14 April 2022

Global Registry

Created on 18 November 2004, pursuant to Article 6 of the Agreement concerning the establishing of global technical regulations for wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles (ECE/TRANS/132 and Corr.1) done at Geneva on 25 June 1998

Addendum 22: United Nations Global Technical Regulation No. 22

United Nations Global Technical Regulation on In-vehicle Battery Durability for Electrified Vehicles

Established in the Global Registry on 9 March 2022

UNITED NATIONS

UN Global Technical Regulation on In-vehicle Battery Durability for Electrified Vehicles

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I. Statement of technical rationale and justification

A. Introduction

1. Owing to the pressing need to reduce emissions of greenhouse gases (GHG) and other air pollutants, the market share of electrified vehicles is expected to grow in the future. A key component of these vehicles is the traction battery that is used to store and deliver energy to power the movement of the vehicle and the systems within it. Improvements in the performance of batteries to deliver increased driving range, reduced charging times and greater affordability are a significant focus for manufacturers and technological developments in this area are expected to accelerate the uptake of electrified vehicles by consumers.

2. Despite the expected improvements in the performance of new electrified vehicles, the continued in-use performance of the battery over time is not currently regulated. The primary motivation for this GTR therefore stems from the recognition that the environmental performance of electrified vehicles may be affected by excess degradation of the battery system over time.

3. Loss of electric range and loss of vehicle energy efficiency are both primary concerns. Loss of electric range could lead to a loss of utility, meaning electric vehicles are driven less and therefore displace less distance travelled that might otherwise be driven in conventional vehicles. A loss in utility could also dampen consumer sentiment and curb the market growth necessary for electric vehicle sales to deliver on fleet emissions reductions. Loss of vehicle efficiency could impact the upstream emissions by increasing the amount of electricity needed per vehicle distance travelled. Both can affect not only the utility of the vehicle to the consumer, but also the environmental performance of the vehicle. Loss of environmental performance is important, in particular because governmental regulatory compliance programs often credit electrified vehicles with a certain level of expected environmental benefit, which might not be realized over the life of the vehicle if excess battery degradation occurs.

4. In addition to changes in range and energy consumption, hybrid electric vehicles are often equipped with both a conventional and electric powertrain, and for these vehicles the criteria pollutant emissions from the conventional powertrain could be impacted by the degradation of the battery over time.

5. This GTR therefore aims to provide a harmonised methodology to address these concerns by introducing a method by which the health of the battery can be monitored over time and by setting minimum performance requirements for the durability of the battery.

B. Procedural background

6. The Informal Working Group (IWG) on Electric Vehicle and the Environment (EVE) was set up in June 2012 following the approval by WP.29/AC.3 of ECE/TRANS/WP.29/AC.3/32. This document established two distinct IWGs to examine environmental and safety issues related to Electric Vehicles (EVs): the IWG on EVE, reporting to the Working Party on Pollution and Energy (GRPE), and the IWG on Electric Vehicle Safety (EVS), reporting to the Working Party on Passive Safety (GRSP). The proposal was supported by the European Commission, the United States of America, China, and Japan.

7. A second mandate for the IWG on EVE, divided into Parts A and B was approved in November 2014 by AC.3 to conduct additional research to address several recommendations that grew out of the first mandate, and develop UN GTR(s), if appropriate. The second mandate was separate from the IWG on EVS.

8. Part A of the second mandate of the IWG on EVE (ECE/TRANS/WP.29/AC.3/40) included “battery performance and durability” as one of the topics authorized for study and potential GTR development. Specifically, Part A authorized activity “to further develop the recommendations for future work outlined in the Electric Vehicle Regulatory Reference

Guide by: (i) conducting additional research to support the recommendations; (ii) identifying which recommendations are suitable for the development of (a) global technical regulation(s) (GTR(s)) by the World Forum for Harmonization of Vehicle Regulations (WP.29); and (iii) developing a work plan. The work of the IWG on EVE on battery performance and durability under Part A of the EVE mandate was reported to WP.29 in a status report as informal document WP.29-170-31 at the 170th meeting of WP.29, 15-18 November 2016.

9. At the close of Part A the IWG on EVE recommended that GRPE and WP.29 endorse the option of extending the mandate of the IWG on EVE to continue active research into the topic of battery performance and durability without committing to the development of a GTR at that time. This was endorsed and work continued on this topic within Part B of the mandate.

10. The IWG on EVE presented a draft status report to GRPE in May 2019 on the research on in-vehicle battery durability and performance. The status report indicated that there was sufficient information to allow a UN GTR for in-vehicle battery durability to be started. The IWG on EVE recommended at the 79th GRPE in May 2019 that the UN GTR on in-vehicle battery durability be developed under a new mandate.

11. AC.3 subsequently approved document ECE/TRANS/WP.29/AC.3/57 authorizing the IWG on EVE to develop a new UN GTR on in-vehicle battery durability which will be developed in 2 phases:

Phase 1:

(a) Deliver a first version of a UN GTR on in-vehicle battery durability to AC.3 by November 2021 with;

(i) Definition of and requirements for electrified vehicle battery performance criteria

(ii) Requirements for reading and/or displaying battery health information and usage data from the vehicle; and

(iii) A provisional in-service conformity test which will include generic usage criteria and a statistical method.

Phase 2:

(b) Develop a second version of the UN GTR on in-vehicle battery durability with the following:

(i) The development of a methodology to define Normal Usage Indices (NUI) based on data read from vehicles

(ii) Refined performance criteria requirements for in-vehicle battery durability through assessment of further modelling and data collected from real vehicles and the use of NUIs

C. Technical background

Battery degradation in electrified vehicles

12. The effect of battery degradation on environmental performance is likely to differ significantly among the various electrified vehicle architectures (PEV, OVC-HEV and NOVC-HEV). The primary forms of battery degradation are capacity degradation and power degradation. Capacity degradation is the loss of energy capacity, resulting in a loss of electric driving range (for PEVs and OVC-HEVs) and possibly increased use of the engine during hybrid operation (for NOVC-HEVs). Power degradation is the loss of battery power, which can also lead to increased use of the engine for OVC-HEV and NOVC-HEVs and possibly reduced performance of the vehicle overall.

13. There are at least six major vehicle operating parameters that affect in-vehicle battery durability. Each differs in importance depending on electrified vehicle architecture:

(a) Discharge rates, as determined by vehicle duty cycle and operator use including, but not limited to, vehicle speed, auxiliary loads, towing, payload and ambient conditions;

(b) Charge rates, as determined by type (normal, fast, super-fast) and frequency of charging;

(c) State of charge (SOC) window used in system operation of the battery and the amount typically used between charge events (depth of discharge);

(d) Battery temperature during operation (operation includes all temperature exposures from vehicle purchase through retirement, both while being operated and during periods of charging and inactivity);

(e) Time (calendar life);

(f) Other uses not reflected in calendar life or distance travelled, such as Vehicle to Grid (V2G).

14. The extent and nature of battery degradation that will occur is a result of complex mechanisms and heavily dependent on the battery cell chemistry and operating conditions. A variety of physical and electrochemical processes influence the durability of battery cells and these have been documented comprehensively within a literature review commissioned by the IWG on EVE. For typical lithium-ion batteries the primary mechanisms leading to capacity degradation were summarised as:

(a) Loss or deposition of cyclable lithium or a loss of balance between electrodes;

(b) Loss of electrode area; and

(c) Loss of electrode material or conductivity.

15. These aging processes are often further complicated by the fact that many of the mechanisms are associated with a rise in cell impedance, leading to a reduction in maximum cell power.

Management of battery degradation

16. Whilst manufacturers have found it possible to establish the durability of specific battery implementations sufficiently to bring the products to market with some degree of confidence that normal provisions for customer satisfaction and warranty terms are being met, not every manufacturer is establishing durability in the same way. Manufacturers employ a wide variety of testing regimes often tailored to specific product configurations, applications, customer groups, and geographic considerations.

17. To reduce the effect of capacity degradation on range, manufacturers may choose to slightly oversize a PEV or OVC-HEV battery to allow the range to be maintained by widening of the state-of-charge (SOC) window to make more capacity available as capacity degrades. Others may choose to design for a beginning-of-life range, and account for degradation by warranting the battery to a specified degree of capacity retention over a specified period of time or distance travelled. In the latter case, the consumer is expected to understand that a potential reduction in electric range is to be expected during the life of the vehicle.

18. Despite the expected loss of electric range and battery capacity retention over time, regulatory practice does not uniformly account for it. For example, US EPA range labelling rules for PEVs and OVC-HEVs effectively treat driving range as a beginning-of-life criterion, by measuring range at beginning of-life and omitting any adjustment for future capacity degradation, while still accounting for some cold temperature and high speed operation. For OVC-HEVs, however, manufacturers are indirectly compelled to account for degradation in range, in that it directly affects the calculated in-use emissions later in life. OVC-HEV greenhouse gas (GHG) emissions are calculated using the SAE J1711 procedure, which accounts for utility factor, a function of all-electric range. If range degrades during useful life, the utility factor correction would change and thus, the calculated GHG emissions would increase. Because vehicles are considered noncompliant if their emissions exceed the certified emission level by more than 10 percent during the useful life, manufacturers that do

not factor capacity degradation into their OVC-HEV designs risk exceeding the GHG standards in-use. Accordingly, for OVC-HEVs, manufacturers typically use a combination of battery oversizing and an energy management strategy that provides for a consistent range throughout the useful life.

