COMMISSION IMPLEMENTING DECISION (EU) 2019/1119
of 28 June 2019

on the approval of efficient vehicle exterior lighting using light emitting diodes for use in internal combustion engine vehicles and non-externally chargeable hybrid electrified vehicles as an innovative technology for reducing CO\textsubscript{2} emissions from passenger cars pursuant to Regulation (EC) No 443/2009 of the European Parliament and of the Council

(Text with EEA relevance)

THE EUROPEAN COMMISSION,

Having regard to the Treaty on the Functioning of the European Union,

Having regard to 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\textsubscript{2} emissions from light duty vehicles (1), and in particular Article 12(4) thereof,

Whereas:


(2) Efficient LED lighting is a lighting module equipped with light emitting diodes sources that has lower power consumption than conventional halogen lighting.


(4) The application concerns CO\textsubscript{2} savings from the use of efficient LED lighting as assessed by reference to the Worldwide Harmonised Light Vehicle Test Procedure (WLTP) set out in Commission Regulation (EU) 2017/1151 (3).

(5) Efficient LED lighting has already been approved by Commission Implementing Decisions 2014/128/EU (4), (EU) 2015/206 (5), (EU) 2016/160 (6), (EU) 2016/587 (7) and (EU) 2016/1721 (8) as an innovative technology capable of reducing CO\textsubscript{2} emissions by reference to the New European Driving Cycle (NEDC) set out in Commission Regulation (EC) No 692/2008 (9). Based on the experience gained from those Decisions, as well as taking into account the current application, it has been satisfactorily and conclusively demonstrated that efficient LED lighting including one or more appropriate combinations of efficient LED lights, such as the low beam headlamp, high beam headlamp, front position, front fog, rear fog, front turn signal, rear turn signal, licence plate and reversing lamps, meet the eligibility criteria referred to in Article 12 of Regulation (EC) No 443/2009 and Implementing Regulation (EU) No 725/2011.

(6) The CO\textsubscript{2} savings from the use of efficient LED lighting may be partially demonstrated on the WLTP test. However, the applicants have provided a testing methodology with which it can be demonstrated, in a way capable of producing repeatable, verifiable and comparable results, that the savings achieved, whilst taking the partial coverage into account, are at least 0,5 g CO\textsubscript{2}/km.

(7) In order to ensure continuity, in particular with regard to the transition from the application of the NEDC to the WLTP CO\textsubscript{2} emissions test, it is appropriate to maintain halogen lighting as the baseline technology as provided for in Implementing Decisions 2014/128/EU, (EU) 2015/206, (EU) 2016/160, (EU) 2016/587, and (EU) 2016/1721.
Manufacturers should have the possibility to apply with a type-approval authority for the certification of CO₂ savings from the use of efficient LED lightings in internal combustion engine vehicles and non-externally chargeable hybrid electrified vehicles. The manufacturer should for that purpose ensure that the application for certification is accompanied by a verification report from an independent verification body confirming the level of CO₂ savings to be certified and that all relevant conditions are met.

If the type approval authority finds that the LED lighting does not satisfy the conditions for certification, the application for certification of the savings should be rejected.

In order to facilitate a wider deployment of efficient LED lighting in new vehicles, a manufacturer should also have the possibility to apply for the certification of the CO₂ savings from several efficient LED lightings by a single certification application. It is however appropriate to ensure that, where that possibility is used, a mechanism is applied that incentivises the deployment of only those LED lighting that offer the highest efficiency.

The CO₂ savings certified pursuant to this Decision are to be taken into account for the calculation of the average specific CO₂ emissions of manufacturers starting from calendar year 2021.

For the purposes of determining the general eco-innovation code to be used in the relevant type approval documents in accordance with Annexes I, VIII and IX to Directive 2007/46/EC of the European Parliament and of the Council (°), the individual code to be used for the innovative technology for efficient LED Lightings for internal combustion engine vehicles and non-externally chargeable hybrid electrified vehicles should be specified.

