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LENS L-vehicles Emissions and Noise mitigation Solutions

D4.1
Procedure for measuring in-lab LV exhaust emissions

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Executive summary

This report serves as a comprehensive guideline for all exhaust gas emission measurement testbench activities conducted in the context of the LENS project. It encompasses critical areas such as the vehicle selection procedure, which not only aims to represent the diversity of the European L-category fleet but also incorporates considerations for tampered vehicles, special vehicles, and imports from China. The report also concerns the measurement procedure, offering a detailed overview of the entire process, from preparation and setup to measurement and post-processing, while emphasizing the importance of effective data management. Furthermore, it presents a rigorous comparison of all consortium labs, showcasing the outcomes of a Round Robin report. Notably, the results indicate strong correlations across all participating labs, with exceptional consistency observed in CO_2 measurements.

List of abbreviations

CLD	Chemiluminescence Detector
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CVS	Constant Volume Sampling
ECU	Engine Control Unit
FID	Flame Ionization Detector
FTIR	Fourier Transform Infrared Spectroscopy
HC	Hydrocarbons
LV	L-category vehicle
NDIR	Non-Dispersive Infrared
NOx	Nitrogen Oxides
NMHC	Non-Methane Hydrocarbons
OEM	Original Equipment Manufacturer
PM	Particulate Matter
PN	Particulate Number
RDC	Real Driving Cycles
RR	Round Robin
WMTC	World Motorcycle Test Cycle

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1 LENS in-laboratory LV exhaust emission testing

Within the LENS project, 150 vehicles are tested for exhaust emissions in-laboratory as well as on the road. The exhaust emission tests are performed by several partners at various locations and laboratories. In order to ensure consistent and reliable measurements, a procedure scheme for the different type of measurements was setup.

Several exhaust emission tests are planned within the LENS, starting from a Round Robin test at all measurement facilities over standard homologation tests to real-drive alike chassis dyno test. This report describes the different procedures for in-laboratory tests including boundary conditions and data management. At first the procedure for selecting the test vehicles explained, followed by the description of the single tests.

1.1 Vehicle Selection Procedure

In LENS, the selection of vehicles is a critical step to ensure that accurate and representative data is collected for the fleet of Category L-vehicles. Category L-vehicles primarily consist of motorcycles, and the selection process involves a combination of sales figures, considerations for China Imports, and mileage requirements. This chapter outlines the detailed procedure for selecting these vehicles and managing the selection process through a shared SharePoint file.

This vehicle selection procedure with its criteria is based on the vehicle table (see Table 1-1), defining the types and of different L-category vehicles.

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Table 1-1:Excerpt of the LENS application document "Table 4: First draft of test matrix in LENS"

Category	LV sub-category	EXHAUST EMISSION TESTS			NOISE EMISSION TESTS			
					On-road	Test Track		
		On-road	On-road & chassis	Chassis dyno	On-road (On-board sensor)	Real-world pattern on test track	Real-world & TA on test track	TA on test track
L1e	L1eB - Two-wheel moped 	20	4	6	1	20	4	6
L2e	3-wheel moped 	4			2	4		
L3e & L4e	L3e-A1 Low-performance 	18	4	6	2	18	4	6
	L3e-A2 Medium-performance 	18	4	6	2	18	4	6
	L3e-A3 High-performance 	18	4	6	2	18	4	6
	L3e-AxE Enduro 			4				4
L5e Tricycle	 	2	2	2	1	2	2	2
L6e	L6e-A Light on-road quad 	2	2	2	1	2	2	2
	L6e-B Light quadri-mobile 	2		2	1	2		2
L7e	L7e-B1 All terrain quad 	3	1	2	1	3	1	2
	L7e-B2 Side By Side Buggy 	3	1	2	1	3	1	2
Number of vehicles per type of test		**90**	**22**	**38**	**14**	**90**	**22**	**38**
TOTAL VEHICLES		**150**				**150**		

1.1.1 Vehicle Selection Criteria

Sales Figures

The first criterion for selecting Category L-vehicles is based on their sales figures in the years of EU4 and EU5 compliance as these regulations span from January 2017 until today and these figures are available for whole Europe. Sales figures provide a clear indication of the popularity and prevalence of a particular model. Only motorcycles that have demonstrated substantial sales during these compliance years will be considered for inclusion in the project.

China Imports

In addition to vehicles based on sales figures, Project LENS also takes into account motorcycles imported from China. This inclusion recognizes the latest developments in the vehicle sales market and ensures that the fleet represents a diverse range of motorcycles, including those from international sources.

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Minimum Mileage Requirement

To maintain data integrity and avoid any potential inaccuracies related to de-greening effects, all selected vehicles must have a minimum mileage. This minimum milage value must be between the typical de-greening milage of 3 times the EU5 standard test cycle WMTC type I and a recommendation of 3000 km (see LENS Deliverable 6.1). Due to availability and practicability reasons a minimum milage of 500 km was set. This mileage requirement helps ensure that the vehicles' components have settled into normal operating conditions, minimizing the impact of any initial wear and tear.

Management through SharePoint

To streamline the vehicle selection process and avoid duplication, a SharePoint file has been set up within the project's collaborative workspace. This file serves as a central repository for tracking selected vehicles and those intended for measurement. The following guidelines outline how the SharePoint file is utilized:

1. Inputting Selected Vehicles

Measurement partners are responsible for adding the vehicles they have selected for measurement into the SharePoint file. Each entry should include the vehicle's make, model, year, sales figures data, and mileage information. Partners must also specify whether the vehicle is a China import.

2. Preventing Duplicate Measurements

To ensure data accuracy and avoid redundancy, a strict policy is in place to prevent the measurement of the same vehicle more than once. Partners must cross-check the SharePoint file to ensure that their selected vehicle has not already been chosen by another partner.

3. Avoiding Same Engine Family

In an effort to diversify the dataset, partners are encouraged to select vehicles that do not belong to the same engine family as those already chosen. This approach helps to capture a broader representation of Category L-vehicles.

4. Constant Updates

The SharePoint file should be updated regularly to reflect the current status of vehicle selection. Partners are encouraged to communicate any changes promptly, ensuring that the selection process remains up-to-date throughout the project's duration.