19. A number of further measures are employed by manufacturers to limit battery degradation. These typically include, but are not limited to, the use of properly optimised battery management systems (BMS) and battery thermal management. BMS can reduce stress on the battery and prolong battery life by controlling some operations to protect the battery cells, maintain cell charge balancing and moderate the battery temperature. For example, BMS might control enhanced cooling systems, limit fast charging events through modulation of the charging current, control the available state of charge window, keep the cell voltages balanced, or reduce the maximum available torque as necessary to protect battery health. The inputs to BMS can include anything from ambient conditions and driver behaviour to individual cell metrics. Each manufacturer, vehicle, battery and cell could have unique and highly optimised BMS, that are updated and improved with every iteration. BMS are very complex and generally considered highly proprietary and should not be tampered with out of environmental and safety concerns. Another important factor is the battery thermal management capability. While some batteries are only passively cooled by ambient air, others are actively cooled and heated by use of forced air, liquid coolant, or refrigerant, which leads to greater BMS control over battery operating temperature and hence longer life.

Prediction and/or estimation of battery degradation

20. Accelerated aging is a familiar technique used by many manufacturers as a component of their battery durability testing methods. This technique assumes that a regime of rapid aging cycles can be translated to a projected useful life in service. However, it is uncertain whether the translation from accelerated aging to an in-use life projection is equally applicable to all forms of lithium-ion chemistries either currently in use or in the future.

21. One of the major mechanisms by which capacity and power degradation occurs in these chemistries is the microscopic fragmentation that accompanies swelling and contraction of anode and cathode materials during cycling. Specific chemistries differ significantly in this respect, suggesting that the relation between rapid cycling and long-term cycling may also differ significantly. An accelerated test that accurately projects useful life for one chemistry may therefore predict poor life for another chemistry, even though both chemistries may achieve an equal life in actual use.

22. Furthermore, accelerated ageing cannot take into account the real use of batteries inside vehicles and therefore can only partially estimate the real degradation.

23. To monitor degradation in-use, most manufacturers employ some form of in situ, on-board capacity estimation through the BMS. This estimation can vary in accuracy and precision depending on a number of factors including the sensors and estimation algorithm used, the charge/discharge behaviour of the user, and the cell type and cell model parameters. Proprietary algorithms are used to handle inaccuracies and output an estimate that can be utilised by other systems within the vehicle.

24. There are currently no requirements on the accuracy of on-board monitors and the estimates generated are not typically easily accessible to the vehicle user. The IWG on EVE has therefore made a decision to set the performance requirement in this field.

D. Technical rationale and justification

25. The mandate of the first phase of this GTR on in-vehicle battery durability includes the development of:

(a) Requirements for reading and/or displaying battery health information and usage data from the vehicle;

(b) Requirements for electrified vehicle battery durability performance criteria; and

(c) A provisional in-service conformity test which will include generic usage criteria and a statistical method.

26. This section sets out the key considerations of the IWG on EVE in developing the respective elements of Phase 1 of the GTR as set out above.

State-of-Certified Range and State-of Certified Energy (SOCR and SOCE) monitors

27. Whilst the term State of Health (SOH) is commonly applied to refer to the health of a battery at a given point in its life, this term is not commonly defined and is determined through a variety of different methodologies. It was therefore chosen to define two new related metrics for use within the GTR: the State of Certified Energy (SOCE) and the State of Certified Range (SOCR). Both metrics represent a percentage of the certified battery energy or electric range remaining at a given point in time. In the case of SOCE, it was decided to base the metric on the Usable Battery Energy (UBE).

28. Metrics based upon electric range and UBE were both chosen as the values can be determined through the respective certification test methodologies already applied within the Contracting Parties and are based on key performance parameters relating to battery health. These metrics are intended to provide both the basis of information made available to consumers and also values for assessment against Minimum Performance Requirements (MPR) relating to battery durability by manufacturers and authorities. The IWG decided to exclude NOVC-HEVs from Phase 1 of the GTR development. While batteries of NOVC-HEVs can experience degradation, NOVC-HEVs have no electric range, and their battery UBE is not typically determined at certification. Moreover, battery degradation in an NOVC-HEV is likely to result in degradation of fuel economy, which can be detected by existing in-service conformity practices. The IWG will continue to consider the need for extending this GTR to NOVC-HEVs in the future.

29. From discussions within the IWG it was concluded that it would not be appropriate to define the process or algorithm by which the SOCR or SOCE monitors determine their estimated values. It would be highly complex to define an algorithm that could accurately account for the range of battery cell chemistry and battery management strategies in use within the market. Instead, it was determined to allow manufacturers to determine their own means to estimate these metrics, whilst ensuring the accuracy through an in-use verification procedure.

Battery performance requirements

30. The key battery durability requirements set out within this GTR are defined in terms of MPR. MPR are expressed as a minimum allowable value of SOCE or SOCR after a given length of time or distance travelled. This follows a similar format applied by manufacturers when providing warranty for electrified vehicles.

31. In determining appropriate MPR values for this GTR the IWG on EVE considered a range of publicly available data as well as input from stakeholders within the IWG, which is summarised paragraphs 32. to 37. below.

32. Warranty analysis was conducted by the US EPA to understand the current warranty offering from manufacturers for electric vehicle batteries. The review primarily focussed on the US market, but values were also consistent with typical offerings within the European market. The review showed that batteries are covered for failure for between 7 to 10 years and typically up to 160,000 km[*]. Warranties that define failure in terms of a specific capacity retention specified between 60 and 75 per cent retention, most commonly 70 per cent. Warranty offerings of 8 years or 160,000 kilometres were found to be the most common. It has been highlighted by manufacturers that warranty offerings are not based solely on the technical performance of the battery and include further considerations from a commercial and customer satisfaction perspective. Nevertheless, the review provides an insight into the degree of confidence in products currently on the market.

[*] Only one vehicle manufacturer provides warranty up to 1,000,000 km

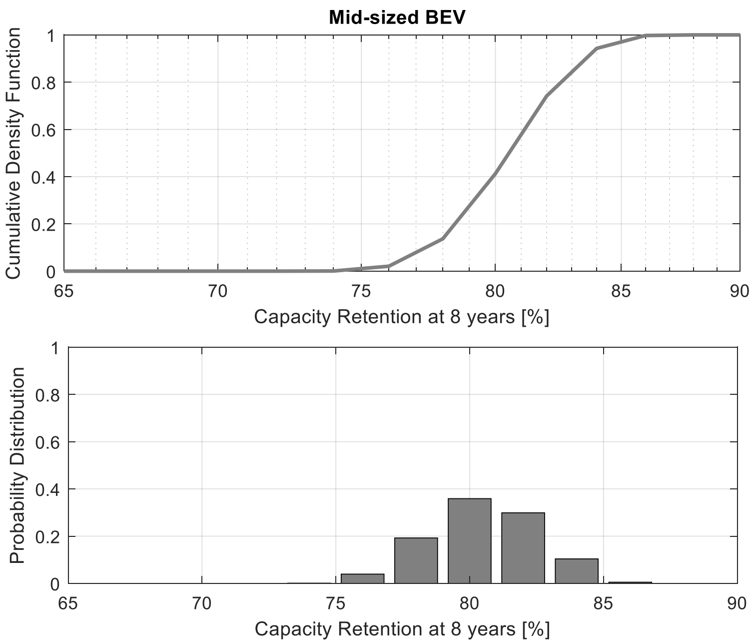
33. The European Commission's Joint Research Centre (JRC) has developed a dedicated in-vehicle battery durability assessment module within its 'Transport tEchnology and Mobility Assessment' (TEMA) platform. This is based on performance-based models as this class of models is the most suitable to be used with large-scale real-world driving data. TEMA is a modular big data platform designed to reproduce mobility behaviours of vehicles from datasets of navigation system data of conventional fuel vehicles and quantify possible impacts of new vehicle technologies on real-world mobility while supporting transport policy assessment.

34. TEMA combines recent performance-based capacity and power fade models for Lithium-ion batteries from literature with information on battery and vehicle architectures, together with real world vehicle driving data from different geographical areas of Europe, to develop a scenario-based analysis for predicting in-vehicle performance degradation of automotive traction batteries. The analysis includes the calendar and cycle capacity fade of three Lithium-ion variants ($LiFePO_4$, NCM with spinel Mn and NCM-LMO) in different vehicle architectures (OVC-HEV and PEV of different driving range segments), combined with different recharging strategies to explore the effect of different driving duty cycles related to different mobility patterns and environmental temperatures. Preliminary analyses on vehicle battery power fade have been also carried out.

35. The TEMA model was used to estimate the capacity retention of traction batteries after a range of distances and time periods to allow consideration of appropriate choices for MPR. Example TEMA modelling results in Figure I/1 for two different mid-sized BEVs configurations either charged with slow or fast charging show greater than 70 per cent capacity retention after 8 years. This result is generally consistent with prevailing warranty practice observed in the warranty survey. Additionally, good agreement was previously found between TEMA modelling results and electric vehicle lifetime performance testing data provided by Environment and Climate Change Canada and Transport Canada during work within the previous mandate of the IWG on EVE.

Figure I/1

Example of a capacity retention curve generated from JRC TEMA modelling for two different BEV configurations

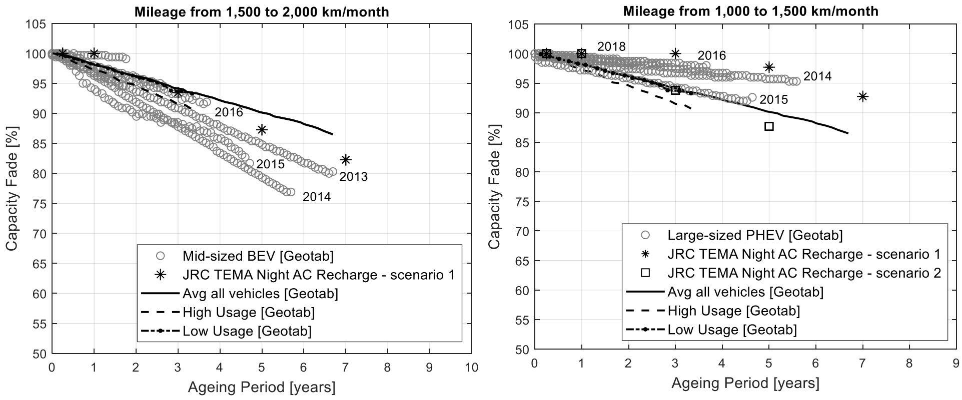


36. Geotab is a U.S. company that collects in-use data from vehicle fleets, and provides a publicly available set of estimated battery degradation histories computed from data collected from different makes and model years of BEVs and PHEVs. Raw data is sourced from telematics from 6,300 fleet and consumer vehicles, covering 21 vehicle models and

representing 64 distinct combinations of makes, models and years. The data is then converted to SOH estimates by means of a proprietary algorithm applied to the collected data, such as current and voltage measurements during charge and discharge. The data (see Figure I/2) also provides some insight into extreme vehicle use, extreme climates and charging methods. SOH estimates from Geotab were examined to understand the typical battery durability of existing vehicles in the fleet and also to compare with ageing predictions from the JRC's TEMA model, resulting in good correlation.