HAS ADOPTED THIS DECISION:

**Article 1**

**Approval**

The technology used in efficient light emitting diodes (LED) lighting is approved as an innovative technology within the meaning of Article 12 of Regulation (EC) No 443/2009, where that innovative technology is used for the purpose of external lighting in internal combustion engine passenger cars and non-externally chargeable hybrid electrified passenger cars.

**Article 2**

**Definition**

For the purpose of this Decision, efficient LED lighting means a technology consisting of a lighting module that is equipped with light emitting diode (LED) sources that are used for the exterior lighting of a vehicle and that has a lower power consumption than conventional halogen lighting.

**Article 3**

**Application for certification of CO₂ savings**

1. Any manufacturer may apply for the certification of CO₂ savings from one or several exterior efficient LED lightings where those are used for the external lighting of internal combustion engine M₁ vehicles and non-externally chargeable hybrid electrified M₁ vehicles. The efficient LED lighting shall include one or a combination of the following LED lights:

(a) low beam headlamp (including adaptative front lighting system);

(b) high beam headlamp;

(°) OJ L 90, 10.4.2008, p. 17
(c) front position lamp;
(d) front fog lamp;
(e) rear fog lamp;
(f) front turn signal lamp;
(g) rear turn signal lamp;
(h) licence plate lamp;
(i) reversing lamp;
(j) cornering lamp;
(k) static bending lamp.

The LED light or the combination of LED lights forming the efficient LED lighting shall as a minimum provide the CO\(_2\) reduction specified in Article 9(1)(b) of Implementing Regulation (EU) No 725/2011 as demonstrated using the testing methodology set out in the Annex to this Decision.

2. An application for the certification of the savings from one or a combination of efficient LED lighting shall be accompanied by an independent verification report confirming that the conditions set out in paragraph 1 are met.

3. The type approval authority shall reject the application for certification if it finds that the conditions set out in paragraph 1 are not met.

\textbf{Article 4}

\textbf{Certification of CO\(_2\) savings}

1. The reduction in CO\(_2\) emissions from the use of an efficient LED lighting referred to in Article 3(1) shall be determined using the methodology set out in the Annex.

2. Where a manufacturer applies for the certification of the CO\(_2\) savings from more than one efficient LED lighting referred to in Article 3(1) in relation to one vehicle version, the type approval authority shall determine which of the efficient LED lighting tested delivers the lowest CO\(_2\) savings, and record the lowest value in the relevant type approval documentation. That value shall be indicated in the certificate of conformity in accordance with Article 11(2) of Implementing Regulation (EU) No 725/2011.

3. The type approval authority shall record the verification report and the test results on the basis of which the savings were determined and shall make that information available to the Commission on request.

\textbf{Article 5}

\textbf{Eco-innovation code}

The eco-innovation code No 28 shall be entered into the type approval documentation where reference is made to this Decision in accordance with Article 11(1) of Implementing Regulation (EU) No 725/2011.

CO\(_2\) savings recorded by reference to that eco-innovation code may be taken into account for the calculation of the average specific emissions of a manufacturer starting from calendar year 2021.
Article 6

Entry into force

This Decision shall enter into force on the twentieth day following that of its publication in the Official Journal of the European Union.

Done at Brussels, 28 June 2019.

For the Commission
The President
Jean-Claude JUNCKER

ANNEX

Methodology to determine the CO₂ savings of efficient LED lighting by reference to the Worldwide Harmonised Light Vehicle Test Procedure

1. INTRODUCTION

In order to determine the CO₂ emission reductions that can be attributed to efficient LED lighting consisting of an appropriate combination of external vehicle LED lights for the use in internal combustion engine M1 vehicles and non-externally chargeable hybrid electrified M1 vehicles, it is necessary to establish the following:

1. the test conditions;
2. the test equipment;
3. the procedure to determine the power savings;
4. the procedure to determine the CO₂ savings;
5. the procedure to determine the uncertainty of the CO₂ savings.