Conclusion

The vehicle selection procedure for Project LENS is designed to create a representative and accurate list of Category L-vehicles. By considering sales figures, China imports, and implementing a mileage requirement, the project aims to capture a comprehensive view of the vehicle fleet. The use of the SharePoint file enhances coordination among measurement partners and ensures that no vehicle is

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measured twice or from the same engine family, thereby optimizing the quality of the collected data. Regular updates to the file are crucial to maintaining the integrity of the selection process.

1.2 Laboratory Measurement Procedure

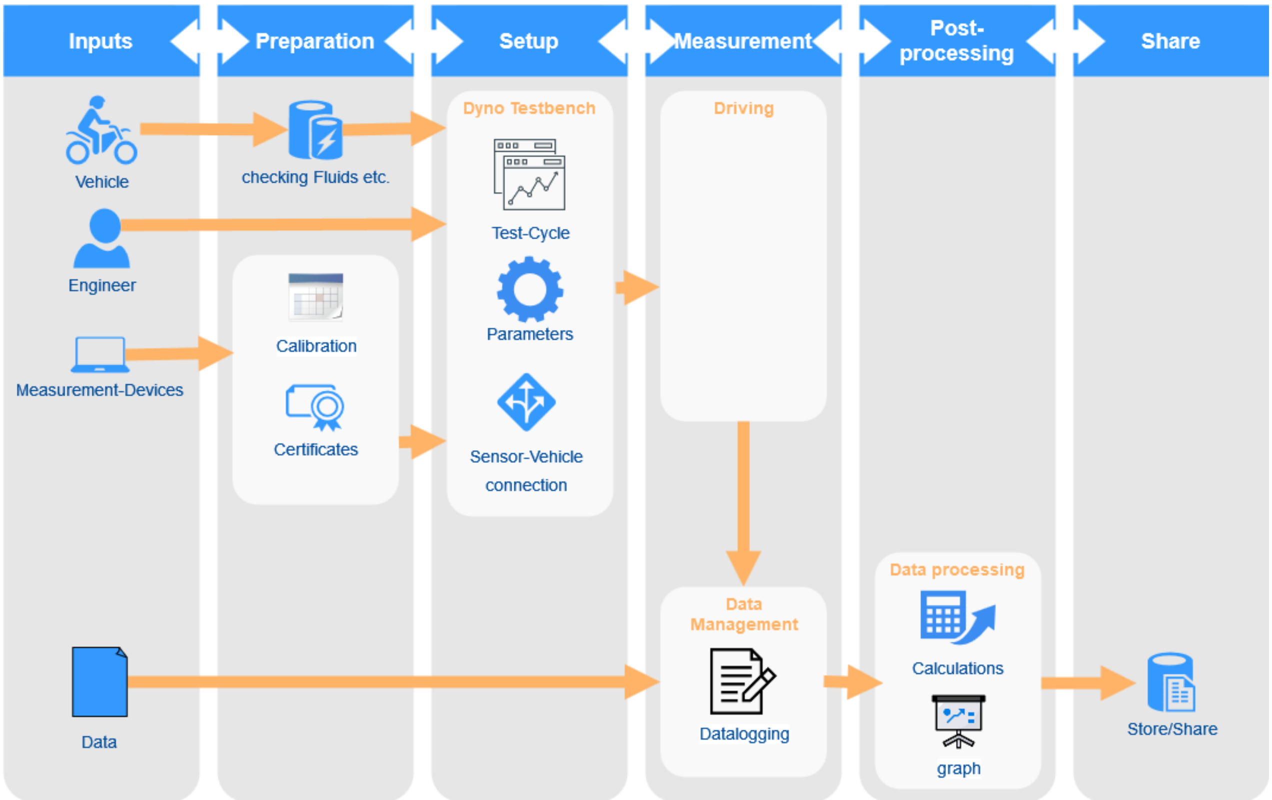

Figure 1-1:Scheme of the measurement procedure

In the following, a detailed description of the workflow (Figure 1-1) for exhaust gas emission measurements of L-category vehicles on a chassis dynamometer is given.

1.2.1 Inputs

As starting point of the workflow, the various input factors are described.

Vehicle

It is imperative that vehicles meet the requirements of the vehicle selection procedure to ensure comprehensive coverage of the entire L-category and an accurate representation of the European fleet. By adhering to these selection criteria, it can be guaranteed that the vehicle sample includes diverse types and models, reflecting the full spectrum of L-category vehicles on European roads.

This approach enables us to gather data that accurately represents the real-world scenarios and characteristics of these vehicles, ultimately leading to more effective regulatory and policy decisions within the European automotive landscape.

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Engineer

An engineer trained on the laboratory equipment and emission measurement procedure as well as an experienced test driver have to conduct the measurements.

Measurement Devices

Standard measurement devices, requirements procedures as defined in the homologation legislation Regulation (EU) No. 134/2014 and No. 168/2013 as well as in the Round Robin procedure approved devices for measurement of chassis dynamometer emission measurements have to be used together with special measurement equipment as explained later.

Data

Meta data

Before initiating measurements, it is crucial to compile and fill in the relevant input data for the specific vehicle being tested. This involves selecting the appropriate drive cycle based on the vehicle's subclass, considering factors such as capacity, rated power, and maximum speed. Additionally, resistance parameters for the chassis dynamometer are calculated based on the vehicle's weight (chapter Chassis Dyno Settings). This static data, along with various other vehicle-specific details, can be pre-filled in advance, streamlining the measurement setup process. Further details regarding data structure and types can be found in Chapter 1.2.5 Measurement Procedure. providing a comprehensive framework for data preparation and organization for the measurement process.

Cyclic data

To maintain consistency and accuracy in data analysis, it is imperative that all measurement devices used in Project LENS have the capability to provide data with a minimum resolution of 1Hz. This ensures that all the variations in emissions and driving performance can be captured with sufficient quality. Furthermore, all data collected during the measurements must be time-aligned to create a coherent dataset. Failure to achieve time alignment during data acquisition will necessitate post-processing efforts, as detailed in Chapter 1.2.6 Postprocessing and Data Management, where each partner will be responsible for aligning the data chronologically. By adhering to these requirements, Project LENS ensures that data collected from various sources can be effectively compared and analyzed.

