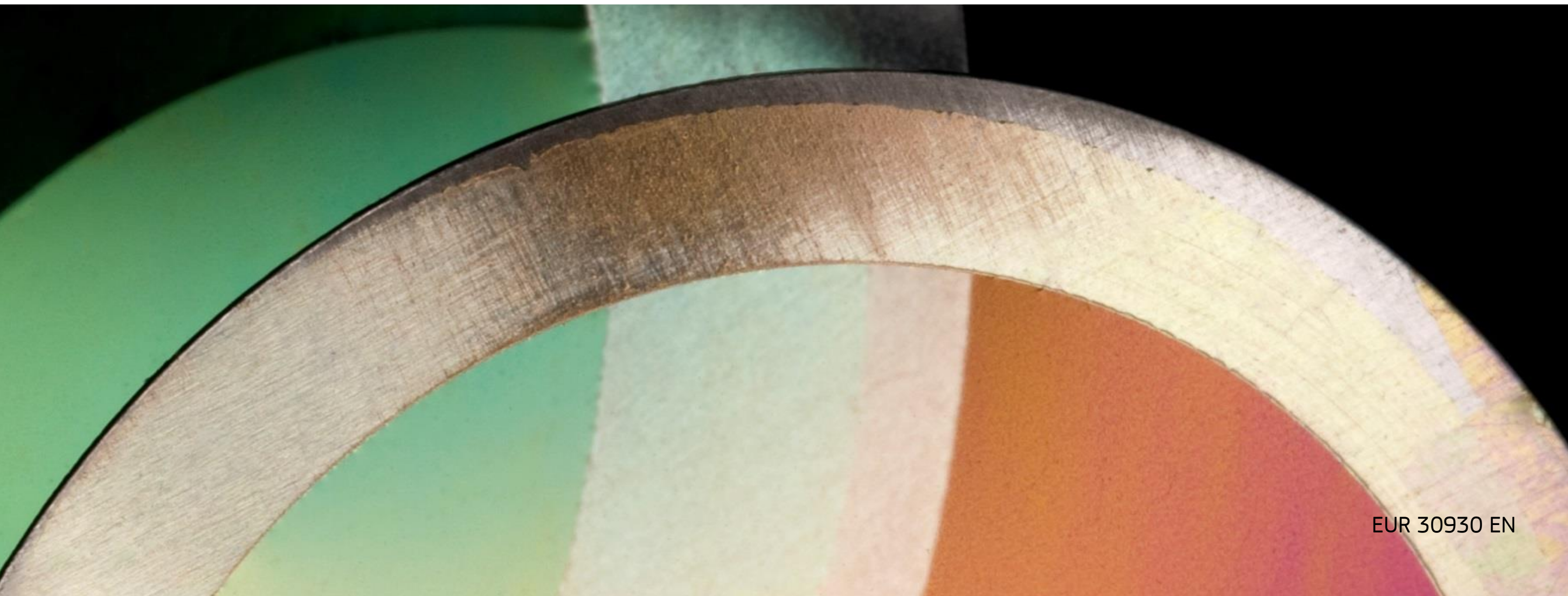
European Commission

JRC TECHNICAL REPORT

Eco-innovative technologies reducing CO_2 emissions of light-duty vehicles: evaluation of interactions

Lodi, C., Serra, S., Currò, D., Gil-Sayas, S., Marotta, A., Bonnel, P., Riemersma, I.

2022



EUR 30930 EN

Contact information
Name: Simone Serra
Address: European Commission, Joint Research Centre (JRC), Via E. Fermi 2749
Email: simone.serra@ec.europa.eu

Name: Alessandro Marotta
Address: European Commission, Joint Research Centre (JRC), Via E. Fermi 2749
Email: alessandro.marotta@ec.europa.eu

EU Science Hub
https://ec.europa.eu/jrc

JRC127106

EUR 30930 EN

PDF	ISBN 978-92-76-45459-5	ISSN 1831-9424	doi:10.2760/258688
Print	ISBN 978-92-76-45461-8	ISSN 1018-5593	doi:10.2760/86427

Luxembourg: Publications Office of the European Union, 2022

How to cite this report: Lodi, C., Serra, S., Currò, D., Gil-Sayas, S., Marotta, A., Bonnel, P., Riemersma, I., *Eco-innovative technologies reducing CO2 emissions of light-duty vehicles: evaluation of interactions*, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-45459-5, doi:10.2760/258688, JRC127106.

Contents

Disclaimer

This JRC technical report describes some best practices for evaluating the interaction between technologies when more than one eco-innovation is fitted on a light-duty vehicle (LDV). The European Commission may approve such technologies in order for their CO_2 savings to be credited when determining a manufacturer's average specific CO2 emissions according to Regulation (EU) 2019/631.

This report is intended to facilitate the implementation of that Regulation and the implementing Regulations (EU) No 725/2011 and (EU) No 427/2014. It is itself not legally binding. Any authoritative reading of the law should only be derived from Regulation (EU) 2019/631 itself and other applicable legal texts.

Acknowledgements

The authors gratefully acknowledge DG CLIMA and JRC colleagues for their helpful and constructive comments that significantly contributed to improving the final version of this document. A special thanks goes to the colleagues Georgios Fontaras, Yannis Drossinos, Filip François, Sotirios Kakarantzas and Susanna Lindvall, who provided insight and expertise that greatly assisted the work.

Authors

Lodi, C., Serra, S., Currò, D., Gil-Sayas, S., Marotta, A., Bonnel, P., Riemersma, I.

Abstract

Article 11 of Regulation (EU) 2019/631 [1] provides a possibility for manufacturers of passenger cars and light commercial vehicles to take into account CO_2 savings from innovative technologies, which cannot be fully quantified when using the standard emission test procedure (currently WLTP) for meeting their specific CO_2 emission targets. Such 'eco-innovations' have to be approved by the Commission on the basis of an application by one or more vehicle manufacturers and/or component suppliers.

If more than one technology is installed on a vehicle, the combined CO_2 savings may be less than the sum of the individual savings because the functioning of the one has an effect on the other. This effect is referred to as an 'interaction'. Where such an interaction cannot be ruled out, the vehicle manufacturer shall indicate any form of interaction both at the stage of the application submission and at the stage of type approval.

This report introduces two methods to determine the interaction, i.e. a "Combined" and a "Separated" method.

Both methods yield the same results in the example case.

The interaction has been detailed by calculating the CO_2 savings of vehicles with two eco-innovations installed according to both methods. In particular, the combination of efficient alternator/motor-generator and exterior LED lighting eco-innovations has been considered.

The interaction between the technologies studied in this report ranged from 0 to 7% of reduction of independent CO_2 savings from both technologies.

As an alternative to the detailed calculation method, this report introduces the use of pre-defined interaction reduction coefficients (PIRCs).

Annex 1 to this report provides the background information and parameter used for equations and numerical examples.

1 Introduction

Regulation (EU) 2019/631 [1] sets tailpipe CO_2 emission targets for new light-duty fleets in the Union, including binding targets for manufacturers.

For complying with those targets, Regulation (EU) 2019/631 allows manufacturers to take into account the CO_2 savings coming from innovative technologies which cannot be adequately quantified by the standard type 1 test procedure (WLTP). Such technologies have to be approved by the European Commission based on an application by manufacturers or suppliers, including an appropriate testing methodology.

The testing methodology to quantify such CO_2 savings has to be capable of demonstrating the CO_2 emissions benefits of the innovative technology in real-world driving conditions, realistically and with strong statistical significance. Where relevant, it has to take into account the interaction with other eco-innovations applied in the vehicle. An interaction may occur when two or more innovative technologies are installed on a vehicle and the savings from one of them are influenced by the functioning of the other technologies and vice-versa. In such situations, the total CO_2 savings may not reflect the sum of the savings from each technology considered separately and independently from the presence of the others.

An example of an interaction between two approved eco-innovations is the combination of an exterior LED lighting system and an efficient alternator. The interaction between these technologies is acting in both directions. On the one hand, compared to halogen lights, the presence of LED lights reduces the real-world average electrical consumption of the vehicle and, therefore, reduces the effect of the presence of an efficient alternator on the CO_2 savings. On the other hand, the presence of the efficient alternator results in lower CO_2 emissions per amount of electrical energy produced, and, therefore, reduces the CO_2 benefits of the LED lighting system.

For the certification of the CO_2 savings in accordance with Article 11 of Implementing Regulation (EU) 725/2011 [2], and Article 11 of Implementing Regulation (EU) 427/2014 [3] the independent and certified body has to draw up a report on the interaction between several eco-innovations fitted to a vehicle version or, where applicable, interpolation family. The report has to specify the CO_2 savings from the different technologies taking into account the impact of the interaction(s).

2 Methods

2.1 Introduction to eco-innovations

Article 11 of Regulation (EU) 2019/631 [1] provides a possibility for manufacturers to take into account CO_2 savings from innovative technologies, named "eco-innovations", in order to meet their specific CO_2 emissions targets. Only technologies which had been fitted in 3 % or less of all new cars or vans registered in the year n-4, n being the year of application, meet the innovativeness criterion and may be considered eligible as eco-innovations.