2. SYMBOLS, PARAMETERS AND UNITS

*Latin symbols*

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFS</td>
<td>Adaptive Front lighting System</td>
</tr>
<tr>
<td>B</td>
<td>Baseline</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>C&lt;sub&gt;CO₂&lt;/sub&gt;</td>
<td>CO₂ savings [g CO₂/km]</td>
</tr>
<tr>
<td>C</td>
<td>Number of classes of the adaptive front lighting system</td>
</tr>
<tr>
<td>CF</td>
<td>Conversion factor ([l/100 km] - (g CO₂/km) [gCO₂/l])</td>
</tr>
<tr>
<td>EI</td>
<td>Eco-innovative</td>
</tr>
<tr>
<td>HEV</td>
<td>Hybrid Electrified Vehicle</td>
</tr>
<tr>
<td>K&lt;sub&gt;CO₂&lt;/sub&gt;</td>
<td>CO₂ correction factor, ( \left( \frac{\mathrm{gCO}_2}{\mathrm{km}} \right) / \left( \frac{\mathrm{Wh}}{\mathrm{km}} \right) ) as defined in Regulation (EU) 2017/1151 Sub-Annex 8 Appendix 2</td>
</tr>
<tr>
<td>K&lt;sub&gt;CO₂&lt;/sub&gt;</td>
<td>Average of the T values of K&lt;sub&gt;CO₂&lt;/sub&gt; ( \left( \frac{\mathrm{gCO}_2}{\mathrm{km}} \right) / \left( \frac{\mathrm{Wh}}{\mathrm{km}} \right) )</td>
</tr>
<tr>
<td>m</td>
<td>Number of efficient exterior LED lights composing the package</td>
</tr>
<tr>
<td>MT</td>
<td>Minimum threshold [g CO₂/km]</td>
</tr>
<tr>
<td>n</td>
<td>Number of measurements of the sample</td>
</tr>
<tr>
<td>NOVC</td>
<td>Not Off-Vehicle Charging</td>
</tr>
<tr>
<td>P</td>
<td>Power consumption of the vehicle light [W]</td>
</tr>
<tr>
<td>P&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Power consumption of the corresponding i light in a baseline vehicle [W]</td>
</tr>
<tr>
<td>P&lt;sub&gt;in&lt;/sub&gt;</td>
<td>Power consumption of the corresponding n sample for each class vehicle [W]</td>
</tr>
<tr>
<td>P&lt;sub&gt;c&lt;/sub&gt;</td>
<td>Power consumption for each class of vehicle (average of the n measurements) [W]</td>
</tr>
<tr>
<td>P&lt;sub&gt;LSFS&lt;/sub&gt;</td>
<td>Power consumption of the Low beam AFS [W]</td>
</tr>
<tr>
<td>P&lt;sub&gt;LS&lt;/sub&gt;</td>
<td>Average power consumption of the corresponding eco-innovative vehicle light [W]</td>
</tr>
</tbody>
</table>
ΔP_i — Power savings of each efficient exterior LED light [W]
S_{CO_2} — Standard deviation of the total CO₂ savings [g CO₂/km]
s_{CO_2} — Standard deviation of the K_{CO_2} \left( \left( \frac{gCO_2}{km} \right) / \left( \frac{Wh}{km} \right) \right)
s_{K_{CO_2}} — Standard deviation of average of the T values of K_{CO_2} \left( \left( \frac{gCO_2}{km} \right) / \left( \frac{Wh}{km} \right) \right)
s_{Pc} — Standard deviation of average of power consumption for each class of vehicle [W]
s_{P_{EI}} — Standard deviation of the LED light power consumption in eco-innovative vehicle [W]
s_{P_{EI}} — Standard deviation of the average LED light power consumption mean in eco-innovative vehicle [W]
s_{P_{S_{AFS}}} — Uncertainty or Standard deviation of average of power of the Low beam AFS [W]
T — Number of measurements performed by the manufacturer for the extrapolation of the K_{CO_2}
t — Driving duration of the Worldwide Light vehicles Test Cycle (WLTC) [s], which is 1 800 s
UF — Usage factor for the vehicle light [-] as defined in Table 6
v — Mean driving speed of the Worldwide Light vehicles Test Cycle (WLTC) [km/h]
V_{Pe} — Consumption of effective power [l/kWh]
share_c — Time percentage per speed band in each vehicle class
\partial CO_{2} \over \partial P_{EI} — Sensitivity of calculated CO₂ savings related to the LED light power consumption
\partial CO_{2} \over \partial K_{CO_2} — Sensitivity of calculated CO₂ savings related to the CO₂ correction factor
\eta_A — Efficiency of the alternator [-]
\eta_{DCDC} — Efficiency of the DC-DC converter [-]

