, the exhaust particulate matter (PM) test which involves measuring PM emissions while the vehicle is idling, using a cooker hood extractor filter to visualize the particles. Third, the exhaust PM swipe test, which visualizes PM emissions after the vehicle has driven using a paper towel to show the particles. Fourth, the brake dust PM test, which involves the visualization of brake dust after the vehicle has driven, using a cotton bud to show the particle deposition. Fifth, the driving style test with smartphone app, which assesses driving behaviour and provides feedback on decreasing pollutant emissions while driving. And finally the diesel particle filter (DPF) inspection, which measures the state of the DPF by using a modified smoke detector. These instruction and example films are intended to be used by WP3 in an awareness pilot and can be found on the official uCARe website.

In the simple lab-grade equipment category, two emission test methods have been developed and performed. The parking lot method involves measuring tailpipe nitrogen oxides (NOx) and particle number (PN) emissions, while theschool square methods measureparticle matter concentration in city streets and near schools. The resulting scripts for performing tests in public (e.g., on parking lots) are foreseen to be used in a WP3 pilot, e.g., at a fairground event.

Both the DIY tests and the simple lab-grade equipment tests distinctively contribute to two highly promising use-cases: awareness campaigns and educational purposes. These can spark a change in vehicle owner behaviour and stimulate increased consciousness about harmful emissions among (future) vehicle owners.

Table of contents

List of Figures

List of Tables

Definitions & Abbreviations

DIY	Do-it-yourself
NOx	Nitrogen oxides
PM	Particulate matter
PN	Particle number/count
CO	Carbon monoxide
DPF	Diesel particulate filter
RPM	Revolutions per minute
SEMS	Smart emissions measurement system
PEMS	Portable emissions measurement system
OBD	On-board diagnostics
CAN	Controller area network

1 Introduction

1.1 Background uCARe

With four million people dying annually due to outdoor pollution, improvement of air quality has become one of society's main challenges. In Europe, traffic and transport have a large effect on air quality, specifically passenger cars and commercial vehicles and to a lesser extent non-road mobile machinery. While technical improvements and more stringent legislation have had a significant impact, traffic and transport emissions are still too high and air quality is still poor. Although the use of electric and other zero-emission propulsion technologies may drastically reduce the pollutant exhaust emissions from traffic, the slow introduction of such vehicles as well as the trend of increasing vehicle lifetimes means that vehicles with internal combustion engines are expected to dominate the fleet beyond 2030. The uCARe project provides the opportunity to improve emissions of vehicles, not by improving vehicle technology, but by actively involving vehicle users and enabling their contribution to clean driving.

So far, expertise on pollutant emissions has mainly been used to advise European policy makers on limited effectiveness of emission legislation (through real-world emission factors such as VERSIT+, HBEFA and COPERT) and how to reduce traffic and transport pollutant emissions. The numerous mitigation methods are rarely extended to include the perspectives of users; uCARe enables a next essential step: providing user targeted emission reduction measures. These measures will be implemented and evaluated in real-life pilot projects.

The overall aim of uCARe is *to reduce the overall pollutant emissions of the existing combustion engine vehicle fleet by providing vehicle users with simple and effective tools to decrease their individual emissions and to support stakeholders with an interest in local air quality in selecting feasible intervention strategies that lead to the desired user behaviour*. The overall aim is accompanied by the following objectives:

1. To identify **user-influenced vehicle emission aspects** (such as driving behaviour and vehicle component choice).
2. To determine the **emission reduction potential** of each vehicle emission aspect with help of the uCARe model developed within a toolbox.
3. To develop a **toolbox**, containing models and emission reduction measures, that enables stakeholders to identify the most appropriate intervention strategies that reflect the specific users and their motivation.
4. **Support policy makers** and other **stakeholders with an interest in air quality,** such as municipalities and branch organizations, **in identifying intervention strategies** that translate the measures into desired behaviour of the user.
5. **To test and evaluate** intervention strategies in a set of pilot projects conducted with various target user groups in at least four European countries. The pilot projects illustrate effectiveness and feasibility of the toolbox and intervention strategies developed on its basis.
6. Perform an **impact assessment** of the intervention strategies effectiveness, in terms of cost, penetration, achieved emission reduction and lasting effects.
7. **Actively feed** European cities and international parties with uCARe learning and results, via awareness raising campaigns, communication tools, interactive web application and other dissemination activities. Open access to the broad public to the toolbox, data and developed tools.
8. Summarise the findings **in blueprints for rolling out** different user-oriented emission reduction programmes, based on successful pilots.

This deliverable is part of WP1 – Assessment of user impact on pollutant emissions. Beyond conventional (PEMS/SEMS) and cheap (OBD/CAN/sensor-based) measurements, uCARe also offers easy-to use tests and tricks to monitor the state of a vehicle by making use of looking, smelling, and touching, and simple household and DIY products: Citizen Science.

The tests and tricks are illustrated, filmed and documented for later use in social media channels and public performance in, for instance, a fairground setting (relevant for WP3). Low-cost assessment methods are intended to be used to create awareness for a broad public, by enabling anybody to get an indication of the performance of a vehicle.