1.2.2 Preparation

The success of any measurement test within Project LENS depends significantly on thorough preparation. This chapter outlines the essential steps and considerations when preparing for a measurement test. Preparation involves ensuring the vehicle's condition, documenting critical information, and maintaining measurement device integrity.

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Test cell

The test room with the chassis dynamometer and the gas sample collection device shall have a temperature of 298,2 ± 5 K (25 ± 5 °C). The room temperature shall be measured in the vicinity of the vehicle cooling blower (fan) before and after the type I test.

Soak area

The soak area shall have a temperature of 298,2 ± 5 K (25 ± 5 °C) and be such that the test vehicle to be preconditioned can be parked1..

Vehicle Preparation

Test vehicle preconditioning

Test vehicle preconditioning according to Regulation (EU) No. 134/2014 and No. 168/2013.

The test vehicle shall be moved to the test area and the following operations are performed:

- The fuel tanks shall be filled with test fuel (fuel documentation has to be stored).
- The vehicle has to be operated through at least one test cycle as specified for the vehicle (sub-) category in Regulation (EU) No 168/2013 or Regulation (EU) No 134/2014 for preconditioning; measurements are not necessary during preconditioning cycle and the vehicle does not have to be cold.
- After completion of preconditioning, the test vehicle shall be moved from the dynamometer and may be driven or pushed to the soak area to be parked.
- The vehicle shall be stored for between 6 and 36 hours prior to the cold start type I test or until the engine oil temperature or the coolant temperature or the sparkplug seat/gasket temperature (only for air-cooled engine) equals the air temperature of the soak area within 2 K.

Vehicle Condition Checks

Before conducting any measurement test, it is imperative to note the condition of the vehicle Any deviations from standard conditions[2] should be documented, as calculation results will be based on these parameters. As the tests should reflect the actual emission of the test vehicle, no changes to the vehicle condition should be made except for the vehicle fluids and any safety related issues. Fluids have to be checked for emission and safety reasons. This includes engine oil, coolant, and transmission fluid, among others.

Fuel Properties Documentation

Fuel properties play a significant role in emissions testing, as they can affect the combustion process and emission characteristics. Detailed documentation of fuel properties, including fuel type, density,

[1] Regulation (EU) No 168/2013

[2] Regulation (EU) No 168/2013 and Regulation (EU) No 134/2014

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octane rating, C:H:O-share, information about lubrication (fuel/oil mixture, external loss lubrication, etc.), is essential for accurate analysis and comparison of test results.

Battery Status Check

As used vehicles are tested, there is a chance that the battery is in bad condition. Therefore, the battery has to be checked before the test and charged if needed. A battery in bad condition has to be replaced to avoid any interruptions or alterations in emissions data caused by recharging during the test.

1.2.3 Measurement Device Preparation

Device Descriptions and Datasheets

Each measurement device used in the testing process should be accompanied by detailed descriptions and datasheets. These documents provide comprehensive information about the device's specifications, operating procedures, and calibration requirements. Sharing this information with the consortium and recording it in the database ensures transparency and facilitates the standardization of measurement processes.

Compliance with Calibration Intervals

Measurement devices must adhere to regular calibration intervals as specified by the manufacturer. Calibration ensures the accuracy and reliability of the devices, ultimately leading to more precise and consistent measurement results. The calibration schedule should be strictly followed and documented to maintain data quality.

1.2.4 Setup

Chassis Dyno Settings

For laboratory measurements, the chassis dyno settings adhere to regulations, specifically Regulation (EU) No 168/2013 and and Regulation (EU) No 134/2014, which are based on the vehicle's mass. Deviations from these procedures and setting should be avoided, however if deviations occur for whatever reasons, these settings should be explicitly noted in the test data file and the database to maintain transparency and accuracy.

Reference mass m_{ref} (kg)	Equivalent inertia mass m_i (kg)	Rolling resistance of front wheel a (N)	Aero drag coefficient b (N/(km/h)²)
At every 10 kg	At every 10 kg	$a = 0,088 \times m_i$ (*)	$b = 0,000015 \times m_i + 0,02$ (**)

(*) The value shall be rounded to one decimal place.
(**) The value shall be rounded to four decimal places.

Figure 1-2: Classification of equivalent inertia mass and running resistance used for L-category vehicles

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Constant Volume Sampling System (CVS)

Laboratory measurements in Project LENS are conducted using Constant Volume Sampling Systems (CVS), which may be of the open or closed type. The CVS systems are used for the collection and dilution of the exhaust gases, as well as for the determination of the exhaust gas mass flow. These systems have been rigorously compared during the Round Robin procedure to ensure repeatability and reproducibility of the measurements across laboratories . Special care has to be taken that all exhaust gases are collected by the CVS system. This has to be ensured by leakage checking procedures, for example by checking the background concentrations before and after the test. When performing PN/PM measurements no rubber or rubber type connection pipes or hoses must be used, as these will influence the PN/PM measurement results.

Measurement Devices

Two major measurement data types are addressed in the next chapters: the exhaust gas emission components and additional engine data.

Exhaust gas emission components:

The following emission components have to be measured mandatory by using standardized emission measurement devices (see Emission Measurement Devices): CO, CO_2, HC, NOx.

The following emission components should be measured with dedicated measurement devices if possible: Particle number (PN_{23}, PN_{10}, PN_4), Particle mass.

Additional engine data

Additional engine data is used for postprocessing and for calculation of emission factors. These data can be measured by recording engine ECU data (see Recording of Engine Control Unit (ECU) measurement data) or by using separate and specific measurement devices like ignition / sparkplug sensors. Mandatory data are:

- Engine speed (rpm)
- Additional data which should be collected are:
- Throttle angle, lambda, gear, calculated load, coolant and oil temperature, intake pressure, ignition timing

Emission Measurement Devices

Standardized emission evaluation in the laboratory utilizes a range of measurement devices, including:

- FID (Flame Ionization Detector): Hydrocarbon emission.
- CLD (Chemiluminescence Detector): Nitrogen oxide (NO_x) emission.
- NDIR (Non-Dispersive Infrared): Gaseous emissions such as carbon monoxide (CO), carbon dioxide (CO_2).

