Vehicle Certification Agency

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Decision Number: 2022/539054-VCA

Issue: 3

Official Decision – Eco-Innovation Approved

Legislation

Statutory Instruments 2019 no. 550, *The Road Vehicle Emission Performance Standards (Cars and Vans) (Amendment) (EU Exit) Regulations 2019.*
(In particular: Amendment of Commission Implementing Regulation (EU) No 725/2011 and 427/2014)

Details

Reason for Record: Application approved

Application Details

Applicant Name and Address:	ACEA, Rond-Point Schuman 6, 1040 Brussels, Belgium (formerly: Avenue des Nerviens 85, B- 1040 Brussels, Belgium)
Application Title/Description:	12V efficient charging through intelligent control of hybrid vehicle recuperated kinetic energy for use in hybrid powered passenger cars (M1) and light commercial vehicles (N1)
Date submitted:	12/07/2021

Assessment Details

Assessment Number:	EOX539054
Date of Assessment Completion:	12/09/2022

Conclusion

The above-mentioned Application was assessed by the Vehicle Certification Agency in accordance with the above-mentioned legislation and was found to comply in all respects.

As of the date below, this Official Decision, and its Annexes, may allow manufacturers to benefit from a reduction of its average specific CO_2 emissions in the United Kingdom, by means of the CO_2 savings from the use of the innovative technology approved by this Official Decision. This shall be done in accordance with the above-mentioned legislation and shall reference this Decision in the application for a GB type-approval for the vehicles concerned.

Signature:	CMcCabe C McCABE Chief Technical and Statutory Operations Officer
Date:	12/09/2022
Assigned eco innovation code for UK:	99

UK Approval Authority | Vehicle Certification Agency
16-Dec-22

Information regarding Certification of CO_2 Savings

1. A manufacturer may apply to VCA for certification of the CO_2 savings in the UK from the use of the innovative technology by reference to this Decision.

2. The manufacturer shall ensure that the application for the certification is accompanied by a verification report from an independent and certified body confirming that the technology conforms to the intended scope of the approved eco-innovation and meets any relevant technical requirements as set out in the Annexes.

3. the manufacturer shall ensure that the certified CO_2 savings and the eco-innovation code are recorded in the certificate of conformity of the vehicles concerned.

4. VCA shall ensure that CO_2 savings achieved from the use of the innovative technology have been determined using the methodology set out in the Annexes.

5. Where a manufacturer applies for the certification of the CO_2 savings for more than one type of this innovative technology in relation to one vehicle version, VCA shall determine which of those tested delivers the lowest CO_2 savings. That value shall be used for the purpose of paragraph 6.

6. VCA shall record the certified CO_2 savings calculated in accordance with the approved methodology (with the quantified uncertainty subtracted from the total savings to be certified) and the eco-innovation code referred to in this Decision in the relevant type-approval documentation.

7. In the case pre-defined CO_2 savings determined in accordance with Article 4(2)(ea) of Retained Implementing Regulation (EU) No 725/2011 and 427/2014, the relevant pre-defined savings value may be entered directly into the type approval documentation, provided that VCA is in a position to confirm that the vehicle is fitted with the technology in accordance with the specifications of this Decision.

8. VCA shall record all the elements considered for the certification in a test report and keep that together with the verification report referred to in paragraph 2.

9. VCA shall only certify CO_2 savings from the use of the innovative technology if it finds that the technology conforms with this Decision, and if the CO_2 savings determined in accordance with paragraph 6 are 0,5 g CO_2/km or higher, as specified in Article 9(1)(b) of Retained Implementing Regulation (EU) No 725/2011 in the case of passenger cars, or in Article 9(1)(b) of Retained Implementing Regulation (EU) No 427/2014 in the case of light commercial vehicles.

10.

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Annexes

	Title	Number of pages
Annex I	*12VPS APPLICATION UK_FINAL v1.75* (REDACTED for clarity and confidentiality)	19
Annex II	*SD_04_ACEA_12VPS_Calculation_tool v6_14*	1

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ANNEX I

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UK Approval Authority
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16-Dec-22

[redacted]

UK Approval Authority
Vehicle Certification Agency
16-Dec-22

1. [redacted] Applicants

Company Name	Company Full Name	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
AUDI	Audi AG	[redacted]	[redacted]	[redacted]	[redacted]	
BMW	Bayerische Motoren Werke AG	[redacted]	[redacted]	[redacted]	[redacted]	
Daimler AG	Daimler AG	[redacted]	[redacted]	[redacted]	[redacted]	
FCA	FCA Italy S.p.A	[redacted]	[redacted]	[redacted]	[redacted]	
HONDA	Honda Motor Europe Ltd	[redacted]	[redacted]	[redacted]	[redacted]	
JLR	Jaguar Land Rover LTD	[redacted]	[redacted]	[redacted]	[redacted]	
OPEL	OPEL Automobile GmbH –(GM Legacy)	[redacted]	[redacted]	[redacted]	[redacted]	
PSA	Automobile Citroen Automobile Peugeot PSA Automobiles SA OPEL Automobile GmbH -PSA	[redacted]	[redacted]	[redacted]	[redacted]	

2. Executive summary of the application (for publication)

Title of the Innovative Technology

12V efficient charging through intelligent control of hybrid vehicle recuperated kinetic energy for use in hybrid powered passenger cars (M1) and light commercial vehicles (N1)

Contact details

Applicant's Name:	ACEA
Applicant's Address:	Avenue des Nerviens 85, B-1040 Brussels, Belgium
Contact Person:	[redacted] / Jaguar Land Rover LTD Abbey Road, Whitley, Coventry, CV3 4LF, United Kingdom

Summary

Hybrid vehicles and certain conventional vehicles with capability to recuperate kinetic energy and redeploy the energy for torque assist to the combustion engine are also capable of redeploying the energy more efficiently to supply the vehicle 12V board net through a DC/DC converter, therefore reducing the need for actively charging the 12V board net by burning fossil fuel. When the recuperated kinetic energy is more abundant than the demand to supply the 12V board net under the type approval condition, off-cycle benefit of such system can be quantified.

Building on the previously submitted application for 48V motor generator plus 48V/12V DC/DC converter technology by ACEA (approved Implementing Decision EU 2020/1167), which takes account only the generator function benefit versus a conventional alternator technology, this application focuses on the system benefit on top of the 48V MG application, taking account for the regenerative braking / energy harvest and torque assist function. Combined with the 48V MG application, the total benefit of 48V hybrid vehicles and certain conventional vehicles in efficiently charging the 12V board net can be realistically represented.

The proposed methodology delivers a WLTP based CO_2 saving potential through intelligent control of recuperated kinetic energy. The simplified calculation methodology uses input data from component and type approval testing and calculates the off-cycle CO_2 savings.

Innovativeness

The market penetration of NOVC-HEV hybrid electric vehicles in 2017 was 2.6% in the EU 28 (that is EU27 + U.K.) and 2.4% in the U.K. and therefore smaller than 3%

Necessity

The function to supply energy to the vehicle boardnet is essential for the safe operation of the vehicle.

Measurement methodology

The testing methodology is the "simplified method" according to Regulation (EU) 2018/258, Article 4, section b iii (ea).