1.2 Purpose of the document

The purpose of this document is to describe the results of the Citizen Science task in uCARe. These results are clustered in two categories.

- Do-it-yourself emission test methods with simple household products
- Emission test methods with simple lab-grade equipment

In the DIY category, several emission test methods have be developed, performed and filmed. These measurements are using simple household products in safe (stationary) conditions. The results of the test methods will be correlated with emissions under normal (driving) conditions.

The resulting instruction and example photos and films are intended to be used by WP3 in an awareness pilot.

Also in the simple lab-grade equipment category several emission test methods have been developed, performed and filmed. These measurements use simple lab-grade equipment in safe (stationary) conditions, or mini-PEMS (or portable emissions measurement systems). The quality of the test results has been validated against lab-grade equipment.

The resulting scripts for performing tests in public (e.g. parking lot) are foreseen to be used in a WP3 pilot, e.g. at a car fair.

1.3 Document Structure

The structure of this document follows the categories identified in section 1.2.

Chapter 2 provides a 'catalogue', i.e. a very short description for each measurement.

Chapter 3 describes the DIY tests in more detail. In addition to the test method, also the expected (in-/)accuracy is discussed.

Chapter 4 describes the measurements using simple lab-grade equipment. Considering the circumstances in which these measurements are intended to be performed, the accuracy will be discussed.

Chapter 5 links the measurements to the different types of campaigns in which they can be used.

1.4 Deviations from original DoW

1.4.1 Description of work related to deliverable as given in DoW

"In this deliverable, the citizen science tests are described with reference to the websites, YouTube video clips and other media outcome for use in WP3."

1.4.2 Time deviations from original DoW

None.

1.4.3 Content deviations from original DoW

None.

2 Catalogue

Table 2-1: Catalogue of available test descriptions

Name of test	Purpose	Difficulty	Section
CO meter test	Gives insight into the CO emissions of an idling vehicle.	◇◇◇◇	3.1
Exhaust PM test with extractor filter	Gives indicative insight into the PM emission of an idling vehicle.	◇◇◇	3.2
Exhaust PM swipe test	Gives indicative insight into the PM emissions of a vehicle depending on the use.	◇◇	3.3
Brake dust PM test with cotton bud.	Gives indicative insight into the PM emissions of the braking system depending on the use.	◇◇	3.4
Driving style test with smartphone app	Gives feedback on the driving style regarding unnecessary braking und hard accelerations.	◇	3.5
DPF inspection with ionization-type household smoke detector	Gives insight into the state of the DPF of the vehicle.	◇◇◇◇◇	3.6
Parking lot test	Gives accurate NOx concentration and particle matter measurements.	◇◇◇◇◇	4.1
School square test	Gives accurate particle concentration measurements.	◇◇◇◇◇	4.2

Difficulty: From easy (◇) to difficult (◇◇◇◇◇); relative to category, i.e. easy lab-grade can be more difficult than a difficult DIY test

Section: 3.x are DIY tests; 4.x are measurements using lab-grade equipment.

3 DIY test descriptions

In this chapter the Citizen Science do It Yourself tests are discussed. There are six successful tests highlighting varying topics; going from Carbon Monoxide (CO) emission to driving style improvement. For five of them an instruction video has been developed. In chapter 3.7 the unsuccessful tests and second choices are listed for future reference. Some test ideas did not give the desired result, while other ideas were simply improved.

3.1 CO meter test

This test will give the user insight into the CO emission of their vehicle. The emission is tested with a warm engine at idle(running while stationary), using a cheap CO meter. The CO meter will return a value that can be related to legislation values. This will give the user a feeling for what values are considered good and how much their vehicle emits in practice compared to this.

3.1.1 Equipment used

- CO meter for home application (approx. €20)
- Transparent airtight box (approx. €5)
- Compression fitting (approx. €2)
- Hose (approx. €1)
- Syringe (approx. €2)
- Computer with Excel

Figure 3-1: CO meter test equipment

3.1.2 Steps in the test

1. Place the CO meter in the sealed box.
2. Take the vehicle for a short drive of around 15 minutes until the engine is warmed up.
   This step is skipped when the user wants to know the CO emissions of his vehicle after a cold start.
3. Let the vehicle's engine run at idle speed.
4. Use the syringe to take a sample from the exhaust.
5. Empty the syringe sample into the box.
6. Wait for 15 minutes for the measurement to stabilize.
7. Read the CO meter result.

8. Use the online calculation tool to determine CO ppm in the exhaust gas.

Figure 3-2: CO test step 4 (left) and step 5 (right)

3.1.3 Accuracy assessment

This test provides a good insight into the CO emission of the vehicle. The results of the cheap CO meter were compared to a TEN 5-gas analyser data. As can be seen below the Flamingo FA370 (cheap CO meter) shows reliable results between 20 and 200 ppm CO. The outcome can be directly compared to the legally allowed values for the corresponding Euro class.