Additionally, other devices like FTIR (Fourier Transform Infrared Spectroscopy), PM (Particulate Matter) systems, and PN (Particle Number) systems may be used. A cross-correlation of FTIR results

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with standardized measurement equipment validated in the Round Robin test is mandatory and ensures data consistency. Use of particulate matter measurement systems should follow the UN Global Technical Regulation 15[3], calibration of these systems should be in accordance with ISO 27891. Furthermore, the type and measurement principle as well measurement resolution and accuracy has to be noted for every no-standard measurement equipment.

Validation of Emission Measurement Devices

The standard measurement systems of each laboratory are compared against these from the other measurement partners laboratories during the Round Robin procedure to ensure consistency and reliability in data collection (see “Round Robin”). As within the measurement campaign besides these standardized instruments also non-approved or scientific measurement devices for emissions are used, a correlation with approved measurement devices, is an essential process to ensure the consistency and reliability of emissions measurements. By establishing a relation between these diverse instruments through correlation studies, the gap between non-standard and approved devices can be bridged. This approach enables to validate the accuracy and precision of non-approved instruments, ultimately enhancing the trustworthiness of emission data.

Recording of Engine Control Unit (ECU) measurement data

Utilizing vehicle Engine Control Unit (ECU) data offers two valuable approaches. The first approach involves incorporating CAN bus data into the measurement dataset using dbc files provided by the OEM. This method significantly enhances data quality, as it allows for the inclusion of critical parameters such as engine speed, throttle angle, Lambda, and more. The precise and real-time nature of CAN bus data, facilitated by dbc files, ensures high-quality measurements. The second approach leverages OBD protocols, which may be limited by the vehicle’s age. While OBD provides valuable information, its availability primarily applies to newer vehicle models compliant with recent EU regulations (EU4 and EU5). Furthermore, OBD may not support the same transfer rates and frequencies as CAN bus, making it essential to consider data quality and compatibility based on the specific vehicle and its compliance history. These two approaches collectively enhance the comprehensiveness and reliability of emissions measurement data in Project LENS.

Additional Devices

Incorporating additional measurement devices into Project LENS brings invaluable benefits in terms of data quantity and quality. Devices such as fuel consumption meters not only provide critical data for emissions testing but also serve to check for any leakage in emission measurements, utilizing carbon method calculations. For situations where engine speed data is not readily available through OBD or CAN data, a dedicated engine speed measurement device becomes essential to ensure comprehensive data capture. Furthermore, the use of thermocouples can allow for the measurement of temperatures at critical points, adding depth to the dataset. One particularly advantageous addition is the implementation of a lambda sensor in the exhaust system. When combined with accurate fuel

[3] UN Regulation No. 154 GTR 15

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measurement, this sensor enables the calculation of additional parameters such as exhaust mass flow, significantly enhancing the depth and precision of emissions data collected in the project.

Laboratory Test Cycles

WMTCs (World Motorcycle Test Cycles)

Laboratory measurements are conducted using standardized test cycles, according to the EU regulation in charge at the homologation state of the specific vehicle. These test cycles provide standardized speed profiles for emissions testing.

For vehicles, homologated according to EU4[4] and EU5[4] the test cycles are a set of world motorcycle test cycles (WMTC), which are specific to EU4 and EU5 regulations and depend on the size class of the vehicle.

For vehicles, homologated according to EU3[5], EU2[5] and EU1[6] the specific test cycles of these homologation regulations have to be used. Nevertheless, all preparation procedures are applied according to chapter 1.2.2 Preparation, chapter 1.2.3 Measurement Device Preparation and chapter 1.2.4 Setup.

RDCs (Real Driving Cycles)

RDCs are used for laboratory measurements, offering the flexibility to replicate real-world driving conditions. These cycles can be post-processed from actual on-road motorcycle rides or synthetically generated based on real driving patterns. For each vehicle class, speed capability and power class (L1e-B, L3e-A1, and L3e-A3) a specific RDC cycle has been developed to cope with the different speed capabilities of the vehicle classes.

Table 1-2: RDCs for laboratory measurements

RDC	Vehicle Class	v-max [km/h]	Max Power [kW]
RDC-L1e-B	L1e-B	45	2,3
RDC-L3e-A1-high	L3e-A1	>=112	>=10, <=11
RDC-L3e-A1-low	L3e-A1	<112	<10
RDC-L3e-A2-high	L3e-A2	>=134	>11
RDC-L3e-A2-low	L3e-A2	<134	>11
RDC-L3e-A3-high	L3e-A3	>=165	>=50
RDC-L3e-A3-low	L3e-A3	>134	>34, <50

[4] EU 168/2014
[5] Directive 2002/51/EC of the European Parliament and of the Council of 19 July 2002 on the reduction of the level of pollutant emissions from two- and three-wheel motor vehicles and amending Directive 97/24/EC
[6] Directive 97/24/EC of the European Parliament and of the Council of 17 June 1997 on certain components and characteristics of two or three-wheel motor vehicles

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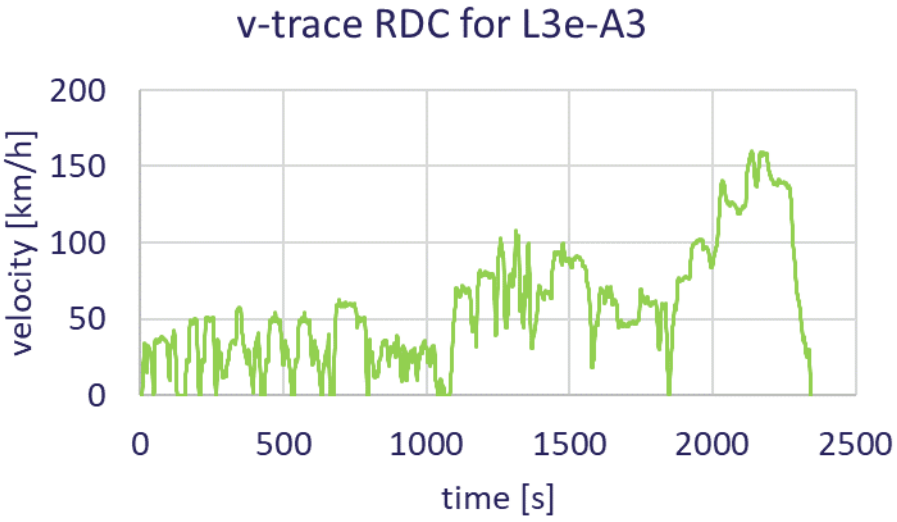

