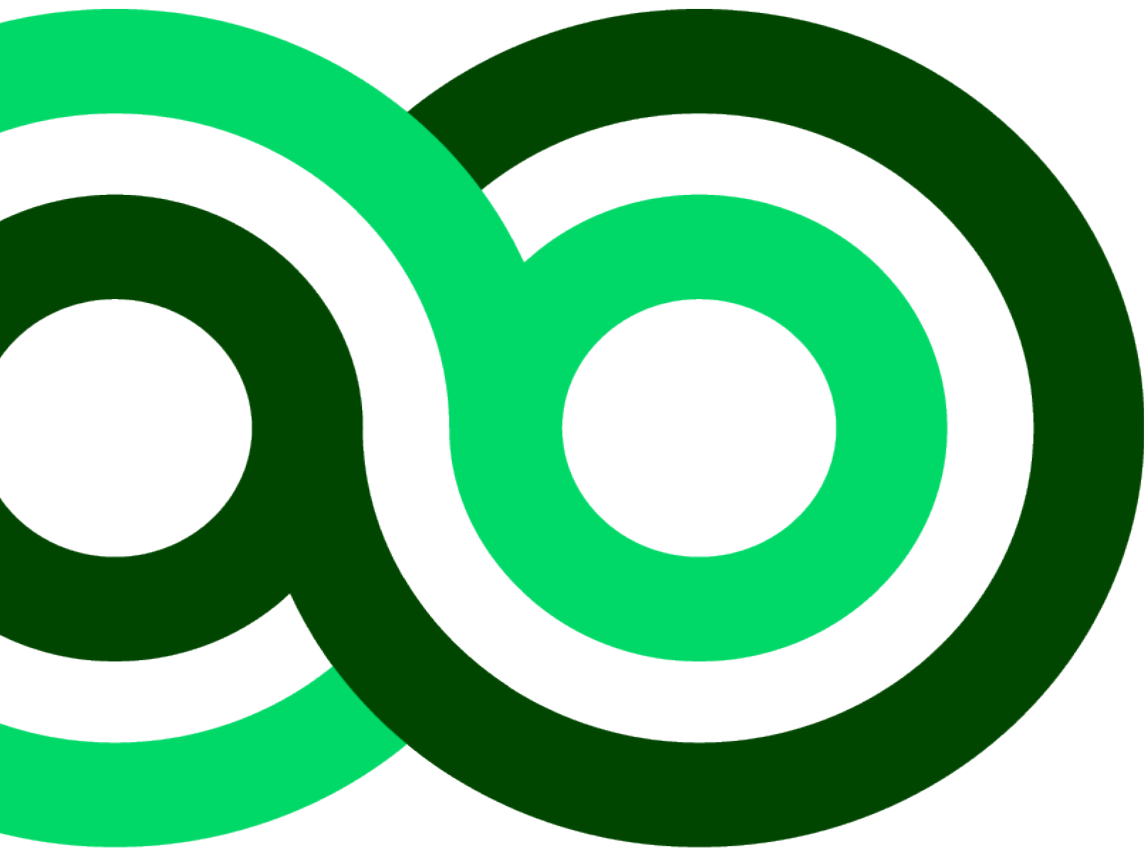


TEST PROCEDURE

Driving Range





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GNT Driving Range Test Procedure

This document describes a stand-alone procedure to determine driving range together with a nominal and a worst case driving range of ICEs, PEVs and FC-, NG/biomethane- and LPG vehicles, amending the documents ***GNT_WLTC+_Test_Procedure*** and ***GNT_PEMS+_Test_Procedure***. The purpose of this test procedure is to identify the vehicles driving range under real world conditions and among nominal and worst case conditions and to verify with the OEM's claim of driving range. The manufacturer's specification according to the standardized test cycle WLTP differs from individual practical operation. This occurs also in electric mode because heating, ventilation, air conditioning etc. are switched off during WLTP. Operation on motorways is only taken into account to a small extent (18%).

This document features a standardized REESS discharge and recharge test procedure to determine the energy drawn from the grid and to determine battery capacity (amount of energy in the REESS that is usable) for PEVs. The recharging process shall also be defined in a similar way to vehicles owned by consumers. Owners of electric cars do not only pay for the amount of energy "filled" into the REESS, but the entire amount of energy obtained from the grid, including charging losses. In case of ICE, FC-, NG/biomethane- and LPG vehicles the size of the fuel tank as specified by the manufacturer is identified as capacity.