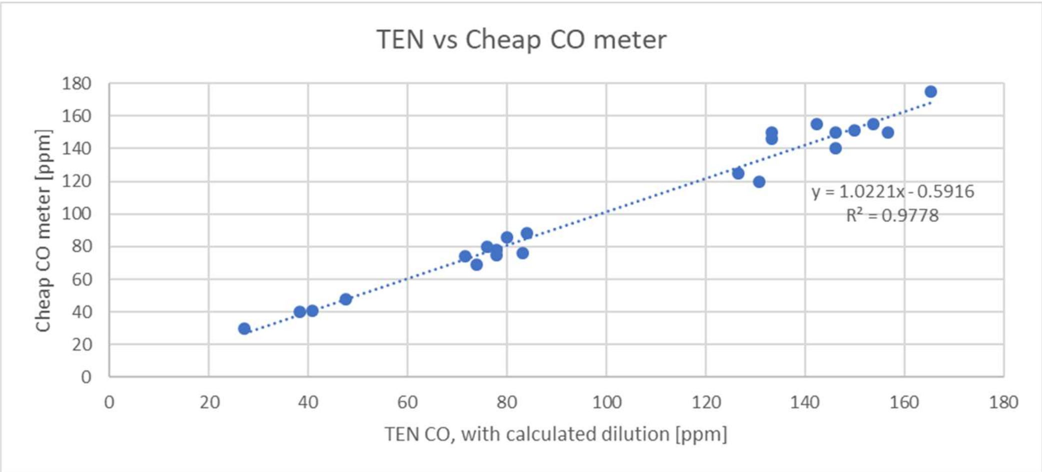

Figure 3-3: Validation of the cheap CO meters with a TEN 5-gas analyser

The validation tests were performed with 3 different CO meters, 3 different box sizes and 4 different sample sizes. The dilution was calculated using:

$$CO_{diluted} = CO_{TEN} * \frac{V_{Sample}}{V_{Box}}$$

This result was compared to the displayed CO ppm on the cheap CO meter. A correlation (R^2) of 0.9778 was found between the two, indicating a very good match in measurement results.

3.1.4 Materials delivered

DIY instruction video:

https://www.youtube.com/watch?v=sl5NXgg_Q-c

DIY instruction video with voice-over:

https://www.youtube.com/watch?v=ktvmuP8JoE0

Excel calculation tool:

https://www.project-ucare.eu/wp-content/uploads/2020/02/DIY-CO-METER-TOOL.xlsx

3.2 Exhaust PM test with extractor filter

This test will give the user insight into the particulate matter (PM) emission of their vehicle. The emission is tested with a warm engine at idle using a piece of extractor filter. The filter will turn dark when a lot of PM is emitted by the vehicle. In the video a couple of samples are shown as reference. This will give the user a sense of how much PM their vehicle emits and how this compares to other vehicles.

3.2.1 Equipment used

- Extractor filter (approx. €2)
- Scissors (approx. €2)
- Rubber band (approx. €1)

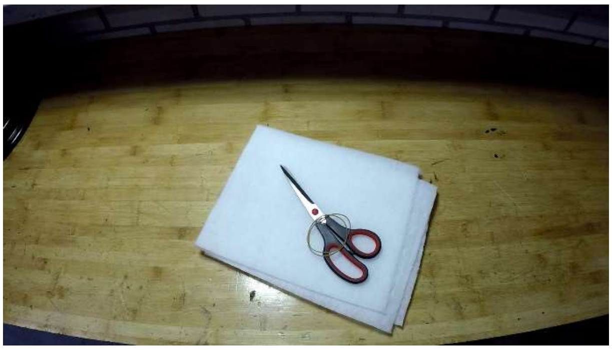

Figure 3-4: Exhaust PM with extraction filter equipment

3.2.2 Steps in the test

1. Cut the extractor filter into a rectangle with a size of approximately 18x14cm.
2. Take the vehicle for a short drive of around 15 minutes, afterwards turn off the engine.
3. Put the extractor filter over the exhaust using a rubber band.
4. Let the vehicle idle for 5 minutes.
5. Turn off the engine and remove filter.
6. Let the filter dry for 10 minutes.
7. Compare filter to showcased filters.

Figure 3-5: Exhaust PM with filter test step 3 (left) and step 7 (right)

3.2.3 Accuracy assessment

This test provides a good indication of the PM emission of the vehicle. The method shows a clear grey-scale on the filter. The more PM the vehicle emits, the darker the tissue becomes. The particles come out in different sizes, so the filter may not block very small particles. A dirty filter therefore means the vehicle emits a lot of particles, but a clean filter does not guarantee low particle emissions. This method will illustrate the amount of particles the vehicle emits while idling.

3.2.4 Materials delivered

DIY instruction video:

https://www.youtube.com/watch?v=oDzAUnm4cXU

DIY instruction video with voice-over:

https://www.youtube.com/watch?v=n_ec1JRB5pw

3.3 Exhaust PM swipe test

This test gives the user insight into the PM emission of their vehicle. The emission is tested under all driving conditions the owner exposes the vehicle to. The amount of PM is visualized by swiping a paper towel through the exhaust tip and looking at how much soot has accumulated, after initially cleaning it. Depending on the usage a different outcome is expected. This will give the user a sense of how much PM their vehicle emits and what the effects of cold starts and aggressive driving are.