In demonstrating the CO_2 savings, a comparison should be made between the same vehicles with and without the eco-innovation. The testing methodology used to quantify the savings should provide verifiable, repeatable, and comparable results. In order to assess the real-world CO_2 savings from the innovative technologies, the testing conditions may differ from those defined for type-approval. To avoid double-counting, the CO_2 savings under type-approval testing conditions must be subtracted from the CO_2 savings under modified testing conditions. In addition, the usage factor of the technology for the modified conditions ($\mathrm{UF_{MC}}$), which represents its mean share of activation in real-world operation, has to be considered. Similarly, a usage factor for the type-approval conditions might also be used ($\mathrm{UF_{TA}}$).

A crucial aspect is the definition of the baseline vehicle against which the eco-innovation vehicle should be benchmarked. The definition of a baseline vehicle is evaluated on a case-by-case basis. It may not be sufficient to simply deactivate the eco-innovation on the eco-innovative vehicle without considering other negative impacts of the eco-innovation (e.g. increase in the mass of the vehicle or the drag resistance) [4].

The CO_2 savings of an innovative technology are generally determined by Eq. (1) [4]:

$$\mathbf{C_{CO_2}} = \sum_{i=1,2,..}\left(\mathbf{B_{MC,i}} - \mathbf{E_{MC,i}}\right) \cdot \mathbf{UF_{MC,i}} - \left(\mathbf{B_{TA}} - \mathbf{E_{TA}}\right) \cdot \mathbf{UF_{TA}} \qquad \text{[gCO2/km]} \qquad (1)$$

Where:

$\mathrm{C_{CO_2}}$ CO_2 savings [gCO_2/km],

$\mathrm{B_{MC,i}}$ CO_2 emissions of the baseline vehicle under modified conditions i [gCO_2/km],

$\mathrm{E_{MC,i}}$ CO_2 emissions of the eco-innovation vehicle under modified conditions i [gCO_2/km],

$\mathrm{B_{TA}}$ CO_2 emissions of the baseline vehicle under type-approval conditions [gCO_2/km]

$\mathrm{E_{TA}}$ CO_2 emissions of the eco-innovation vehicle under type-approval conditions [gCO_2/km],

$\mathrm{UF_{MC,i}}$ Usage factor for the modified conditions i [-],

$\mathrm{UF_{TA}}$ Usage factor for type-approval conditions [-].

According to the legislation, the minimum emission reduction to be achieved by an innovative technology shall be 0.5 g CO_2/km. Where, due to one or more interactions the total savings are less than 0.5 g CO_2/km times the number of eco-innovations, only those eco-innovation savings that meet the 0.5 g CO_2/km threshold shall be taken into account for calculating the total savings [2], [3].

The total contribution of innovative technologies to reducing the average specific emissions of CO_2 of a manufacturer may not be more than 7 gCO_2/km.

2.2 Methods for the evaluation of the interaction between eco-innovations

In order to evaluate the CO_2 savings from two or more eco-innovations fitted to one vehicle, two alternative methods are considered in this report, hereinafter referred to as "combined method" and "separated method", respectively (Figure 1). Both methods are designed to provide the same CO_2 savings result, taking the interaction between the eco-innovations into account. Depending on the testing methodologies used to calculate the savings of each eco-innovation, it is possible to apply one method or the other.

The "combined method" is based on Eq. (1) with the baseline vehicle not having any eco-innovation and the eco-innovation vehicle having all the eco-innovations installed. This means that this method requires the definition of a single set of modified conditions that cover the (combined) real-world operation of all the eco-innovations fitted to the vehicle. Considering *n* eco-innovations fitted, the savings resulting from the application of the combined method (i.e. ${C_{CO_2}}^{(C)}$) are expressed by Eq. (2).

$$C_{{CO_2}_{tot}} = C_{{CO_2}_{eco_1,+eco_2...+eco\_n}}^{(C)} \qquad [gCO2/km] \qquad (2)$$

The "separated method" determines the CO_2 savings from an eco-innovation obtained without considering any of the other innovative technologies (i.e. independent CO_2 savings - I), and adds the CO_2 savings from each of the other eco-innovations taking into account the presence of the other eco-innovations in the baseline (i.e. CO_2 savings taking account of an efficient baseline - EB). For example, the CO_2 savings from a vehicle with LED lights on-board (i.e. independent LED lights savings) are added to the CO_2 savings from a vehicle with the same LED lights in the baseline vehicle and an efficient alternator/motor generator (i.e. the efficient baseline has LED lights on-board).

In some cases, choosing which technology is present in the efficient baseline is crucial. This occurs when a technology affects the performance of another technology, but the latter does not affect the performance of the former. For example, this can be the case of an electrical consumer and a free electrical energy producer. The electrical consumer (i.e. 12V board net) uses always the same amount of energy independently from the energy source and the vehicle uses less energy than the energy provided by the producer (i.e. alternator/motor generator). This energy depends on the vehicle's consumers. In the case of *n* eco-innovations fitted to one vehicle type, variant or version, the savings resulting from the application of the separated method is expressed by Eq. (3).

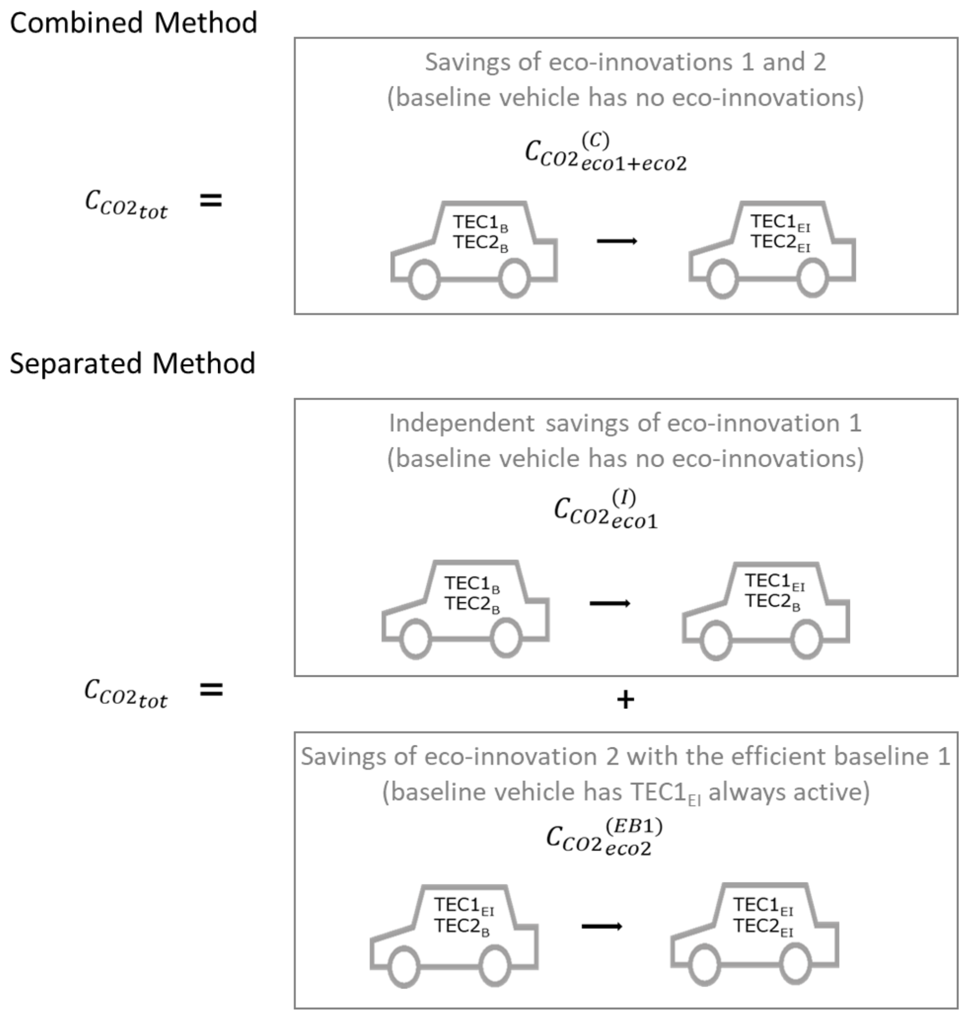
$$C_{{CO_2}_{tot}} = C_{{CO_2}_{eco_1}}^{(I)} + C_{{CO_2}_{eco_2}}^{(EB_1)} + C_{{CO_2}_{eco_3}}^{(EB_2)} + \cdots + C_{{CO_2}_{eco_n}}^{(EB_{n-1})} \qquad [gCO2/km] \qquad (3)$$

The superscripts EB_i in Eq. (3) indicate the number of other eco-innovations considered in the baseline vehicle when evaluating the CO_2 savings (i.e. defined *n* the number of the eco-innovations in the vehicle, EB_1 indicates the efficient baseline with *one* eco-innovation on board, and EB_{n-1} indicates the one with *n-1* eco-innovations). The order in which the eco-innovations are chosen in Eq. (3) does not affect the final CO_2 savings result provided that each technology has a certain CO_2-reducing impact on the others. If, on the contrary, there is a technology that does not have CO_2-reducing impact due to the presence of the others, this technology shall be eco_1 in Eq. (3) (i.e., $C_{{CO_2}_{eco_1}}^{(I)}$).