The vehicle's driving ranges can be calculated by the vehicle's energy consumption results measured under the procedures ***GNT_WLTC+_Test_Procedure*** and ***GNT_PEMS+_Test_Procedure*** together with the identified REESS / tank capacity proposed in this document. By this way three driving ranges are presented in the following:

- **"Nominal range":**
Determined by using the laboratory measurement energy consumption conducted from the results (WLTC_{+cold_def}, WLTC_{+warm_def} and BAB in accordance to ***GNT_WLTC+_Test_Procedure***)
- **"Real world range":**
Determined by using the on-road energy consumption conducted from PEMS + measurements (PEMS_{+cold}, PEMS_{+eco} and PEMS_{+heavy} in accordance to ***GNT_PEMS+_Test_Procedure***)
- **"Worst case range":**
Determined by using the highest energy consumption results from test PEMS_{+heavy}, BAB (in accordance to ***GNT_WLTC+_Test_Procedure***) and WLTC_{+CAT} (in accordance to ***GNT_WLTC+_CAT_Test_Procedure***)

For ICE, FC-, NG/biomethane- and LPG-vehicles paragraphs 1 to 5 shall not be performed. Driving range calculation shall be performed according to paragraph 6.2 and 6.3 of this document.

Real World Driving Range Test Procedure

1. General test requirements for PEVs:
 - 1.1. The test vehicle shall be driven in normal road traffic and in compliance with the traffic regulations (in countries without speed limits not faster than 130 km/h) until the charge indicator for the traction battery on the vehicle's dashboard shows a value of at least 10% or the vehicle's dashboard indicates a capacity-related performance restriction. The test drives on the road (GNT_PEMS+) can be used for this test. If a mobile current and voltage measurement on the road is not possible, the test drive can alternatively be carried out on the roller dynamometer. Permissible speed profiles are those that reflect normal road traffic and comply with the traffic rules. For example, GNT_WLTC+, GNT_PEMS+, WLTP, ADAC-Eco-Test (all versions), ARTEMIS 130 are permitted.
 - 1.2. From the beginning of the test (beginning means SOC=100%) until the break-off criterion defined in paragraph 3.4 of this document is reached, the electric current of all REESSs and the electric voltage of all REESSs shall be determined according to paragraph 5 (a) and (b) of this document. The measurements can be recorded in separate measurement files.
 - 1.3. For the test same chassis dyno settings as for chassis dyno tests in accordance to ***GNT_WLTC+_Test_Procedure***, Sub-Annex 4, ANNEX XXI shall be used.
2. First Phase of REESS discharge procedure for PEVs
 - 2.1. The Test shall be started with REESS 100 % charged. Test vehicle shall be driven according to paragraph 1.1 of this document.
 - 2.2. The charge indicator may indicate more than 10 % when arriving at the laboratory. However, it shall not display less than 10 %.
 - 2.3. If display shows less than 10% or the vehicle's dashboard indicates a capacity-related performance restriction the REESS has to be fully recharged and the test has to be restarted.
 - 2.4. With a residual capacity of at least 10 %, the vehicle shall be conditioned for minimum 6 hours at 23 °C ± 3 °C ambient temperature. The ambient temperature, air pressure and humidity shall be recorded during this time.
 - 2.5. After the preconditioning, the vehicle shall be installed on the chassis dyno, using the settings mentioned in paragraph 1.3. of this document.

3. Second phase of REESS discharge procedure for PEVs: Standardised final REESS discharge.
 - 3.1. After the vehicle has been installed on chassis dyno, turn ignition on and accelerate vehicle until 80 km/h is reached within 12-20 s.
 - 3.2. Discharge cycle:

The test vehicle shall be driven on the test bench at a constant speed of 80 km/h (in the default driving mode, without additional loading and without air conditioning), considered as the first constant speed segment, until a remaining range of 5 - 10 km is indicated by the on-board instrument or the speed can no longer be maintained. For dashboards without a numerical display of the remaining range, the vehicle has to be driven at 80 km/h (in the default driving mode, without additional loading and without air conditioning), until the penultimate line disappears or if there is no penultimate line the vehicle has to be driven until the speed can no longer be maintained.
 - 3.3. Then the vehicle speed shall be reduced to the second constant speed segment at 50 km/h (in the default driving mode, without additional loading and without air conditioning), until Break-off criterion defined in paragraph 3.4 of this document is met.
 - 3.4. Break-off criterion:

The break-off criterion is reached when the vehicle exceeds the prescribed speed trace tolerance as specified in paragraph 1.2.6.6 of Sub-Annex 6, ANNEX XXI, **GNT_WLTC+ Test_Procedure** for 4 consecutive seconds or more in the second constant speed segment. The vehicle shall be braked to a standstill within 60 seconds.
 - 3.5. The ignition shall be turned off. At this moment the REESS will be considered as empty.
 - 3.6.