3.3.1 Equipment used

- Paper towel (approx. €1)
- Soapy water (approx. €1)

Figure 3-6: Exhaust PM swipe test equipment

3.3.2 Steps in the test

1. Clean the (cold) exhaust tip inside and outside using paper towel (and possibly soapy water).
2. Drive for at least 100 km cumulatively, e.g., in normal use on several days.
3. Swipe a piece of paper towel through the (cooled down) exhaust tip.
4. Examine black coal/soot on the paper towel.

5. Repeat the test with less cold starts and less hard accelerations.

Figure 3-7: Exhaust PM swipe test step 1 (left) and step 4 (right)

3.3.3 Accuracy assessment

This test gives indication of the PM emissions of the vehicle. The method shows the soot residue on the paper towel. It is capable of displaying three possibilities; no visible PM, some PM and a lot of PM. The test should be performed multiple times, so the outcome will give insight into the effect of cold starts/driving short distances and aggressive driving behaviour on PM emissions.

3.3.4 Materials delivered

DIY instruction video:

https://www.youtube.com/watch?v=i2jisrfyJx0

DIY instruction video with voice-over:

https://www.youtube.com/watch?v=dMzubwr4lY4

3.4 Brake dust PM test with cotton bud

This test gives the user insight into the brake dust PM emission of their vehicle. The emission is tested under all driving conditions the owner exposes the vehicle to. The amount of brake dust PM is visualized by swiping a cotton bud over the rim and looking at how much dust has accumulated. Brake dust particles get a static charge as they are worn off the brake pad surface and will therefore stick to the wheels. Depending on the usage a different outcome is expected. This will give the user sense of how much brake dust PM their vehicle emits and what the effects of different driving styles and different routes are.

3.4.1 Equipment used

- Paper towel (approx. €1)
- Soapy water (approx. €1)
- Cotton buds (approx. €1)

Figure 3-8: Break dust PM test equipment

3.4.2 Steps in the test

1. Clean the rims of the vehicle.
2. Swipe a cotton bud over the wheel rim to check if it is really clean.
3. Drive for at least 100 km cumulatively in dry weather, e.g., over several days.
4. Inspect wheels and swipe cotton bud over the wheel.
5. The "dirt" on the cotton bud is dust from the vehicle's brakes.
6. Repeat the test with different driving style.

Figure 3-9: Brake dust PM test step 1 (left) and step 5 (right)

3.4.3 Accuracy assessment

This test gives an indication of the PM emissions of the braking system of the vehicle. The grayscale colour difference cannot be directly expressed into an exact amount of brake dust particles, but it will give an insight in the often overlooked pollutant emissions of the braking system. This method will illustrate the effect of aggressive driving behaviour on brake PM emission. It can also shed light on an improper functioning braking system, by comparing the dust on the wheels on the left and the right side (more brake dust on the front wheels than on the rear wheels is normal and expected).

3.4.4 Materials delivered

DIY instruction video:

https://www.youtube.com/watch?v=C81ddn8bpGY

DIY instruction video with voice-over:

https://www.youtube.com/watch?v=y9S_dbXmpjA

3.5 Driving style test with a smartphone application

This test gives the user insight into the importance of a driving style on pollutant emissions and fuel consumption. This method uses a smartphone application that measures the acceleration and deceleration of the vehicle while driving. In general, driving aggressively and braking excessively increases fuel consumption and pollutant emissions. The app will give feedback during the drive and rates it with a score between 1 and 10 afterwards. This will help users to improve their driving style.

3.5.1 Equipment used

- Smartphone
- Tape (approx. €5)

Figure 3-10: Driving style test equipment

3.5.2 Steps in the test

0. Install the smartphone app.
1. Put two pieces of tape on the smartphone.
2. Tape the phone to the passenger floor mat of the car. Make sure the phone is placed face up, with the top of the phone in the forward direction.
3. Launch up the smartphone app and press start drive.
4. Start driving.
5. Finish your drive and look at your score.
6. Repeat route and try to improve your score.

Figure 3-11: Driving style test step 1 (left) and 2 (right)

3.5.3 Accuracy assessment

This test provides a good assessment of the user's driving style. Fixating the telephone will reduce false readings from oscillations. A score between 1 and 10 provides direct feedback for the driver. The smoother the drive was, the higher the score will be. The driving style cannot be simply expressed in exact emissions, but the app will motivate users to improve their driving. Hard accelerations and hard braking are often unnecessary and result in increased emissions. Hard braking is especially bad, since it wastes kinetic energy and at the same time creates brake dust PM emissions. By creating awareness of these bad habits, not only pollutant emissions will decrease, but also fuel consumption.

3.5.4 Materials delivered

DIY instruction video:

https://www.youtube.com/watch?v=ywwtb69nbi4

DIY instruction video with voice-over:

https://www.youtube.com/watch?v=eX8IVX6_D-g

Smartphone app:

Apple AppStore:

https://apps.apple.com/app/id1496013824

Google PlayStore:

https://play.google.com/store/apps/details?id=com.tno.ucare&hl=en_US

3.6 Diesel particle filter inspection with ionization-type household smoke detector

This test gives the user insight into the performance/state of the diesel particulate filter (DPF) of their diesel-fuelled vehicle. The test uses an off-the-shelf ionization-type household or industrial smoke detector, which is available for tens of euros and is modified to provide an analogue voltage output and to provide a quantitative measurement equivalent to the sum of the diameters of the particles (total particle length), analogous to considerably more expensive electric charge-based instruments (DiSCMini, eTAPS, Partector, etc.). More elaborate designs with custom-made heated enclosure were exploited previously for on-road (PEMS-type) measurement.