Subscripts
Index (c) refers to number of class of the adaptive front lighting system measurement of the sample
Index (i) refers to each vehicle lights
Index (j) refers to measurement of the sample
Index (t) refers to each number of measurements of T

3. TESTING CONDITIONS

The testing conditions shall fulfil the requirements of UN/ECE Regulations Nos 4 (\(^1\)), 6 (\(^2\)), 7 (\(^3\)), 19 (\(^4\)), 23 (\(^5\)), 38 (\(^6\)), 48 (\(^7\)), 100 (\(^8\)), 112 (\(^9\)), 119 (\(^10\)) and 123 (\(^11\)). The power consumption shall be determined in accordance with point 6.1.4 of UN/ECE Regulation No 112, and points 3.2.1 and 3.2.2 of Annex 10 to that Regulation.

\(^1\) OJ L 4, 7.1.2012, p. 17.
\(^7\) OJ L 323, 6.12.2011, p. 46.
For the low beam adaptive front lighting system (AFS) falling within at least two of the Classes C, E, V or W as defined in Regulation UN/ECE No 123, unless it is agreed with the technical service that Class C is the representative/average LED intensity for the vehicle application, power measurements shall be done at the LED intensity of each class (Pc) as defined in Regulation UN/ECE 123. If Class C is the representative/average LED intensity for the vehicle application, power measurements shall be done in the same way as for any other exterior LED light included in the combination.

**Test equipment**

The following equipment shall be used, as shown in the Figure below:

- a power supply unit (i.e. variable voltage supplier);
- two digital multimeters, one for measuring the DC-current, and the other for measuring the DC-voltage. In the Figure, a possible test set-up is shown, when the DC-voltage meter is integrated in the power supply unit.

![Test set-up](image)

**Measurements and determination of the power savings**

For each efficient exterior LED light included in the combination the measurement of the current shall be performed as shown in the Figure at a voltage of 13,2 V. LED module(s) operated by an electronic light source control gear, shall be measured as specified by the applicant.

The manufacturer may request that other measurements of the current shall be done at other additional voltages. In that case, the manufacturer shall hand over verified documentation on the necessity to perform those other measurements to the type-approval authority. The measurements of the currents at each of those additional voltages shall be performed consecutively at least five times. The exact installed voltages and the measured current shall be recorded in four decimals.

The power consumption shall be determined by multiplying the installed voltage with the measured current. The average of the power consumption for each efficient exterior LED light (\(P_{\text{EI}}\)) shall be calculated. Each value shall be expressed in four decimals. When a stepper motor or electronic controller is used for the supply of the electricity to the LED lights, the electric load of that component part shall be excluded from the measurement.