Sequence of charge depletion and recharge for PEVs, Figure 1

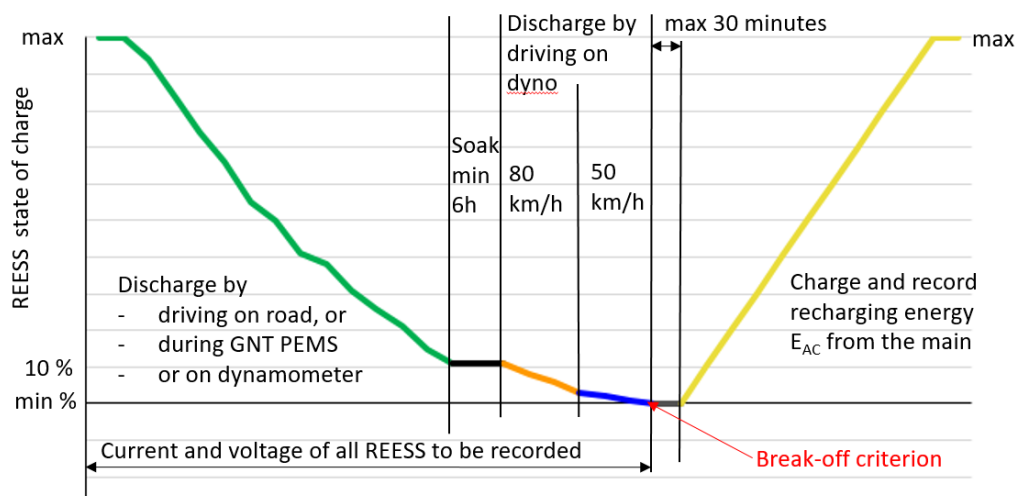


Figure 1: Sequence of charge depletion and recharge for PEVs

4. Standardized REESS recharge procedure for PEVs:
 - 4.1. The REESS shall be recharged not later than 30 minutes after the end of discharge procedure described in paragraph 3 of this document.
 - 4.2. The REESS shall be charged at a stable ambient temperature of $23^{\circ}\text{C} \pm 3^{\circ}\text{C}$
 - 4.3. The charging limit of the REESS shall be set to "100%" or to "max", if applicable.
 - 4.4. The on-board charger, if fitted with the standard vehicle charging cable supplied by the manufacturer, only shall be used for recharging. Therefore two options can be considered:
 - (a) If applicable with supplied cable charging at 400V, 16A (11 kW). Three-phase charge at 400V with a CEE16 socket shall be used.
 - (b) If the supplied cable permits 230V, 16A (3.7 kW) only, recharging at 230V with a CEE7 socket allowed.
 - 4.5. End-of-charge criterion:
The end-of-charge criterion is reached when the on-board or external instruments indicate that the REESS is fully charged.
 - 4.6. The recharging process shall not be interrupted.
5. Data measurement and recording:

The energy measurement equipment, placed between the vehicle charger and the mains, shall measure the recharged electric energy E_{AC} delivered from the mains. Measurement equipment, placed at the side of the vehicle's traction battery, shall determine the electric energy $E_{DC\text{-}charge}$ absorbed by the REESS. Electric energy measurement may be stopped when the End-of-charge criterion, as defined in paragraph 4.5 of this document, is reached. The following data shall be measured and recorded:

 - (a) The current $I_{DC\text{-}charge}$ in Ampere at the side of the vehicle's traction battery shall be measured in accordance to paragraph 2, Sub-Annex 8-Appendix 3, ANNEX XXI of **GNT_WLTC+ Test Procedure** at a storage rate of 0.1 Hz as an average of the high resolution data.
 - (b) The Voltage $U_{DC\text{-}charge}$ in Volt at the side of the vehicle's traction battery shall be measured in accordance to paragraph 3, Sub-Annex 8-Appendix 3, ANNEX XXI of **GNT_WLTC+ Test Procedure** at a storage rate of 0.1 Hz as an average of the high resolution data. The calculated (from high resolution data) amount of energy $E_{DC\text{-}charge}$ of the traction battery in Wh shall be stored at a rate of 0.1 Hz as an average of the high resolution data.