The simplified calculation methodology uses input data from extended type approval testing and component testing.

3. [redacted]

[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

4. Choice of testing methodology.

The application for the approval of an innovative technology as an eco-innovation is in reference to the standard test procedure as prescribe in Regulation (EU) 2018/258 and (EU) 2018/259, to the Worldwide Harmonised Light Vehicle Test Procedure (WLTP) referred to in Commission Regulation (EU) 2017/1151 from 14 March 2018.

5. Technical Description

Hybrid vehicles and certain conventional vehicles, with capability to recuperate kinetic energy and redeploy the energy for vehicle propulsion or torque assist to the combustion engine, are also capable, in real-world conditions, of redeploying the energy more efficiently to supply the vehicle 12V board net through a DC/DC converter, therefore reducing the need for actively generating to serve the 12V boardnet by burning fossil fuel. When the recuperated kinetic energy is more abundant than the demand to supply the 12V boardnet under the type approval condition, off-cycle benefit of such a system can be quantified.

Building on the previously submitted application for 48V motor generator plus 48V/12V DC/DC converter technology by ACEA, which was approved as Implementing Decision (EU)2020/1167, where only the Generate Function benefit versus that of a conventional alternator technology is taken into account, this application focuses on the system benefit on top of the 48V MG application, taking account for the additional effect of regenerative braking / energy harvesting and torque assist function. Combined with the 48V MG application, the total benefit of hybrid vehicles and certain conventional vehicles in efficiently charging the 12V board net can be realistically represented. This application is only for use with 48V systems (systems that operate at <60V DC) because it builds on Implementing Decision EU 2020/1167 which is for 48V systems.

The proposed methodology delivers a WLTP based CO_2 saving potential through intelligent control of recuperated kinetic energy that is harvested during a vehicle's deceleration. The simplified calculation methodology uses input data from component and type approval testing and calculates the off-cycle CO_2 savings.

5.1. Active generate function.

The active generate (charging) function is the default mode for the baseline vehicle (see figure 1 below) for power generation. Depending on the power demand of the vehicle power net, the motor generator is controlled to generate sufficient electricity to meet such demand by taking mechanical energy from the internal combustion engine crankshaft (i.e. generator directly coupled to crankshaft).

On the eco-innovation vehicle (see figure 2), however, the active Generate function is used much less frequently since the recuperation / harvested energy is able to satisfy most of the electrical power demand. Only when the recuperated energy is not sufficient to support the vehicle's 12V load, is the active Generate function used by the eco-innovation vehicle to supply electricity to the 12V power net.

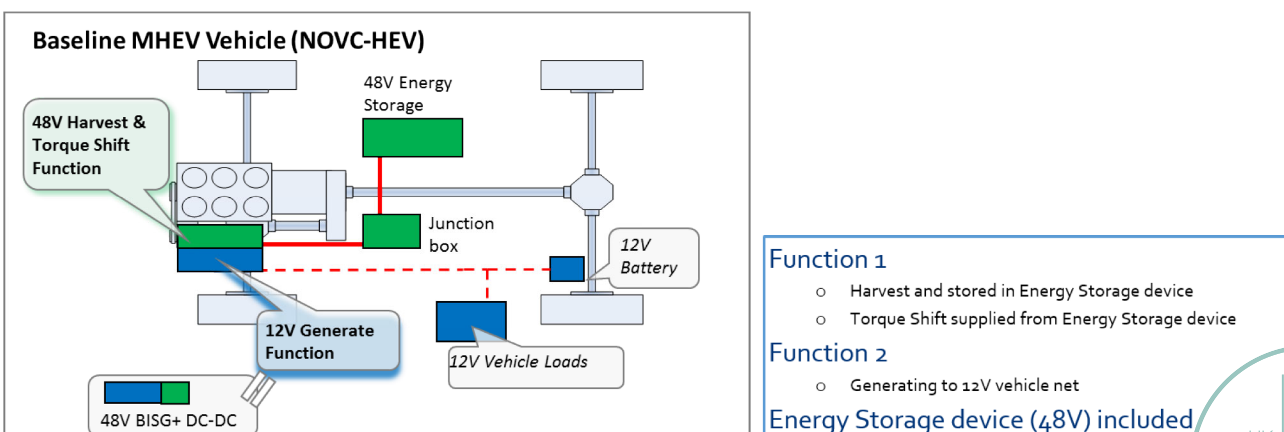

Figure 1. Baseline with its two distinct functions

5.2. Recuperation function.

A vehicle equipped with a motor generator (e.g. NOVC-HEV) harvests energy when the vehicle is moving and the brake pedal is applied and/or when the accelerator pedal is released. The amount of energy that can be harvested depends on the specification of the motor generator, deceleration rate calibration setting, battery state-of-charge and the vehicle properties. The recuperated electrical energy can later be used by the motor generator to torque assist the internal combustion engine for vehicle propulsion, directly reducing the use of fossil fuel. Furthermore, an eco-innovation vehicle can also use the recuperated electrical energy directly for the vehicle 12V power boardnet demand, by virtue of having a 48V to 12V DC-DC converter, thence supporting essential vehicle functions such as lighting and ventilation, or other navigation or entertainment functions.

It can be further reasoned that due to the different level of active charging level, the amount of kinetic-electric energy conversion, which can be counted as recuperation, is lower for the baseline vehicle than the eco-innovation, although the same amount of energy has been actually converted. Thus, in the calculation method proposed in chapter 11, the baseline vehicle recuperation is reduced by the constant power consumption of the vehicle power net, since power is already consumed and cannot be used for torque assist/shift function.