An advantage is that the separated method can be applied when it is not possible to define modified conditions which cover the real-world operation of all the eco-innovations on-board, as required for the application of the combined method. Indeed, modified conditions are always defined separately for each technology, but the combined method requires unique modified conditions for all technologies, i.e. a unique set of operating conditions to trigger the real-world operation of all technologies.

The combined and separated methods can be used as long as the values in Eq. (1) are expressed as functions of the technology's specific parameters and not as e.g. pre-defined CO_2 savings values. A simplified diagram of the combined and separated methods is presented in Figure 1.

Figure 1*: Simplified diagram of the combined and separated methods (TEC stands for "technology")*



Source: JRC, 2021.

Once the CO_2 savings from two or more eco-innovations fitted to one vehicle are obtained with the combined or separated method, Interaction Reduction Coefficients (IRCs) can be defined for each technology combination, as per Eq. (4):

$$\mathrm{IRC} = 100 - \left(\frac{\mathrm{C_{CO_2}}{}^{(\mathrm{I})}_{\mathrm{tot}} - \mathrm{C_{CO_2}}_{\mathrm{tot}}}{\mathrm{C_{CO_2}}{}^{(\mathrm{I})}_{\mathrm{tot}}}\right) \quad [\%] \qquad (4)$$

Where $C_{CO_2}{}^{(I)}_{tot} = C_{CO_2}{}^{(I)}_{eco_1} + C_{CO_2}{}^{(I)}_{eco_2} + \cdots + C_{CO_2}{}^{(I)}_{eco_n}$ are the total independent CO_2 savings from all technologies on-board, $\mathrm{C_{CO_2}}_{\mathrm{tot}}$ are the total savings when interaction is taken into account as defined in Eq. (2) and (3) and $\left(\frac{\mathrm{C_{CO_2}}{}^{(\mathrm{I})}_{\mathrm{tot}} - \mathrm{C_{CO_2}}_{\mathrm{tot}}}{\mathrm{C_{CO_2}}{}^{(\mathrm{I})}_{\mathrm{tot}}}\right)$ is expressed as a percentage.

2.3 Interaction and certification of CO_2 savings

The identification and quantification of interactions between eco-innovations have to be conducted during the type-approval process for a vehicle fitted with more than one approved eco-innovation.

Where interaction between eco-innovations cannot be ruled out, the vehicle manufacturer shall indicate this in the application to the type-approval authority and shall provide a report from the independent and certified body on the impact of the interaction between several eco-innovations fitted to one vehicle type, variant, version or, where applicable, interpolation family (according to Article 11(4) of Commission Implementing Regulation (EU) No 725/2011 [2] and (EU) No 427/2014 [3]).

When two or more eco-innovations are fitted to one vehicle, the total uncertainty in determining the CO2 savings has to be evaluated taking into account the interaction between the eco-innovations. The total uncertainty $s_{C_{CO_2}}$ can be obtained by applying the IRC to the total independent uncertainty of all technologies.

$$s_{C_{CO_2}} = \mathrm{IRC} \cdot s_{C_{CO_2\,tot}}{}^{(I)} \qquad \text{[gCO2/km]} \qquad (5)$$

Where $s_{C_{CO_2\,tot}}{}^{(I)}$ is the total independent uncertainty in the determination of the CO_2 savings, obtained as an arithmetic sum of the independent uncertainties for each technology.

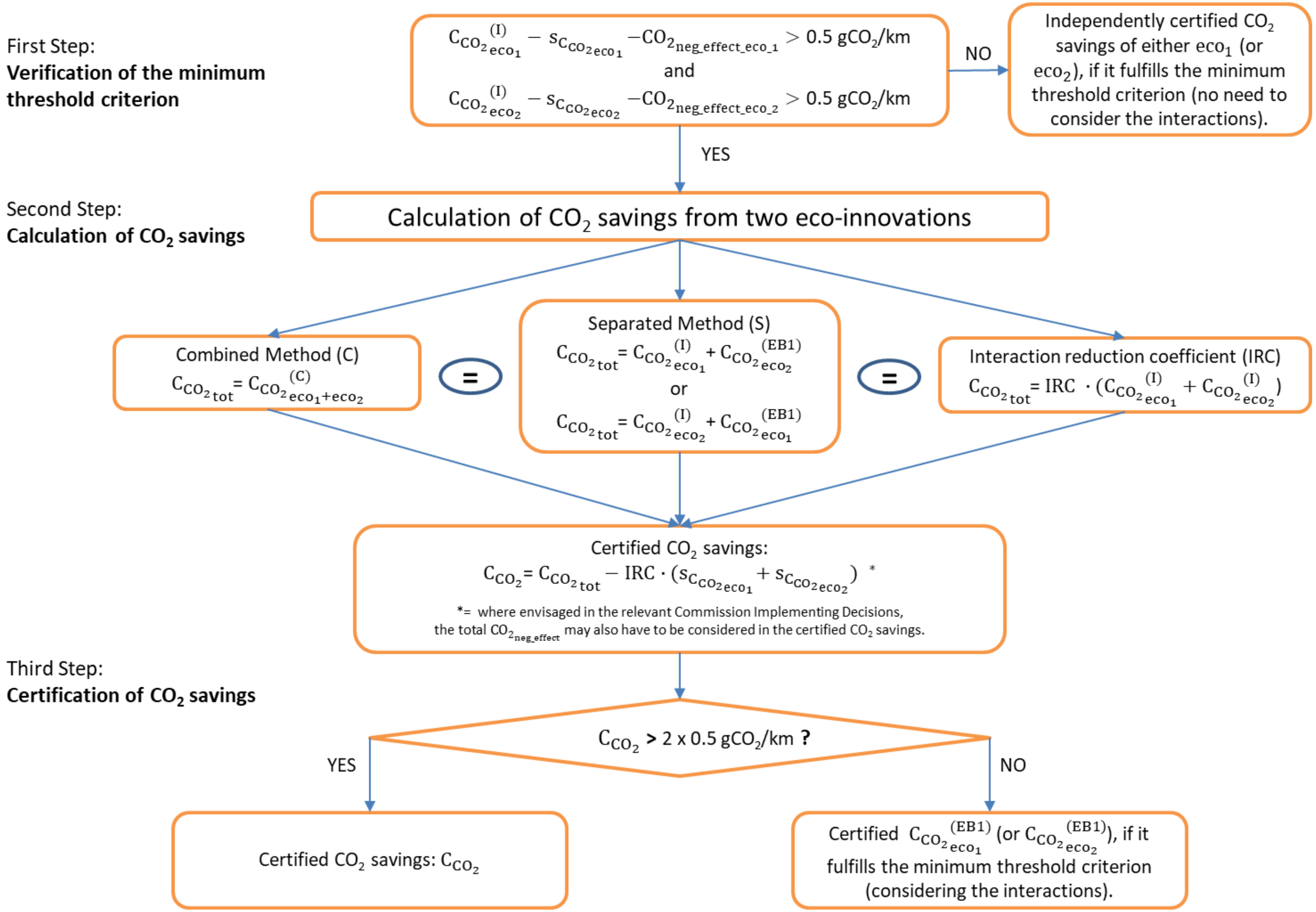
The certified CO_2 savings (C_{CO_2}) can thus be obtained by Eq. (6).

$$C_{CO_2} = \mathrm{IRC} \cdot \left(C_{CO_2\,tot}^{(I)} - s_{C_{CO_2\,tot}}{}^{(I)} \right) = C_{CO_2\,tot} - s_{C_{CO_2}} \qquad \text{[gCO2/km]} \qquad (6)$$

Figure 2 and Figure 3 summarise the steps to be followed for the certification of the CO_2 savings in case two or three eco-innovations are fitted. The procedural steps can be also applied to the case with “n” eco innovations on-board, as indicated by Eq. (2) and Eq. (3).