- (c) The currents I_{AC_i} ($i=1-3$) in Ampere and the Voltages U_{AC_i} ($i=1-3$) in Volt on the AC side shall be measured at an adequate sampling frequency (high resolution data) and should be recorded with 0.1 Hz as an average of the high resolution data. The calculated (from high resolution data) amount of energy E_{AC} delivered from the mains in Wh shall be stored at a storage rate of 0.1 Hz as an average of the high resolution data. Units, accuracy and resolution of measurements shall be as shown in Table 1.

Table 1: Parameters, units, accuracy and resolution of measurements

Parameter	Units	Accuracy	Resolution
Electrical energy ⁽¹⁾	Wh	± 1 per cent	0,001 kWh ⁽²⁾
Electrical current	A	$\pm 0,3$ per cent FSD or ± 1 per cent of reading ⁽³⁾ ⁽⁴⁾	0,1 A
Electric voltage	V	$\pm 0,3$ per cent FSD or ± 1 per cent of reading ⁽³⁾	0,1 V

⁽¹⁾ Equipment: static meter for active energy.

⁽²⁾ AC watt-hour meter, Class 1 in accordance with IEC 62053-21 or equivalent.

⁽³⁾ Whichever is greater.

⁽⁴⁾ Current integration frequency 20 Hz or more.

- (d) The duration $T_{100\%}$ of the recharging process in seconds until the REESS is fully charged according the end-of-charge criterion as defined in paragraph 4.5 of this document shall be logged.
- (e) The ambient temperature at start of charging process shall be logged.
- (f) The current $I_{DC_discharge}$ in Ampere at the side of the vehicle's traction battery (measured from SOC=100 % until the break-off criterion is reached) shall be measured in accordance to paragraph 2, Sub-Annex 8-Appendix 3, ANNEX XXI of GNT_WLTC+_Test_Procedure at a storage rate of at least 1 Hz.
- (g) The Voltage $U_{DC_discharge}$ in Volt at the side of the vehicle's traction battery (measured from SOC=100 % until the break-off criterion is reached) shall be measured in accordance to paragraph 3, Sub-Annex 8-Appendix 3, ANNEX XXI of GNT_WLTC+_Test_Procedure at a storage rate of at least 1 Hz. The calculated amount of energy $E_{DC_discharge}$ of the traction battery in Wh at a storage rate of at least 1 Hz. If the traction battery has been emptied in several journeys with separate measurement files, $E_{DC_discharge}$ results in:

$$E_{DC_discharge} = \sum_{i=1}^n E_{DC_discharge_i}$$

n... number of journeys in preconditioning phase and standardized REESS discharge phase

6. Determination of Driving Range:

The vehicle's driving Range can be calculated by the vehicle's energy consumption results measured under the procedures **GNT_WLTC+ Test Procedure** and **GNT_PEMS+ Test Procedure** together with the identified REESS / tank capacity from this test procedure or, respectively, the manufacturers specifications for nominal tank capacities. In this consideration, the real world driving range is distinguished in three separate orders: A nominal range in km, a real world range in km and a worst case range in km. Since the charging losses do not take into account the charging and discharging losses of the traction battery itself, the usable energy of the traction battery $E_{DC_discharge}$, (energy that can be drawn from the battery) must be determined to determine the driving range.

It shall be noted that fuel/energy consumption values, as well as the available battery capacity are dependant on the ambient temperature and load profile.

6.1. Calculation Procedure for PEVs:

6.1.1. Charging losses:

The charging losses are determined by the difference of the electric energy from the mains and the absorbed energy from the REESS. Charging and discharging losses of the traction battery itself due to chemical and physical processes in the battery are not taken into account.:

$$\Delta E_{ch-loss} = E_{AC} - E_{DC-charge}$$

[Wh]

where:

$\Delta E_{ch-loss}$ is the charging losses, Wh

E_{AC} is the electric energy delivered from the mains, Wh

$E_{DC-charge}$ is the electric energy absorbed by the vehicle, in Wh, over the complete charging time, calculated by the measured current and voltage, as prescribed in paragraph 5 (a) and (b) in this document, with the formula:

$$E_{DC-charge} = \frac{1}{3600} \times \int_0^{T_{100\%}} I_{DC-charge} \times U_{DC-charge} dt$$