Figure I/2

Example comparison between estimated results from the TEMA model with in-use data from Geotab



37. Further analysis of the publicly available Geotab data was conducted by Japan and the Alliance for Automotive Innovation, where available SOH data was extrapolated to time points of 5 and 8 years to understand the expected SOH. Japan's analysis indicated that 90 percent of the vehicle models within the sample were able to achieve approximately 80 percent SOH after 5 years and 70 percent after 8 years. The Alliance for Automotive Innovation conducted similar analysis, but also included probability estimates which indicated that between 85 and 90 percent of the current fleet covered by the Geotab data would be able to meet an 80 percent SOH target after 5 years.

38. Following consideration of the available evidence and views of stakeholders within the IWG on EVE, two sets of MPR values were introduced based upon two different time and distance combinations. This approach allows coverage of the wide range of different distance-based requirements needed across Contracting Parties and provides the option for a Contracting Party to optionally apply only one of the MPR if appropriate for their market.

39. The MPR values selected were deemed to be sufficiently achievable based on the available evidence presented within the IWG, whilst also being sufficiently stringent to achieve the goal of preventing substandard products from entering the market. Following discussion within the IWG, the same MPR were set for OVC-HEVs and PEVs.

40. It was highlighted by manufacturers that the understanding and estimation of SOCR after a given duration of use or distance travelled currently presents an increased challenge compared to SOCE. There are many factors other than those originating from the battery leading to greater uncertainty of SOCR, including the measurement, test to test variability and precision of range retention calculations. As the majority of the evidence assessed by the IWG was also based primarily on remaining capacity or battery energy, it was decided to only monitor but not subject SOCR to an MPR requirement within Phase 1. No electric range based MPR have been selected at this point in time due to the above concerns with SOCR estimation. Inclusion of MPR for SOCR in future has, however, been highlighted as an area of importance for a number of Contracting Parties. Therefore, a placeholder for these values has been included to allow inclusion within a future amendment to the GTR.

41. Electrified vehicles of category 2 are at an earlier stage of adoption within the fleets of many Contracting Parties and subsequently in-use data relating to battery durability is scarce for these vehicles. For this reason, it is difficult presently to determine a suitable and

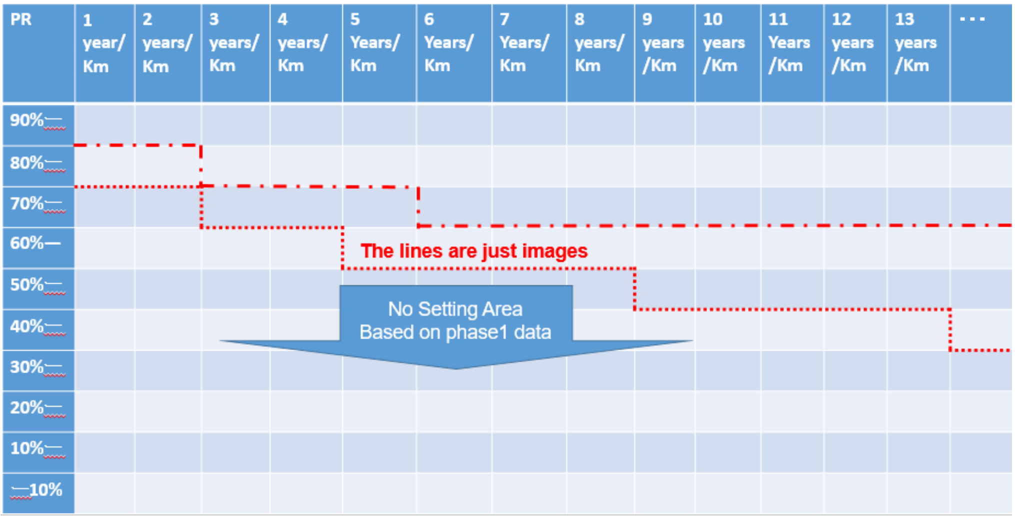
achievable MPR for category 2 vehicles. It has been raised by manufacturers that in future the batteries of these vehicles may also be used for supplementary purposes, in addition to propulsion, which could have further impacts on battery durability that are not currently well understood. MPR values for category 2 vehicles therefore remain reserved for inclusion in a future amendment to this GTR.

42. Battery longevity is a key consideration for consumers and regulating agencies, therefore there is an incentive for manufacturers to accredit batteries that perform beyond the minimum requirements of this GTR. To allow manufacturers to market or quantify the benefits of any improved battery technology they may have installed within their vehicles the GTR also allows for a Declared Performance Requirement (DPR) to be proposed by manufacturers, based upon a higher value of SOCE/SOCR. To ensure the accuracy of any declared values, the DPR would be considered to act in place of the MPR for the purposes of in-use verification. The DPR is not intended to indicate a regulatory warrantied value. Manufacturer warranties are beyond the scope of this GTR. A manufacturer may wish to warranty batteries beyond the MPR without attaching additional warranty benefits to a DPR.

43. The new MPR setting concept as depicted with the matrix below, Figure I/3, was proposed by Japan in order to let each Contracting Party decide its own MPR as option. The matrix exemplified the area to be defined as substandard category of MPR and the area that the MPR can be determined.

The IWG considered this proposal and decided to not adopt it during the first phase.

Figure I/3
Sample of MPR Matrix



In-use verification

44. To ensure the accuracy of the SOCE/SOCR monitors and also ensure that MPR are being met it was necessary to introduce a two part in-use verification process, with Part A verifying the accuracy of the monitors and Part B verifying the battery durability against MPR.

45. Part A verification involves measurement of the UBE/electric range under the applicable test procedure and determination of a measured SOCE/SOCR by dividing by the respective values from certification. These measured values can then be compared to the on-board values from the SOCE/SOCR monitors to ensure the accuracy is within a given tolerance. For this purpose, the resolution of the on-board values from SOCE/SOCR was set to 1 part in 100, and the required accuracy defined by a statistical process as described below.

46. A pass or fail decision on a sample of vehicles will be reached through a statistical process, which evaluates the average of the ratios of measured/on-board-indicated SOCE/SOCR from a series of vehicles tested. After testing a minimum of 3 vehicles a

decision on either a pass or fail decision or on testing a further vehicle will be reached, on the basis of a statistical formula considering the quantitative deviation of the latter average from a value A = (1 + tolerance) and the variance of these ratios over the whole test series with a tolerance = 5% granted for a single test due to technical reasons. The method proposed is particularly suitable for cases where a quantity (such as SOCE/SOCR) is likely to differ from the 'true' measured quantity continuously and reflects the method used for evaluating the conformity of production (CoP) in UN Regulation No. 154.

47. As Part A verification is expected to involve a relatively small number of sample vehicles to limit the testing burden, it is important to ensure that the sample result is not unduly impacted by the abnormal use or poor maintenance of a vehicle within the sample. A vehicle survey has therefore been introduced within Annex 1 containing information designed to ensure that the vehicle has been properly used and maintained according to the specifications of the manufacturer. Any vehicles not meeting the required criteria may be removed from the test sample.

48. Due to the accuracy of the SOCE/SOCR monitors being assured through verification in Part A, it is possible to verify the battery durability of a sample of vehicles within Part B through remote collection of the on-board SOCE/SOCR values, together with information on the age of the vehicles and the distance travelled. Where a vehicle has been equipped with V2X capabilities, an equivalent virtual distance will be calculated using the V2X discharge energy and the certified energy consumption. This will be summed with the distance travelled to calculate the total distance. This approach avoids the need for further testing of vehicles within Part B and enables a simple route to the assessment of a large sample size of vehicles, thereby minimising the impact that outliers (e.g. vehicles that have been used abnormally) may have on the sample result.

49. It is recognised that SOCE/SOCR values read from a sample of vehicles are likely to be in the form of a distribution, with values for individual vehicles dependent on the vehicle usage and any inherent variation in the performance of the vehicle or traction battery. Where a vehicle has been used abnormally (e.g. with prolonged periods of storage or being regularly used in extremes of temperature) this may also give rise to more significant degradation of battery health. To reduce the impact of vehicles that may have been used abnormally, it was decided to make the overall pass decision dependent on more than or equal to 90 per cent of monitor values read from the vehicle sample being above the MPR. This approach thereby ensures that the MPR is being met by the significant majority of the vehicle sample, whilst accounting for abnormal usage.

50. To further minimise influence of abnormally used vehicles, a maximum of 5 per cent of the values taken from smaller durability families that consist of less than 500 vehicles may be excluded from the verification sample in Part B with appropriate reasoning.

51. To support this two part in-use verification process, whilst minimising the burden of increased testing for manufacturers within Part A, two family concepts were developed within the GTR. This includes the concept of a monitor family for use in Part A and a battery durability family for Part B. This is likely to reduce the need for additional testing where multiple battery durability families may have the same characteristics with respect to verification of the SOCR/SOCE monitors. In addition, the Part A in-use verification for the vehicles in the same monitor family may be combined between different regions with the agreement of all Contracting Parties involved. This contributes not only to minimise the testing burden but also to increase the verification robustness. However, this concept shall not be applied for Part B since battery deterioration might be different in different regions due to different usage patterns and ambient conditions.