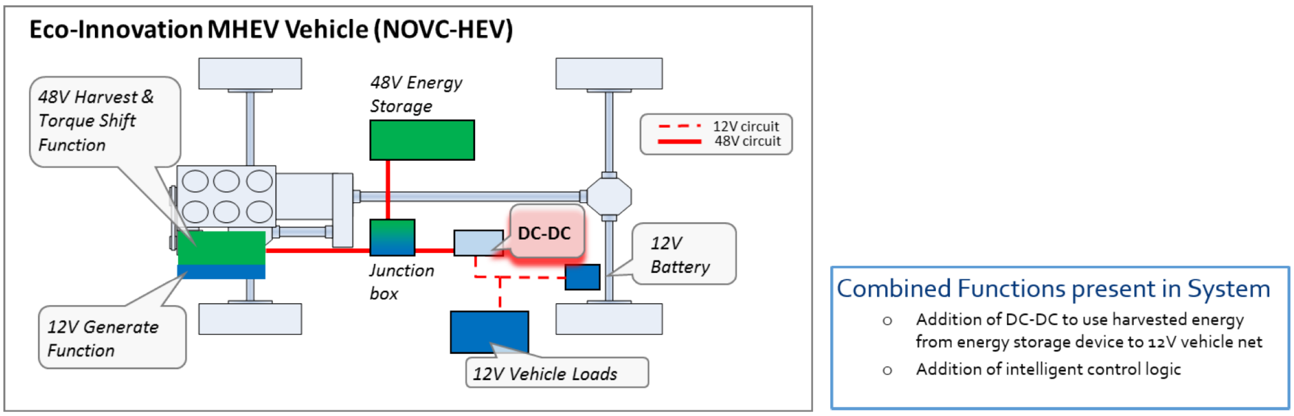

Figure 2. Eco-Innovation with Functions now Combined

5.3. Torque assist/shift function.

The torque assist or torque shift function is the motoring of the motor generator to directly support the propulsion of the vehicle (as such meaning the motor-generator is not a peripheral device as defined by the regulators) and assist the internal combustion engine so that the engine is consuming less fossil fuel and more often operates in a more efficient region on the engine efficiency map. As shown in Figure 3 below, when the vehicle is operating its engine at the blue point on the efficiency map, the vehicle controller would decide to shift some of the load to the electric motor move the engine operating point to the green spot. As a result the engine is operating in the high efficiency region and the overall fuel consumption and CO_2 emissions are reduced. The torque assist/shift function is the default mode for the NOVC-HEV baseline vehicle to make use of its recuperated energy; its controller contains references or tables relating to the conversion efficiencies (of the baseline vehicle's powerpack) or to the equivalent fuel "cost" in energy terms for a particular energy path and can therefore arbitrate where the harvested energy can most efficiently be "spent" to reduce fuel consumed.

In the case of the eco-innovation vehicle, the intelligent controller is able to use recuperated / harvested energy most efficiently and can additionally choose to direct this electrical energy via the DC/DC converter to the vehicle 12V board net. Once again, the controller contains references or tables relating to the conversion efficiencies (of the eco-innovation vehicle's powerpack) or to the equivalent fuel "cost" in energy terms for a particular energy path and can therefore arbitrate where the harvested can most efficiently be "spent" to reduce fuel consumed.

It is important to keep in mind that recuperation energy gained from harvesting that energy in slowing the vehicle has been gained without having spent fuel and therefore it is important to spend this energy as efficiently as possible within the boundary conditions presented during the customer's use of the vehicle: much effort is therefore expended by the OEMs to ensure that the controller is maximising the value of this energy for the functions of a given powerpack system installed in a particular vehicle.

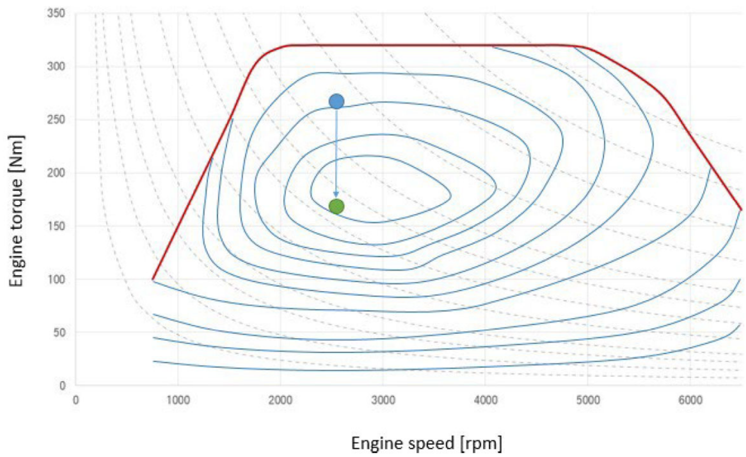

Figure 3. Example of torque assist/shift function on an engine efficiency map.

5.4. Efficient Energy Flow.

In figure 4, line “1” represents the energy to support 350W for 1800 seconds (i.e. the duration of the WLTC) and is met by the “Base – Generate” column for the Baseline vehicle in Type Approval condition. Line “2” represents the energy to support 750W for 1800 seconds and is met by the “Base-Generate” column for the Baseline vehicle in the +400W Real-world condition.

For a given vehicle being driven over a given driving cycle, the decelerations provide a total harvested energy, that is to say, the total recuperated energy that is available for torqueshift, DCDC, 48V battery charging. This total harvested energy available to “spend” is the same for both the baseline the eco-innovation vehicle and is shown in figure 4 as line “3”.

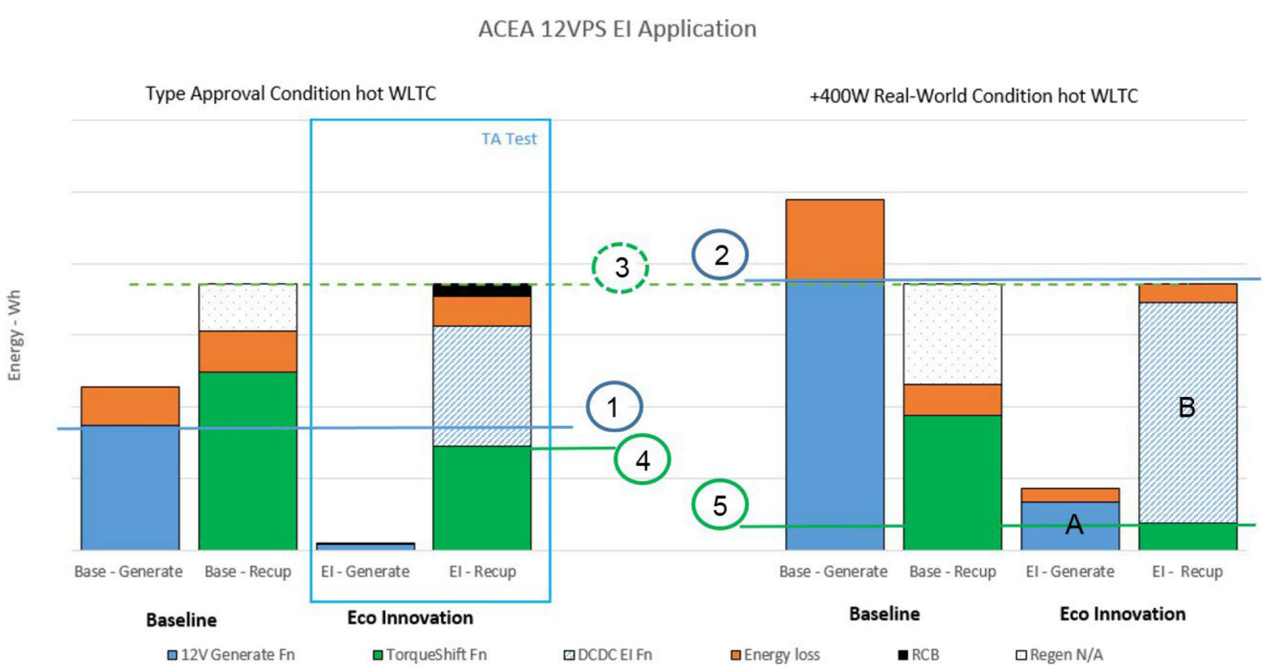

Figure 4. Energy plots comparing type approval condition vs real world condition

For the Type Approval condition, we can see that the Eco-innovation vehicle seldom invokes its active Generate Function (refer to fig2) since it uses Recuperate Function (refer to fig2) to convert and store kinetic energy gathered during vehicle decelerations (i.e. not generated by burning fuel) to then supply electrical energy to the vehicle 12V boardnet. With the combined Functions possible in the eco-innovation vehicle, there is therefore less demand for active Generation and the energy flow benefits from the conversions being more efficient; that is to say, in order for the system to support 750W for 1800sec, shown as line “2”, a small amount of active Generate energy, shown as “A”, is added to the significant Recuperated Energy passed via the DCDC (according to the controller’s demand), shown as “B” and in this way the energy losses are minimised.