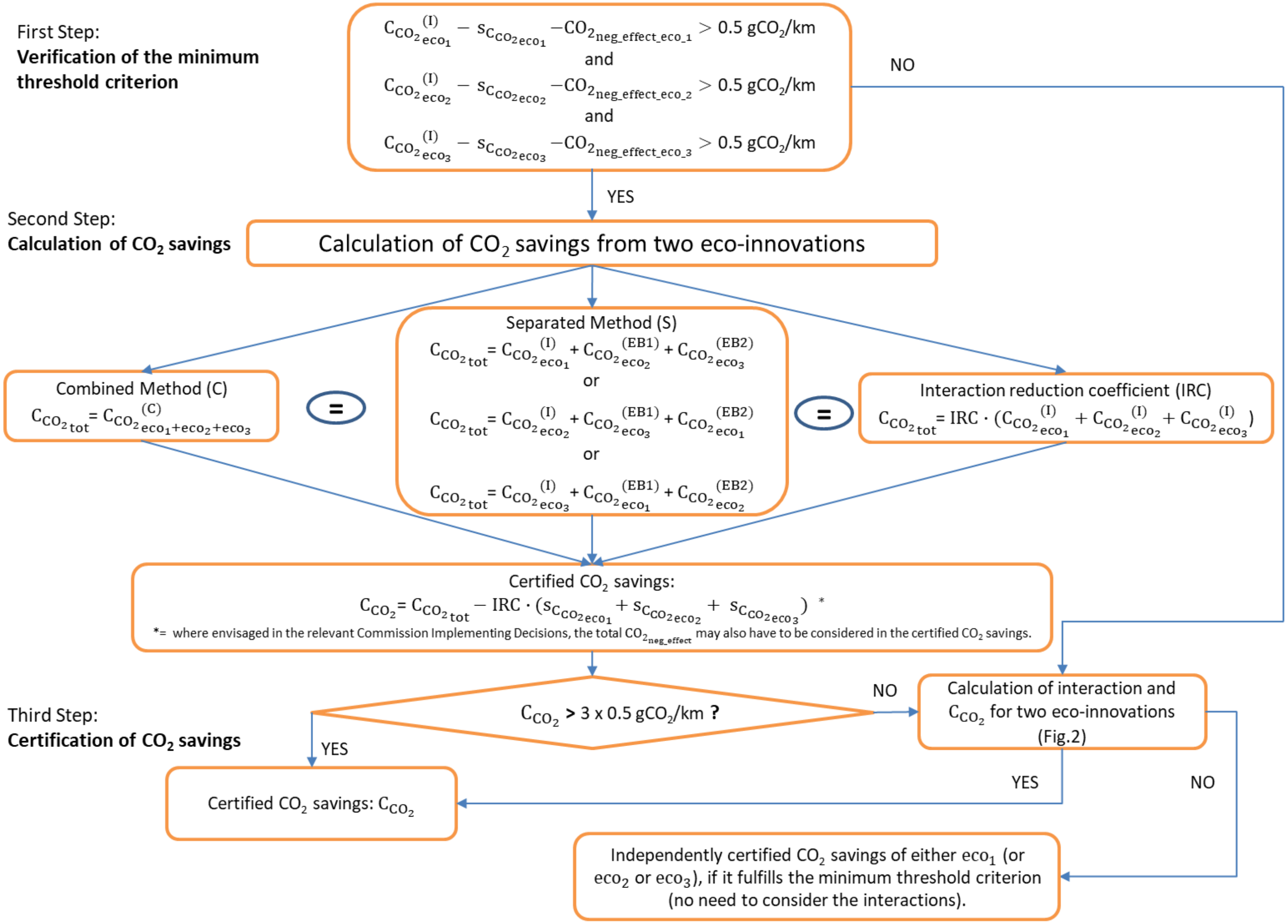
It has to be noted that Figure 3 represents an example of possible situations: in fact if $C_{CO_2\,tot}$ is lower than 3 times 0.5 g/km, there might be a further check for pairs of technologies (e.g. eco_1 + eco_2 might have combined savings, including interaction, higher than 2 times 0.5 g/km).

Figure 2: Procedure for quantifying interactions as part of the certification of two eco-innovations fitted to one vehicle type, variant or version



Source: JRC Analysis, 2021.

Figure 3. Procedure for quantifying interactions as part of the certification of three eco-innovations fitted to one vehicle type, variant or version



Source: JRC Analysis, 2021.

3 Applying the two methods for determining the interaction – case: efficient alternator/motor-generator and exterior LED lighting

3.1 Introduction

In this section, the two methods for quantifying the interaction between eco-innovations are applied to an example case combining an efficient alternator or a 12V/48V motor-generator and exterior LED lighting.

The methodologies for determining the CO_2 savings of these eco-innovations separately (i.e. independent CO_2 savings - I) are taken from the applicable Commission Implementing Decisions (CIDs) as summarised in Table 1:

Table 1. Relevant Commission Implementing Decisions

Technology	**Commission Implementing Decision**
12V Efficient alternator	(EU) 2020/174 [5]
12V Motor-generator	(EU) 2020/1232 [6]
48V Motor-generator plus 12V/48V DC/DC converter	(EU) 2020/1167 [7]
Exterior LED lighting	(EU) 2019/1119 [8]

Source: JRC Analysis, 2021.

These electrical technologies are characterised by usage factors equal to 1 for both the modified and the type-approval conditions as the technologies are always active and are not supposed to be removed or disconnected from the vehicle during its lifetime. In the case of exterior LED lighting, the mean share of technology usage (i.e. temporal share of usage of each LED light) is included in the definition of the modified conditions that take into account the UF of each LED light. All four technologies of Table 1 have a common set of modified conditions (e.g. common values of power consumption under real-world conditions).

Therefore Eq. (1) can be simplified as follows:

$$\mathrm{C_{CO_2}} = (\mathrm{B_{MC}} - \mathrm{E_{MC}}) - (\mathrm{B_{TA}} - \mathrm{E_{TA}}) \qquad [\mathrm{gCO_2/km}] \qquad (7)$$

The calculations can be further simplified when considering that the CO_2 savings from these technologies are only affecting the vehicle CO_2 emissions due to its electrical consumption. Equation (6) can therefore be expressed as follows, where Be and Ee are respectively baseline and eco-innovative vehicle CO_2 emissions due to electric consumption:

$$\mathrm{C_{CO_2}} = (\mathrm{Be_{MC}} - \mathrm{Ee_{MC}}) - (\mathrm{Be_{TA}} - \mathrm{Ee_{TA}}) \qquad [\mathrm{gCO_2/km}] \qquad (8)$$

Equation (8) is therefore used for all the examples provided below.

The interaction between these technologies is acting in both directions: the presence of exterior LED lighting reduces the real-world average electrical consumption and therefore the CO_2 savings due to the installation of an efficient alternator, while the presence of the efficient alternator reduces the benefits of having exterior LED lights on-board as the amount of saved electrical energy is produced at a more favourable CO_2 emissions conversion factor (i.e. with lower associated CO_2 emissions).

3.2 Combined method

In order to apply the combined method, the baseline vehicle has to be considered equipped with a baseline alternator (i.e. efficiency of 67% [4]) and exterior halogen lighting. The eco-innovation vehicle has both an efficient alternator/motor-generator and exterior LED lighting.

The terms of Eq. (7) can be expressed as follows:

$$\mathrm{Be_{MC}} = (\mathrm{P_{other}} + \mathrm{P_{HL}}) \cdot \frac{1}{\eta_A} \cdot \frac{k}{v} \qquad [\mathrm{gCO_2/km}]$$

$$\mathrm{Ee_{MC}} = (\mathrm{P_{other}} + \mathrm{P_{LED}}) \cdot \frac{1}{\eta_E} \cdot \frac{k}{v} \qquad [\mathrm{gCO_2/km}]$$

$$\mathrm{Be_{TA}} = \mathrm{P_{TA}} \cdot \frac{1}{\eta_A} \cdot \frac{k}{v} \qquad [\mathrm{gCO_2/km}]$$

$$\mathrm{Ee_{TA}} = \mathrm{P_{TA}} \cdot \frac{1}{\eta_E} \cdot \frac{k}{v} \qquad [\mathrm{gCO_2/km}]$$

Where:

n_A	efficiency of the baseline alternator	[-]
n_E	efficiency of the efficient alternator/motor-generator ([1])	[-]
k	$V_{Pe} \cdot CF$	[gCO_2/kWh]
CF	Fuel conversion factor	[gCO_2/l]
P_{TA}	Vehicle's average electric power requirement under type-approval conditions	[W]
P_{HL}	Electric power requirement of halogen lighting	[W]
P_{LED}	Electric power requirement of exterior LED lighting	[W]
P_{other}	Vehicle's average electric power requirement under real-world conditions except exterior lighting	[W]
V_{Pe}	Consumption of effective power - Willans' Factor	[l/kWh]
v	Mean driving speed of the homologation cycle	[km/h]

As consequence, Eq. (8) will result as per Eq. (9):

$$C_{CO_2}{}^{(C)}_{EA+LED} = \frac{k}{v} \cdot \left[(\mathrm{P_{other}} - \mathrm{P_{TA}}) \cdot \left(\frac{1}{\eta_A} - \frac{1}{\eta_E} \right) + \frac{\mathrm{P_{HL}}}{\eta_A} - \frac{\mathrm{P_{LED}}}{\eta_E} \right] \qquad [\mathrm{gCO2/km}] \qquad (9)$$

([1]) In the case of 48V motor-generator plus 48V/12V DC/DC converter, n_E is calculated by the product of the 48V motor-generator's efficiency and the DC/DC one.