Figure 1-3: Example for a RDC for L3e-A3 vehicles developed by TUG

1.2.5 Measurement Procedure[7]

The typical test procedure is as follows:

1. 1 x Pre-conditioning cycle (followed by a soak period for a minimum of 6 hours to a maximum of 36 hours).
2. 1 x Cold WMTC (followed by a soak period for a minimum of 6 hours to a maximum of 36 hours).
3. 1 x Cold RDC test (step 2 WMTC acts as pre-conditioning cycle for step 3).

1.2.6 Postprocessing and Data Management

Project LENS places a significant emphasis on the collection and management of emission measurement data, both for on-road and laboratory-based assessments. The data encompasses various types, including vehicle data, test data, and measurement data. To maintain consistency and accessibility, a comprehensive data management system has been established, and all data are stored in the LENS Database (LENSDB). This chapter outlines the key aspects of data management within Project LENS.

Data Types

Vehicle Data

- **Make and Model:** The make and model of the vehicle being tested.

[7] According to EURLEX 134 and 168

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- **Size Class:** Categorization of the vehicle based on its size (L-subcategory).
- **Technology:** The technological features and specifications of the vehicle.
- **EU Emission Standard:** The European Union emission standard to which the vehicle complies.
- **VIN (Vehicle Identification Number):** A unique identifier for each vehicle.
- **MY (Model Year):** The year of manufacture of the vehicle.
- **Additional Engine Data:** acording to MS Excel template file "*DB_Input_EmissionTemplate_<VersionNo>.xlsm*"

Test Data

- **Cycle:** The specific testing cycle used for the emissions measurement.
- **Start Conditions:** Information about the conditions at the start of the test.
- **Fuel:** Type and specifications like RON/MON, density, energy content, and other available data of the fuel used.
- **Type of CVS system used (open / closed)**
- **Road Load Parameters:** Parameters that account for road conditions and load on the vehicle during testing.

Measurement Data

- Emission Data: Emission measurements, reported in grams per second (g/s) or as a count per second (#/s), depending on the measurement device.
- Driving Data: Information about the vehicle's speed, distance covered, and other relevant driving-related parameters.
- Engine Data: Engine-specific data, including engine speed (which is obligatory for all measurements), throttle position, and other engine-related metrics.
- Environmental Data: Environmental conditions at the time of measurement, such as humidity, temperature, and atmospheric pressure.
- Other Data: Any additional data relevant to the emissions measurement.

The LENSDB serves as the centralized repository for all emission measurement data within Project LENS. This database is designed to efficiently store, manage, and facilitate access to the diverse range of data collected during the project. The front end of the LENSDB is programmed in C#, based on the .Net framework 4.5.2. MariaDB 10.5.15 acts as storage back end. The LENSDB runs on a server, where partners can access directly via the front end (credentials needed) to view and download data. New test data will be uploaded by the DB manager. Key features of the LENSDB include:

- **Accessibility**: The LENSDB is accessible to all members of the project, after signing an agreement on access.

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- **Data Integrity**: The database employs stringent data validation protocols to maintain the integrity and accuracy of the information stored within.
- **Data Security**: Robust security measures are in place to protect sensitive data from unauthorized access or breaches.
- **Search and Retrieval**: Users can easily search for specific data points or datasets using predefined search criteria, making it convenient to extract the required information.

Further information as well as instructions for the use of LENSDB is described in the user guide *Emissions_DB_APP_Introduction_<VersionNo>.pdf*, which can also be found on LENS Sharepoint.

Input template file for providing emission data for LENSDB

Project LENS employs a standardized approach to inputting vehicle, test and measurement data into the LENSDB. The data shall be provided to the LENSDB manager using the MS Excel template file *DB_Input_EmissionTemplate_<VersionNo>.xlsm*. The template file can be found on LENS Sharepoint and contains additional information about which data is mandatory for import into the LENSDB and how the data should be processed (e.g., correct time alignment of the instantaneous data). If changes are made to the MS Excel template file (e.g., due to newly available measured variables), the new version of the MS Excel template file is uploaded to the LENS Sharepoint by the DB Manager which replaces the old version. A template file should be filled in for each vehicle. Each template file supplemented with data should be uploaded to the LENS Sharepoint and the DB Manager should be informed about it. The contact details of the DB manager can be found in the LENSDB access agreement.

Conclusion

Efficient management of emission measurement data is crucial for the success of Project LENS. By categorizing and storing data types in the LENSDB and providing open access to project members, Project LENS ensures that all stakeholders can contribute, access, and analyze data seamlessly. The standardized input template file and data validation processes further enhance data quality and reliability, allowing for robust research and insights into emissions-related issues.

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2 Round Robin

This technical report presents the findings of a Round Robin study that aimed to make an intercomparison of emission measurement devices at different sites across Europe. The study specifically focused on the measurement of key pollutants such as hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x), carbon dioxide (CO_2), non-methane hydrocarbons (NMHC), and particulate number (PN_{23}). The participating laboratories included TU-Graz (Graz, Austria), EMISIA (Thessaloniki, Greece), IDIADA (Santa Oliva, Spain), CVUT (Prague, Czech), BMW (Munich, Germany), and KTM (Mattighofen, Austria).

To facilitate the study, two motorcycles were provided by OEM consortium partners KTM and BMW, which were tested in all the above-mentioned laboratories on the same test cycle. These motorcycles served as standardized vehicles, ensuring consistent emissions across the different testing locations.

The primary objective of this Round Robin study was to compare the performance of different emission measurement devices in laboratory use. By utilizing standardized motorcycles, the participating sites could assess the accuracy, precision, and reliability of their equipment, ensuring a fair and unbiased evaluation of emission characteristics.