The baseline vehicle however, which has two separate and distinct functions (see fig1) that are not linked by a DC-DC converter and intelligent controller, can <u>only</u> use recuperated energy to torque shift the engine (mechanical to electrical and back to mechanical) and must actively use its Generate Function more often to support the vehicle 12V load.

5.5. Torque Shift vs Recuperation ratio in Real-World Condition.

In real-world electrical load condition (as described by Technical Guidelines[7]), an intelligent controller will be calibrated to facilitate the improved efficiency in energy conversion available with utilising the combined Functions and, with a higher vehicle 12V load (+400W), will de-prioritise energy flow to Torque Assist and prioritise energy flow of recuperated energy to 12V boardnet: this can be seen clearly in Figure 4 above, by comparing energy lines “4” and “5”. The controller of any NOVC-HEV will include tables or models of the energy conversion efficiencies and, as such, has the capability to choose and therefore optimise the use of the recuperated energy available.

For the purposes of this eco-innovation application, a document is prepared by ACEA [redacted] that shows anonymously provided data from manufacturers to illustrate how this ratio of torque-shift to 12V energy provision changes in real-world condition (compared to type approval condition) across a range of series production vehicles available in the market: this essentially provides the mean behaviour realised by the calibrated controller’s effect on the system. For the purpose of calculating a conservative CO_2 benefit for this eco-innovation, the mean of these data is taken forward to represent the generic behaviour of series production controllers in NOVC-HEVs. Were the torque shift energy usage seen at Type Approval condition simply carried across to the real-world condition, the influence of the calibrated controller of the system would be grossly under-represented and be viewed unrealistic.

6. [redacted]

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7. [redacted]

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8. Identification and technical description of the baseline technology

The Commission Implementing Regulation No 725/2011, establishing a procedure for approval and certification of innovative technologies for reducing CO_2 emissions for passenger vehicles, sets out the following legal requirements:

According to Art 5.1 (b) the applicant shall designate a baseline vehicle that shall not be fitted with the innovative technology. However according to Art 5.2 the applicant can consider to demonstrate Art 8 (demonstration of CO_2 emissions) and Art 9 (eligibility criteria) without the use of a baseline vehicle. Then the applicant shall include necessary details justifying that conclusion and a methodology providing equivalent results.

Art 9.2. explains that an innovative technology shall be considered as not covered by the standard test cycle if the total CO_2-savings of the innovative technology do not include any savings demonstrated under the standard test cycle. Thus, the testing methodology shall ensure that the savings outside the standard test cycle are covered.

Under the scope of current application a baseline vehicle is a vehicle with hardware identical to the eco-innovation vehicle. For the individual Generate Function, the baseline vehicle uses the motor generator in the same way that a conventional alternator is used as described in the COMMISSION IMPLEMENTING DECISION (EU) 2019/313 and (EU) 2019/314 from SEG Automotive GmbH and the ACEA 48V High Efficiency Motor Generator plus 48V/12V DC/DC converter (EU)2020/1167. For the Harvest and TorqueShift Function, the baseline vehicle simply harvests and stores kinetic energy, converted from vehicle decelerations, and redeploys for propulsion or engine torque assist function (in accordance with the regulatory description), such energy is to be considered through suitable energy flow measurement and the use of appropriate energy to CO_2 conversion factor and component efficiencies (e.g 48V Efficient Motor Generator efficiency from previous approved verification data).

9. [redacted]

[redacted]

10. [redacted]

[redacted]

11. Testing methodology

11.1. Testing conditions

The regulated type approval test for emission testing should be used as a basis for measurements/test procedure of eco-innovation (COM 725/2011 amended by 2018/258). This application refers to WLTP and the verification methodology results in CO_2 savings from eco-innovation for WLTP fleet compliance from 2021 (according to COM 725/2011 amended by 2018/258 Art 2 paragraph 3).

11.2. Testing methodology

This application describes a methodology as referred to in Regulation (EU) 2018/258, Article 4, section b iii (e) and a simplified calculation methodology according to section b iii (ea). The simplified method only uses input data from extended type approval vehicle test and component test to calculate the off-cycle CO2 savings. The aim of the proposed testing methodology is to truthfully represent the benefit of an eco-innovation vehicle as described in chapter 5 in supplying the 12V vehicle power net in a more efficient manner on top of the various approved/submitted 48V motor generator plus DC/DC converter with minimal extra testing burden so as to increase the applicability of the eco-innovation. The methodology proposed has also the practicable merit because an eco-innovation vehicle, as described in chapter 5, invariably benefits from the CO_2 reduction in torque assist/shift and thence a purely experimental based test methodology would struggle to differentiate the benefit of torque assist/shift from that benefit of the more efficient supply of 12V power.

The testing methodology evaluates the CO2 emissions of the baseline vehicle (B) and the eco-innovation (E) vehicle in both the type approval (TA) and the real world driving (MC) situations. Therefore, four sets of calculations (BTA, BMC, ETA and EMC) are made to work out the active generation function, recuperation function and torque assist/shift function in each of the situations as explained in the following paragraphs. Section 11.7 describes a simplification, as in Article 4, section b iii (ea), to enable the four sets of calculations (BTA, BMC, ETA and EMC) to be made without input data from the real world driving (MC) situations.

Test measurements are taken for ETA during a “hot WLTC”, which is a further WLTC test that is performed immediately after a standard WLTC type approval test. According to the general principles laid down in paragraph 3.2 of the Technical Guidelines [7], the type approval test is to be used "as test cycle for validation purposes within the testing methodologies in terms of velocity-over-time function" and then the “hot WLTC” approach ensures that the beginning of assessment starts with the balanced charge condition from the end of the type approval test and, like the CO_2MPAS methodology for idle fuel consumption from the Joint Research Centre (https://co2mpas.io/), the stable temperature of the various fluids and propulsion system structures allows the methodology to more readily discern the fuel consumption effect of the eco-innovation versus the baseline technology.

11.3. Motor Generator (MG) tests

The hardware testing of the motor generator will align with the testing methodology in the 48V high efficiency motor generator plus DC/DC converter Implementing Decision (EU) 2020/1167.

11.4. DC/DC converter test

The hardware testing of the DC/DC converter will align with the testing methodology in the 48V high efficiency motor generator plus DC/DC converter Implementing Decision (EU) 2020/1167.

11.5. Total recuperation energy available.

Among the 4 situations (BTA, BMC, ETA and EMC), the ETA is the only one which is fully tested from an extended test of the vehicle type approval test. Using data from the test measurement, electrical current through the motor generator and current measurements from standard WLTP RCB procedure are used to calculate the following energy items:

a: active generating energy in Wh, integrated from motor generator generating power during the time that the accelerator pedal is being depressed.

X: derived electrical energy in Wh that comes from recuperation through the DC/DC converter.