**Additional measurements for Low beam Adaptive Front Lighting System (AFS)**

*Table 1*

**Classes of Low beam AFS**

<table>
<thead>
<tr>
<th>Class</th>
<th>See point 1.3 and footnote 2 of UN/ECE Regulation 123</th>
<th>% LED Intensity</th>
<th>Activation Mode (*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Base Passing Beam (Country)</td>
<td>100 %</td>
<td>50 km/h &lt; speed &lt; 100 km/h (or when no mode of another passing beam class is activated (V, W, E))</td>
</tr>
</tbody>
</table>
Class | See point 1.3 and footnote 2 of UN/ECE Regulation 123 | % LED Intensity | Activation Mode (*)
--- | --- | --- | ---
V | Town | 85 % | Speed < 50 km/h
E | Motorway | 110 % | Speed > 100 km/h
W | Adverse Conditions | 90 % | Windshield wiper active > 2 min

(*) Activation speeds to be checked for each vehicle application in accordance with UN/ECE Regulation No 48 section 6, chapter 6.22, paragraphs 6.22.7.4.1 (class C), 6.22.7.4.2 (class V), 6.22.7.4.3 (class E), 6.22.7.4.4 (class W).

Where the power measurements at the LED intensity of each class are needed, after conducting the measurements of each $P_c$, the power of the Low beam AFS ($P_{EI_{AFS}}$) shall be calculated as a weighted average of the LED Power during the WLTC speed bands, with the following Formula 1.

**Formula 1**

\[
P_{EI_{AFS}} = \sum_{c=1}^{C} WLTC\_share_c \cdot P_c
\]

Where:

- $P_c$ is the power consumption (mean of the $n$ measurements) for each class;
- WLTC\_share\_c is the WLTC time percentage per speed band in each class (WLTC last 1 800 s in total):

<table>
<thead>
<tr>
<th>Speed band</th>
<th>Time</th>
<th>WLTC_share_c (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 50 km/h:</td>
<td>1 058 s</td>
<td>0,588 (58,8 %)</td>
</tr>
<tr>
<td>50 – 100 km/h</td>
<td>560 s</td>
<td>0,311 (31,1 %)</td>
</tr>
<tr>
<td>&gt; 100 km/h</td>
<td>182 s</td>
<td>0,101 (10,1 %)</td>
</tr>
</tbody>
</table>

When the Low beam AFS only has 2 classes not covering all WLTC speeds (e.g. C & V), the weighting of Class C power shall also include the WLTC time not covered by the 2nd class (e.g. Class C time 't' = 0,588 + 0,101)

The resulting power savings of each efficient exterior LED light ($\Delta P_i$) shall be calculated with the following Formula 2:

**Formula 2**

\[
\Delta P_i = P_{b_i} - P_{EI_{AFS}}
\]

where the power consumption of the corresponding baseline vehicle light is as specified in Table 3:

<table>
<thead>
<tr>
<th>Vehicle light</th>
<th>Total electric power ($P_{b_i}$) [W]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low beam headlamp</td>
<td>137</td>
</tr>
<tr>
<td>High beam headlamp</td>
<td>150</td>
</tr>
<tr>
<td>Vehicle light</td>
<td>Total electric power ($P_B$) [W]</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>Front position</td>
<td>12</td>
</tr>
<tr>
<td>License plate</td>
<td>12</td>
</tr>
<tr>
<td>Front fog lamp</td>
<td>124</td>
</tr>
<tr>
<td>Rear fog lamp</td>
<td>26</td>
</tr>
<tr>
<td>Front turn signal lamp</td>
<td>13</td>
</tr>
<tr>
<td>Rear turn signal lamp</td>
<td>13</td>
</tr>
<tr>
<td>Reversing lamp</td>
<td>52</td>
</tr>
<tr>
<td>Cornering lamp</td>
<td>44</td>
</tr>
<tr>
<td>Static Bending lamp</td>
<td>44</td>
</tr>
</tbody>
</table>

4. **CALCULATION OF THE CO$_2$ SAVINGS AND STATISTICAL MARGIN**

4.1. **Calculation of the CO$_2$ savings**

The total CO$_2$ savings of the lighting package shall be calculated in accordance with the specific powertrain of the vehicle (i.e. Conventional, NOVC-HEV).