The study placed particular emphasis on standard equipment used for measuring pollutants like HC, CO, NO_x, CO_2, and NMHC. However, also incorporated is the measurement of particulate matter using specialized particle number (PN) measurement devices if available. By evaluating PN emissions, the study aimed to gain insights into the contribution of ultrafine particles, which have significant implications for air quality and human health and are, therefore, of major interest within the LENS project.

Throughout this report, the methodologies employed at each testing location will be outlined, highlighting the key findings, and analyze the comparative performance of the different emission measurement devices. The results obtained from this comprehensive Round Robin study will contribute valuable insights to the field of emission measurement and assist in advancing the development of improved emission control technologies.

By providing a thorough analysis of the Round Robin study conducted across TU-Graz (Graz, Austria), EMISIA (Thessaloniki, Greece), IDIADA (Santa Oliva, Spain), CVUT (Prague, Czech), BMW (Munich, Germany), and KTM (Mattighofen, Austria), this report points out the accordance and discrepancies in measurement procedures and results of the various laboratories in order to enable a minimization of the measurement deviations.

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2.1 Round Robin Procedure

Motorcycles

Table 2-1: Specs of KTM 1290 Superadventure

	Technical Data
Mass (empty) [kg]	245
fuel	Gasoline
Engine type	2-cylinder V75°, 4-stroke
Engine displacement [ccm]	1301
Rated power [kW]	118
Rated speed [min^{-1}]	9300
idle speed [min^{-1}]	1400
mileage [km]	˜48.000

Table 2-2: Specs of BMW R1250RS

	Technical Data
Mass (empty) [kg]	260
fuel	Gasoline
Engine type	2-cylinder shiftcam boxer, 4-stroke
Engine displacement [ccm]	1254
Rated power [kW]	100
Rated speed [min^{-1}]	7750
idle speed [min^{-1}]	1050
mileage [km]	˜8.000

Round Robin Time schedule

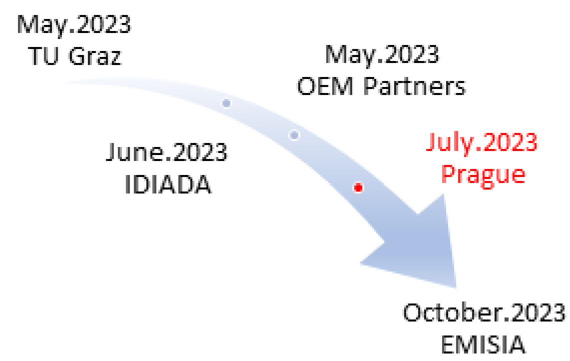

Figure 2-1: Timeschedule for the Round Robin

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2.2 Measurement Equipment Tested

Chassis Dyno

The primary purpose of a chassis dyno for two-wheelers is to simulate real-world road-load and assess the vehicle's power output, torque, emissions, and other performance characteristics. By subjecting the motorcycle to controlled load conditions, the chassis dyno enables comprehensive testing and data collection in a controlled laboratory environment. Regarding European legislation for homologation, there are specific accuracy requirements outlined for chassis dynos. These requirements are specified in the European Union's regulations, particularly in the type-approval process for motorcycles[8]. The legislation ensures that the measurements obtained using a chassis dyno meet specific accuracy criteria to ensure consistency and comparability across different testing facilities and manufacturers. The European legislation defines accuracy requirements for various parameters measured during the homologation process. Some of the key parameters and their associated accuracies include Power Measurement. The accuracy of power measurement on a chassis dyno for two-wheelers is typically specified as a percentage of the measured value. To ensure a good correlation of the chassis dynos used by the laboratories participating in the Round Robin, a coast down of the vehicles is executed during Round Robin to compare the road load simulating accuracies.

Constant Volume Sampling

The CVS (Constant Volume Sampling) system is an important component in emission measurement devices used to analyze exhaust gases from vehicles and other combustion sources. It is designed to capture and collect a representative sample of the exhaust gas for subsequent analysis. The key function of a CVS system is to maintain a constant volume of gas flow during the sampling process. This is achieved by sampling the exhaust flow rate and diluting the sample with clean air. The diluted sample is then directed to various analyzers for quantifying pollutant concentrations. As some of the Round Robin participants use open and some closed CVS this should be part of the comparison process.

[8] Regulation (EU) No 168/2013 Appendix 3

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Open CVS[9]

- Higher DF needed to capture all the exhaust emissions.
- Prove 100% of the emissions are sampled.
- Conditioning of the dilution air not possible
- Particles of brake and tires can affect the PN/PM measurements, in case the muffler is close to wheel.
- Constant time delay between muffler and analyzer.
- No modification of muffler needed (no connection).
- Better represents the real-world engine behavior.

Closed CVS[10]

- Mixing point is apart (will affect the PN agglomeration process).
- Underpressure is attached to the exhaust system (will affect gas dynamic, especially of two-stroke engines).
- Complex connection[11] to the muffler (maybe the muffler must be modified).
- Varying time delay between muffler and analyzer.
- Lower DF possible (higher concentrations in bag).
- Conditioning of the dilution air possible (higher accuracy due to higher concentrations and minimizing background HC).

Emission Bench

Gas analyzers are essential for measuring the concentrations of specific pollutants in the exhaust gas. Common gas analyzers used in motorcycle emission testing include those for hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x), carbon dioxide (CO_2), and oxygen (O_2). These analyzers employ different measurement principles, such as FID, NDIR and CLD, to determine pollutant concentrations accurately.

PN-Sampling System

As an integral component of the LENS measurement program, all participants in the Round Robin study have mutually agreed to incorporate PN_{23} measurements into the round robin procedure. This inclusion serves as a fundamental reference point for comparing the PN-measurement systems employed within the LENS consortium. PN_{23}, recognized as a well-established standard in passenger car homologation testing, is also measurable by all consortium partners. Additionally, certain partners will conduct PN measurements for even smaller particles down to 2.5 nm. However, it should be noted that these devices used for measuring such particles are prototype laboratory equipment and, therefore, cannot be adequately benchmarked within the context of the round robin study.