Y: torque assist/shift energy in Wh, integrated from motor generator motoring power during the time that the accelerator pedal is being depressed.

Z: battery RCB in Wh, as calculated in standard WLTP RCB procedure.

From the above energy items, the recuperation energy that was available for the functions of torque assist/shift, 12V power net and charging the 12V battery can be calculated as:

$$\Sigma_{recup\_EI} = X + Y + Z = \frac{(350\text{W} \times 0.5hr - \text{a} \times \eta_{DCDC})}{\eta_{DCDC}} + \text{Y} + \text{Z}$$

Where:

0.5hr: time duration of the WLTC.

350W: nominal 12V load according to the technical guideline.

The calculated recuperated energy should be the same for the EMC. However, as explained in section 5.1, the recuperated energy for BTA and BMC need to be reduced by the constant power consumption of the generation function as the equations below.

$$\Sigma_{recup\_BTA} = \Sigma_{recup\_EI} - \frac{350\text{W} \times 0.5\ hr \times T_{recup}}{T_{rotate} \times \eta_{DCDC}}$$

$$\Sigma_{recup\_BMC} = \Sigma_{recup\_EI} - \frac{750\text{W} \times 0.5\ hr \times T_{recup}}{T_{rotate} \times \eta_{DCDC}}$$

Where:

T_{rotate}: the length of time that the engine is rotating during WLTC cycle.

T_{recup}: the length of time that the vehicle is recuperating during WLTC cycle.

750W: the 12V load when the additional 400W delta described by the technical guideline is applied

11.6. Calculation of BTA, BMC, ETA and EMC in energy term.

For the baseline vehicle, all the available recuperate energy is used for torque assist/shift function. Therefore, the combined energy balance for supporting the 12V power net and the torque assist/shift is calculated as in equation below:

$$B_{TA} = \frac{350\text{W} \times 0.5hr}{\eta_{DCDC} \times \eta_{MG}} - \Sigma_{recup\_BTA} \times \eta_{MG}$$

$$B_{MC} = \frac{750\text{W} \times 0.5hr}{\eta_{DCDC} \times \eta_{MG}} - \Sigma_{recup\_BMC} \times \eta_{MG}$$

For eco-innovation vehicle, the ETA can be calculated directly as

$$E_{TA} = \frac{\text{a}}{\eta_{MG}} - \text{Y} \times \eta_{MG}$$

The EMC calculation is not as straightforward, as the energy y for torque assist/shift is expected to be reduced due to the increased 12V power net consumption compared to energy Y under type approval condition. The value y can be measured directly by instrumenting an eco-innovation vehicle with a load bank to increase the 12V power net consumption, or a conservative value can be used as described in 11.7. With a y value determined by either options, the EMC can be calculated as:

$$E_{MC} = \frac{(750\text{W} \times 0.5hr - (\Sigma_{recup\_EI} - y) \times \eta_{DCDC})}{\eta_{DCDC} \times \eta_{MG}} - y \times \eta_{MG}$$

With BTA, BMC, ETA and EMC available, the EI benefit in energy term can be calculated as:

$$EI = (B_{MC} - B_{TA}) - (E_{MC} - E_{TA}) = \frac{Y+Z}{\eta_{MG}} + \left(\frac{(750\text{W} - 350\text{W}) \times 0.5\ hr \times T_{recup}}{T_{rotate} \times \eta_{DCDC}} - Y\right) \times \eta_{MG} - \text{y} \times \frac{1-\eta_{MG}^2}{\eta_{MG}}$$

$$= \frac{Y+Z}{\eta_{MG}} + \left(\frac{\Delta \times 0.5\ hr \times T_{recup}}{T_{rotate} \times \eta_{DCDC}} - Y\right) \times \eta_{MG} - \text{y} \times \frac{1-\eta_{MG}^2}{\eta_{MG}}$$

Where:

Δ is the difference in 12V load in real world driving condition compared to the type approval condition as agreed in the Technical Guidelines and equal to 400W.

y is the measured torque assist energy when the 12V power net consumption is increased by 400W. A conservative value can also be used for y.

In the case of a start-stop vehicle, a parameter k is defined to account for the increased generation power of the baseline vehicle due to the fact that 12V power net continues to consume energy when the engine is stopped and as such the generation function would need to produce a higher constant power to account for the shorter generation time and the 12V battery energy loss.

$$if\ engine\ start\ stop,\ k = \frac{T_{rotate}}{1800} + (1 - \frac{T_{rotate}}{1800}) \div \eta_{battery}$$

Thus, the formula to calculate the EI benefit for a start-stop vehicle is modified to:

$$EI = (k-1) \times \frac{(750\mathrm{W}-350\mathrm{W})\times 0.5\,hr}{\eta_{MG}\times\eta_{DCDC}} + \frac{Y+Z}{\eta_{MG}} + \left(\frac{\mathrm{k}\times(750\mathrm{W}-350\mathrm{W})\times 0.5\,hr\times T_{recup}}{T_{rotate}\times\eta_{DCDC}} - Y\right)\times\eta_{MG} - \mathrm{y}\times\frac{1-\eta_{MG}^2}{\eta_{MG}}$$

$$= (k-1) \times \frac{\Delta\times 0.5\,hr}{\eta_{MG}\times\eta_{DCDC}} + \frac{Y+Z}{\eta_{MG}} + \left(\frac{\mathrm{k}\times\Delta\times 0.5\,hr\times T_{recup}}{T_{rotate}\times\eta_{DCDC}} - Y\right)\times\eta_{MG} - \mathrm{y}\times\frac{1-\eta_{MG}^2}{\eta_{MG}}$$

To analyse the deterioration effect of BISG and DCDC efficiency drop, it is clear that EI is a monotonically decreasing function of both η_{MG} and η_{DCDC}, therefore a decreased value of efficiency would increase the calculated eco innovation benefit.

11.7. Conservative value for torque assist/shift energy

The change in the provision to torque assist/shift energy to maintain best system efficiency at the increased 12V power net load is crucial for the derivation of the eco-innovation benefit under real-world condition. It is recognised that obtaining this single value experimentally requires extra instrumentation of every homologated vehicle and doubled amount of additional testing; testing every derivative would be too onerous and impracticable. It is therefore advisable to use a conservative method to determine the maximum level of torque assist/shift energy for all vehicles (described in section 5.5 above) when the additional 400W electrical load is being applied.

Considering each vehicle has a different absolute torque assist/shift energy under type approval condition, a ratio of the torque assist/shift energy under real-world condition to the torque assist/shift energy under type approval condition is surveyed among OEMs and the mean plus one standard deviation ratio CR is taken as the conservative ratio which leads to a conservative value for y:

$$y = Y \times CR$$

The mean value ratio approach that looks to define the difference in behaviour between type approval and real-world condition reflects the 350W baseline and the 400W delta approach, which is proposed by the regulator in the technical guidelines.