3.6.1 Equipment used

For citizen science purposes, the smoke alarm was modified by providing a stabilized supply voltage instead of the standard 9 Volt battery power supply, soldering two wires to the on-board integrated circuit to export analog voltage signal, and disconnecting the sound alarm. The analog voltage signal was fed into a high input impedance, unity gain operating amplifier (a voltage-following chip, a several EUR component readily available at local electronics hobby stores), the output of which was directed to a Raspberry-Pi-compatible analog-to-digital convertor circuit, and read by a Raspberry-Pi microcomputer/ Total cost tens of EUR setup using hobby store components. The detector was placed in an enclosure made from household plumbing components from a local plumbing store. A piece of 6 mm diameter copper pipe was used as the sampling probe. A micro-size industrial membrane pump was used, although a low-cost aquarium aeration pump would also be suitable, bringing the cost of the entire setup to under 100 euros.

Figure 3-12: DPF inspection tool in action

3.6.2 Steps in the test

The detector is used as a 4-gas or 5-gas analyser used throughout the EU for periodic emissions inspection and for automotive diagnostics purposes.

First, the engine needs to be warmed up, shortly after operating at a load (i.e., a car being driven into a parking lot), and active DPF regeneration must not be taking place. The sample probe is first exposed to ambient air, serving as a zero calibration reference, and then inserted into the tailpipe. Any reading above the instrument noise is an indication of a leaky or defunct diesel particle filter.

3.6.3 Calibration

The zero calibration of the unit takes place using relatively clean ambient air. The span calibration of the unit is verified by exposing the sample probe to a very high particle concentration (near the saturation limit), i.e., from cigarette smoke. The limit of detection is determined by leaving the unit to sample air in the location intended for testing for at least several hours, as the triple of the standard deviation of the voltage readings (covering 99.7% of the assumed normal distribution).

3.6.4 Accuracy assessment

The realistic practical detection limit is estimated to be on the order one million of particles per cm^3 (10^6 #/cm^3). Lower detection limits, for instance, hundreds of thousands of particles percm^3 during vehicle exhaust tests and on the order of 10^5 #/cm^3 during laboratory aerosol tests, were observed, but this was under research laboratory conditions, at the university.

3.6.5 Limitations and alternative methods

The detection limit of around 10^6 #/cm^3 is higher than the proposed limits for periodic technical/emissions inspection (the international New Periodic Technical Inspection initiative, NPTI) of 100-250 thousands #/cm^3, a value likely to be achieved by considerably more expensive (currently on the order of 10 000 EUR, with possible decrease to thousands of EUR in several years) diffusion charger detectors. However, the detection limit is sufficient to distinguish a compliant DPF (particle concentrations from undetectable to thousands or tens of thousands #/cm^3) from absent or substantially damaged DPF (particle concentrations are easily in millions to tens of millions #/cm^3).

The ionization type smoke detector uses a miniature radioactive source (alpha emitter ^{241}Am, 3-30 kBq depending on the model used), considered to be insignificant and below the reportable limit. All radiation is contained within the ionization chamber. According to tests done by the manufacturer of the detector, about 6-7 cm of air or a sheet of paper is sufficient to lower the radiation to non-detectable limits. This type of detector was readily sold at hardware stores in the U.S. for household use for decades, without handling and disposal constituting a problem. The ionization chamber was not modified in any way from the original design, and placing the entire unit into an additional enclosure (required to contain the sampled exhaust) provides additional protection. However, concerns about radioactive materials, whether warranted or not, pose a major limit on the utilization of the unit.

An alternative DPF integrity test, despite not being sound from a metrology view, is a visual assessment of the soot deposits in the exhaust system. This is described above in Section 3.3.

3.6.6 Materials delivered

Poster at the European Aerosol Conference 2019:

https://www.project-ucare.eu/wp-content/uploads/2019/11/EAC2019_P1-176_Vojtisek.pdf

3.7 Unsuccessful attempts and second choices

The tests described in section 3.1 - 3.5 were the result of some trial and error. And some ideas did not work at all. This section describes the unsuccessful attempts, both as a challenge for others to find solutions that do work and to prevent others to try alternatives that proved to be a second choice.

3.7.1 CO meter with constant flow

This test was almost the same as the CO meter with sample (section 3.1), however here the exhaust of the vehicle was directly connected to the box with the CO meter. The exhaust gasses formed a flow through the box and by the CO meter. The CO meter was clearly made for a non-flowing, homogeneous environment. The CO ppm readout would simply keep rising as time went by. Instead of getting an insight into the amount of CO by receiving a ppm readout, it would give an indication by the time it took to reach maximum value/start beeping.