[9] BMW, TUG

[10] KTM, IDIADA, EMISIA, CVUT

[11] Very important is to not use silicon adapter which are commonly used due to their flexibility. These combined with the hot exhaust temperatures of motorcycles will have an impact on particulate emissions.

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2.3 Settings

Parameters

Chassis dyno settings, including road load and inertia, are critical parameters that need to be properly configured for accurate and representative testing of vehicles. These settings ensure that the chassis dyno simulates real-world road-load and provides reliable data for performance and emission analysis. It's important to ensure same parameters within the round robin. Therefore, the most important ones are listed below:

Table 2-3: testbench settings for the round robin vehicles

	KTM 1290 Superadventure	BMW R1250RS
Fuel	Gasoline provided by TUG	Gasoline provided by TUG
Dyno inertia simulated	320 kg	330 kg
Road Load Parameters F0 [N] F1 [N/(km/h)] F2 [N/(km/h)²]	 28,2 0,0 0,0248	 29,0 0,0 0,0250
Gearshift table	Provided by KTM	Based on N/V ratio 1. gear 106,0 2. gear 74,00 3. gear 56,00 4. gear 46,00 5. gear 41,00 6. gear 37,00
Min. CVS sample flow [m³/min]	6,0	6,0
Testing temperatures [°C]	22,5±2,5	22,5±2,5

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2.4 Measurement Program

Chassis Dyno evaluation – Coast Down

The coast down procedure on a chassis dyno for a motorcycle involves the deceleration of the vehicle from a specific speed (in this case, 120 km/h) with the clutch disengaged. This procedure helps to determine the accuracy of the chassis dynamometer's road load and inertia simulation, which are important factors in assessing same driving behaviors through all labs. Here's a description of the coast down procedure:

- Preparation: Ensure that the motorcycle is securely positioned on the chassis dyno and properly connected to the measurement equipment. Make sure the dyno is configured with the appropriate settings, including the road load and inertia parameters.
- Clutch Disengagement: With the motorcycle at a steady speed of 120 km/h, the clutch is disengaged. This action separates the engine power from the drivetrain, allowing the vehicle to coast freely without any additional propulsion force.
- Data Acquisition: The dyno's data acquisition system starts recording relevant parameters such as speed and time as the motorcycle begins to decelerate.
- Deceleration Phase: As the motorcycle coasts, it naturally decelerates due to the combined effects of simulated aerodynamic drag- and tire rolling resistance by the chassis dyno, as well as mechanical losses in the drivetrain. The dyno measures the deceleration rate and records the corresponding data.
- Data analysis: After the coast down procedure is completed, the recorded data is analyzed to determine the vehicle's drag and rolling resistance.

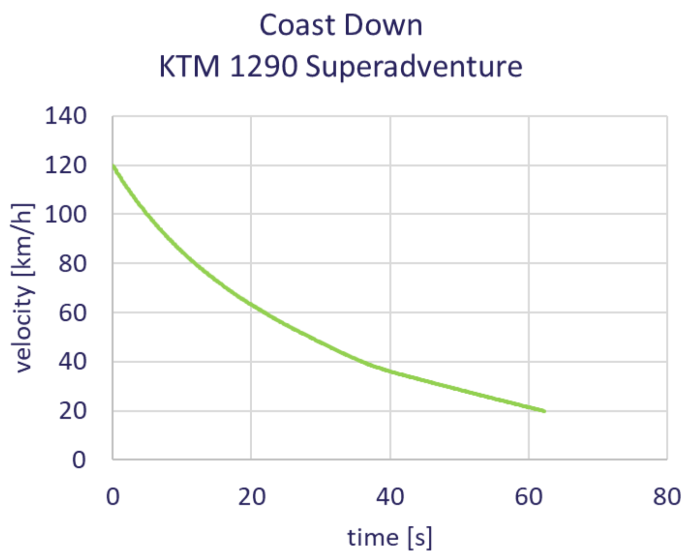

Figure 2-2: Coast down of the KTM 1290 Superadventure

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Emission Evaluation – WMTC

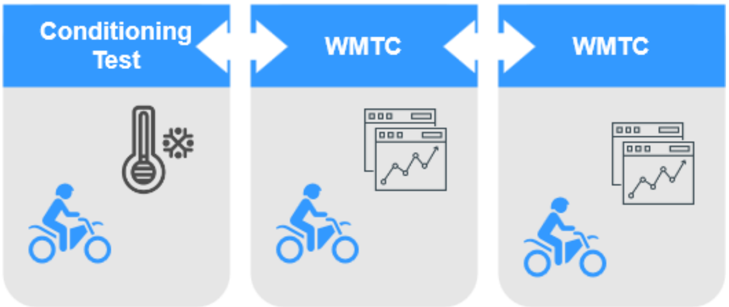

Figure 2-3: Rest procedure for the round robin

Conditioning

Prior to conducting the emission measurements, the motorcycle undergoes a pre-conditioning process. This process involves preparing the vehicle to ensure consistent and repeatable results. It may include tasks such as warm-up procedures, engine idling, or specific mileage accumulation under controlled conditions. The purpose is to stabilize the motorcycle's operating parameters. The pre-conditioning consists of a WMTC cycle the day before the measurement.

WMTC cold

The motorcycle is then subjected to a standardized test cycle (WMTC), including a cold start (22.5 ±2.5°C). The test cycle defines the specific speed pattern with which the emission measurements are conducted, and it varies depending on the applicable regulations and the intended use of the motorcycle (e.g., urban commuting, highway cruising). For both Round Robin Motorcycles the driving cycle will be the WMTC 3-2, as defined in the European regulation.

WMTC warm

After conducting the “cold” WMTC there is a soaking time of at least 6 hours to provide all system temperatures of the test vehicle to match ambient conditions. Subsequently, there is another test conducted the same day. This one should provide slightly lower emissions as the “cold” WMTC, as known from previous investigations, but will serve as a backup run and can be used to analyze variances, especially in phase two and three of the WMTC as the engine will become warm over the first phase.