3.3 Separated method

First, the total CO_2 savings is calculated by combining the CO_2 savings from the efficient alternator, obtained without considering exterior LED lighting on-board (i.e. independent CO_2 savings from EA), with the CO_2 savings from the exterior LED light considering the presence of the efficient alternator in the baseline (i.e. CO_2 savings from exterior LED lights considering an efficient baseline). The equation terms can be expressed as follows:

$$C_{CO_2}{}_{EA}^{(I)} = (P_{RW} - P_{TA}) \cdot \left(\frac{1}{\eta_A} - \frac{1}{\eta_E}\right) \cdot \frac{k}{v} \qquad [gCO_2/km]$$

$$C_{CO_2}{}_{LED}^{(EB1)} = (P_{HL} - P_{LED}) \cdot \frac{1}{\eta_E} \cdot \frac{k}{v} \qquad [gCO_2/km]$$

The total CO_2 savings can thus be expressed as per Eq. (10):

$$C_{CO_2}{}_{EA+LED}^{(S)} = C_{CO_2}{}_{EA}^{(I)} + C_{CO_2}{}_{LED}^{(EB1)} = \left[(P_{other} - P_{TA}) \cdot \left(\frac{1}{\eta_A} - \frac{1}{\eta_E}\right) + \frac{P_{HL}}{\eta_A} - \frac{P_{LED}}{\eta_E}\right] \cdot \frac{k}{v} \qquad [gCO_2/km] \qquad (10)$$

The separated method provides the same result as the combined one (i.e., Eq. (10) is equivalent to Eq. (9)).

If the separated method is applied in the other direction, i.e. by combining the CO_2 savings from the exterior LED lights, obtained without considering the efficient alternator on-board (i.e. independent CO_2 savings from exterior LED lights), with the CO_2 savings from the efficient alternator considering the presence of the exterior LED lights in the baseline (i.e. EA CO_2 savings considering an efficient baseline), the equation terms can be summarised as follows:

$$C_{CO_2}{}_{LED}^{(I)} = (P_{HL} - P_{LED}) \cdot \frac{1}{\eta_A} \cdot \frac{k}{v} \qquad [gCO_2/km]$$

$$C_{CO_2}{}_{EA}^{(EB1)} = (P_{other} + P_{LED} - P_{TA}) \cdot \left(\frac{1}{\eta_A} - \frac{1}{\eta_E}\right) \cdot \frac{k}{v} \qquad [gCO_2/km]$$

The total CO_2 savings can thus be expressed as per Eq. (11):

$$C_{CO_2}{}_{EA+LED}^{(S)} = C_{CO_2}{}_{LED}^{(I)} + C_{CO_2}{}_{EA}^{(EB1)} = \left[(P_{other} - P_{TA}) \cdot \left(\frac{1}{\eta_A} - \frac{1}{\eta_E}\right) + \frac{P_{HL}}{\eta_A} - \frac{P_{LED}}{\eta_E}\right] \cdot \frac{k}{v} \qquad [gCO_2/km] \qquad (11)$$

As shown, the order in which the eco-innovations are chosen for the separated method does not affect the final CO_2 savings result in this example case. This is because each technology has a CO_2 saving reduction impact on the other.

3.4 Numerical examples

In this section, both methods for the interaction between the two types of electrical technologies are applied to numerical examples. The reference values used in the examples are described in Annex 1 and Annex 2.

The innovative technologies are (i) an alternator/motor-generator with an efficiency (including the DC/DC converter, when applicable) of 77% (η_E), and (ii) a package of different exterior LED lighting (see Annex 2) with a total power of 16.85 W (P_{LED}) (see Table 11 of Annex 1).

The following emission values can thus be obtained (see Eq. (8)):

$\mathrm{Be_{MC}} = 14.81\ \mathrm{gCO_2/km}$

$\mathrm{Ee_{MC}} = 12.06\ \mathrm{gCO_2/km}$

$\mathrm{Be_{TA}} = 6.91\ \mathrm{gCO_2/km}$

$\mathrm{Ee_{TA}} = 6.01\ \mathrm{gCO_2/km}$

The main features of baseline and eco-innovation vehicle and the resulting CO_2 savings are summarised in Table 2:

Table 2. CO_2 savings from efficient alternator/motor-generator and exterior LED lighting (combined method)

Combined Method		
Baseline vehicle	Eco-innovation vehicle	Total CO_2 savings
$\mathrm{P_{HL}} = 64.7\ \mathrm{W}$ $\eta_\mathrm{A} = 0.67$	$\mathrm{P_{LED}} = 16.85\ \mathrm{W}$ $\eta_\mathrm{E} = 0.77$	$\mathbf{C_{CO_2}}{}_{\mathbf{EA+LED}}^{\mathbf{(C)}} = \mathbf{1.85\ gCO_2/km}$

Source: JRC analysis, 2021.

The total CO_2 savings can also be obtained by using the separated method. Table 3 includes the main features of baseline and eco-innovation vehicle and the resulting CO_2 savings according to the separated method.

Table 3. CO_2 savings from efficient alternator/motor-generator and exterior LED lighting (separated method)

Separated Method		
Independent savings from exterior LED lighting	Savings from efficient alternator/motor generator with efficient baseline	Total CO_2 savings
Baseline vehicle: $\mathrm{P_{HL}} = 64.7\ \mathrm{W}$ $\eta_\mathrm{A} = 0.67$ Eco-innovation vehicle: $\mathrm{P_{LED}} = 16.8\ \mathrm{W}$ $\eta_\mathrm{A} = 0.67$ $\mathrm{C_{CO_2}}{}_{\mathrm{LED}}^{(\mathrm{I})} = 0.95\ \mathrm{gCO_2/km}$	Baseline vehicle $\mathrm{P_{LED}} = 16.85\ \mathrm{W}$ $\eta_\mathrm{A} = 0.67$ Eco-innovation vehicle $\mathrm{P_{LED}} = 16.8\ \mathrm{W}$ $\eta_\mathrm{E} = 0.77$ $\mathrm{C_{CO_2}}{}_{\mathrm{EA}}^{(\mathrm{EB1})} = 0.95\ \mathrm{gCO_2/km}$	$\mathrm{C_{CO_2}}{}_{\mathrm{LED}}^{(\mathrm{I})} + \mathrm{C_{CO_2}}{}_{\mathrm{EA}}^{(\mathrm{EB1})} =$ $= \mathbf{1.85\ gCO_2/km}$
Independent savings from efficient alternator/motor generator	Savings from exterior LED lighting with efficient baseline	Total CO_2 savings
Baseline vehicle	Baseline vehicle:	

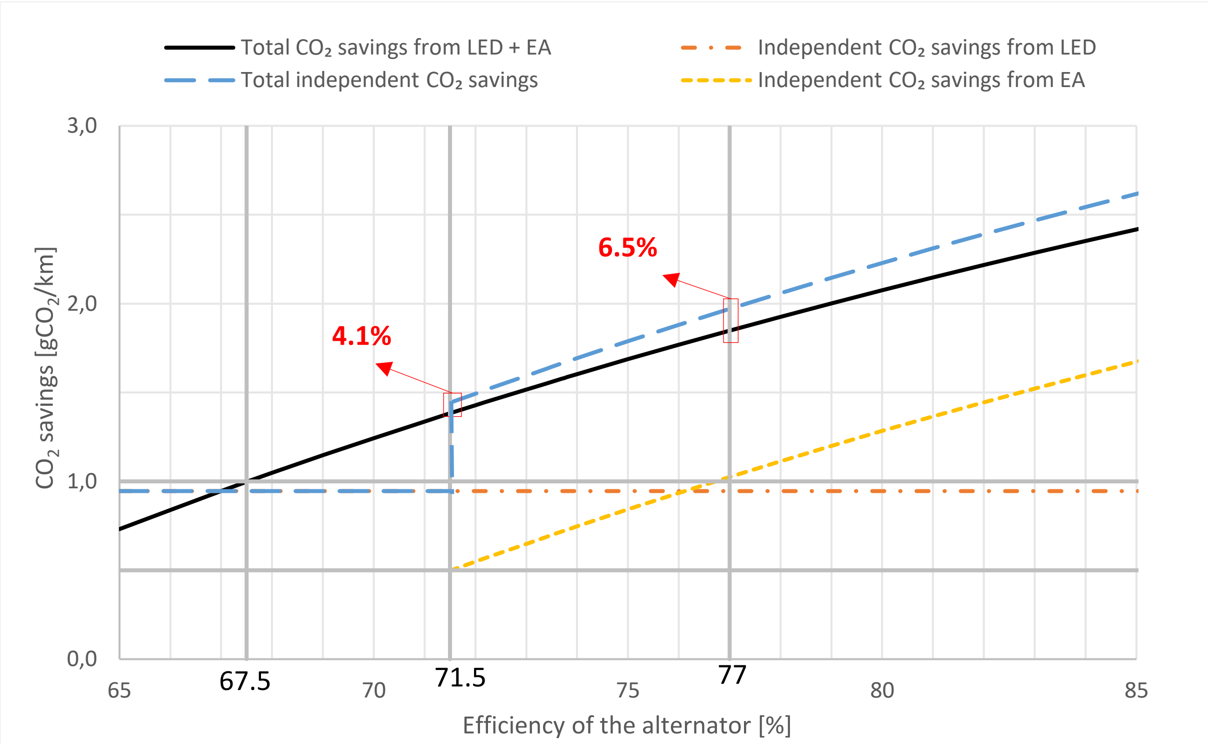
$\eta_A = 0.67$ $P_{HL} = 64.7\ W$ Eco-innovation vehicle $\eta_E = 0.77$ $P_{HL} = 64.7\ W.$ $C_{CO_2}{}^{(I)}_{EA} = 1.03\ gCO_2/km$	$\eta_E = 0.77$ $P_{HL} = 64.7\ W$ Eco-innovation vehicle: $\eta_E = 0.77$ $P_{LED} = 16.85\ W$ $C_{CO_2}{}^{(EB1)}_{LED} = 0.82\ gCO_2/km$	$C_{CO_2}{}^{(I)}_{EA} + C_{CO_2}{}^{(EB1)}_{LED} =$ $= \mathbf{1.85\ gCO_2/km}$

Source: JRC analysis, 2021.