3.7.2 Tyre pressure road load visualization

This test was aimed at giving an insight into the impact of incorrect tyre pressure. The test was tried with powdered sugar and cardboard. The vehicle was placed on a flat surface, the material was lain on floor right before the wheel(s). The vehicle was driven over the material slowly and the material was photographed. This was repeated using different tyre pressures. With a lower tyre pressure, the total area of contact is bigger than on correct tyre pressure.

The main problem with this test was that it was very hard to see any difference between an extremely low tyre pressure and a correct one. The difference was very small and hard to see by just comparing photographs.

3.7.3 Tyre pressure rolling resistance test

This test was aimed at giving an insight into the impact of incorrect tyre pressure. The test was tried using an elastic cord, a ratchet strap and different types of spring scales. The vehicle was placed on a flat surface, the ratchet strap was connected to a sturdy pole, the elastic cord was connected to the tow hook of the vehicle and the spring scale was put in between the elastic cord and the ratchet strap. For the test the tension on the ratchet strap was increased until the vehicle started moving slightly, then the spring scale was read. This was repeated using different tyre pressures. With a lower tyre pressure, the static friction is higher than with correct pressure.

The main problem with this test was the small difference between low and correct tyre pressure, combined with a very low reproducibility of the test. The small difference together with the poor reproducibility made results non-conclusive. Poor reproducibility could result from multiple factors: a non-flat surface, a hard to read spring scale, inconsistently rubbing/sticking brakes on the vehicle, etc. On top of that, for pollutant emissions the rolling resistance is way more important than static friction, deeming this test unsuccessful.

3.7.4 Brake PM, alternatives with stickers and brake dust barrier spray

These test was almost the same as the tyre PM with cotton bud wheel swipe (section 3.4), however here the brake dust would be visualized by pieces of double sided tape on the wheel of the vehicle or with a spray. However, brake dust has a static charge and therefore sticks aggressively to wheels. When braking, the brake pads are pressed onto the rotor, charging each particle as it is slung into the air. After applying the stickers and having driven some kilometres, the stickers turned out slightly darker than before. However, not only brake dust sticks to the tape, but also road dirt. Therefore, the discolouring of the stickers cannot be directly appointed to brake dust emission. Using the brake dust barrier on one half of the wheel should lead to a difference which can be seen easily. One half of the wheel would get dirty with brake dust, while the other remained brake dust free. The main problem with this alternative is that it’s hard to see brake dust on dark wheels and applying the barrier spray must be done with precision and patience.

3.7.5 Exhaust PM, alternative with other filter materials

The exhaust PM test (section 3.3) was tried using different types of material. For the test the following materials were tried: paper towel, disposable duster tissues, vacuum cleaner bags, dust masks and of course extraction filters. The extraction filter was by far the best option. The second best was the vacuum cleaner bag, whereas the paper towel, disposable duster tissue and dust mask were unsuccessful to say the least. The first two were simply not able to handle the water vapor, while the dust mask was restricting exhaust flow severely.

3.7.6 Cup spill test

This test was aimed at giving the user insight into the importance of a driving style on emissions and fuel consumption, and how to improve their driving style, just like the accelerometer app test (section 3.5). For this test a shaker bottle was used, in which holes were drilled horizontally over 360 degrees. The idea was that the bottle was filled with coloured water (water + ink) and placed on top of a paper towel inside the transparent box. While driving aggressively the fluid would spill in a certain direction, leaving a mark on the paper towel. Afterwards the driver could examine in what domain of driving there could be improved smoothness. The four domains being: steering left, steering right, acceleration and braking.

There were a couple of flaws. First of all, when cornering smoothly and steadily at high speed (highway) the lateral acceleration would cause fluid spillage, even though this is not necessarily due to bad or aggressive driving behaviour. This meant two of the four domains were not useful for this test. One thing that is unmistakably true is that unnecessary braking leads to increased fuel consumption and increased pollutant emissions. This leaves two domains for the smooth driving test: acceleration and braking. The idea was to weigh the bottle filled with water before and after the test. The weight loss should indicate the amount of unnecessary braking and accelerating, improving your driving style is done by minimizing the total weight loss in water. Doing this with an app which directly gives a score is much easier, less messy, more accurate and more suited for the desired goal of citizen science.

4 Measurements using simple lab-grade equipment

In this chapter the tests using simple lab-grade equipment are discussed. There are two parts: a parking lot measurement of old diesel vehicles and the school square ambient particle measurement. The main difference between these tests and the DIY ones is the equipment complexity and cost. For this chapter's tests professionals are required to show people the pollutant emissions.

4.1 Parking lot measurement

On May 18th, 2019 Toyota organized a contest called 'We Want Your Diesel'. The goal was to find the most polluting passenger vehicle in the Netherlands, crush it and replace it by a new Toyota Corolla Hybrid. For the campaign ten candidate vehicles were selected from a database delivered by Toyota. These ten vehicles' owners were invited and their vehicles were measured, in an idle test and increased rpm idle test. The exhaust gas was tested for NO_x concentration and particle matter (particle number and opacity measurements). The values acquired by the measurement were then compared to a reference based on average Euro-1 vehicle emissions. Using this, a scrapping score was given. The vehicle with the highest score, a 1985 VW Golf GTD, was deemed the most polluting and therefore crushed.