6.1.2. Total losses:

The total losses are determined by the difference of the electric energy from the mains and the usable energy of the traction battery $E_{DC-discharge}$, (energy that can be drawn from the battery).

$$\Delta E_{total-loss} = E_{AC} - E_{DC-discharge} \text{ [Wh]}$$

where:

$\Delta E_{total-loss}$ is the total losses, Wh

E_{AC} is the electric energy delivered from the mains, Wh

$E_{DC-discharge}$ is the electric energy drawn from the battery in Wh, over the complete phase of RESS discharge procedure, calculated by the measured current and voltage, as prescribed in paragraph 5 (f) and (g) in this document, with the formula:

$$E_{DC-discharge} = \frac{1}{3600} \times \int_{SOC_{max}}^{T_{Break-off\ criterion}} I_{DC-discharge} \times U_{DC-discharge} dt$$

6.1.3. "Nominal" Range:

The calculation of a nominal driving range ($R_{nominal}$) in km considering electric energy absorbed by the vehicle ($E_{DC-discharge}$) over the average energy consumption values in Wh/100km from laboratory measurements in WLTC default- ($EC_{WLTC_cold_def}$), warm- ($EC_{WLTC_warm_def}$) and BAB-cycle, conducted in **GNT_WLTC+_Test_Procedure**, is described in the following formula:

$$R_{nominal} = \frac{E_{DC-discharge}}{1/3 \times (EC_{WLTC_cold_def} + EC_{WLTC_warm} + BAB)} \times 100 \text{ [km]}$$

6.1.4. "Real-World" Range:

The calculation of a real world driving range ($R_{real\ world}$) in km considering electric energy absorbed by the vehicle (E_{DC}) over the average energy consumption values in Wh/100km from PEMS-measurement in default- ($EC_{PEMS+,def}$), eco- ($EC_{PEMS+,eco}$) and heavy-condition ($EC_{PEMS+,heavy}$), conducted in **GNT_PEMS+_Test_Procedure**, is described in the following formula:

$$R_{real\ world} = \frac{E_{DC}}{1/3 \times (EC_{PEMS+cold} + EC_{PEMS+,eco} + EC_{PEMS+,heavy})} \times 100 \text{ [km]}$$

6.1.5. "Worst-Case" Real-World Driving Range:

The calculation of the worst case driving range ($R_{\text{worst case}}$) is described, taking the lowest driving range from the calculated ranges based on the energy consumption in Wh/100km from the laboratory tests BAB (EC_{BAB} , **GNT_WLTC+_Test_Procedure**), WLTC in cold ambient conditions ($EC_{WLTC,CAT}$, **GNT_WLTC+_CAT_Test_procedure**) and the energy consumption in Wh/100km from PEMS measurement in heavy-conditions ($EC_{PEMS,heavy}$, **GNT_PEMS+_Test_Procedure**):

$$R_{BAB} = \frac{E_{DC-discharge}}{EC_{BAB}} \times 100 \quad [\text{km}]$$

$$R_{WLTC,CAT} = \frac{E_{DC-discharge}}{EC_{WLTC,CAT}} \times 100 \quad [\text{km}]$$

$$R_{PEMS,heavy} = \frac{E_{DC-discharge}}{EC_{PEMS,heavy}} \times 100 \quad [\text{km}]$$

$$R_{\text{worst case}} = \min (R_{BAB} , R_{WLTC,CAT} , R_{PEMS,heavy}) \quad [\text{km}]$$

6.2. Calculation Procedure for ICE, NG/biomethane- and FC- vehicles:

6.2.1. "Nominal" Range:

The calculation of a nominal driving range ($R_{nominal}$) in km considering tank capacity according manufacturer specification (C_{Tank}) in kg or l over the average energy consumption values in kg/100km or l/100km from laboratory measurements in default- ($FC_{WLTC_cold_def}$), warm- ($FC_{WLTC_warm_def}$) and BAB-cycle, conducted in **GNT_WLTC+_Test_Procedure**, is described in the following formula:

$$R_{nominal} = \frac{C_{Tank}}{\frac{1}{3} \times (EC_{WLTC_def} + EC_{WLTC_warm} + BAB)} \times 100 \text{ [km]}$$

6.2.2. "Real-World" Range:

The calculation of a real world driving range ($R_{real \text{ world}}$) in km considering tank capacity according manufacturer specification (C_{Tank}) in kg or l over the average energy consumption values in kg/100km or l/100km from PEMS-measurement in default- ($FC_{PEMS,def}$), eco- ($FC_{PEMS,eco}$) and heavy-condition ($FC_{PEMS,heavy}$), conducted in **GNT_PEMS+_Test_Procedure**, is described in the following formula:

$$R_{real \text{ world}} = \frac{C_{Tank}}{\frac{1}{3} \times (FC_{PEMS+cold} + FC_{PEMS,eco} + FC_{PEMS,heavy})} \times 100 \text{ [km]}$$

6.2.3. "Worst-Case" Real-World Driving Range:

The calculation of the worst case driving range ($R_{worst \text{ case}}$) is described, taking the lowest driving range from the calculated ranges based on the energy consumption (in kg/100km) from the laboratory tests BAB (FC_{BAB} , **GNT_WLTC+_Test_Procedure**), WLTC in cold ambient conditions ($FC_{WLTC,CAT}$, **GNT_WLTC+_CAT_Test_Procedure**) and the gas or fuel consumption in kg/100km or l/100km from PEMS+ measurement in heavy Conditions ($FC_{PEMS,heavy}$, **GNT_PEMS+_Test_Procedure**):

$$R_{BAB} = \frac{C_{Tank}}{FC_{BAB}} \times 100 \text{ [km]}$$

$$R_{WLTC,CAT} = \frac{C_{Tank}}{FC_{WLTC,CAT}} \times 100 \text{ [km]}$$

$$R_{PEMS,heavy} = \frac{C_{Tank}}{FC_{PEMS,heavy}} \times 100 \text{ [km]}$$

$$R_{worst \text{ case}} = \min (R_{BAB} , R_{WLTC,CAT} , R_{PEMS,heavy}) \text{ [km]}$$

6.3. Calculation Procedure for LPG- vehicles:

6.3.1. "Nominal" Range:

The calculation of a nominal driving range ($R_{nominal}$) in km considering tank capacity according manufacturer specification (V_{Tank}) in litres over the average energy consumption values in l/100km from laboratory measurement in WLTC default- ($FC_{WLTC_cold_def}$), warm- ($FC_{WLTC_warm_def}$) and BAB-cycle, conducted in **GNT_WLTC+_Test_Procedure**, is described in the following formula:

$$R_{nominal} = \frac{V_{Tank}}{\frac{1}{3} \times (EC_{WLTC_def} + EC_{WLTC_warm} + BAB)} \times 100 \text{ [km]}$$

6.3.2. "Real-World" Range:

The calculation of a real world driving range ($R_{real\ world}$) in km considering tank capacity according manufacturer specification (V_{Tank}) in liters over the average fuel consumption values in l/100km from PEMS-measurement in default- ($FC_{PEMS,def}$), eco- ($FC_{PEMS,eco}$) and heavy-condition ($FC_{PEMS,heavy}$), conducted in **GNT_PEMS+_Test_Procedure**, is described in the following formula:

$$R_{real\ world} = \frac{V_{Tank}}{\frac{1}{3} \times (FC_{PEMS+cold} + FC_{PEMS,eco} + FC_{PEMS,heavy})} \times 100 \text{ [km]}$$

6.3.3. "Worst-Case" Real-World Driving Range:

The calculation of the worst case driving range ($R_{worst\ case}$) is described, taking the lowest driving range from the calculated ranges based on the fuel consumption (in l/100km) from the laboratory tests BAB (FC_{BAB} , **GNT_BAB_Motorway_Test_Procedure**), WLTC in cold ambient conditions ($FC_{WLTC,CAT}$, **GNT_WLTC+_CAT_Test_Procedure**) and the fuel consumption in l/100km from PEMS measurement in heavy-conditions ($FC_{PEMS,heavy}$, **GNT_PEMS+_Test_Procedure**):

$$R_{BAB} = \frac{V_{Tank}}{FC_{BAB}} \times 100 \text{ [km]}$$

$$R_{WLTC,CAT} = \frac{V_{Tank}}{FC_{WLTC,CAT}} \times 100 \text{ [km]}$$

$$R_{PEMS,heavy} = \frac{V_{Tank}}{FC_{PEMS,heavy}} \times 100 \text{ [km]}$$

$$R_{worst\ case} = \min (R_{BAB} , R_{WLTC,CAT} , R_{PEMS,heavy}) \text{ [km]}$$