Since the sum of the independent savings from efficient alternator/motor-generator and exterior LED lighting are 1.98 g CO_2/km (i.e. 0.95 g CO_2/km + 1.03 g CO_2/km, the CO_2 savings-reduction effect due to the interaction is 0.13 g CO_2/km or 6.5% and IRC equal to 93.5% (see Eq. 4).

An example of the influence of the efficiency of the alternator versus the CO2 savings from an efficient alternator and exterior LED lighting is represented in Figure 4. It is possible to observe that the interaction becomes higher when the efficiency of alternator increases, which means a larger reduction in the final savings.

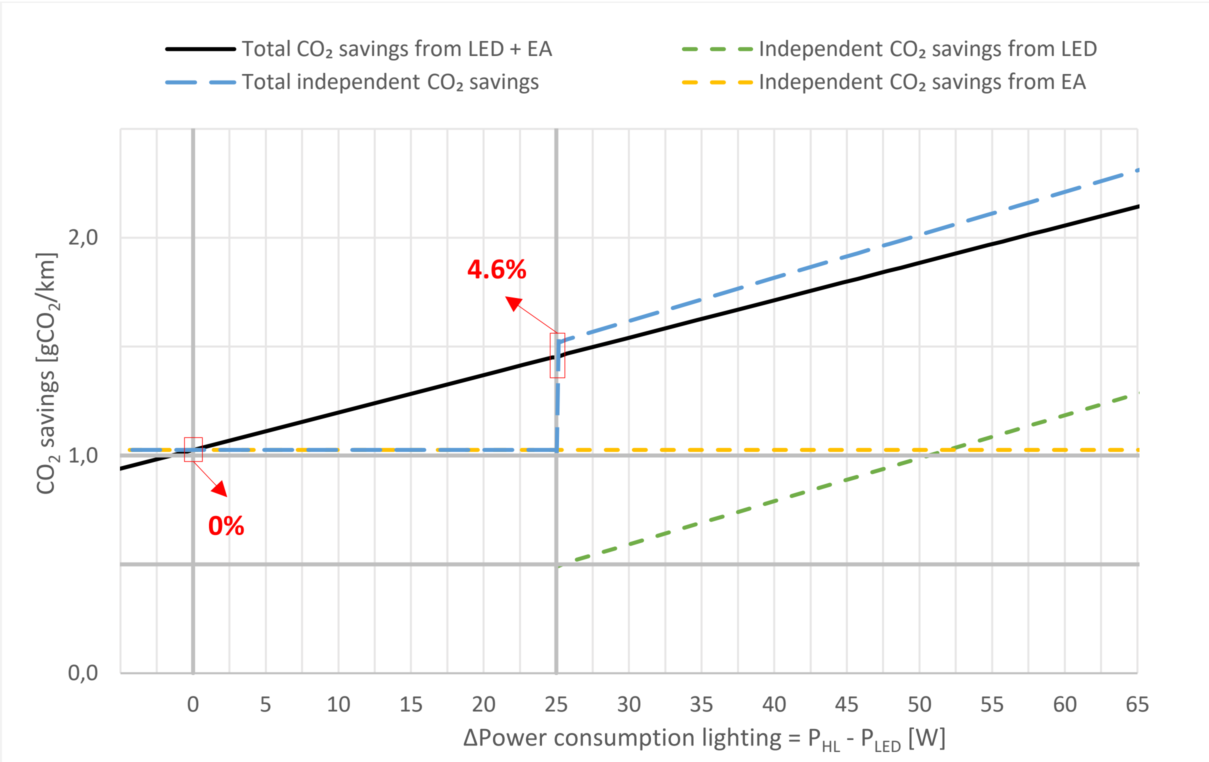
Figure 4. Influence of efficiency of alternator over the CO_2 savings from alternator and exterior LED lighting ($P_{LED} = 16.85\ W$)



Source: JRC analysis, 2021.

The influence of the saved electrical power of the LED lighting versus the CO_2 savings from an efficient alternator and exterior LED lighting is represented in Figure 5

Figure 5. Influence of power consumption of exterior LED lighting over CO_2 savings from efficient alternator and exterior LED lighting ($\eta_E = 0.77$)



Source: JRC analysis, 2021.

It is possible to observe that the interaction becomes higher when the saved electrical power increases, which means a larger reduction in the final savings.

4 Pre-defined interaction reduction coefficients (PIRCs) for Efficient alternator/ motor-generator and exterior LED lighting

To simplify the evaluation of the CO_2 savings from two or more eco-innovations fitted to one vehicle, conservative pre-defined interaction reduction coefficients (PIRCs) can be used as an alternative to the detailed calculation methods for the interactions presented in the previous sections.

The PIRCs are applied according to Eq. (12). Similarly to the IRCs, they are multiplied to the total independent CO_2 savings (i.e. sum of CO_2 savings from each eco-innovation without considering any of the others on-board) to obtain the certified CO_2 savings (C_{CO_2}), taking into account the interaction and the uncertainty.

$$C_{CO_2} = \mathrm{PIRC} \cdot \left(C_{CO_2}{}_{tot}^{(I)} - s_{CO_2}{}_{tot}^{(I)} \right) \qquad [gCO_2/km] \qquad (12)$$

These coefficients need to be on the conservative side, to avoid that they would overestimate the actual CO_2 reduction. The process to establish a conservative value for the PIRCs consists of the following steps:

The relevant influencing parameters for the eco-innovations are identified.

These parameters are varied between realistic minimum and maximum values to calculate the total CO_2 savings. As a result, a range of IRC values is found.

The lowest CO_2 savings of the range (i.e. the lowest IRCs) are used as a basis for the PIRC value and a safety margin is added to ensure the PIRC value will be conservative

The PIRC, expressed as a percentage, is rounded down to the nearest integer value.

As an example, PIRC values for efficient alternator/motor-generator and the exterior LED lighting will be determined in this section.

To evaluate range of interaction values, several combinations of efficient alternator/motor-generator and exterior LED lighting have been considered, leading to different CO_2 savings. The influencing parameters which have been considered as relevant are the efficiency of the efficient alternator/motor-generator (η_E) and the power consumption of the exterior LED lighting (P_{LED}). For each of these influencing parameters realistic ranges have been defined, as summarised in Table 4.

Table 4. Realistic ranges for the influencing parameters considered for each innovative technology when calculating CO_2 savings

Innovative technology	**Influencing parameter**	**Realistic range of the influencing parameter**
Efficient alternator	η_E [-]	From 0.738 (2) to 0.85
Exterior LED lighting	PLED [W]	From 8.5 W to 40 W

Source: JRC analysis, 2021.

The ranges of the influencing parameters in Table 4 have been defined such that CO_2 savings from each individual technology vary from 0.5 gCO_2/km to a realistic maximum value for LED lighting. On the other hand, for efficient alternator/motor-generator the minimum CO_2 savings corresponds to the minimum eligible efficiency to a realistic maximum value. For example, in the case of the efficient alternator/motor-generator, a maximum achievable efficiency of 85% has been considered. The interaction reduction coefficient (IRC) rates have been calculated according to Eq. (4). Table 5 shows the resulting IRCs ranges. As can be seen in this table, the impact of interaction for different combinations of the two technologies generates a maximum reduction of the total independent CO_2 savings of 7.02%.

(2) For petrol-fuelled vehicles only. The range includes the minimum efficiencies of other fuels, which are higher than 0.738.

Table 5. IRCs ranges and PIRCs due to the interaction between efficient alternator/motor-generator and exterior LED lighting

Technologies	**IRCs**	**PIRCs**
Efficient alternator/motor-generator + exterior LED lighting	From 92.98% to 95.29%	91%

Source: JRC analysis, 2021.

Based on the IRCs results, Table 5, it is possible to define generic conservative PIRCs for these technology combinations, as shown in Table 5. The conservative values are obtained by the following approach:

1. The lowest CO2 reduction of the IRCs range is selected Table 5
2. This is multiplied by a safety margin of 0.98
3. The resulting value is rounded down to the nearest integer value.