E. Technical feasibility, anticipated costs and benefits

52. The use of SOH monitoring within some electrified vehicles is already common practice and the improvement of monitor accuracy is an area under active development by manufacturers. Updating these monitors to ensure the specific requirements within this GTR are met and to allow information to be provided to the consumer may, however, entail some further development costs for manufacturers. Inclusion of SOCR for monitoring purposes

only should allow manufacturers time to gather sufficient data and further develop their understanding of range deterioration to make the inclusion of range-based MPR technically feasible in future.

53. The Part A verification of SOCE/SOCR accuracy will involve additional testing by manufacturers and, optionally, by authorities who choose to further verify monitor accuracy. The additional costs associated with testing have been mitigated to an extent by making use of the relevant test procedure already applied for range (or UBE) determination in the respective Contracting Party. This should allow manufacturers to incorporate verification into any existing verification programme planned for those vehicles.

54. Any costs associated with verification within Part B are likely to be borne by the authorities of the Contracting Parties applying this regulation and will depend on the extent and means by which they choose to collect data for verification. Costs may be borne by the manufacturer in the case of a fail for a battery durability family relating to the costs of measures agreed with the relevant authorities to bring those vehicles back into compliance.

55. This GTR is likely to give rise to benefits for manufacturers and authorities through the prevention of inferior products which could undermine the market. Introduction of inferior products within the market could disadvantage those manufacturers who have invested in the development of technology aimed at ensuring battery longevity and could also undermine the environmental benefits that can arise from electrified vehicles, as well as public acceptance.

56. The longevity of battery life is a key concern for prospective consumers of electrified vehicles. The health of a vehicle's battery upon entry into the second-hand market is also a significant point of consideration for the consumer and is not easily understood in the absence of access to accurate battery health monitors. The availability of both accurate battery health information and assurances on battery longevity for consumers that is provided by this GTR are therefore likely to have a positive impact on the cost retention of electric vehicles and consumer confidence in buying an electrified vehicle.

F. Future development of the GTR

57. The mandate for development of this GTR included the future development of improvements to the GTR within Phase 2 that includes, but not limited to:

(a) The development of a methodology to define Normal Usage Indices (NUIs) based on data read from vehicles; and

(b) Refined performance criteria requirements for in-vehicle battery durability through assessment of further modelling and data collected from real vehicles and the use of NUIs.

58. The concept of an NUI is a data field stored on the vehicle that represents a history or assessment of lifetime usage patterns of the vehicle that are influential to battery degradation. For example, one NUI might characterise temperature exposures during the life of the vehicle, while another might characterise charging rates or number of fast-charging events. The definition of NUIs was highlighted within the discussions of the IWG on EVE as a technically challenging task that will require further data collection and validation to achieve. It could, however, provide an alternative and more robust means of handling SOCE/SOCR values recorded from vehicles that have been used abnormally in future. The possibility of incorporating NUIs within this GTR should therefore be explored.

59. The implementation of this GTR by Contracting Parties will enable the collection of further data on SOCE and SOCR to better inform our understanding of battery health degradation. This information will, in turn, allow further refinement of the GTR, including MPR values, based upon the latest available battery technologies employed within the market. This will be important given the rapid development of technology in the field of battery technology for electrified vehicles that is already underway.

60. The monitoring of SOCR values following the implementation of this GTR will provide a sound basis for the consideration of appropriate range-based MPR in a future

revision to this GTR. Equally, the monitoring of both SOCE and SOCR for category 2 vehicles should allow the inclusion of MPR for this category of vehicle in future.

II. Text of the GTR

1. Purpose

This Global Technical Regulation provides a worldwide harmonized method to set and verify minimum performance requirements on in-vehicle battery durability of Pure Electric Vehicles (PEVs) and Off-vehicle Charging Hybrid Electric Vehicles (OVC-HEVs).

2. Scope and application

This GTR applies to vehicles of categories 1–2 and 2, that have a technically permissible maximum laden mass not exceeding 3,855 kg, and to vehicles of category 1–1, that (a) are PEV or OVC-HEV vehicles, and (b) have an originally installed battery as defined in this GTR.

At the option of the Contracting Party, the scope may be limited to 3,500 kg for the relevant categories.

While manufacturers commonly estimate or publicise other range-based metrics for informational purposes (such as, for example, an in-use range under real driving conditions, or the remaining range available before the next charging event), the range-related provisions of this GTR are concerned only with the certified range as would be measured by the applicable certification test procedure.

The authorities shall make a decision about the applicability of this GTR to Small Volume Manufacturers for their jurisdiction.

3. Definitions

The following definitions shall apply in this Global Technical Regulation.

3.1. *"Battery"* means, in the context of this GTR, a rechargeable electrical energy storage system (REESS) installed in an electrified vehicle and used mainly for traction purposes.

3.2. *"Originally installed battery"* means the battery that is installed in the vehicle at the time of manufacture, or if the vehicle is manufactured without an installed battery, the battery that is installed in the vehicle when it is first operated on the road.

3.3. *"Usable Battery energy (UBE)"* means the energy supplied by the battery from the beginning of the test procedure used for certification until the applicable break-off criterion of the test procedure used for certification is reached.

3.4. *"Certified usable battery energy"* ($UBE_{certified}$) refers to the UBE that was determined during the certification of the vehicle, according to Annex 3 of this GTR.

3.5. *"Measured usable battery energy"* ($UBE_{measured}$) means the UBE determined at the present point in the lifetime of the vehicle by the test procedure used for certification, according to Annex 3 of this GTR.

3.6. *"Electric Range"* refers to the range that would be determined by the range test procedure used for certification of the vehicle, if the test was performed at the present point in the lifetime of the vehicle and with the originally installed battery.

3.7. *"Certified range"* ($Range_{certified}$) refers to the electric driving range that was determined during certification of the vehicle, according to Annex 3 of this GTR.

3.8. *"Measured range"* ($Range_{measured}$) means the electric range determined at the present point in the lifetime of the vehicle by the test procedure used for certification, according to Annex 3 of this GTR.

3.9. *"State of certified energy"* (SOCE) means the measured or on-board UBE performance at a specific point in its lifetime, expressed as a percentage of the certified usable battery energy.

3.10. *"State of certified range"* (SOCR) means the measured or on-board electric range at a specific point in its lifetime, expressed as a percentage of the certified range.

3.11. *"Minimum Performance Requirement"* (MPR) means the minimum durability performance, in terms of SOCE or SOCR at a specific point in the life of the vehicle, that constitutes compliance with the durability provisions of this GTR.

3.12. *"Declared Performance Requirement"* (DPR) means an SOCE or SOCR value declared by the manufacturer that is greater than that of the corresponding MPR and which then becomes the minimum durability performance that constitutes compliance of that manufacturer with the durability provisions of this GTR.

3.13. *"SOCR monitor"* means an apparatus installed in the vehicle that maintains an estimate of the state of certified range by means of an algorithm operating on data collected from the vehicle systems.

3.14. *"SOCE monitor"* means an apparatus installed in the vehicle that maintains an estimate of the state of certified energy by means of an algorithm operating on data collected from the vehicle systems.

3.15. *"On-board SOCR*" ($SOCR_{read}$) means an estimate of state of certified range produced by an SOCR monitor.

3.16. *"On-board SOCE"* ($SOCE_{read}$) means an estimate of state of certified energy produced by an SOCE monitor.

3.17. *"Measured SOCR"* ($SOCR_{measured}$) means the state of certified range as determined by the measured range divided by the certified range, according to paragraph 6.3.2. of this GTR.

3.18. *"Measured SOCE"* means the state of certified energy as determined by the measured usable battery energy divided by the certified usable battery energy.

3.19. *"V2X"* means the use of the traction batteries to cover external power and energy demand, such as V2G (Vehicle-to-Grid) for grid stabilization by utilising traction batteries, V2H (Vehicle-to-Home) for utilizing traction batteries as residential storage for local optimisation or emergency power sources in times of power failure, and V2L (Vehicle-to-Load, only connected loads are supplied) for use in times of power failure and/or outdoor activity in normal times.

3.20. *"Total discharge energy during V2X"* means the total amount of discharged energy during V2X which needs to be provided according to Annex 2.

3.21. *"Off-vehicle charging hybrid electric vehicle"* (OVC-HEV) means an OVC-HEV vehicle as defined in UN GTR No. 15.

3.22. *"Pure electric vehicle"* (PEV) means a PEV vehicle as defined in UN GTR No.15.

3.23. *"Maximum charging power"* means the highest available charging power for the considered Part B family.

4. Abbreviations

DPR	Declared Performance Requirement
MPR	Minimum Performance Requirement
OTA	Over the Air
REESS	Rechargeable Electrical Energy Storage System
SOC	State of Charge
SOCE	State of Certified Energy
SOCR	State of Certified Range
UBE	Usable Battery Energy
V2G	Vehicle to Grid
V2H	Vehicle to Home
V2L	Vehicle to Load

5. Requirements

5.1. State-of-Certified Range and State-of Certified Energy (SOCR and SOCE) monitors

The manufacturer shall install SOCR and SOCE monitors that operate during the life of the vehicle. The SOCR monitor shall maintain an estimate of the state of certified range (on-board SOCR), and the SOCE monitor shall maintain an estimate of the state of certified energy (on-board SOCE).

The manufacturer shall determine the algorithms by which on-board SOCR and on-board SOCE are determined for the vehicles they produce. The manufacturer shall update the on-board SOCR and SOCE with sufficient frequency as to maintain the necessary degree of accuracy during all normal vehicle operation.

The on-board SOCR and SOCE shall have a resolution of 1 part in 100 and be reported as the nearest whole number from 0 to 100.

The manufacturer shall make available the most recently determined values of the on-board SOCR and on-board SOCE via the OBD port and optionally over-the-air (OTA).