Figure 4-1: Measuring the NOx and PN during the Toyota campaign

4.1.1 Equipment used

- Portable SEMS; for Nitrogen Oxides (NOx) concentration, using and automotive sensor
- TSI-NPET; for number of particles (PN)
- Smoke opacity meter; for visible smoke, as used in PTI
- 4-gas analyzer; for establishing stability of exhaust gas, as used in PTI

4.1.2 Steps in the test

1. Warm up the engine
2. Let the engine idle
3. Establish that the exhaust gas is stable
4. Measure NO_x and PM
5. Let the engine idle at increased RPM
6. Establish that the exhaust gas is stable
7. Measure NO_x and PM

4.1.3 Accuracy assessment

The equipment is of professional quality and validated [1].

4.1.4 Materials delivered

The "High emission vehicles in Toyota campaign" report [2].

4.2 School square particle measurements

In May and June 2019, a pilot series of measurements of particle concentrations took place in the streets of Prague with the cooperation with the City of Prague and several citizen groups. The goal was to explore the exposure of children traveling to and from school to nanoparticles emitted by motor vehicles, and in general, how citizens can reduce their exposure to nanoparticles by personal choice of the mode and route of transport in Prague.

The methodology was to be designed not only to be scientifically sound, but also to allow for relatively short tests, conducted in cooperation with citizens and/or school children, the results of which could be readily interpreted during subsequent debates at public meetings, lectures, and in classrooms.

One such debate took place on June 24, 2019, at the Na Beránku elementary school in Prague 4 Modřany district. Prior to the debate, several series of nanoparticle measurements with a hand-held diffusion charger and a GPS receiver were conducted in the vicinity of the school.

4.2.1 Equipment used

A hand-held diffusion charging classifier (DiSCMini, Testo AG, Germany) was used to measure total particle number concentration. A hand-held GPS receiver was used to record instantaneous position.

Figure 4-2: Measuring particles at a school yard

4.2.2 Steps in the test

The tests were supervised by a research scientist knowledgeable in vehicle emissions and air quality to ensure suitable design and execution of the tests and interpretation of data, and to provide background information and comments to the test participants and the general community. The instruments were operated by interested citizens. Notes were taken (in writing or recorded comments) of the circumstances such as temperature, qualitative assessment of wind force and direction, traffic level, passage of vehicles, and various events associated with high particle concentrations (i.e., passage of a riding lawnmower in an otherwise vehicle-free area, passage of a vehicle emitting visible smoke, abrupt accelerations of vehicles, vehicle left idling in the parking lot, passage or presence of cigarette smokers).

The following tests were performed in the morning prior to, during and after the "peak traffic" of children:

a) A periodic measurement of particle concentrations at frequented locations, including the school entrance, to demonstrate the evolution of particle concentrations with time
b) Walk-through measurements of particle concentrations along typical travel paths, including sidewalks, pedestrian and bicycle paths separated from streets, parking lots, to demonstrate distribution of particle concentrations in the area
c) Measurements of particle concentrations at the entrance/exit to the school parking lot and in the parking lot area, to demonstrate the contribution of individual vehicles to the particle concentrations, to demonstrate differences among individual vehicles in terms of their contribution to the particle concentrations, and, to the extent the conditions permit, to demonstrate various phenomena such as the difference between leaving the engine idling and shutting it off during a short stay at the parking lot, or the effect of aggressive acceleration while leaving the parking lot on particle production

Following the tests (multiple are recommended to ensure sufficient data to demonstrate underlying phenomena), data were downloaded and analysed in a common spreadsheet application (Microsoft Excel, OpenOffice Calc and LibreOffice Calc are all useful). In addition to analyses and interpretations done by citizens and school children, independent analysis was done by the supervising scientist.

4.2.3 Accuracy assessment

The diffusion charger response is well correlated to the lung deposited surface area (sum of the products of the surface area of the particle multiplied by the probability of its deposition in human lungs), and reasonably well correlated to the particle number concentration.

The largest source of measurement uncertainty is not the instrument properties, but the randomness of the conditions, ranging from differences in background and instantaneous particle concentrations originating from atmospheric conditions (dispersion of pollutants) to differences in the production of particulate matter among individual vehicles and, for an individual vehicle, over time, based on the operating conditions of the vehicle and their history.

Therefore, data from any individual measurement or measurement campaign cannot be readily generalized in a quantitative manner, but nonetheless, relative comparisons of (typically rather substantial and readily observable) differences observed within the campaign can be exploited for educational and demonstrational purposes.