Feasibility study – RDC

The LENS project aims to investigate the real-world emissions of category L-vehicles. To accomplish this goal, one crucial step involves conducting real-world driving cycles on a chassis dyno. To ensure uniformity and assess the capabilities of different laboratories, a Real Drive Cycle (RDC) developed by TU Graz is implemented within the Round Robin study. The RDC, specifically designed to represent the driving pattern of motorcycles in the L3e-A3 category, aligns perfectly with the two high-performance motorbikes utilized in the study, allowing all participants to conduct the test with their equipment and analyze the flexibility of their respective labs.

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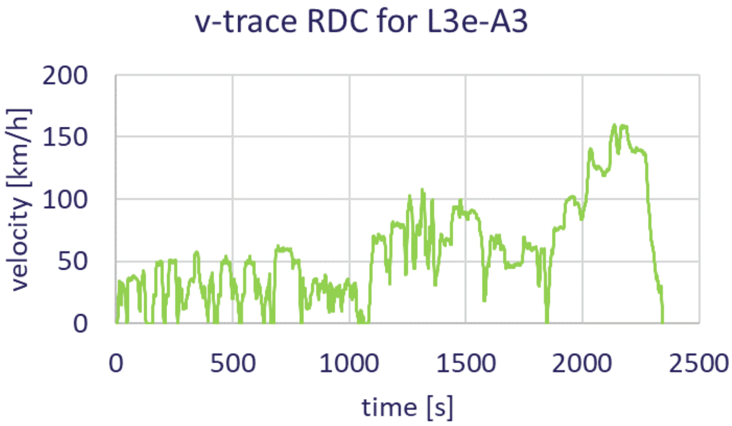

Figure 2-4: RDC mandatory to be driven during the Round Robin

2.5 Evaluation

Emission Evaluation

The Round Robin procedure in the Project LENS, involving emissions evaluation for two distinct motorcycles, the BMW R1250RS and the KTM 1290 Superadventure, was conducted with the goal of assessing the consistency and comparability of emission measurements across different laboratories. This chapter provides insights into the results obtained from the Round Robin evaluation, highlighting areas of alignment and deviations.

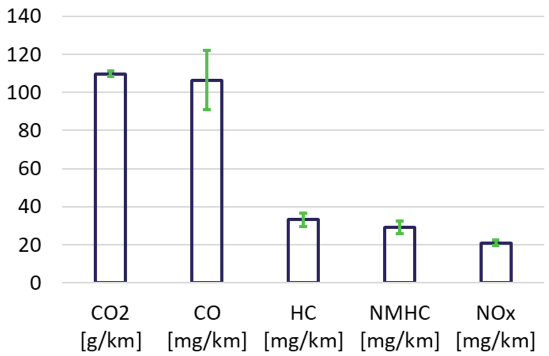

Figure 2-5: RR results of BMW R1250RS

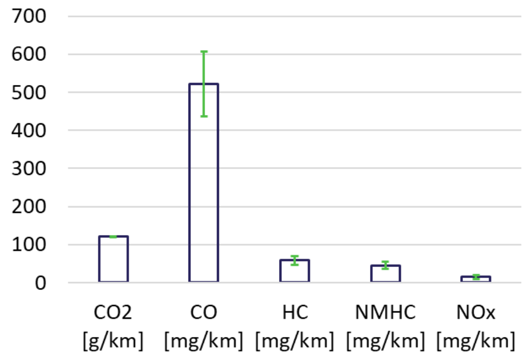

Figure 2-6: RR results of KTM 1290 Superadventure

The figures above show the Round Robin results for the two motorcycles. The graphs illustrate the mean values (indicated by the solid line bars) for the WMTC emissions obtained from the participating labs at TUG, BMW, KTM, IDIADA, EMISIA. The laboratory at CVUT Prague did not finalize the RR test yet. Additionally, the standard deviations are represented in green, providing insights into the variability of emissions data across the different testing facilities.

CO_2 Emissions

One notable finding from the Round Robin evaluation was the high degree of alignment in CO_2 emissions data across all participating laboratories. Even though different laboratories utilized two

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distinct approaches, open and closed Constant Volume Sampling Systems (CVS), the standard deviation in CO_2 emissions measurements was consistently within one percent. This level of consistency demonstrates the robustness and reliability of CO_2 measurement techniques employed by the laboratories.

Deviations in Other Emission Components

However, for other emission components, deviations became more apparent, with variations depending on the motorcycle being tested. Specifically, the tests of the BMW R1250RS exhibited minor deviations in emissions data when compared across laboratories.

In contrast, the tests of the KTM 1290 Superadventure showed more substantial deviations in CO emissions, while emissions of hydrocarbons (HC), non-methane hydrocarbons (NMHC), and nitrogen oxides (NOx) showed only minor discrepancies. These differences in emission result with respect to the two motorcycles can be caused by inconsistencies of the testing laboratories or by inconsistent behavior of the motorcycles.

Manufacturer Insights

Following consultations with the motorcycle manufacturer revealed that the instability observed in CO emissions for the KTM 1290 Superadventure was considered as a typical behavior for their LC8 engine. The manufacturer's explanation shed light on the unique characteristics of this engine's emissions profile, emphasizing the importance of understanding and acknowledging the specific attributes of different engines when interpreting emissions data.

Overall Alignment and Achievements

Despite the deviation observed in CO emissions for the KTM, the laboratory results from the participating partners showed remarkable alignment for all other emission components. This alignment reaffirms the success of the Round Robin comparison and validates the reliability of the measurement techniques employed across different laboratories.

The Round Robin results serve as a valuable reference point for comparing measurements conducted by various labs throughout the LENS project. Additionally, they offer an opportunity to cross-correlate data obtained from additional measurement devices, such as the Fourier Transform Infrared Spectroscopy (FTIR). This cross-correlation can provide valuable insights into the consistency and compatibility of data collected through various measurement methods, further enhancing the project's overall data quality and reliability.

In summary, the Round Robin evaluation in the Project LENS has provided valuable insights into emissions measurements, highlighting the importance of considering engine-specific behaviors when interpreting data. The alignment observed in most emission components reinforces the reliability of the project's measurement protocols and sets the stage for robust data comparison and analysis throughout the project duration. Nevertheless, considering the CO emission deviation of the tests with the KTM Superadventure showed that deviations can occur.

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