For the purposes of consumer information, the manufacturer shall make easily available to the owner of the vehicle the most recently determined value of the SOCE monitor via at least one appropriate method. The resolution for the customer values shall be determined in agreement with the authorities. For example:

(a) dashboard indicator;

(b) infotainment system;

(c) remote access (such as via mobile-phone applications).

5.2. Battery Performance Requirements

The battery durability requirements of this GTR are defined in terms of Minimum Performance Requirements (MPR*i*), which represent minimum allowable values for SOCE and SOCR at specific points in the lifetime of the vehicle. Vehicles falling under the categories of OVC-HEVs and PEVs shall meet both of the Minimum Performance Requirements in Tables 1 and 2 below. The MPRs may differ depending on the category of the vehicle and type of propulsion.

In order to address regional considerations, a Contracting Party may optionally elect to enforce only one of the two Minimum Performance Requirements (MPR*i*) in each of the tables below (i.e. either the one ending at 5 years or 100,000 km, or the one ending at 8 years or 160,000 km).

Table 1
Battery Energy based (SOCE) MPR

Vehicle age/km for categories 1-1 and 1-2 in the scope of this GTR	*OVC-HEV*	*PEV*
From start of life to 5 years or 100,000 km, whichever comes first	80 per cent	80 per cent
Vehicles more than 5 years or 100,000 km, and up to whichever comes first of 8 years or 160,000 km	70 per cent	70 per cent

Vehicle age/km for category 2 in the scope of this GTR	*OVC-HEV*	*PEV*
From start of life to 5 years or 100,000 km, whichever comes first	(Reserved)	(Reserved)
Vehicles more than 5 years or 100,000 km, and up to whichever comes first of 8 years or 160,000 km	(Reserved)	(Reserved)

Table 2
Range based (SOCR) MPR

Vehicle age/km for categories 1-1 and 1-2 in the scope of this GTR	*OVC-HEV*	*PEV*
From start of life to 5 years or 100,000 km, whichever comes first	(Reserved)	(Reserved)
Vehicles more than 5 years or 100,000 km, and up to whichever comes first of 8 years or 160,000 km	(Reserved)	(Reserved)

Vehicle age/km for category 2 in the scope of this GTR	*OVC-HEV*	*PEV*
From start of life to 5 years or 100,000 km, whichever comes first	(Reserved)	(Reserved)
Vehicles more than 5 years or 100,000 km, and up to whichever comes first of 8 years or 160,000 km	(Reserved)	(Reserved)

SOCR and SOCE monitors of vehicles of category 2 and SOCR monitors of category 1-1 and 1-2 vehicles shall be installed and their values monitored in view of setting the values in the tables in a future amendment of this GTR.

A manufacturer may elect to declare a Declared Performance Requirement (DPR*i*) having an SOCE and/or SOCR value that is higher than that of the corresponding MPR. The DPR*i* shall then replace the MPR*i* for the purposes of determining compliance by that manufacturer.

The manufacturer shall ensure that batteries installed in vehicles comply with the rules specified in paragraph 6.4.2. for the MPR*i* (or DPR*i* if applicable).

At the request of the manufacturer and for vehicles designed with V2X, the equivalent virtual distance calculated following the equation below will be reported by each vehicle.

$$\boldsymbol{Virtual\ distance}\ (km) = \left(\frac{\text{total discharge energy during V2X } [Wh]}{\text{worst case certified energy consumption of PART B family } [\text{Wh/km}]}\right)$$

Where:

"worst case certified energy consumption of Part B family" means the worst case certified energy consumption of a Part B family which needs to be provided according to Annex 2.

At the option of the manufacturer, instead of using the worst case certified energy consumption value of the Part B family, the manufacturer may be allowed to use any higher energy consumption value.

The total distance used for confirming the compliance with the minimum performance requirements will consist of the sum of the distance driven and the virtual distance. The total percentage of the virtual distance shall be recorded and monitored.

6. In-Use Verification

6.1. Definitions of Families

Vehicles having the same characteristics with respect to their evaluation under Part A or Part B below shall be grouped into vehicle families for the purpose of compliance verification. Families under Part A shall have the same characteristics with respect to verification of the SOCR/SOCE monitors. Families under Part B shall have the same characteristics with respect to verification of battery durability.

Families with the same characteristics with respect to compliance verification shall be defined as follows:

6.1.1. For Part A: Verification of Monitors

Only vehicles that are substantially similar with respect to the following elements may be part of the same monitor family:

(a) Algorithm for estimating on-board SOCR and on-board SOCE;

(b) Sensor configuration (for sensors used in determination of SOCR and SOCE estimates);

(c) Characteristics of battery cell which have a non-negligible influence on accuracy of monitor;

(d) Type of vehicle (PEVs or OVC-HEVs).

At the request of the manufacturer, with the approval of the responsible authority and with appropriate technical justification, the manufacturer may deviate from the above criteria for families.

6.1.2. For Part B: Verification of Battery Durability

Only vehicles that are substantially similar with respect to the following elements may be part of the same battery durability family:

(a) Type and number of electric machines, including net power, construction type (asynchronous/ synchronous, etc.), and any other characteristics having a non-negligible influence on battery durability;

(b) Type of battery (dimensions, type of cell, including format and chemistry, capacity (Ampere-hour), nominal voltage, nominal power;

(c) Battery management system (BMS) (with regards to battery durability monitoring and estimations);

(d) Passive and active thermal management of the battery;

(e) Type of electric energy converter between the electric machine and battery, between the recharge-plug-in and battery, and any other characteristics having a non-negligible influence on battery durability;

(f) Operation strategy of all components influencing the battery durability;

(g) Declared maximum charging power.

At the request of the manufacturer, with the approval of the responsible authority and with appropriate technical justification, the manufacturer may deviate from the above criteria for families.

6.2. Information gathering

The following information shall be made available to the authorities by the manufacturer in a format to be agreed between the authorities and the manufacturer: annual report on relevant warranty claims; and annual statistics on repairs for both batteries and other systems that might influence the electric energy consumption of the vehicle. Such information shall be made available once a year for each battery durability family for the duration of the period defined in paragraph 5.2. after the last vehicle of this family is sold.

6.3. Part A: Verification of SOCR/SOCE monitors

6.3.1. Frequency of verifications

The manufacturer shall complete the procedure for in-use verification for Part A with a frequency agreed with the authorities, until 5 or 8 years as defined in paragraph 5.2. after the last vehicle of each monitor family is sold and report the results of the verification to the authorities. The authorities may decide to proceed with their own verification of Part A, at a frequency and magnitude based on risk assessment, or request more information from the manufacturers. With the agreement of all Contracting Parties involved, the verification of Part A for vehicles in the same monitor family may be combined between different Contracting Parties. In such cases the relevant Contracting Parties shall be considered as a single authority for the purposes of this verification.

At the option of the Contracting Party, the verification of the monitors shall not be mandatory if the annual sales of the monitor family are less than 5,000 vehicles in the market for the previous year. Such families may still be selected to be tested for Part A, at the request of the responsible authorities.

6.3.2. Verification procedure

In order to verify the SOCR/SOCE monitors, the values for range and usable battery energy shall be measured at the time of the verification and the related values from the monitors shall be collected before the verification test procedure. To support future improvement of the GTR, indicator values shall be collected again after the verification test procedure. Those indicators read after the verification test procedure shall not be considered in the Part A verification.

The measured SOCR and measured SOCE values shall be determined by dividing the measured values for range and usable battery energy by the certified values for range and usable battery energy, respectively, expressed in per cent.

$$SOCE_{measured} = \frac{UBE_{measured}}{UBE_{certified}} * 100$$

$$SOCR_{measured} = \frac{Range_{measured}}{Range_{certified}} * 100$$

In cases where $UBE_{measured}$ is higher than the $UBE_{certified}$, the $SOCE_{measured}$ shall be set to 100 per cent. In cases where $Range_{measured}$ is higher than the $Range_{certified}$, the $SOCR_{measured}$ shall be set to 100 per cent.

6.3.3. Statistical Method for Pass/Fail decision for a sample of vehicles

Separate statistics shall be calculated for the SOCR monitor and the SOCE monitor.

An adequate number of vehicles (at least 3 and not more than 16) shall be selected from the same monitor family for testing following a vehicle survey (see Annex 1) which contains information designed to ensure that the vehicle has been properly used and maintained according to the specifications of the manufacturer. The following statistics shall be used to take a decision on the accuracy of the monitor.

For evaluating the SOCR/SOCE monitors normalised values shall be calculated:

$$x_i = SOC_{read,i} - SOC_{measured,i}$$

Where

$SOC_{read,i}$ is the on-board SOCR/SOCE read from the vehicle i ; and

$SOC_{measured,i}$ is the measured SOCR/SOCE of the vehicle i.

For the total number of N tests and the normalised values of the tested vehicles, x_1, x_2, ... x_N, the average X_{tests} and the standard deviation s shall be determined:

$$X_{tests} = \frac{(x_1 + x_2 + x_3 + \cdots + x_N)}{N}$$

and

$$s = \sqrt{\frac{(x_1 - X_{tests})^2 + (x_2 - X_{tests})^2 + \ldots + (x_N - X_{tests})^2}{N - 1}}$$

For each N tests $3 \leq N \leq 16$, one of the three following decisions can be reached, where the factor A shall be set at 5:

(a) Pass the family if $X_{tests} \leq A - \left(t_{P1,N} + t_{P2,N}\right) \cdot s$

(b) Fail the family if $X_{tests} > A + \left(t_{F1,N} - t_{F2}\right) \cdot s$

(c) Take another measurement if:

$$A - \left(t_{P1,N} + t_{P2,N}\right) \cdot s < X_{tests} \leq A + \left(t_{F1,N} - t_{F2}\right) \cdot s$$

where the parameters $t_{P1,N}$, $t_{P2,N}$, $t_{F1,N}$, and t_{F2} are taken from Table 3.