11.8. Calculation of the Eco Innovation benefit in CO_2 terms.

For sub 60V mild hybrid and conventional vehicles, the CO_2 savings shall be calculated in accordance with the formula below:

$$C_{CO2} = \frac{EI}{0.5hr}\cdot\frac{V_{Pe}\cdot CF}{v}$$

Where:

v: Mean driving speed of the WLTP [km/h], which is 46.5 km/h

V_{Pe} Consumption of effective power specified in the Table 1

CF Conversion factor (l/100 km) - (g CO_2/km) [gCO_2/l] as defined in Table 2

Table 1 Consumption of effective power

Type of Engine	Consumption of effective power (V_{Pe}) [l/kW.h]
Petrol	0,264
Petrol Turbo	0,280
Diesel	0,220
LPG	0.342

LPT Turbo	0.363
E85	0.367
E85 Turbo	0.389
CNG	0.259 (m^3/kW.h)
CNG Turbo	0.275 (m^3/kW.h)

Table 2 Fuel conversion factor

Type of Fuel	**Conversion factor (l/100 km) — (g CO_2/km) (CF) [g CO_2/l]**
Petrol	2330
Diesel	2640
LPG	1629
E85	1657
CNG	1795 (gCO_2/m^3)

For hybrid vehicles using a voltage over 60V, the KCO_2 factor should be used to convert the energy to CO_2 as below:

$$C_{CO2} = \frac{EI}{23.3} \cdot K_{CO2}$$

Where:

K_{CO2}: CO_2 correction factor, $[(\frac{gCO_2}{km})/(\frac{Wh}{km})]$, as defined in paragraph 2.2 of Appendix 2 to Sub-Annex 8 to Annex XXI to Regulation (EU) 2017/1151.

Based on the formulae presented above, an Excel calculation tool is also attached [redacted]

11.9. Determination of CO_2-savings for entire interpolation family during certification

In order to ensure that certification is finally done with a “worst case” approach where the lowest CO2-savings are applied for the entire interpolation family the results of “vehicle low” and “vehicle high” are compared and the vehicle with the lowest CO2 saving is identified and used for certification for the entire family.

12. [redacted]

[redacted]

13. [redacted]

[redacted]

14. Uncertainty analysis and quantification of statistical uncertainties to the complete testing methodology

14.1. Formulae to Calculate the Statistical Error in the CO_2 Savings

Regarding Article 6(1) of Regulations (EU) No 725/2011/ No. 258/2018 and (EU) No 427/2014 it shall be demonstrated that the minimum threshold is exceeded in a statistically significant way. It means the standard deviation should not be greater than the difference between the total CO_2 savings and the minimum threshold:

$$MT \leq C_{CO_2} - s_{C_{CO_2}}$$

With:

MT: The minimum threshold (0.5 g CO_2/km)

C_{CO_2}: Total CO_2 saving

$s_{C_{CO_2}}$: Standard deviation of the total CO_2 saving

With regards to the Technical Guidelines (*chapter 6.3*) the uncertainty for the total CO_2 saving of the proposed testing methodology is determined by the following formula:

$$s_{C_{CO_2}} = \sqrt{\sum_{j=1}^{m} \left(\left. \frac{\partial C_{CO_2}}{\partial x_j} \right|_{x_j=\overline{x_j}} \cdot s_{\overline{x_j}} \right)^2} \leq 30\% \text{ of } C_{CO_2}$$

With:

$s_{C_{CO_2}}$: Standard deviation of the total CO_2 saving rounded to two decimal places

$\frac{\partial C_{CO_2}}{\partial x_j}$: Sensitivity of calculated CO_2 saving related to the variable x_j

$s_{\overline{x_j}}$: Standard deviation of $\overline{x_j}$

m: Number of variables with uncertainty

From the equation generating the value of EI, the considered variables with a statistical uncertainty due to measurements are as follows:

Measurement	Engine rotating duration	Vehicle recuperation duration	Motor generator efficiency	DC/DC converter efficiency	Torque assist/shift energy	REESS charge balance
Variable	T_{rotate}	T_{recup}	η_{MG}	η_{DCDC}	Y	Z
Standard deviation variable	$s_{T_{rotate}}$	$s_{T_{recup}}$	$s_{\eta_{MG}}$	$s_{\eta_{DCDC}}$	s_Y	s_Z

Using equation 4 in the Technical Guidelines 6.3.2, the total uncertainties using the propagation law can be calculated as:

$$s_{C_{CO_2}} = \sqrt{\left(\frac{\partial C_{CO_2}}{\partial T_{rotate}} \cdot s_{T_{rotate}}\right)^2 + \left(\frac{\partial C_{CO_2}}{\partial T_{recup}} \cdot s_{T_{recup}}\right)^2 + \left(\frac{\partial C_{CO_2}}{\partial \eta_{BISG}} \cdot s_{\eta_{BISG}}\right)^2 + \left(\frac{\partial C_{CO_2}}{\partial \eta_{DCDC}} \cdot s_{\eta_{DCDC}}\right)^2 + \left(\frac{\partial C_{CO_2}}{\partial Y} \cdot s_Y\right)^2 + \left(\frac{\partial C_{CO_2}}{\partial Z} \cdot s_Z\right)^2}$$

$$= \frac{V_{Pe} \cdot CF}{0.5hr \cdot v} \sqrt{\begin{array}{c} \left(\frac{(\eta_{battery} - 1)}{1800 \times \eta_{battery}} \cdot \frac{\Delta \times 0.5\ hr}{\eta_{MG} \times \eta_{DCDC}} - \frac{\Delta \times 0.5\ hr \times T_{recup}}{T_{rotate}^2 \times \eta_{DCDC} \times \eta_{battery}}\right)^2 \times s_{T_{rotate}}^2 + \\ \left(\frac{k \times \Delta \times 0.5\ hr}{T_{rotate} \times \eta_{DCDC}}\right)^2 \times s_{T_{recup}}^2 + \\ \left(y - Y - \left(\frac{(k-1) \times \Delta \times 0.5\ hr}{\eta_{DCDC}} + Y + Z - y\right) \cdot \frac{1}{\eta_{MG}^2}\right)^2 \times s_{\eta_{MG}}^2 + \\ \left(\left(\frac{(k-1) \times \Delta \times 0.5\ hr}{\eta_{MG}} + \frac{k \times \Delta \times 0.5\ hr \times T_{recup}}{T_{rotate}}\right) \cdot \frac{1}{\eta_{DCDC}^2}\right)^2 \times s_{\eta_{DCDC}}^2 + \\ \left(\frac{1}{\eta_{MG}} - \eta_{MG}\right)^2 \times s_Y^2 + \\ \left(\frac{1}{\eta_{MG}}\right)^2 \times s_Z^2 \end{array}}$$

15. [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted].

15.7. Interactions with existing technologies

According to the JRC Technical Guideline (abstract 6.5) and Article 3(a) of Regulation (EU) No 725/2011 and Article 3(1) of Regulation (EU) No 427/2014 the identification and quantification of interaction between eco-innovations has to be performed by the OEM when applying for a type-approval certificate for a vehicle fitted with more than one eco-innovation technology.

Given the system operation where converted kinetic energy is stored in the second energy storage device and redeployed in the most efficient manner, this eco-innovation is classified at Kinetic Energy Class 7 and therefore has no interaction with the Eco-Innovation LED and Solar Roof technologies.

Other Interactions are not obvious and will need assessment from the Technical Service.