4.2.4 Materials delivered

Video from the public lecture and discussion of the results:

http://www.pedagogicke.info/2019/07/tomas-hajzler-co-dychame-kazde-rano-u.html

4.2.5 The aftermath

The Čistou stopou Prahou (Zero emissions Prague) initiative and the Pražské matky (Prague Mothers) citizen groups have actively participated in the test campaign and in the discussion and reported on the results in their documents (in Czech):

https://www.cistoustopou.cz/knihovna/o-emisich-z-dopravy-1054

https://www.prazskematky.cz/aktuality/zpatky-do-skoly-radeji-pesky/

On Aug 30, 2019, major national online news, idnes.cz, reported on the campaign and the recommendations:

https://www.idnes.cz/auto/zpravodajstvi/mamataxi-skoly-emise-prazske-matky-pruzkum-cvut.A190704_144906_automoto_taj

4.2.6 Related projects

The results of comparison of exposure to nanoparticles among travel modes and among different travel paths were reported on in May 2019 in the media, including two major TV stations, in Czech:

"Walk on quiet streets, leave the car at home"

https://zpravy.aktualne.cz/domaci/premyslejte-kudy-jdete-budete-zit-dele-varuje-praha-ukazuje/r~baa18ac46d7411e9b6a9ac1f6b220ee8/

"Measurements show that you cannot hide from emissions in your car"

https://www.idnes.cz/auto/zpravodajstvi/smog-emise-pevne-castice-michal-vojtisek-emisni-zona.A190506_204229_automoto_fdv

https://ct24.ceskatelevize.cz/veda/2806793-auto-pred-zplodinami-neochrani-ridici-dychaji-horsi-vzduch-nez-chodci-ukazal-rozsahly

https://auto.tn.nova.cz/clanek/novinky/do-mesta-autem-mhd-nebo-pesky-kdo-v-praze-nadycha-vic-skodlivin.html

To investigate the effects of morning cold start of an automobile on children, particle concentrations and particle size distributions at child head level in a back seat of a car during "take-off" from a garage were measured with absent DPF and with fully functional DPF. This was originally one of the measurements planned for the uCARe project; however, a group of journalists secured funding for the test earlier, in March 2019.

The results were reported in a three-minute documentary aired on the main evening news by the Czech Television (the largest public TV station in the country) on March 19, 2019.

https://ct24.ceskatelevize.cz/ekonomika/2763629-dvousetnasobna-koncentrace-rakovinotvornych-latek-odstraneny-filtr-pevnych-castic

https://www.idnes.cz/auto/autoservis/filtr-pevnych-castic-emise.A190314_152458_automoto_fdv

5 Usage of the measurements

In this chapter, various use-cases for the previously described tests are discussed. The measurement tests in chapter 3 and 4 contain a wide variety, both in terms of difficulty and topics. Chapter 3 mostly contains tests where building the measuring equipment as well as performing the measurement can easily be done by untrained enthusiasts, without the need of a large budget. Chapter 4 contains more precise and expensive equipment that requires to be handled by professionals. These categories distinctively contribute to two highly promising uses which are elaborated below.

5.1 Awareness campaigns

The first use-case is awareness campaigns. Awareness campaigns should act as an eye-opener for vehicle owners and trigger a change of behaviour in them.

Change of behaviour is assumed to follow the pattern of Unfreeze – Change – Refreeze. In the Unfreeze the awareness of a problem with the current behaviour should lead to a preparedness to change the behaviour. During the Change, the alternative behaviour should be experienced and with rewards/feedback the alternative behaviour will be encouraged. In the Refreeze stage the reward/feedback is diminishing and the new behaviour should become the habit.

For the Unfreeze part of the change of behaviour, demonstration and discussion is essential. Demonstration and discussion is more effective than providing readable or audio-visual material. Even more powerful is learning by doing.

The material from chapter 3 and 4 are intended to be used as effective tools in the Unfreeze stage of a pilot, either a uCARe pilot or a pilot outside uCARe. Chapter 4 is about demonstrating emissions and sparking a discussion, whereas chapter 0 is more in line with learning by doing.

Creating awareness can be a goal by itself. In particular if there is a shock unfreeze followed by a recommendation/advice, this can be effective. Often times vehicle owners are completely unaware of the emissions of their vehicle and how these affect the environment and public health. A parking lot measurement at an classic car fair, followed by a maintenance advice could really set off increased consciousness around their vehicle’s emissions.

5.2 Educational purposes

The second use-case is of educational nature. As discussed previously, often times vehicles owners are unaware of harmful emissions coming out of the tailpipe of their vehicle. Educating people from a young age, will result in increased consciousness on harmful emissions with (future) vehicle owners.

All DIY experiments in chapter 3 can be performed by people from 15 years of age and older, though for the experiments at the hot tailpipe some parental guidance might be needed. Educating kids can be done both in and out of school. For example, these experiments can be implemented in a Science & Society class context and give valuable hands-on experience. Additionally, students could sample multiple cars (from their own family and the neighbours), and even use the data for some interesting statistics on the vehicles in their community. A possible risk is that the owners of the dirtiest cars will not appreciate the feedback. These can spark a change in vehicle owner behaviour and stimulate increased consciousness about harmful emissions among (future) vehicle owners.

References

[1] R. Vermeulen, “SEMS operating as a proven system for screening real-world NOx and NH3 emissions,” TAP paper 58, 20th International Transport and Air Pollution Conference 2014, Graz.

[2] Q. Vroom and N. Ligterink, “High emission vehicles in Toyota campaign,” *TNO 2019 R11250,* 2019.