Table 3
Pass/fail decision criteria for the sample size

	PASS		*FAIL*	
Tests (N)	$t_{P1,N}$	$t_{P2,N}$	$t_{F1,N}$	t_{F2}
3	1.686	0.438	1.686	0.438
4	1.125	0.425	1.177	0.438
5	0.850	0.401	0.953	0.438
6	0.673	0.370	0.823	0.438
7	0.544	0.335	0.734	0.438
8	0.443	0.299	0.670	0.438
9	0.361	0.263	0.620	0.438
10	0.292	0.226	0.580	0.438
11	0.232	0.190	0.546	0.438
12	0.178	0.153	0.518	0.438
13	0.129	0.116	0.494	0.438
14	0.083	0.078	0.473	0.438
15	0.040	0.038	0.455	0.438
16	0.000	0.000	0.438	0.438

6.3.4. Corrective measures for the SOCR and SOCE monitors

A fail decision for the sample means that the monitors fail to report accurately the durability of the system and appropriate action shall be taken by the manufacturer with the agreement of the responsible authority. This may lead to the requirement that the manufacturer repairs or replaces the faulty monitor including the relevant sensors or by applying software measures in all affected vehicles in the monitor family.

A pass decision or correction of the non-compliance is required for proceeding with Part B.

6.4. Part B: Verification of Battery Durability

6.4.1. Frequency of verifications

Data shall be collected yearly by the authorities from a statistically adequate sample of vehicles within the same battery durability family. The decision on the number of the vehicles in the sample may be taken by the responsible authority based on risk assessment methodology, but in principle should not be less than 500.

If the number of vehicles in the sample is less than 500, then on the request of the manufacturer and with the agreement of the responsible authority, a maximum of 5 per cent of the values may be excluded from the sample. In such a case, the manufacturer needs to provide adequate information on the reason behind the exclusion for each vehicle to the authority.

If the number of vehicles in the sample is equal to or more than 500, then all vehicles shall be included in the sample. The data read shall be those of the SOCR and SOCE monitors (and other relevant data, such as those defined in Annex 2). SOCR and SOCE monitors of vehicles of category 2 and SOCR monitors of category 1-1 and 1-2 vehicles shall be monitored.

6.4.2. Pass/Fail Criteria for the battery durability family

A battery durability family shall pass if equal to or more than 90 per cent of monitor values read from the vehicle sample are above the MPR*i* or DPR*i*.

A battery durability family shall fail if less than 90 per cent of monitor values read from the vehicle sample are above the MPR*i* or DPR*i*.

6.4.3. Corrective Measures for the Battery Durability Family

In case of a fail for a battery durability family, corrective measures shall be taken with the agreement of the responsible authority in order to bring the family or part of the family affected by the issue into compliance.

6.5. Process flow charts for Part A and Part B

The flow charts below illustrate the various steps in the verification process of Part A (Figure 1) and Part B (Figure 2).

Figure 1
Flow chart for Part A: Verification of Monitors

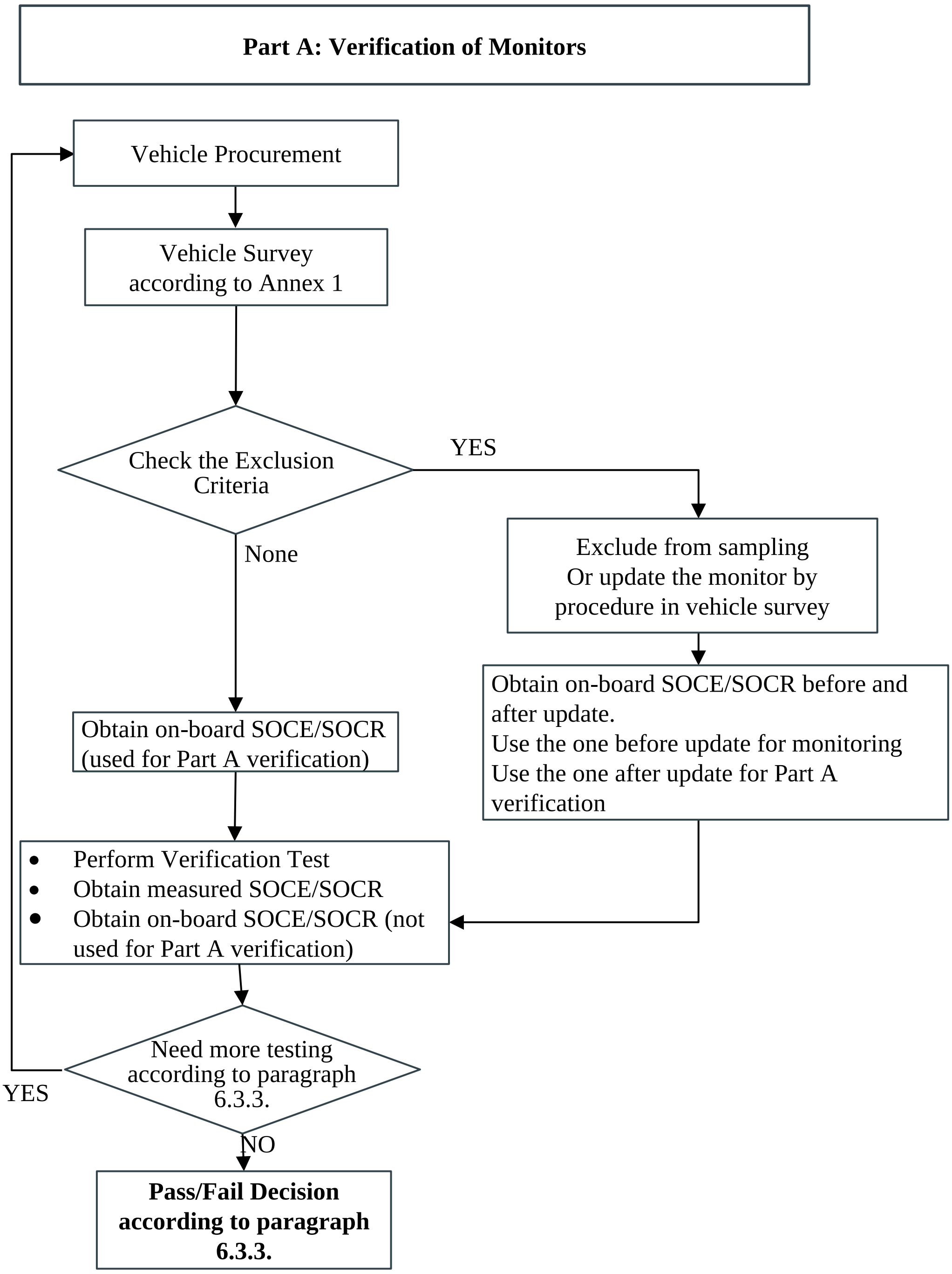
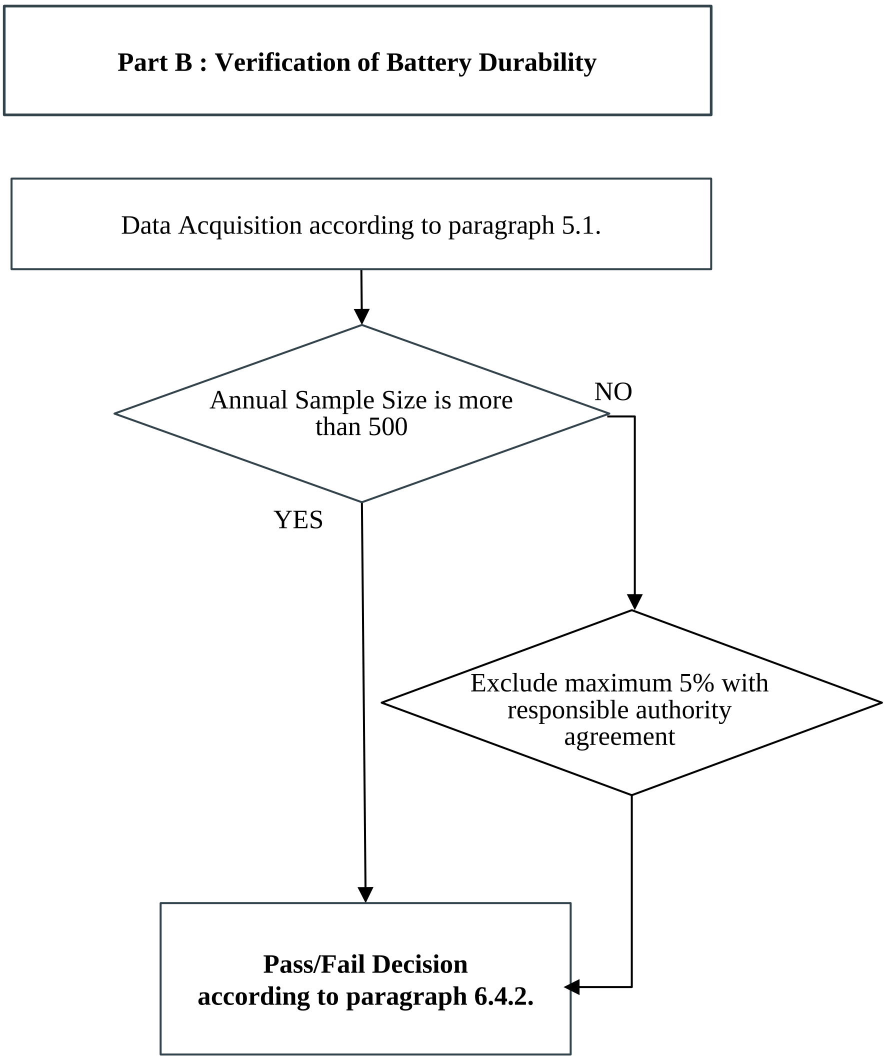


Figure 2
Flow chart for Part B : Verification of Battery Durability



7. Rounding

7.1. When the digit immediately to the right of the last place to be retained is less than 5, that last digit retained shall remain unchanged.