Specifically, while the current application builds on top of the 48V high efficiency generator plus DC/DC implementing decision, the benefits of the two technologies do not overlap and the interaction shall be considered zero.

16. List of references

[1]	PÖTTERING H.-G., NEČAS P. (2009): REGULATION (EC) No 443/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles
[2]	J. BUZEK, GYŐRI E. (2011): Regulation (EU) No 510/2011 of the European Parliament and of the Council of 11 May 2011 setting emission performance standards for new light commercial vehicles as part of the Union's integrated approach to reduce CO_2 emissions from light-duty vehicles
[3]	Barroso, J. M. (2011): COMMISSION IMPLEMENTING REGULATION (EU) No 725/2011 of 25 July 2011 establishing a procedure for the approval and certification of innovative technologies for reducing CO_2 emissions from passenger cars pursuant to Regulation (EC) No 443/2009 of the European Parliament and of the Council
[4]	Barroso, J. M. (2014): Commission Implementing Regulation (EU) No 427/2014 of 25 April 2014 establishing a procedure for the approval and certification of innovative technologies for reducing CO 2 emissions from light commercial vehicles pursuant to Regulation (EU) No 510/2011 of the European Parliament and of the Council
[5]	Juncker, J.-C. (2018): Commission Implementing Regulation (EU) 2018/258 of 21 February 2018 amending Implementing Regulation (EU) No 725/2011 for the purpose of adjusting it to the change in the regulatory test procedure and simplifying the administrative procedures for application and certification
[6]	Juncker, J.-C. (2018): Commission Implementing Regulation (EU) 2018/259 of 21 February 2018 amending Implementing Regulation (EU) No 427/2014 for the purpose of adjusting it to the change in the regulatory test procedure and simplifying the administrative procedures for application and certification
[7]	Technical Guidelines - Revision: July 2018
[8]	FEV Consulting, VDMA, Antrieb im Wandel, Executive Summary Report, 1st March 2018

ANNEX II - please request this calculation tool from the Vehicle Certification Agency by emailing fleetaverage@vca.gov.uk

User inputs		Fill in values		
Source	Item	Value	Unit	Note
Vehicle Definition	Engine type (Diesel:0; Petrol: 1)	0	/	Assume all pressure-charged
Baseline Definition	Baseline alternator setting	2	/	0: conventional alternator; 1: SEG/Ford 48V alternator; 2: OEM verified measurement
Component Test	Eff_BISG	0.80	/	Measured by OEM, Supplier or from 48V Eff Gen+DCDC Eco-Innovation value (Report No. GB19080074 REV01).
Type Approval Test	E_ele_TorqueShift	0	Wh	measured at BISG using current clamp (ave of the three tests).
Type Approval Test	E_ele_ActiveCharging	0	Wh	measured at BISG using current clamp (ave of the three tests).
Type Approval Test	E_ele_Recup_total	0	Wh	measured at BISG using current clamp - not all available to TS and DCDC function (ave of the three tests).
Type Approval Test	E_batt_RCB	0	Wh	measured at battery - 12V battery RCB also included here: most conservative. If increase, larger EI benefit in TA, if decrease, total regen reduced.
Type Approval Test	Time_engine_rotating	0	sec.	From test data post processing (ave of the three tests).
Type Approval Test	Time_recuperating	0	sec.	From test data post processing (ave of the three tests).
MC test	Max_E_ele_TorqueShift_750W	0.00	Wh	From test data post processing (ave of the three 400W tests).
ACEA anonymous data	Max_E_ele_TorqueShift_750W (ACEA CR)	0.00	Wh	Ele_TorqueShift * CR (which is from test data of ACEA members - mean TS seen in 750W condition for all vehicles tested) - similar to Bosch restart energy test campaign.
Fixed inputs				
WLTC	Time	1800	sec.	
WLTC	Distance	23.266	km	
Technical Guideline	Eff_alternator	0.74	/	0.67: conventional alternator; 0.782: SEG/Ford 48V alternator; or enter OEM verified measurement
Technical Guideline	Eff_12V_Batt	0.94	/	
Technical Guideline	Eff_DCDC	0.92	/	TG = 0.92; Verified OEM value can be used (52V to 14.3V as per Eco-Inovation 2020/1167)
Technical Guideline	Willans factor	0.22	l/kWh	Diesel: 0.22; Petrol: 0.28
Technical Guideline	CO2 conversion	2640	g/l	Diesel: 2640; Petrol: 2330
Technical Guideline	Type Approval 12V load	350	W	
Technical Guideline	Real World 12V load	750	W	+400W from TA