4.1.1. **Conventional Vehicles (Internal Combustion Engine only)**

The CO$_2$ savings shall be calculated in accordance with the following Formula 3:

**Formula 3**

$$C_{CO_2} = \left( \sum_{i=1}^{m} \Delta P_i \cdot UF_i \right) \cdot \frac{V_{Pe}}{\eta_A} \cdot \frac{CF}{v}$$

Where:

- $v$: Mean driving speed of the WLTC [km/h], which is 46.60 km/h
- $\eta_A$: Efficiency of the alternator, which is 0.67
- $V_{Pe}$: Consumption of effective power as specified in Table 4

**Table 4**

<table>
<thead>
<tr>
<th>Type of engine</th>
<th>Consumption of effective power ($V_{Pe}$) [l/kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol</td>
<td>0.264</td>
</tr>
<tr>
<td>Petrol Turbo</td>
<td>0.280</td>
</tr>
<tr>
<td>Diesel</td>
<td>0.220</td>
</tr>
</tbody>
</table>
CF: Conversion factor (l/100 km) - (g CO₂/km) [gCO₂/l] as specified in Table 5:

Table 5

<table>
<thead>
<tr>
<th>Type of fuel</th>
<th>Conversion factor (l/100 km) - (g CO₂/km) (CF) [gCO₂/l]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol</td>
<td>2 330</td>
</tr>
<tr>
<td>Diesel</td>
<td>2 640</td>
</tr>
</tbody>
</table>

UF: Usage factor for the vehicle light [-] as defined in Table 6.

Table 6

<table>
<thead>
<tr>
<th>Vehicle light</th>
<th>Usage factor (UF) [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low beam headlamp</td>
<td>0.33</td>
</tr>
<tr>
<td>High beam headlamp</td>
<td>0.03</td>
</tr>
<tr>
<td>Front position</td>
<td>0.36</td>
</tr>
<tr>
<td>License plate</td>
<td>0.36</td>
</tr>
<tr>
<td>Front fog lamp</td>
<td>0.01</td>
</tr>
<tr>
<td>Rear fog lamp</td>
<td>0.01</td>
</tr>
<tr>
<td>Front turn signal lamp</td>
<td>0.15</td>
</tr>
<tr>
<td>Rear turn signal lamp</td>
<td>0.15</td>
</tr>
<tr>
<td>Reversing lamp</td>
<td>0.01</td>
</tr>
<tr>
<td>Cornering lamp</td>
<td>0.076</td>
</tr>
<tr>
<td>Static Bending lamp</td>
<td>0.15</td>
</tr>
</tbody>
</table>

4.1.2. Hybrid Vehicles (NOVC-HEV only)

The CO₂ savings shall be calculated in accordance with the following Formula 4:

Formula 4

\[ C_{CO₂} = \sum_{i=1}^{m} \Delta P_i \cdot UF_i \cdot \eta_{DCDC} \cdot K_{CO₂} \]

Where:

\[ \eta_{DCDC} \]: Efficiency of the DC-DC converter

\[ K_{CO₂} \]: CO₂ correction factor \( \left( \frac{gCO₂}{km} \right) \left( \frac{Wh}{km} \right) \), as defined in paragraph 2.2 of Appendix 2 to Sub-Annex 8 to Annex XXI to Regulation (EU) 2017/1151.
The efficiency of the DC-DC converter ($\eta_{\text{DCDC}}$) shall be evaluated in accordance with the appropriate vehicle architecture, as specified in Table 7:

<table>
<thead>
<tr>
<th>#</th>
<th>Architecture</th>
<th>$\eta_{\text{DCDC}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lights connected in parallel to the low voltage battery (lights fed directly from the high voltage battery via DCDC converter)</td>
<td>0,xx</td>
</tr>
<tr>
<td>2</td>
<td>Lights connected in series after the low voltage battery, and the low voltage battery connected in series to the High voltage battery</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>High Voltage and low voltage batteries have exactly the same voltage (12 V, 48 V, …) as the lights</td>
<td>1</td>
</tr>
</tbody>
</table>

For architecture #1, the efficiency of the DC-DC converter ($\eta_{\text{DCDC}}$) shall be the highest value resulting from the efficiency tests performed in the operative electric current range. The measuring interval shall be equal or lower than 10% of the operative electric current range.