Equation (13) summarises this approach:

$$\mathrm{PIRC} = \mathrm{Integer}\ ((\min(\mathrm{IRC}) \cdot 0.98)) \qquad [\%] \qquad (13)$$

5 Determination of PIRCs for other combinations of technologies

For the technologies that were investigated in this report, i.e. efficient alternator/motor-generator and exterior LED lighting, it was found that there is an interaction between them. As a result, the overall CO_2 reduction when these technologies are combined will be lower than the sum of the individual CO_2 benefits. This is caused by a certain dependency between the technology systems, because the same "type" of energy is being exchanged, in this case electricity.

The PIRC table in the previous section could be complemented for other types of technologies. For those combinations where an interaction is clearly not present, their IRC value can be set to 100%. For other combinations, in particular, those using the same type of energy, an interaction is likely, and the IRC needs to be determined.

In this context, based on the 2018 Technical Guidelines [4] and the experience gained from the NEDC-based eco-innovation approvals, the following other types of technologies are considered, grouped into classes of similar technical features and characteristics:

1. Heat energy storing systems
2. Kinetic energy storing systems
3. Technologies allowing the use of ambient energy sources

Table 5 could be expanded to include such other classes of technologies.

This is illustrated in Table 6 with indicative PIRCs given for those groups. The following remarks need to be kept in mind:

- Incompatible technologies are indicated by grey cells.
- For technology combinations for which the CO_2 savings are independent, the PIRC is 100%.
- For combinations of technology types for which there might be an interaction, is the PIRC is marked as 'TBD' (to be determined).

Table 6. Indicative PIRCs for interaction between other types of technologies

	Exterior LED lights	Efficient Alternator/ motor generator (+ DC/DC, if applicable)	Heat energy storing system	Kinetic energy storing system	Use of ambient energy sources
Exterior LED lights		91%	100%	TBD	100%
Efficient alternator/ motor generator (+ DC/DC, if applicable)	91%		100%	100%	TBD
Heat energy storing system	100%	100%		TBD	100%
Kinetic energy storing system	TBD	100%	TBD		TBD
Use of ambient energy sources	100%	TBD	100%	TBD	

Source: JRC analysis, 2021.

For any combination of more than two technologies, the interactions need to be determined separately by multiplying the relevant PIRCs.

As an example, the CO_2 reduction for a combination of LED lights, efficient alternator and a heat energy storing system would be calculated as follows:

- CO_2 savings from LED lights is multiplied by respectively 91% (i.e. PIRC of LED-efficient alternator) and 100% (i.e. PIRC of LED-heat energy storing system).
- CO_2 savings from efficient alternator is multiplied by respectively 91% (i.e. PIRC of LED-efficient alternator) and 100% (i.e. PIRC of efficient alternator-heat energy storing system).
- CO_2 savings from the heat energy storing system is multiplied by 100% (i.e. PIRC of LED-heat energy storing system) and 100% (i.e. PRC of efficient alternator-heat energy storing system).

The sum of these three savings provides the total savings from the three technologies, compensated for the interactions between them.

6 Conclusions

In this report it has been demonstrated that, when more than one technology is installed, the combined CO_2 savings may be less than the sum of the individual savings because the functioning of the one has an effect on the other eco-innovation. This is referred to as an 'interaction' and is presented as a percentage which reduces the sum of the individual CO_2 savings. Where such an interaction cannot be ruled out, the vehicle manufacturer shall indicate this in the application to the type-approval authority.

Two different methods have been presented to quantify the level of interaction: a combined method and a separated method. These methods were demonstrated to yield the same results in the presented example case; therefore, both may be used to calculate the interaction. The combination of other technologies in the future will confirm the equivalence of the methods' results. The combined method is simpler but requires unique modified conditions for all technologies, i.e. a unique set of operating conditions to trigger the real-world operation of all technologies. As an alternative, the separated method requires more calculation stages, but it can always be applied as modified conditions are always defined separately for each technology, in accordance with the methodologies published in the corresponding CIDs.

The interaction level calculation has been shown in detail for two eco-innovations with an effect on the on-board electric energy consumption, i.e. efficient alternator/motor-generator and the exterior LED lighting. By varying the relevant parameters for these eco-innovations, it was demonstrated that the interaction for any combination of technologies ranges reduces the independent CO_2 savings to their 93% to 95%. This means that the interaction reduces the combined CO_2 savings up to 7% in comparison to the sum of the individual CO_2 savings.

An alternative simplified method was also introduced, for which fixed values are assumed as interactions. These 'Pre-defined Interaction Reduction Coefficients' (PIRCs) were derived by varying the relevant influencing parameters of the eco-innovations and calculating the corresponding range of interactions. To avoid that they would overestimate the actual CO_2 savings, the lowest value of the interaction range is multiplied by a safety margin of 0.98 and rounded down to the nearest integer. Eco-innovations for which it can be proven that their CO_2 savings are independent because they have no energetic overlap, the interaction level (and the PIRC) is set at 100%.

References

[1] EU, "Regulation (EU) 2019/631 of the European Parliament and of the Council of 17 April 2019 setting CO2 emission performance standards for new passenger cars and for new light commercial vehicles, and repealing Regulations (EC) No 443/2009 and (EU) No 510/2011 (recast)."

[2] EU, "Commission Implementing Regulation (EU) No 2018/258 of 21 February 2018 amending Commission Implementing Regulation No 725/2011 of 25 July 2011 establishing a procedure for the approval and certification of innovative technologies for reducing CO2 emissions from passenger cars pursuant to Regulation (EC) No 443/2009 of the European Parliament and of the Council," 2018. http://europa.eu/!Nj39TU (accessed Aug. 04, 2021).

[3] EU, "Commission Implementing Regulation (EU) No 259/2018 of 21 February 2018 amending Commission Implementing Regulation 427/2014 of 25 April 2014 establishing a procedure for the approval and certification of innovative technologies for reducing CO2 emissions from light commercial vehicles pursuant to Regulation (EU) No 510/2011 of the European Parliament and of the Council," 2018. http://europa.eu/!nY68hV (accessed Aug. 04, 2021).

[4] EC, "Technical Guidelines for the preparation of applications for the approval of innovative technologies pursuant to Regulation (EC) No 443/2009 and Regulation (EU) No 510/2011 - Revision: July 2018," 2018. https://circabc.europa.eu/sd/a/a19b42c8-8e87-4b24-a78b-9b70760f82a9/July%202018%20Technical%20Guidelines.pdf (accessed Mar. 20, 2019).

[5] EC, "Commission Implementing Decision (EU) 2020/174 on the approval of the technology used in 12 Volt efficient alternators for use in certain passenger cars and light commercial vehicles as an innovative technology pursuant to Regulation (EU) 2019/631 of the European Parliament and of the Council," 2020. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2020.035.01.0013.01.ENG (accessed Jul. 22, 2020).

[6] EU, "Commission Implementing Decision (EU) 2020/1232 of 27 August 2020 on the approval of the efficient generator function used in 12 Volt motor-generators for use in passenger cars and light commercial vehicles, including certain hybrid electric vehicles and vehicles capable of running on alternative fuels, as an innovative technology pursuant to Regulation (EU) 2019/631 of the European Parliament and of the Council." https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32020D1232

[7] EU, "Commission Implementing Decision (EU) 2020/1167 of 6 August 2020 on the approval of the technology used in a 48 Volt efficient motor-generator combined with a 48 Volt/12 Volt DC/DC converter for use in conventional combustion engine and certain hybrid electric passenger cars and light commercial vehicles as an innovative technology pursuant to Regulation (EU) 2019/631 of the European Parliament and of the Council)." https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2020.258.01.0015.01.ENG

[8] EC, "Commission Implementing Decision (EU) 2019/1119 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 CO2 emissions from passenger cars pursuant to Regulation (EC) No 443/2009 of the European Parliament and of the Council," 2019. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019D1119 (accessed Jul. 20, 2019).

[9] S. Malfettani, C. Lodi, T. Huld, and P. Bonnel, "Latest Developments on the European Eco-innovation Scheme for Reducing CO2 Emissions from Vehicles: Average Input Data for Simplified Calculations," *Transp. Res. Procedia*, vol. 14, pp. 4113–4121, 2016 doi: 10.1016/j.trpro.2016.05.382.