Calculation steps - Usage factors				
	UF - Engine rotating	0.00	/	Rotating time/total time
	UF - Engine stopped	1.00	/	Stopped time/total time
	UF - recuperation	#DIV/0!	/	Recuperating time/Rotating time
Calculation steps - 12V load energy				
	E_ele_12V_TA	175	Wh	12V load total energy during 1800s cycle in type approval condition
	E_ele_12V_RW	375	Wh	12V load total energy during 1800s cycle in real world condition
Calculation steps - Baseline in TA and RW				
	E_mech_TA_base_eng_rot	0.00	Wh	Mechanical Energy consumed to support 12V load when engine is rotating.
	E_mech_TA_base_eng_rot_loss	0.00	Wh	Loss of energy at alternator supporting 12V load when engine is rotating.
	E_mech_TA_base_eng_stop	252.95	Wh	When engine is stopped, 12V load is supported from 12V battery, ultimately from alternator.
	E_mech_TA_base_eng_stop_loss	77.95	Wh	Loss of energy at alternator and 12V battery supporting the 12V load when engine is stopped.
	CO2_TA_base_12V	6.3	g/km	CO2 from fuel burnt to support 12V load.
	E_mech_RW_base_eng_rot	0.00	Wh	Mechanical Energy consumed to support 12V load when engine is rotating.
	E_mech_RW_base_eng_rot_loss	0.00	Wh	Loss of energy at alternator supporting 12V load when engine is rotating.
	E_mech_RW_base_eng_stop	542.03	Wh	When engine is stopped, 12V load is supported from 12V battery, ultimately from alternator.
	E_mech_RW_base_eng_stop_loss	167.03	Wh	Loss of energy at alternator and 12V battery supporting the 12V load when engine is stopped.
	CO2_RW_base_12V	13.5	g/km	CO2 from fuel burnt to support 12V load.
Calculation steps - TA testing of EI				
	E_mech_TA_EI_ActiveCharging	0.00	Wh	Mechanical energy consumed to achieve the measured active charging.
	E_TA_EI_ActiveCharging_loss	0.00	Wh	Loss of energy at BISG due to active charging.
	E_ele_TA_EI_DCDC	190.22	Wh	DCDC energy (48V) needed to support 12V load together with measured active charging.
	E_ele_TA_EI_DCDC_loss	15.22	Wh	Energy loss at DCDC.
	E_ele_TA_EI_recup_available	190.22	Wh	Total recuperated energy that is available for torqueshift, DCDC, 48V battery charging. Conservative compared to test data BISG measured recuperated energy.
	CO2_TA_EI_AC	0.0	g/km	CO2 from fuel burnt for active charging
	E_mech_TA_EI_TorqueShift	0.0	Wh	Mechanical energy saved due to torqueshift
	CO2_TA_EI_TS	0.0	g/km	CO2 saved due to torqueshift
Calculation steps - Baseline Torque Shift in TA and RW				
	E_mech_TA_recup_not_available	#DIV/0!	Wh	Alternator runs constantly, recuperated energy is reduced, as a percentage of recup time of rotate time.
	E_ele_TA_base_TS	#DIV/0!	Wh	Remaining recup energy are available only for torque shift.
	E_mech_TA_base_TS	#DIV/0!	Wh	Mechanical energy saved due to torqueshift
	E_TA_base_TS_loss	#DIV/0!	Wh	Energy loss at BISG.
	CO2_TA_base_TS	#DIV/0!	g/km	CO2 saved due to torqueshift
	E_mech_RW_recup_not_available	#DIV/0!	Wh	Alternator runs constantly, recuperated energy is reduced, as a percentage of recup time of rotate time.
	E_ele_RW_base_TS	#DIV/0!	Wh	Remaining recup energy are available only for torque shift.
	E_mech_RW_base_TS	#DIV/0!	Wh	Mechanical energy saved due to torqueshift
	E_RW_base_TS_loss	#DIV/0!	Wh	Energy loss at BISG.
	CO2_RW_base_TS	#DIV/0!	g/km	CO2 saved due to torqueshift
Calculation steps - RW TS model/AC calculation of EI				
	E_ele_RW_EI_TS	0.00	Wh	Uses "E_ele_TorqueShift_750W * ACEA TorqueShift Conservative Ratio" for simplified calcualtion method. *(If the full test method is used, change cell D65 to take the value from cell D13)*
	E_mech_RW_EI_TS	0.00	Wh	Mechanical energy saved due to torqueshift
	E_RW_EI_TS_loss	0.00	Wh	Energy loss at BISG.
	CO2_RW_EI_TS	0.0	g/km	CO2 saved due to torqueshift
	E_ele_RW_EI_DCDC	190.22	Wh	Remaining recup energy are available for DCDC (48V)
	E_ele_RW_EI_DCDC_loss	15.22	Wh	Energy loss at DCDC when recup energy supports 12V load.
	E_ele_RW_EI_AC	200.00	Wh	Remaining 12V load needs to be supported by active charging.
	E_RW_EI_AC_loss	71.74	Wh	Energy loss at BISG and DCDC when active charging.
	E_mech_RW_EI_AC	271.74	Wh	Mechanical energy consumed to achieve the calculated active charging energy.
	CO2_RW_EI_AC	6.8	g/km	CO2 from fuel burnt for active charging.
Calculation steps - Final CO2 numbers				
	CO2_TA_base	#DIV/0!	g/km	CO2 balance considering charging and torqueshift
	CO2_RW_base	#DIV/0!	g/km	CO2 balance considering charging and torqueshift
	CO2_TA_EI	0.0	g/km	CO2 balance considering charging and torqueshift
	CO2_RW_EI	6.8	g/km	CO2 balance considering charging and torqueshift
Final EI benefit				
	CO2_benefit_final	#DIV/0!	g/km	

Synthesized	0.000
Synthesized - consider engine start stop	#DIV/0!

C_CO2-S_CO2 =	#DIV/0!	g/km	Green if >=0.5g/km

Uncertainty Analysis - SCO2, to be applied to CCO2 and compared to Minimum Threshold for EI

	MT	0.5	g/km	From Technical Guideline
	C_co2	#DIV/0!	g/km	from calculation steps above
	Sco2 threshold	30	%	From Technical Guideline
	n	3		number of samples for MC
	v	46.5	km/h	Average speed over WLTC
	k	1.063829787		start/stop generation factor
	CR	45%		**From ACEA Survey (3 OEM mean conservative value)**

Considered Variables with statistical uncertainty due to measurement

	T_rotate	0.000	s	Engine rotating duration (average of three tests)
	S_T_rotate	0.000	s	stdev of T_rotate
	T_recup	0.000	s	Vehicle Energy Recuperation duration (average of three tests)
	S_T_recup	0.000	s	stdev of T_recup
	Eff_MG	0.800		Efficiency of Motor Generator (48MG+DCDC report)
OEM	S_Eff_MG	0.010		stdev of Efficiency of Motor Generator (48MG+DCDC report)
	Eff_DCDC	0.920		Efficiency of DCDC Converter (48MG+DCDC report)
OEM	S_Eff_DCDC	0.008		stdev of Efficiency of DCDC Converter (48MG+DCDC report)
	Y	0.000	Wh	Torque Assist / Shift Energy (average of three TA tests)
	S_Y	0.000	Wh	stdev of Torque Assist / Shift Energy
	Z	0.000	Wh	REESS charge balance (E_batt_RCB) (average of three tests)
	S_Z	0.000	Wh	stdev of REESS charge balance
3xOEM (min 3 values eac	CR	0.450		y=Y x CR, where CR is conservative ratio of RW torque assist / TA torque assist, from **ACEA Survey** (based on mean + 1 stdev)
	S_CR	N/A		From ACEA Survey - but conservative value selected
	y	0.000	Wh	y=Y x CR
	S_y	0.000	Wh	

Test output data

1	2	3
0	0	0
0	0	0
0	0	0
0	0	0
	0.45	
0.000	0.000	0.000

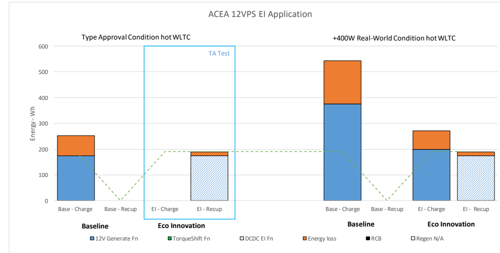
This value is the value returned by ACEA central which is the mean + one standard deviation (from 400W tests) of CR from three OEMs

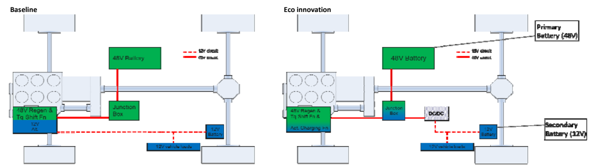
S_CO2 Calculation steps

	(Vpe*CF)/(0.5hr*v)	0.024980645		
	(dCO2/dT_rotate * S_T_rotate)^2	#DIV/0!		Sensitivity to T_rotate
	(dCO2/dT_recup*S_T_recup)^2	#DIV/0!		Sensitivity to T_recup
	(dCO2/dEff_MG*S_Eff_MG)^2	0.047007936		Sensitivity to Eff_MG
	(dCO2/dEff_DCDC*S_Eff_DCDC)^2	#DIV/0!		Sensitivity to Eff_DCDC
	(dCO2/dY*S_Y)^2	0		Sensitivity to Y (torque assist / shift)
	(dCO2/dZ*S_Z)^2	0		Sensitivity to Z (overall charge balance)

Final S_CO2

	SCO2	**#DIV/0!**		Green if <= 30% C_CO2
	30% of C_CO2	#DIV/0!		





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16-Dec-22