4.2. Calculation of the statistical margin

The statistical margin of the lighting package shall be calculated in accordance with the specific powertrain of the vehicle (i.e. Conventional, NOVC-HEV).

4.2.1. Conventional Vehicles (Internal Combustion Engine only)

The statistical margin of the results of the testing methodology caused by the measurements shall be quantified. For each efficient exterior LED light included in the package the standard deviation shall be calculated in accordance with Formula 5:

Formula 5

\[
s_{\eta_{\text{EI}}} = \frac{s_{\eta_{\text{EI}}}}{\sqrt{n}} = \sqrt{\frac{\sum_{i=1}^{n} (P_{\text{EI}} - P_{\text{EI}}^f)^2}{n(n-1)}}
\]

Where:

- $n$: Number of measurements of the sample, which is at least 5

Where the standard deviation of the power consumption of each efficient exterior LED light ($s_{\eta_{\text{EI}}}$) leads to an error in the CO$_2$ savings ($s_{\text{CO}_2}$) that error shall be calculated by means of Formula 6:

Formula 6

\[
s_{\text{CO}_2} = \sqrt{\sum_{i=1}^{m} \left( \frac{\partial \text{CO}_2}{\partial P_{\text{EI}}} \cdot \frac{\text{CF}}{s_{\eta_{\text{EI}}}} \right)^2} = \frac{V_{\text{Pe}} \cdot \text{CF}}{\eta_{\text{A}} \cdot V} \cdot \sqrt{\sum_{i=1}^{m} \left( \frac{U_{\text{EI}} \cdot s_{\eta_{\text{EI}}}}{s_{\text{CO}_2}} \right)^2}
\]
4.2.2. Hybrid Vehicles (NOVC-HEV only)

The statistical margin of the results of the testing methodology caused by the measurements shall be quantified. For each efficient exterior LED light included in the package the standard deviation shall be calculated in accordance with Formula 7:

**Formula 7**

\[
\sigma_{\text{EI}_i} = \frac{1}{\sqrt{n}} \sqrt{\frac{\sum_{j=1}^{n} (P_{\text{EI}_i} - \bar{P}_{\text{EI}_i})^2}{n(n-1)}}
\]

Where:

- \( n \): Number of measurements of the sample, which is at least 5

The \( \text{CO}_2 \)-emission correction factor \( K_{\text{CO}_2} \) shall be determined from a set of \( T \) measurements performed by the manufacturer, in accordance with paragraph 2.2 of Appendix 2 to Sub-Annex 8 to Annex XXI to Regulation (EU) 2017/1151. For each measurement, electric balance during the test and the measured \( \text{CO}_2 \)-emissions shall be recorded.

In order to evaluate the statistical error of \( K_{\text{CO}_2} \), all \( T \) combinations without repetitions of \( T-1 \) measurements shall be used to extrapolate \( T \) different values of \( K_{\text{CO}_2} \) (i.e. \( K_{\text{CO}_2}^T \)). The extrapolation shall be performed in accordance with the method defined in paragraph 2.2 of Appendix 2 to Sub-Annex 8 to Annex XXI to Regulation (EU) 2017/1151.

The standard deviation of \( K_{\text{CO}_2} \) \( (s_{K_{\text{CO}_2}}) \) shall be calculated in accordance with Formula 8.