Example:

If a result is 1.2344 kWh but only three places of decimal are to be retained, the final result shall be 1.234 kWh.

7.2. When the digit immediately to the right of the last place to be retained is greater than or equal to 5, that last digit retained shall be increased by 1.

Example:

If a result is 1.2346 kWh but only three places of decimal are to be retained, and because 6 is greater than 5, the final result shall be 1.235 kWh.

Annex 1

Vehicle Survey

The vehicle survey shall be used for all vehicles selected for testing in Part A of the verification. Vehicles that fall under one of the exclusion criteria below shall be eliminated from testing, or otherwise updated according to the procedures described below.

	x = Exclusion Criteria	**x = Checked and reported**	**Confidential**
Date:			**x**
Name of investigator:			**x**
Location of test:			**x**
Country of registration:		**x**	

Vehicle Characteristics	**x = Exclusion Criteria**	**x = Checked and reported**	**Confidential**
Registration plate number:		**x**	**x**
The vehicle must have ***age and distance*** *travelled (defined as the time elapsed after first registration) below the one required in paragraph 5.2. for the MPR verification*	**x**		
Is the vehicle either PEV or OVC-HEV? If no: the vehicle cannot be selected	**x**		
Date of first registration:		**x**	

VIN:		**x**	
Emission class and character or Model Year		**x**	
Country of registration: *The vehicle must be registered in a Contracting Party*	**x**	**x**	
Model:		**x**	
Engine code:		**x**	
Engine volume (l):		**x**	
Engine power (kW):		**x**	
Electric Engine code:		**x**	
Electric Engine power (kW):		**x**	
Electric powertrain type		**x**	
Energy capacity and type of battery		**x**	
Gearbox type (auto/manual):		**x**	
Drive axle (FWD/AWD/RWD):		**x**	
Tyre size (front and rear if different):		**x**	
Average fuel consumption for PHEVs		**x**	

Is the vehicle involved in a recall or service campaign? **If yes: Which one? Have the campaign repairs already been done?** *The repairs must have been done before selecting the vehicle.*	**x**	**x**	

Vehicle Owner Interview
(the owner will only be asked the main questions and shall have no knowledge of the implications of the replies)

Name of the owner (only available to the accredited inspection body or laboratory/technical service)			x
Contact (address / telephone) (only available to the accredited inspection body or laboratory/technical service)			x

How many owners did the vehicle have?		**x**	
Did the odometer work? *If no, the vehicle cannot be selected.*	**x**		
Was the vehicle used for one of the following?			
As car used in show-rooms?		**x**	
As a taxi?		**x**	
As a delivery vehicle?		**x**	
For racing / motor sports?	**x**		
As a rental car?		**x**	
Has the vehicle carried heavy loads over the specifications of the manufacturer? *If yes, the vehicle cannot be selected.*	**x**		
Have there been major engine, electric motor or vehicle repairs?		**x**	
Have there been unauthorised major engine or vehicle repairs? *If yes, the vehicle cannot be selected.*	**x**		
Was the propulsion battery changed or repaired? *If yes, the vehicle cannot be selected for testing, but information should be collected*	**x**	**x**	
Has there been an unauthorised power increase/tuning? *If yes, the vehicle cannot be selected.*	**x**		
Was any part of the emissions after-treatment system modified? *If yes, the vehicle cannot be selected*	**x**		
Where do you use your vehicle more often?	-	-	-
% motorway	-	**x**	-
% rural	-	**x**	-
% urban	-	**x**	-
Has the vehicle been maintained and used in accordance with the manufacturer's instructions? *If not, the vehicle cannot be selected.*	**x**		
Full service and repair history including any re-works *If the full documentation cannot be provided, the vehicle cannot be selected.*	**x**		
Battery related checks:			
How often did you charge the vehicle when:		**x**	
%with battery almost at 0 charge	**-**	**x**	

%with battery half charged **%with battery almost fully charged**	**-** **-**	**x**	
On average how often were fast or superfast chargers used in a month? **What is your estimation of the percentage of time that the vehicle was used in the following ambient temperature ranges:** **Below -7C:** **Between -7C and 35C:** **More than 35C:**		**x** **x** **x** **x**	

Vehicle Examination and Maintenance by the Testing Centre (please use the relevant entries according to the type of vehicle)	**x= Exclusion Criteria**	**x=checked and reported**	**Relevant for BEV**
Was the vehicle not charged adequately* for the last month? *If the vehicle was not charged adequately for the last month (as evidenced by values read from the vehicle under point 9, Annex 2) and the tester wishes to use it for testing, then it has to be conditioned by driving the vehicle no less than 50 km and in a manner that results in discharge of at least 50 per cent of the usable capacity of the battery, followed by a full recharge.* Note: * Adequately in this sense means that the vehicle was not charged in a manner that would lead to an accurate SOCE/SOCR	**x**		
Fuel tank level (full / empty) Is the fuel reserve light ON? *If yes, refuel before test.*		**x**	
Are there any warning lights on the instrument panel activated indicating a vehicle or exhaust after-treatment system malfunctioning that cannot be resolved by normal maintenance? (Malfunction Indication Light, Engine Service Light, etc?) *If yes, the vehicle cannot be selected*	**x**		
Is the SCR light on after engine-on? *If yes, the reagent should be filled, or the repair executed before the vehicle is used for testing.*	**x**		
Visual inspection exhaust system Check leaks between exhaust manifold and end of tailpipe. Check and document (with photos) *If there is damage or leaks, the vehicle cannot be tested*	**x**		
Exhaust gas relevant components Check and document (with photos) all emissions relevant components for damage. *If there is damage, the vehicle cannot be tested*	**x**		
Air filter and oil filter Check for contamination and damage. Change if damaged or heavily contaminated or less than 800 km before the next recommended change.		**x**	
Wheels (front & rear) Check whether the wheels are freely moveable or blocked or impeded by the brake. *If not freely moveable, the vehicle cannot be selected.*	**x**		**Y**
Drive belts & cooler cover *In case of damage, the vehicle cannot be tested.*	**x**		
Check fluid levels Check the max. and min. levels (engine oil, cooling liquid) / top up if below minimum		**x**	

Vacuum hoses and electrical wiring Check all for integrity. *In case of damage, the vehicle cannot be tested.*	x		Y
Injection valves / cabling Check all cables and fuel lines. *In case of damage, the vehicle cannot be tested.*	x		Y
Ignition cable (gasoline) Check spark plugs, cables, etc. In case of damage, replace them.		x	
EGR & Catalyst, Particle Filter Check all cables, wires and sensors. *In case of tampering or damage, the vehicle cannot be selected.*	x		
Safety condition Check tyres, vehicle's body, electrical and braking system status are in safe conditions for the test and respect road traffic rules. *If not, the vehicle cannot be selected.*	x		Y
Semi-trailer Are there electric cables for semi-trailer connection, where required?		x	Y
Check if less than 800 km away from next scheduled service, if yes, then perform the service.		x	Y
Powertrain Control Module calibration part number and checksum		x	Y
OBD diagnosis (before or after the range test) Read Diagnostic Trouble Codes & Print error log		x	
OBD Service Mode 09 Query (before or after the range test) Read Service Mode 09. Record the information.		x	
OBD mode 7 (before or after the range test) Read Service Mode 07. Record the information			

Remarks for: Repair / replacement of components / part numbers

Annex 2

Values to be read from vehicles:

1. On board SOCE value
2. On board SOCR value
3. Odometer (in km)
4. Date of manufacture of the vehicle
5. Total distance (sum of the distance driven and the virtual distance) [km], if applicable
6. Percentage of virtual distance [in per cent], if applicable
7. Worst case certified energy consumption of PART B family [Wh/km], if applicable
8. Total discharge energy in V2X [Wh], if applicable
9. Last charged by more than 50 per cent SOC swing on [Date]
10. Maximum, minimum, average ambient temperature* the vehicle was exposed to during its lifetime

Note: * ambient temperature to be read as daily averages

Annex 3

Determination of Performance Parameter during Part A Test Procedure

1. General

For the calculation of $SOCE_{measured}$ and $SOCR_{measured}$ according to paragraph 6.3.2. of this GTR, the measured and certified values of usable battery energy (UBE) and electric range (PER for PEVs and EAER for OVC-HEVs) are required:

- $UBE_{measured}$ and $UBE_{certified}$
- $Range_{measured}$ and $Range_{certified}$

This annex describes the determination of these parameters in case of WLTP, in paragraph 2. for PEVs and in paragraph 3. for OVC-HEVs and gives guidance on which measurements need to be performed and which certified values need to be applied for a vehicle selected in the Part A verification procedure. Regions that do not apply UN GTR No. 15 (GTR15) or UN Regulation No. 154, shall define an alternative solution informed by the guidance below.

For the purposes of this annex, for PEVs the term 'battery' includes not only REESS used mainly for traction purposes, but also all other REESSs.

2. Performance parameters for PEVs

2.1. UBE for PEVs

2.1.1. Measured UBE values for PEVs

Parameters	*Explanation*	
$UBE_{measured}$	Shortened Test Procedure (STP)	Consecutive Cycle Procedure (CCP)
	UBE value shall be determined according to GTR15 Annex 8, Table A8/11 Step no. 1.	UBE value shall be determined according to GTR15 Annex 8, Table A8/10 Step no. 1.
	No rounding shall be applied on $UBE_{measured}$.	

2.1.2. Certified UBE values for PEVs

Parameters	*Explanation*	
$UBE_{certfied}$	Shortened Test Procedure (STP)	Consecutive Cycle Procedure (CCP)
	$UBE_{certified}$ is the adjusted measured usable battery energy (UBE) of the vehicle at certification: $UBE_{certified} = UBE_{measured} * AF_{PER}$ where: $UBE_{measured}$ is the measured usable battery energy according to GTR15 Annex 8, Table A8/11 Step no.1 at certification. In case of more than one test (number of tests), the determined UBE values shall be averaged. AF_{PER} is the adjustment factor determined according to GTR15, Annex 8, Table A8/11 Step no. 6.	$UBE_{certified}$ is the adjusted measured usable battery energy (UBE) of the vehicle at certification: $UBE_{certified} = UBE_{measured} * AF_{PER}$ where: $UBE_{measured}$ is the measured usable battery energy according to GTR15 Annex 8, Table A8/10 Step no.1 at certification. In case of more than one test (number of tests), the determined UBE values shall be averaged. AF_{PER} is the adjustment factor determined according to GTR15, Annex 8, Table A8/10 Step no. 7.