List of abbreviations and definitions

Latin symbols

B	baseline vehicle CO_2 emissions	[gCO_2/km]
Be	baseline vehicle CO_2 emissions due to electric consumption	[gCO_2/km]
CF	fuel conversion factor	[gCO_2/l]
CNG	compressed natural gas (G20)	[-]
E85	ethanol fuel blend	[-]
E	eco-innovation vehicle CO_2 emissions	[gCO_2/km]
Ee	eco-innovation vehicle CO_2 emissions due to electric consumption	[gCO_2/km]
HEV	Hybrid Electric Vehicle	[-]
IRC	Interaction Reduction Coefficient	[-]
$\boldsymbol{k}$	coefficient defined as $\mathrm{k} = \mathrm{V_{Pe}} \cdot \mathrm{CF}$	[gCO_2/kWh]
LPG	liquified petroleum gas	[-]
M1	passenger cars	[-]
N1	light commercial vehicles	[-]
NEDC	New European Driving Cycle	[-]
OVC	Off-Vehicle Charging	[-]
$\mathbf{P_{TA}}$	vehicle's average electric power requirement under type-approval conditions	[W]
$\mathbf{P_{HL}}$	electric power requirement of halogen lighting	[W]
$\mathbf{P_{LED}}$	electric power requirement of exterior LED lighting	[W]
$\mathbf{P_{other}}$	vehicle's average electric power requirement under real-world conditions except exterior lighting	[W]
$\mathbf{P_{RW}}$	vehicle's average electric power requirement under real-world conditions	[W]
PIRC	Pre-defined Interaction Reduction Coefficient	[-]
TEC	technology	[-]
s	uncertainty in the determination of CO_2 savings	[gCO_2/km]
UF	usage factor or shading effect	[-]
v	Mean driving speed of the homologation cycle	[km/h]
$\mathbf{V_{Pe}}$	consumption of effective power - Willans' Factor	[l/kWh]

WLTC	Worldwide Harmonized Light-Duty Vehicles Test Cycle	[-]
WLTP	Worldwide Harmonized Light-Duty Vehicles Test Procedure	[-]

Greek symbols

η_A	efficiency of the baseline alternator	[-]
η_E	efficiency of the efficient alternator/motor-generator [3]	[-]

Subscripts

D	diesel engine
EI	eco-innovation
eco	eco-innovation
MC	under modified conditions
mod	modified
P	petrol engine
PT	petrol turbo engine
TA	under type-approval conditions
tot	total

Superscripts

C	combined method
EB	efficient baseline procedure
I	individual procedure
S	separated method

(3) In the case of 48V motor-generator plus 48V/12V DC/DC converter, n_E is calculated by the product of the 48V motor-generator's efficiency and the DC/DC one

List of figures

List of tables

Annexes

Annex 1. Background information and reference values for testing methodology

This annex contains the background information which has been used for the calculation of reference values used in the pilot calculations and in the corresponding numerical examples. These values are mainly taken from the Technical Guidelines version July 2018 [4].

The reference values are usually expressed as average values for mean European conditions on an annual time basis [9]. Where technical data vary between different vehicle versions, a security margin is included in the listed values to ensure that all potential vehicles are covered. Another security factor is included where deterioration effects have to be taken into account.

Efficiency of engine

A reduction of electrical or mechanical power requirement lowers fuel consumption rates and CO_2 emissions. The 'consumption of effective power' V_{Pe} describes the reduced fuel consumption as a function of a reduction of required power at a particular point of the engine map and represents the marginal engine efficiency. Following the 'Willans'' approach', the 'consumption of effective power' is nearly constant and almost independent from engine speed at low engine loads.

Table 7. Engine efficiency expressed with Willans' factors [4]

Type of engine	Consumption of effective power $\mathbf{V_{Pe}}$	Unit
Petrol/E85 (V_{Pe-P})	0.264	l/kWh
Petrol/E85 Turbo (V_{Pe-PT})	0.28	l/kWh
Diesel (V_{Pe-D})	0.22	l/kWh
LPG (V_{Pe-LPG})	0.342	l/kWh
LPG Turbo (V_{Pe-LPG_T})	0.363	l/kWh
CNG (G20) (V_{Pe-NG})	0.259	m^3/kWh
CNG (G20) Turbo (V_{Pe-NG_T})	0.275	m^3/kWh

Source: European Commission, Technical Guidelines for the preparation of applications for the approval of innovative technologies pursuant to Regulation (EC) No 443/2009 and Regulation (EU) No 510/2011 - Revision: July 2018

Efficiency of alternator

The efficiency of the alternator is essential for the conversion from mechanical into electric power and vice versa. In the examples of Section 4 the following values were assumed:

- Baseline alternator (A) efficiency of 67% [4] ($\boldsymbol{\eta_A = 0.67}$)
- Efficient alternator/motor-generator (4) (E) efficiency of 77% ($\boldsymbol{\eta_E = 0.77}$)

Table 8. Driving cycle characteristics [4]

Cycle	Distance [m]	Duration [s]	Mean speed [km/h]
WLTP - Low speed Phase	3 095	589	18.90

(4) The value has to be regarded as an illustrative feature for an efficient alternator/motor-generator. In the case of 48V motor-generator, the efficiency considered includes the DC/DC converter's one.

WLTP - Medium speed Phase	4 756	433	39.50
WLTP - High speed Phase	7 162	455	56.70
WLTP - Extra high-speed Phase	8 254	323	92.00
WLTP	23 266	1 800	46.50

Source: European Commission, Technical Guidelines for the preparation of applications for the approval of innovative technologies pursuant to Regulation (EC) No 443/2009 and Regulation (EU) No 510/2011 - Revision: July 2018

Conversion fuel consumption – CO_2 emission

In Table 9 the factors for the conversion of fuel amount in litres (respectively m3 for CNG) to grams of CO2 are specified.

Table 9. CO_2 conversion factors of fuels [4]

Type of fuel	Conversion factor (CF)
Petrol/E85	2 330 gCO_2/l
Diesel	2 640 gCO_2/l
LPG	1 629 gCO_2/l
CNG (G20)	1 795 gCO_2/m^3

Source: European Commission, Technical Guidelines for the preparation of applications for the approval of innovative technologies pursuant to Regulation (EC) No 443/2009 and Regulation (EU) No 510/2011 - Revision: July 2018

Power requirements of lighting types

The data which have been used for the calculation of the reference values used in the testing methodology for the lighting system is the total power consumption of all exterior lights. If a technology is not activated during the whole time of the vehicle's operation, a usage factor (UF) should be applied to the measured or modelled results of CO_2 savings. The UF is used to weigh the electric power required for each light ($P_{light\ type,i}$) separately and calculates the total power consumption of exterior lights: halogen tungsten lamps for baseline vehicles (P_{HL}) and LED lamps for eco-innovative vehicles (P_{LED}). Characteristics are shown in Table 10 for halogen lights and in Table 11 for LED lights.

Table 10: Power consumption and Usage Factors of exterior Halogen lighting [4]

Type of lighting	Electric power ($P_{HL,i}$) [W]	Usage factor (UF)	$P_{HL,i}$*UF [W]
Low beam headlamp	137	0.33	45.21
High beam headlamp	150	0.03	4.50
Front position	12	0.36	4.32
Fog – front	124	0.01	1.24
Turn signal - front	13	0.15	1.95
Turn signal - side	3	0.15	0.45

Fog – rear	26	0.01	0.26
Turn signal – rear	13	0.15	1.95
License plate	12	0.36	4.32
Reversing	52	0.01	0.52
Total			65

Source: European Commission, Technical Guidelines for the preparation of applications for the approval of innovative technologies pursuant to Regulation (EC) No 443/2009 and Regulation (EU) No 510/2011 - Revision: July 2018

Table 11. Power consumption and Usage Factors of exterior LED lighting. Realistic values considered in the examples

Type of lighting	Electric power ($P_{LED,i}$) [W]	Usage factor (UF)	$P_{LED,i}$*UF [W]
Low beam headlamp	40	0.33	13.20
High beam headlamp	40	0.03	1.20
Front position	2	0.36	0.72
Fog – front	25	0.01	0.25
Turn signal - front	2.5	0.15	0.38
Turn signal - side	0.5	0.15	0.08
Fog – rear	3	0.01	0.03
Turn signal – rear	1.5	0.15	0.23
License plate	2	0.36	0.72
Reversing	4	0.01	0.04
Total			16.85

Total electric power requirements

The vehicle's total electric power requirement during the WLTC testing under type-approval conditions differs from that one of averaged "real-world" driving.

Table 12. Total electric power requirements for M1 and N1 vehicles [4]

Driving conditions	Type of vehicle	Total electric power requirements [W]
Type-approval WLTC	P_{TA-M1}	350
	P_{TA-N1}	350

Real-world driving	P_{RW-M1}	750
	P_{RW-N1}	750

Source: European Commission, Technical Guidelines for the preparation of applications for the approval of innovative technologies pursuant to Regulation (EC) No 443/2009 and Regulation (EU) No 510/2011 - Revision: July 2018

In situations where different types of exterior lamps are considered, the total electric power requirement for real-world conditions is defined as the sum of P_{other} + P_{light}, being P_{light} the P_{HL} for baseline or P_{LED} for eco-innovative vehicle, and P_{other} the electrical power consumption for the rest of the consumers.

KJ-NA-30930-EN-N

The European Commission's science and knowledge service

Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub
ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub - Joint Research Centre

EU Science, Research and Innovation

EU Science Hub

Publications Office of the European Union

doi:10.2760/258688

ISBN 978-92-76-45459-5