**Formula 8**

\[
s_{K_{\text{CO}_2}} = \frac{1}{\sqrt{T}} \sqrt{\frac{\sum_{i=1}^{T} (K_{\text{CO}_2} - \bar{K}_{\text{CO}_2})^2}{T(T-1)}}
\]

Where:

- \( T \): Number of measurements performed by the manufacturer for the extrapolation of the \( K_{\text{CO}_2} \) as defined in paragraph 2.2 of Appendix 2 to Sub-Annex 8 to Annex XXI to Regulation (EU) 2017/1151.
- \( K_{\text{CO}_2}^T \): mean of the \( T \) values of \( K_{\text{CO}_2} \)

Where the standard deviation of the power consumption of each efficient exterior LED light \( (s_{P_{\text{EI}_i}}) \) and the standard deviation of the \( K_{\text{CO}_2} \) \( (s_{K_{\text{CO}_2}}) \) lead to an error in the \( \text{CO}_2 \) savings \( (s_{\text{CO}_2}) \), that error shall be calculated by means of Formula 9.

**Formula 9**

\[
s_{\text{CO}_2} = \left( \sum_{i=1}^{m} \left( \frac{\partial \text{CO}_2}{\partial P_{\text{EI}_i}} \cdot s_{P_{\text{EI}_i}} \right)^2 + \left( \frac{\partial \text{CO}_2}{\partial K_{\text{CO}_2}} \cdot s_{K_{\text{CO}_2}} \right)^2 \right)^{\frac{1}{2}}
\]

\[
= \left( \frac{K_{\text{CO}_2}}{\sqrt{\text{NBDE}} \cdot \text{CO}_2} \right) \cdot \sum_{i=1}^{m} \left( 0F_i \cdot s_{P_{\text{EI}_i}} \right)^2 + \left( \sum_{i=1}^{m} s_{P_{\text{EI}_i}} \cdot 0F_i \right)^2 \cdot \left( \frac{K_{\text{CO}_2}}{\sqrt{\text{NBDE}} \cdot \text{CO}_2} \right)
\]
4.3. Statistical margin for Low beam AFS

Where the Low beam AFS is present, formulae 9 shall be adapted to take into account the additional measurements required.

The value of the uncertainty (\(s_{\text{TEAFS}}\)) that is to be used for the Low beam AFS shall be calculated with the following formulae 10 and 11:

**Formula 10**

\[
\sigma_T = \frac{s_{P_c}}{\sqrt{n}} = \sqrt{\frac{\sum_{i=1}^{n} (P_{i} - \bar{P})^2}{n(n-1)}},
\]

**Formula 11**

\[
s_{\text{TEAFS}} = \sqrt{\sum_{c=1}^{C} (\text{WLTC}_\text{share}_c \cdot \sigma_T)^2},
\]

Where:

- \(n\): Number of measurements of the sample, which is at least 5
- \(\bar{P}\): mean of the \(n\) values of \(P_c\)

5. Rounding

The calculated CO\(_2\) savings value (\(C_{\text{CO}_2}\)) and the statistical margin of the CO\(_2\) saving (\(s_{\text{CO}_2}\)) shall be rounded to a maximum of two decimal places.

Each value used in the calculation of the CO\(_2\) savings may be applied unrounded or rounded to the minimum number of decimal places which allows the combined impact of all rounded values on the savings to be lower than 0.25 gCO\(_2\)/km.

6. Statistical Significance

It shall be demonstrated for each type, variant and version of a vehicle fitted with the efficient LED lightings that the uncertainty of the CO\(_2\) savings calculated in accordance with Formula 6 or Formula 9 is not greater than the difference between the total CO\(_2\) savings and the minimum savings threshold specified in Article 9(1) of Implementing Regulation (EU) No 725/2011 (see Formula 12).

**Formula 12**

\[
MT < C_{\text{CO}_2} - s_{\text{CO}_2},
\]

Where:

- \(MT\): minimum threshold [g CO\(_2\)/km]
- \(C_{\text{CO}_2}\): total CO\(_2\) saving [g CO\(_2\)/km]
- \(s_{\text{CO}_2}\): standard deviation of the total CO\(_2\) saving [gCO\(_2\)/km]

Where the total CO\(_2\) emission savings of the efficient LED lighting as determined in accordance with the testing methodology set out in this Annex are below the threshold specified in Article 9(1)(b) of Implementing Regulation (EU) No 725/2011 the second subparagraph of Article 11(2) of that Regulation shall apply.