Parameters	*Explanation*
	$UBE_{certfied}$ shall be rounded according to paragraph 7 of this GTR: - To the nearest whole number in case unit is Wh - To three significant numbers in case unit is kWh
	In the case the interpolation method is applied, $UBE_{certified}$ shall be determined by selecting - The maximum $UBE_{measured}$ amongst vehicle H and vehicle L; - The AF which is closest to 1.

2.2. Range for PEVs

2.2.1. Measured Range values for PEVs

Parameters	*Explanation*	
$Range_{measured}$	Shortened Test Procedure (STP)	Consecutive Cycle Procedure (CCP)
	Range value (PER_{WLTC}) shall be determined according to GTR15 Annex 8, Table A8/11, Step no. 4.	Range value (PER_{WLTC}) shall be determined according to GTR15 Annex 8, Table A8/10, step no. 5.
	No rounding shall be applied on $Range_{measured}$.	

2.2.2. Certified Range values for PEVs

Parameters	*Explanation*	
$Range_{certified}$	Shortened Test Procedure (STP)	Consecutive Cycle Procedure (CCP)
	Range value (PER_{WLTC}) according to GTR15 Annex 8, Table A8/11 Step no.6. or 9†.	Range value (PER_{WLTC}) according to GTR15 Annex 8, Table A8/10 Step no.7. or 10†.
	$Range_{certified}$ shall be rounded to the nearest whole number according to paragraph 7 of this GTR.	

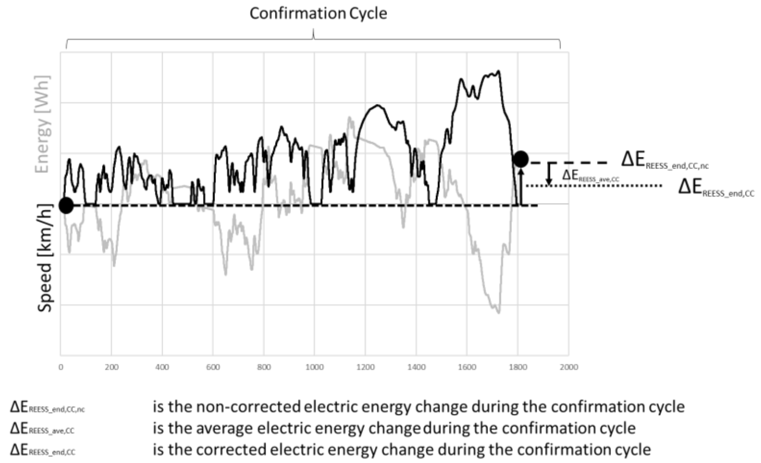
Note: †depending on whether the interpolation <u>method</u> is <u>applied</u> or not

3. Performance parameters for OVC-HEVs

3.1. UBE for OVC-HEVs

3.1.1. Measured UBE values for OVC-HEVs

Parameters	*Explanation*
$UBE_{measured}$	$UBE_{measured}$ shall be the usable battery energy calculated as follows: $$UBE_{measured} = UBE_{measured,nc} - \Delta E_{REESS,CC_{ave}}$$ Where: $UBE_{measured,nc}$ is the non-corrected usable battery energy of the charge-depleting test, Wh; $\Delta E_{REESS,CC_{ave}}$ is the average electric energy change of the confirmation cycle, Wh; CC means confirmation cycle as defined in GTR15 Annex 8, paragraph 3.2.4.4.. The correction with the average electric energy change in the confirmation cycle is required as the break-off criterion, according to GTR 15 Annex 8, paragraph 3.2.4.5., allows a toggling around the absolute reference level. The correction shall compensate for this effect and is visualized in the following figure:

Parameters	*Explanation*
	
	The required input parameter $UBE_{measured,nc}$ is calculated as follows: $$\mathrm{UBE_{measured,nc}} = \sum_{i=1}^{n} \Delta \mathrm{E_{REESS,i}}$$ where: $\Delta E_{REESS,i}$ is the measured electric energy change of battery i, Wh; i is the index number of the considered battery; n is the total number of batteries; and: $$\Delta \mathrm{E_{REESS,i}} = \frac{1}{3600} \times \int_{t_0}^{t_{end}} \mathrm{U(t)_{REESS,i}} \times \mathrm{I(t)_{REESS,i}}\, dt$$ where: $U(t)_{REESS,i}$ is the voltage of battery i, V; $I(t)_{REESS,i}$ is the electric current of battery i, A; t_0 is the time at the beginning of the charge-depleting test, s; t_{end} is the time at the end of the confirmation cycle of the charge-depleting test, s; $\frac{1}{3600}$ is the conversion factor from Ws to Wh.
	The required input parameter $\Delta E_{REESS,CC,ave}$ is calculated as follows: $$\Delta E_{REESS.CC,ave} = \sum_{i=1}^{n} \Delta E_{REESS,avg,i,CC}$$ Where: $\Delta E_{REESS,avg,i,CC}$ is the average of the measured electric energy change of battery *i* during the confirmation cycle, Wh; *i* is the index number of considered battery; *n* is the total number of batteries; and $$\Delta \mathrm{E_{REESS,avg,i,CC}} = \frac{1}{3600} \times \frac{1}{\mathrm{t_{end,CC}} - \mathrm{t_{start,CC}}} \times \int_{\mathrm{t_{start,CC}}}^{\mathrm{t_{end,}}_{CC}} \int_{\mathrm{t_{start,}}_{CC}}^{\mathrm{t_{end,}}_{CC}} \mathrm{U_{REESS,}}_{i}(\mathrm{t}) \times \mathrm{I_{REESS,}}_{i}(\mathrm{t}) dt\, dt$$ where: $U_{REESS,i}(t)$ is the voltage of battery *i*, in V $I_{REESS,i}(t)$ is the current of battery *i*, in A

Parameters	*Explanation*
	$t_{start,CC}$ is the time at the beginning of the confirmation cycle of the charge-depleting test, s; $t_{end,CC}$ is the time at the end of the confirmation cycle of the charge-depleting test, s; $\frac{1}{3600}$ is the conversion factor from Ws to Wh. CC means confirmation cycle as defined in GTR15 Annex 8, paragraph 3.2.4.4.
No rounding shall be applied on $UBE_{measured}$.	

3.1.2. Certified UBE values for OVC-HEVs

Parameters	*Explanation*
$UBE_{certified}$	$UBE_{certified}$ is the adjusted measured usable battery energy (UBE) of the vehicle at certification: $$UBE_{certified} = UBE_{measured} * AF_{OVC-HEV}$$ Where: $UBE_{measured}$ is the measured usable battery energy according to paragraph 3.1.1. of this annex, Wh; $AF_{OVC-HEV}$ is the adjustment factor determined as described below. At the option of the Contracting Party, one out of the following two adjustment factors shall be selected: - Adjustment factor 1: $AF_{OVC-HEV} = \frac{EC_{measured}}{EC_{certified}}$ where: $EC_{certified}$ is the electric energy consumption $EC_{AC.CD}$ according to GTR15 Annex 8, Table A8/8, Step no. 14 at certification, Wh/km; $EC_{measured}$ is the measured electric energy consumption $EC_{AC,CD}$ according to GTR15 Annex 8, Table A8/8, Step no. 13 at certification. Wh/km. - Adjustment factor 2: $AF_{OVC.HEV} = \frac{EC_{measured}}{EC_{certified}}$ where: $EC_{certified}$ is EC according to GTR15 Annex 8, Table A8/9, Step no. 8 at certification, Wh/km; $EC_{measured}$ is measured EC according to GTR15 Annex 8, Table A8/9, Step no. 7 at certification. Wh/km.
	$UBE_{certfied}$ shall be rounded according to paragraph 7 of this GTR: - To the nearest whole number in case unit is Wh - To three significant numbers in case unit is kWh
	In the case the interpolation method is applied, $UBE_{certified}$ shall be determined by selecting: - The maximum $UBE_{measured}$ amongst vehicle H and vehicle L and (if applicable) vehicle M; - The AF which is closest to 1.

3.2. Range for OVC-HEVs

3.2.1. Measured range values for OVC-HEVs

Parameters	*Explanation*
$Range_{measured}$	$Range_{measured}$ is the measured equivalent all-electric range as defined in the equation below: $$EAER_{measured} = \left(\frac{M_{CO2,CS} - M_{CO2,CD,avg}}{M_{CO2,CS}}\right) \times R_{cdc}$$ where:
	$M_{CO2,CD,avg}$ is the arithmetic average charge-depleting CO_2 mass emission according to GTR15, Annex 8, Paragraph 4.4.4.1., g/km;
	$M_{CO2,CS}$ is the charge-sustaining CO_2 mass emission according to GTR15, Annex 8, Table A8/5 Step no. 5, g/km;
	R_{CDC} is the measured length of the charge-depleting test according to GTR15, Annex 8, Table A8/8, Step no. 3, km;
	No rounding shall be applied on $Range_{measured}$.

3.2.2. Certified range values for OVC-HEVs

Parameters	*Explanation*
$Range_{certified}$	$Range_{certified}$ (EAER) according to UN Regulation No. 154, Series of amendments 02 or later, Annex B8, Table A8/9 Step no. 8 or 9† at certification.
	$Range_{certified}$ shall be rounded to the nearest whole number according to paragraph 7 of this GTR.

Note: †depending on whether the interpolation method is applied or not